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Women in Engineering: 3D Printing Interests, Habits, and Persistence

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Abstract

Makerspaces are increasingly merging with academics in undergraduate engineering programs. At Duke University, engineering students are introduced to prototyping in makerspaces in their first-year engineering design course. In later engineering coursework, they are required to use makerspace tools. 3D printers are one tool used by students for prototyping and visualizing, and they can also aid in developing spatial visualization skills, especially when students design and print objects they've designed using a CAD software tool. Printing can inspire students in extracurricular endeavors, and they are a useful tool to creatively explore new ideas for further development. This research is a first step in exploring how students are using 3D printing both in- and outside of required coursework, along with the barriers felt by students in their use of this tool. The goal is to gain insight into 3D printing habits and motivations of engineering undergraduates. Of particular interest is determining any differences between genders in this area, and, if so, what barriers and motivations exist and differ between gender groups.

There are two parts of this study: an online survey and an interview. Engineering undergraduates are recruited for participation, and questions are designed to gage students' 3D printing experience, frequency, and habits, including the intended use of printed items. Students are also asked to identify their response to printing failures, along with their use of in-person and online resources for troubleshooting. Student demographics are also recorded. In interviews, participants are asked in detail about each item in their online print history. Survey results are paired with in-person interview responses.

Research results will inform future work in addressing barriers that affect students, including 3D printing training, makerspace recommendations, initiatives to promote inclusion, and changes to already existing outreach events designed to support students in building confidence, interest, and self-efficacy in technical skills.

Introduction

Makerspaces are becoming an increasingly important part of academics in undergraduate engineering programs. As of 2017, 40 of the top 127 highest ranking U.S. colleges and universities had publicly available makerspaces, shifting on-campus resources from traditional machine shops to more high technology, digital design and rapid prototyping spaces[12].

In university makerspaces, 3D printers are popular tools used for prototyping and visualizing; they are often the first tool for which students seek training in makerspaces[3]. They can also aid in developing spatial visualization skills, especially when students print objects they have designed using a CAD software tool. Use of 3D printers is an intuitive, broadly applicable, hands-on way of sparking interest in STEM; as a result, "students become more responsible, motivated, [and] involved and reach higher levels of learning, in that [3D printing] caters to the diversity of their learning styles"[11]. While the majority of makerspace users on college campuses are engineering students, 3D printing technology is useful to students from all backgrounds and majors. The practice of 3D printing can inspire students in extracurricular endeavors; they are a useful tool to creatively explore new ideas for further development, and they can be used to complete class assignments. Self-paced learning and practice of 3D printing and CAD software skills provides students with an opportunity to develop as self-regulated learners, which is a valuable skill for engineering students[15].

There are many different motivations driving students to pursue engineering and to persist through their college career within the major, but one motivation, the "hands-on, action-oriented character of engineering activities", is more prevalent among men in the major[7]. Perhaps then, improving self-efficacy in women regarding their tinkering abilities through greater access to, and use of, makerspaces can provide another motive for women to persist in engineering and, more importantly, to incorporate engineering as part of their identity. Because of all of the benefits that 3D printing within makerspaces can provide, it's important to ensure access, support, and inclusion of all students.

There is some existing work in the literature in the area of makerspace inclusion, especially for women. According to a study completed at University of Texas at Austin, 72% of students return to makerspaces after their first makerspace experience. Coursework is the most common reason students visit a makerspace for the first time; therefore, it is important that undergraduate engineering courses incorporate makerspaces into their curriculum to ensure that all students have equal opportunity to thrive in campus makerspaces[12]. Extracurricular engineering clubs and organizations make use of campus makerspaces quite often. Based on data from the Academic Pathways Study used to analyze engineering student involvement in extracurricular activities, women place higher importance on extracurricular activities than their male counterparts, as well as reporting higher participation in both engineering-related and non-engineering-related extracurricular activities[7]. As a result, it would follow that women would use makerspaces at a higher rate than men. However, that does not seem to be the case in this study.

After collecting information about several campus makerspaces, Higginbotham outlines common access and use barriers and explores some methods used by makerspace leaders to create a more welcoming space, including programming and orientations[5]. Another study assessed the use of a single campus makerspace (built for non-engineering students) and determined that personal invitations to the space initiated more first visits than larger, group invitations[13]. Through a large campus survey, Hunt et. al. found differences in the makerspace tool training preferences between men and women[6]. They also found evidence supporting the negative effect of a gender difference in self-efficacy on makerspace use. These researchers found that more female-identifying students believe they do not have the skills needed to use the makerspace. Roldan et. al. interviewed engineering undergraduate women and leaders of university makerspaces to identify practices that contributed to a "positive sense of community," giving recommendations to support and foster a community that is welcoming to women[10].

Gendered team dynamics can be seen through makerspace use. Among students, women seem to not perceive barriers in makerspaces when men are not present[2]. According to research by Robinson et al, women are traditionally less interested in tinkering without a greater goal[9]. If students perceive makerspace use as being strictly (or more commonly) for leisure or extracurricular work, the space may be less appealing to women. On a larger scale, this outcome can cause engineering undergraduate women to see less relevance in, and applicability of, engineering topics and how they relate to the greater community than their male-identifying peers and can consequently be less drawn to STEM. Additionally, some believe that makerspace layout and safety have a large impact on the limited use by undergraduate engineering women [8]. Women tend to be more cautious than men and are therefore more hesitant to use a space with potentially hazardous equipment. The seemingly unsafe nature of makerspaces serves as a barrier to use for women.

As campus makerspaces are often open-access spaces allowing use of a wide range of tools without curricular training, it is important to study the help-seeking behaviors of students in these spaces as well. Research in the literature on help-seeking behaviors of engineering and STEM students focuses primarily on the habits of students in their coursework. In a 2015 study, 47 undergraduate engineering students were surveyed and interviewed about their help-seeking practices, and results demonstrated that women seek help from a greater variety of resources than men, but that they also are more likely to fear how they'll be perceived for seeking help [14]. Generally, students' help-seeking decisions in their academic work are motivated by cultural norms, motivation, and self-esteem [4]. If the same fears of how their help-seeking will be perceived exist in makerspaces, the open, unstructured space could be perceived as intimidating to some visitors, even when support staff is present.

As makerspaces have become more prevalent on college campuses, they have become largely incorporated into engineering course curricula, so it is important that women feel a sense of belonging in these spaces, and that they feel that makerspaces can be useful and welcoming. The research herein is a first step in exploring how students are using 3D printing both inside and outside of required coursework, along with the barriers felt by students in their use of this tool. The goal is to gain insight into 3D printing habits and motivations of engineering undergraduates and to inform future makerspace programming, events, and resource creation and implementation. Research results will inform future work in addressing barriers that affect students, including 3D printing training, makerspace recommendations, initiatives to promote inclusion, and changes to already existing outreach events designed to support students in building confidence, interest, and self-efficacy in technical skills. Of particular interest is determining any differences between genders in this area, and, if so, what barriers and motivations exist and differ between gender groups. In addition, this research aims to identify how team composition and work style preferences differ by gender and contribute to 3D printer usage on campus.

Methods

There are five makerspaces available to students at Duke University. Access is available to all students and support is provided by dedicated staff and students assistants. Two of the five available spaces require user safety agreements; the other three are accessible to all without a user agreement. Except for a few specialty pieces of equipment, makerspace tools and materials (including 3D printing filament, scrap wood, and small miscellaneous materials) are available and free of charge for student use at all makerspace locations. Tool training methods in these spaces vary. Some students receive training in their classes, some are trained by makerspace staff, and some students independently learn how to use the tools. Additionally, students can receive special 3D printing privileges such as the ability to clear printers on campus and alter the infill levels of prints by completing a training followed by a quiz. Engineering students are introduced to prototyping in makerspaces (including 3D printing) in their first-year engineering design course. In later engineering coursework, independent studies, research, and extracurricular activities, students are assigned projects and assignments that require or would benefit from makerspace tools. Additionally, students use makerspace tools for entrepreneurial, personal, and creative endeavors.

There are two parts of this study: an online survey and an interview. Undergraduate engineering participants at Duke University were recruited via email, specifically targeting engineering affinity groups, engineering extracurricular clubs, and engineering course listservs, as this was an easy way to reach a large population of engineering undergraduate students. Once a student expressed interest in participating in the study, they completed a survey. This survey was developed with the goal of learning how and why different engineering students use the 3D printers on campus. The survey questions were designed to gauge students' 3D printing experience, frequency, and habits, including the intended use of printed items. Survey questions can be found in Appendix A. In addition, students were asked to identify their response to printing failures, along with their use of in-person and online resources for troubleshooting. Student demographics were also recorded. The researchers worked closely with Duke Learning Innovation on survey design. After completing the survey, those who indicated willingness to be interviewed completed a 30-minute video interview. In this interview, one researcher reviewed the participants' 3D printing history and asked about the design process, intended use, and success of each of their prints. The interview questions can be found in Appendix B. After the interview, a third party transcribed the interview, removed any identifiers in the transcript, and destroyed the video recording files.

Results

Fifty undergraduate engineering students were surveyed in the study. Descriptive statistics of the participating students are presented in Table 1. While students were given nonbinary choices when asked for their gender identity, very few identified outside of the male and female categories, and so results given here are for those two groups (referred to as men and women, respectively, here).

The majority of men and women sampled entered college with no 3D printing experience, as shown in Figure 1. A larger percentage of women (76.7%) than men (52.5%) had no experience, as more men than women reported exposure to 3D printing from high school classes and clubs. Both women and men were most commonly exposed to 3D printing before college through a high school class. However, only 13.3% of women as compared to 28.6% of men had this high school class experience.

Just as in high school, both men and women most commonly learned how to 3D print in a class in college as seen in Figure 2. While the percentage of women and men who learn to 3D print from a class is approximately equivalent (45.7% and 48.3% for women and men, respectively), there is a large difference in the percentage of women and men who reported learning from another student (19.6% and 10.3%, respectively). A similar percentage of women (6.5%) and men (6.9%) reported learning 3D printing in college as part of a club. This is noteworthy as 31% of women reported that they are not involved with any engineering-related extracurricular activities on campus, compared

Table 1: Engineering undergraduate student survey participants

Characteristic ($n = 50$)	**Frequency**	**Percent**
Gender		
Female	29	58
Male	18	36
Non-binary / Genderqueer	2	4
Trans* (e.g., transgender, transman, transwoman)	0	0
Prefer not to answer	1	2
Prefer to self-describe	0	0
Race/Ethnicity (multi-racial students select all that apply)		
Black	3	6
Asian	14	28
White	33	66
American Indian or Alaskan Native	0	0
Native Hawaiian or Pacific Islander	0	0
Middle Easter or North African	1	2
Latinx/Hispanic	10	20
College Year		
First year	10	20
Sophomore	17	34
Junior	7	14
Senior	13	26
Engineering Major		
Biomedical	11	22
Civil	1	2
Electrical and Computer	12	24
Mechanical	23	46
Environmental	2	4
Other	1	2

with only 5.6% of men (see Figure 3).

As seen in Figure 4, 72.2% of surveyed men prefer to work on 3D printing projects alone, while only 48.3% of women reported this preference. More women (37.9%) than men (11.1%) prefer to work on 3D printing projects with a partner. None of the participants indicated that they prefer to work on a team of greater than 5 people. Additionally, men visit makerspaces much more often than women. Figure 5 shows that 61.1% of men visit a makerspace once or twice per week, compared with only 41.4% of women who do the same. Men are generally more comfortable 3D printing on campus than women, as shown in Figure 6.

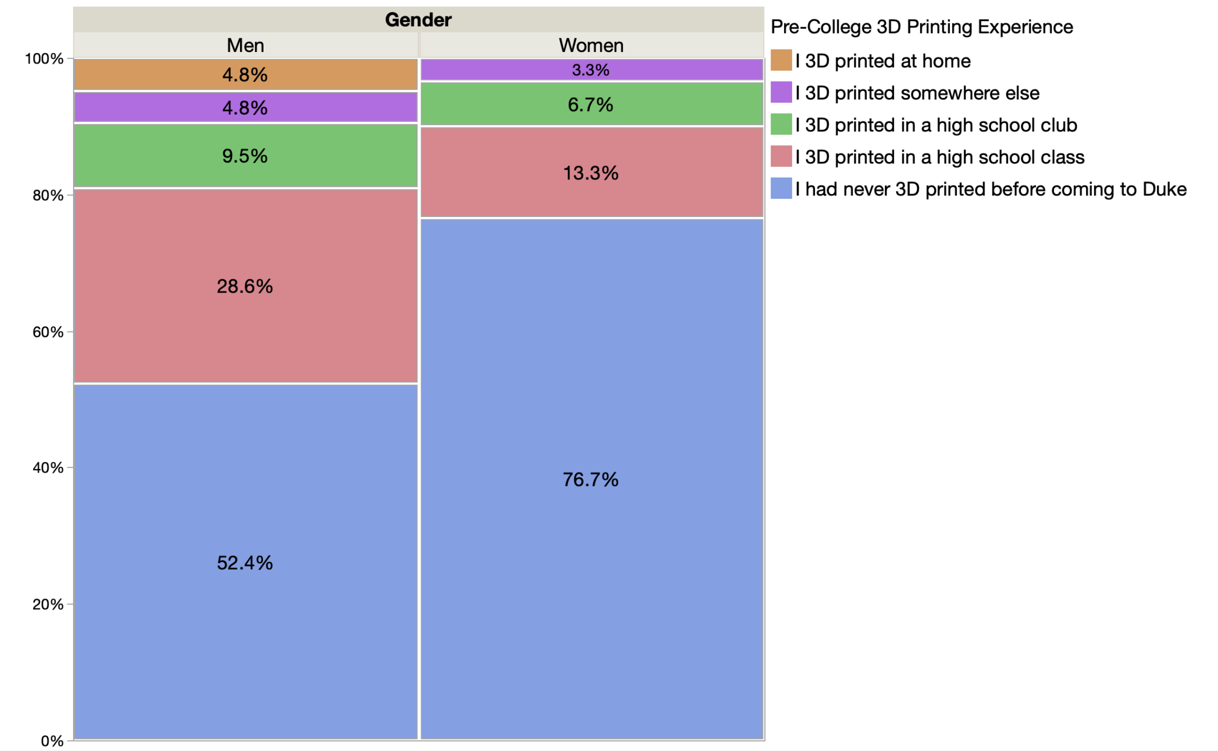

Figure 1: Pre-college 3D Printing Experience for Men and Women

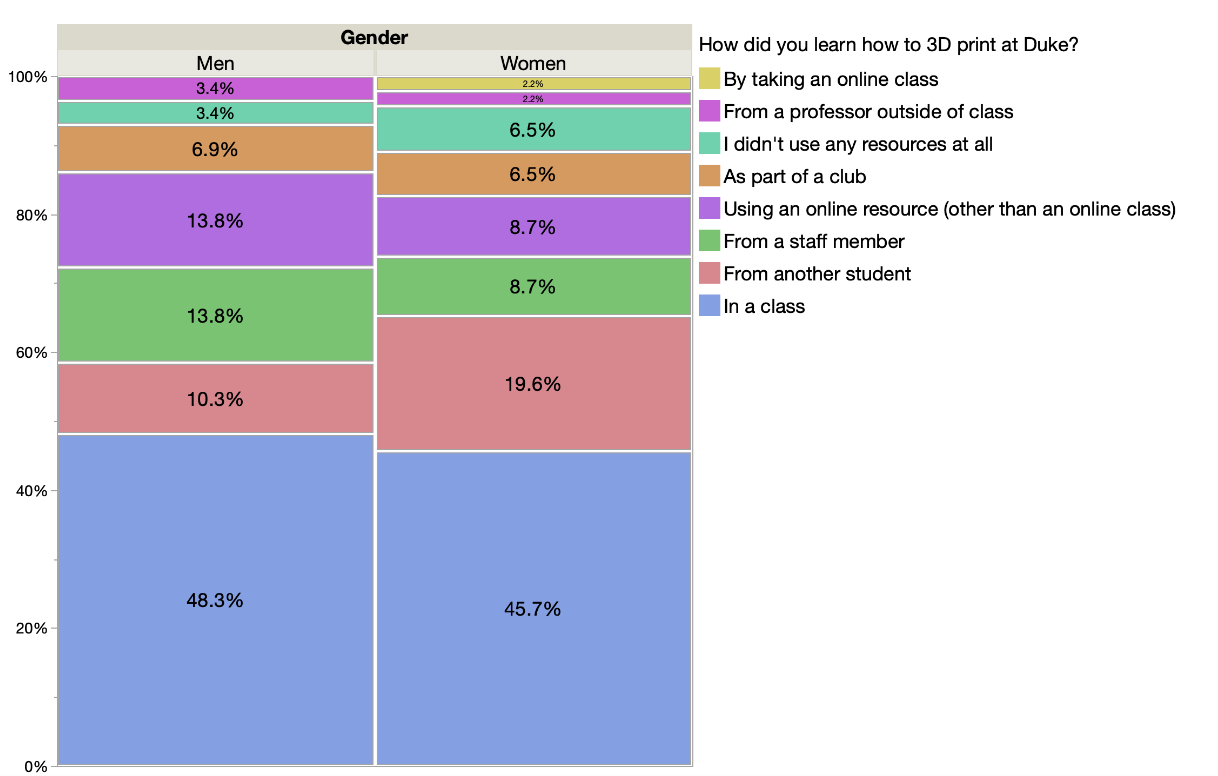

Figure 2: How Students Learn to 3D Print in College

The average comfort level with 3D printing reported by men is 8.4/10.0 while on average, women report 7.5/10.0. The most uncomfortable man rates themselves at a 4.0/10.0 while the most uncomfortable woman rates themselves at a 2.0/10.0. Interestingly, when looking at comfort level versus student year, as shown in Figure 8, the average comfort level is high for all class years and is over 8.0/10.0 for every class year except junior year. Seniors have an average comfort level of 8.75/10.0. This is the highest average comfort level of all four class years.

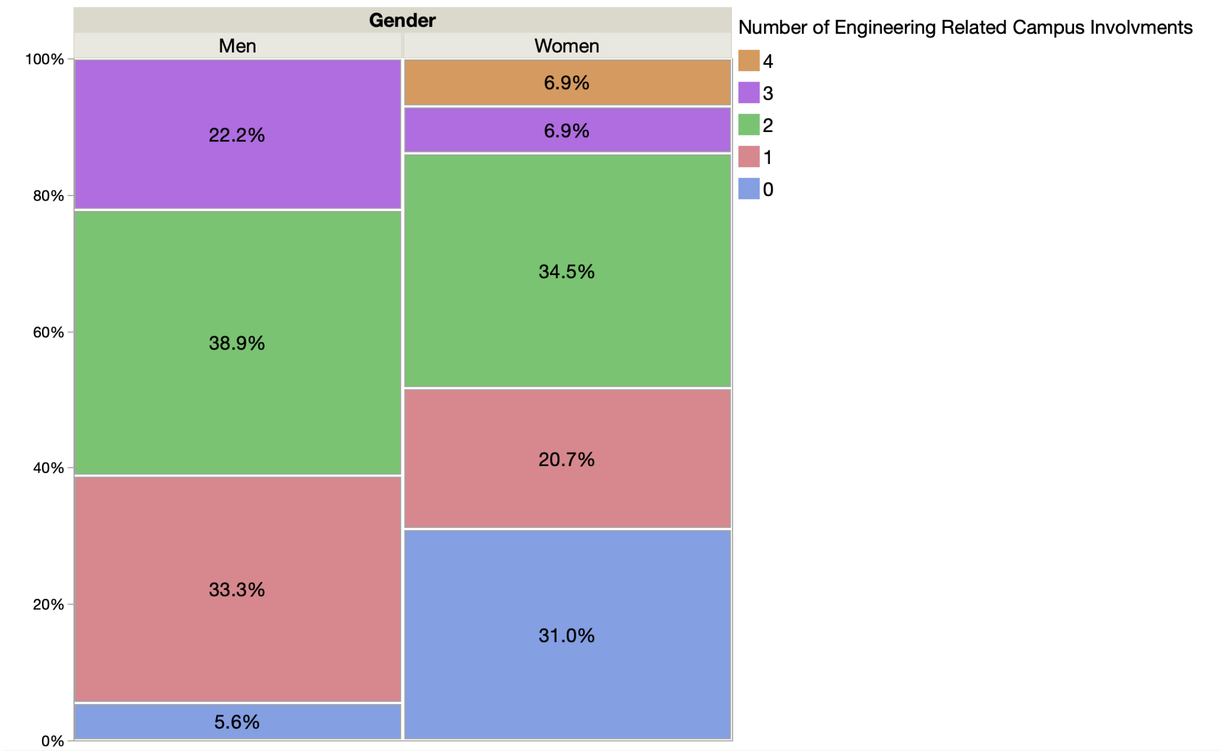

Figure 3: Number of Campus Involvements

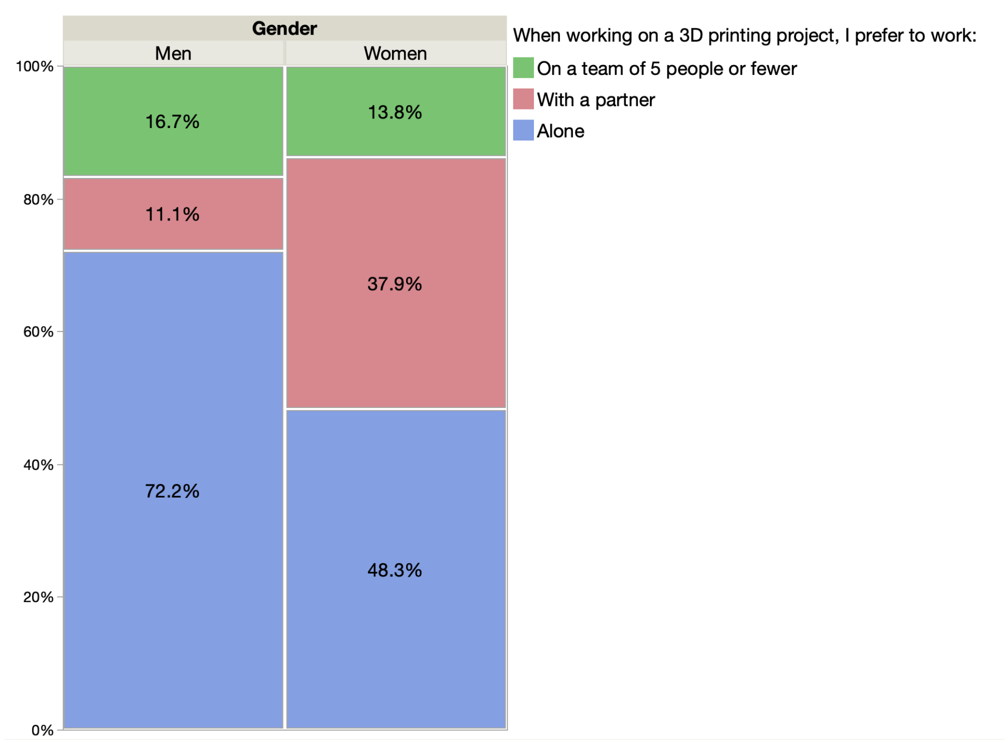

Figure 4: Work Preferences

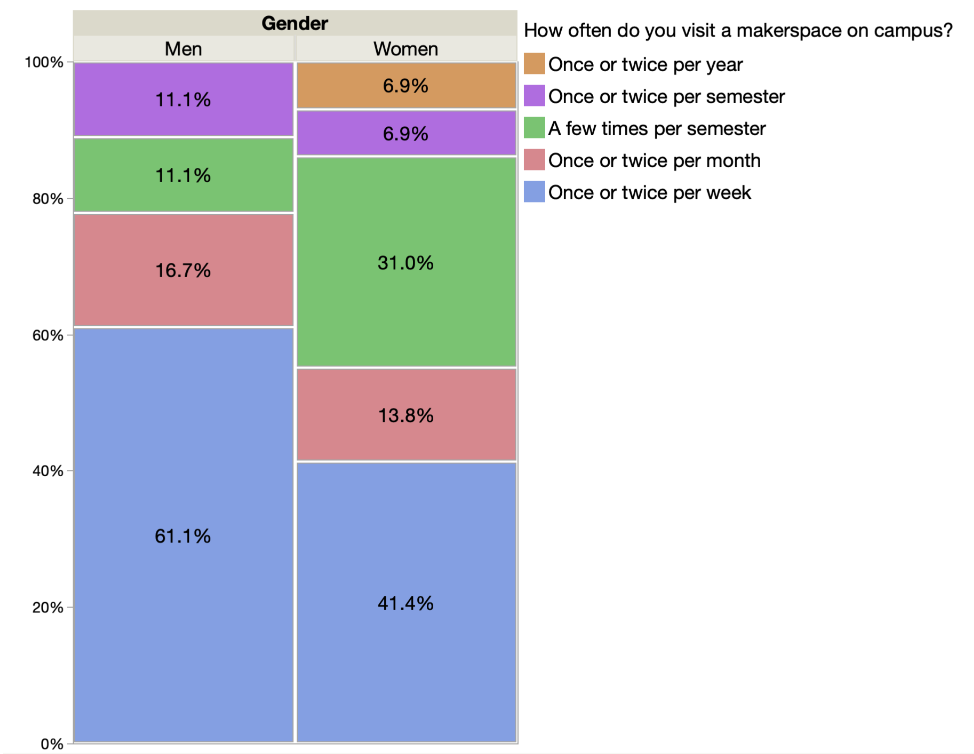

Figure 5: Campus Makerspace Visit Frequency

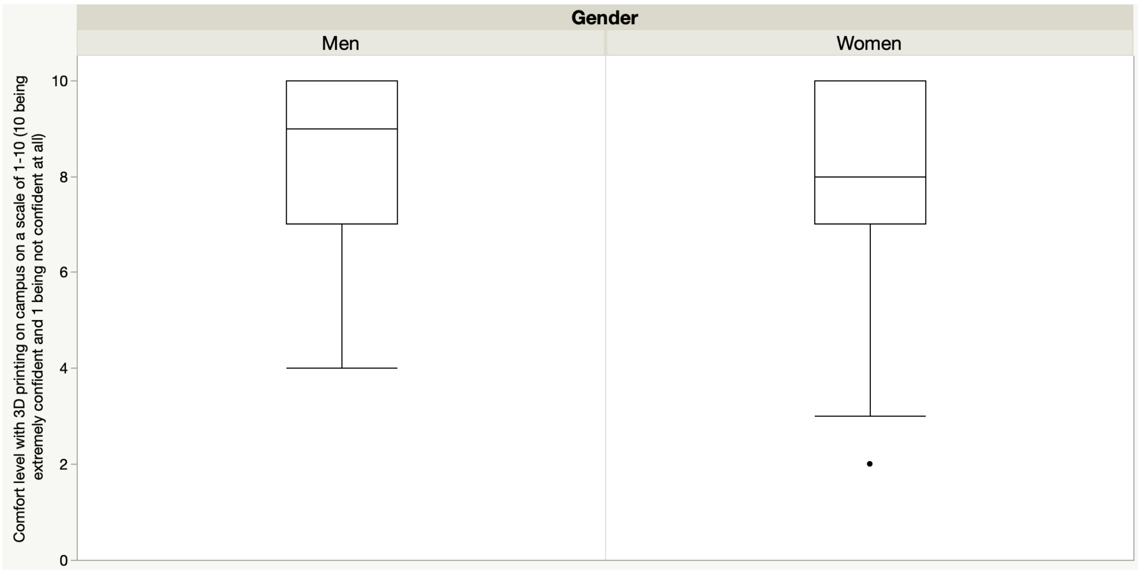

Figure 6: Comfort Level with 3D Printing on Campus

Surveyed men and women seem to be equally willing to ask for help, with 83.3% of men and 82.1% of women indicating that they have received help from the makerspace staff. In addition to asking if students have ever received help, this survey asked participants to identify how they solved the first and most recent 3D printing problems they faced. Many participants (41.3%) responded differently to these two questions. There is a much larger percentage of both men and women who ask for help from a makerspace staff member with their most recent problem compared with the first time they had a 3D printing problem. Of the 41.3% who changed their help-seeking behavior, 42.1% of them chose 'Researching the problem and trying again' and 36.8% of them chose 'Asking for help from a makerspace staff member' to solve their most recent 3D printing problem.

Twenty-two percent of men and 18.5% of women asked for help from a professor or TA the first time they had a 3D printing problem, while only 11.1% of men and 0% of women did the same for the most recent problem they faced. Additionally, approximately double the percentage of men (33.3% compared to 16.7%) and women (22.2% compared to 11.1%) researched how to solve the problem and tried again to solve their most recent 3D printing problem compared with their first 3D printing problem.

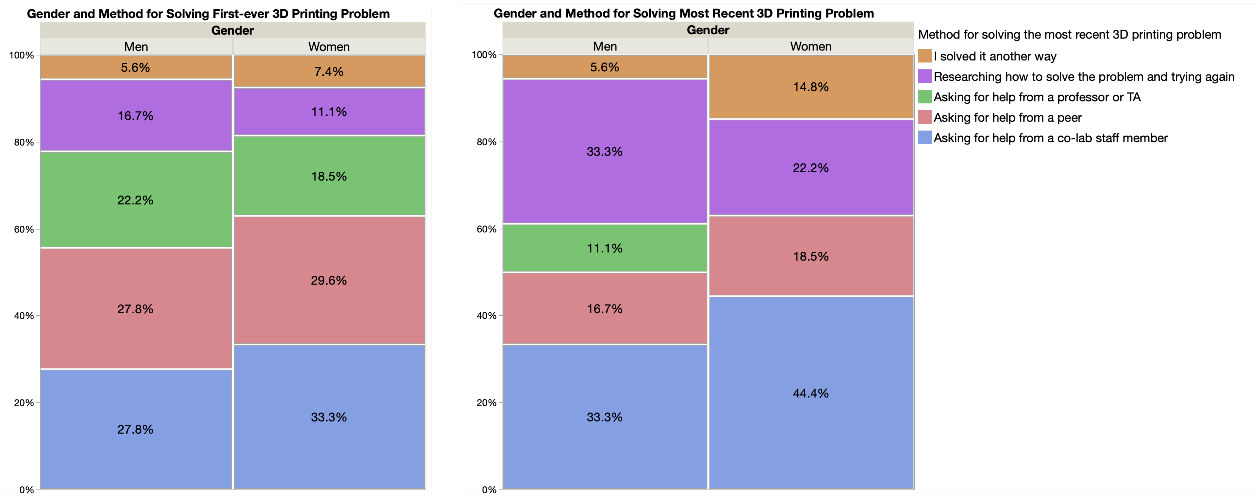

Figure 7: How Students Solve 3D Printing Problems

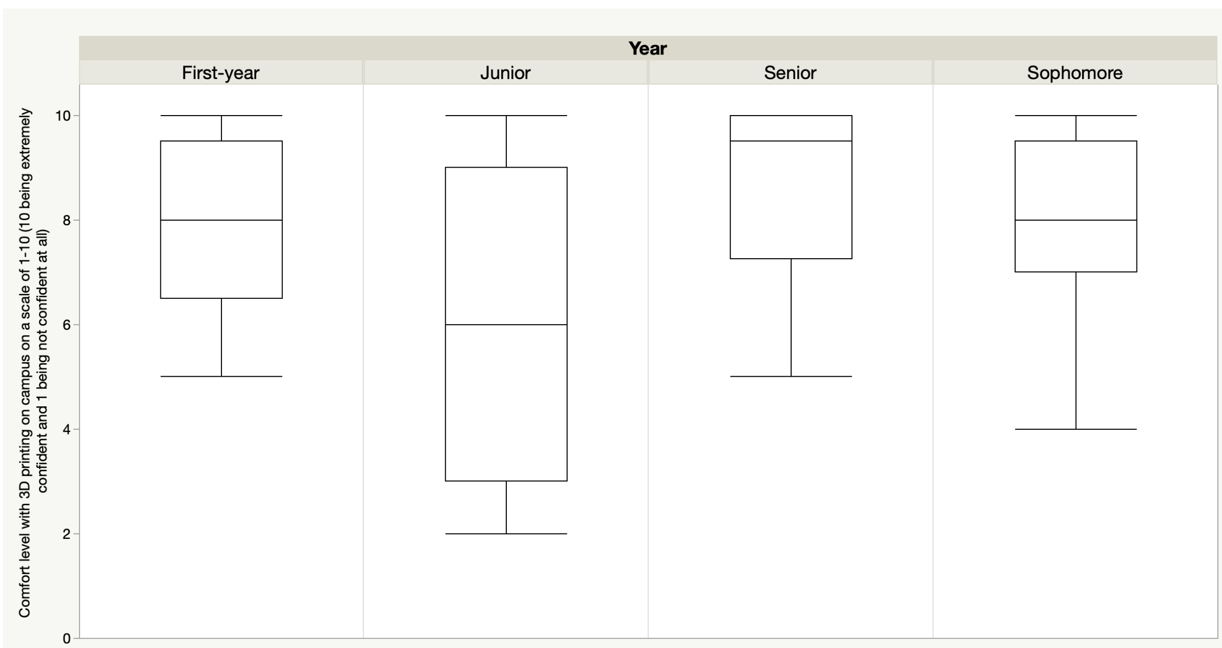

Figure 8: Comfort with 3D Printing by Class Year

Discussion

Based on the data presented in the results section, there are clear gender differences in makerspace, and more specifically, 3D printer use. First, the surveyed men have greater exposure to 3D printing before coming to college, putting men at an advantage over women in terms of comfort and confidence level in 3D printing upon arrival to college. This may result in a large number of women not becoming involved in engineering extracurriculars. They may feel less confident in their abilities or less comfortable working on 3D printing projects alone (Figure 6 and Figure 4, respectively). The results indicate that the majority of students are learning to 3D print in classes, and therefore, 3D printing should be introduced to all students early in their undergraduate education for early exposure. Such activities and assignments may provide the structure and opportunity to level the field in experience and comfort level in using 3D printers.

As seen in Figure 4, more men prefer to work alone than women. This is potentially related to their comfort using 3D printers on campus and as a result, their confidence in their abilities. Men's comfort with 3D printing and their preference to work alone may lead them to visit makerspaces more often than women.

Likely related to the difference in 3D printing exposure discussed above, 31% of women do not get involved with any engineering-related extracurricular activities on campus compared to only 5.6% of men. This limits 3D printing (and makerspace) exposure outside of the classroom, which limits additional 3D printing experiences and learning opportunities. Also related is the frequency of makerspace use between genders. A higher percentage of men visit a makerspace on campus once or twice per week than women. This is likely related to more men participating in engineering extracurriculars and therefore having more opportunities and incentives to 3D print regularly.

As seen in Figure 2, while most men and women learn to 3D print in a class, nearly double the percentage of women learn to print from another student. This may be associated with women's desire to work on a project with a partner, which would facilitate the ability to learn from another student. Additionally, a larger percentage of men than women learn to 3D print from a staff member or online resource.

Both men and women overwhelmingly indicated that when they face a 3D printing problem, they solve it by asking a makerspace staff member for help. This result is consistent with percentages receiving help from the makerspace staff (83.3% of men and 82.1% of women). Approximately double the number of participants researched how to solve the problem and tried printing the part again when encountering their most recent 3D printing problem compared with their first 3D printing problem. This result agrees with those presented in Figure 8, indicating that students become more comfortable with their 3D printing abilities, and that their persistence through setbacks increases as their student career progresses. On average, seniors feel more comfortable 3D printing on campus than their younger peers, indicating that 3D printing experience leads to comfort, and therefore confidence, in 3D printing abilities. As such, a lack of exposure to 3D printing in both high school and college can inhibit women's comfort, and consequently their confidence and success, in 3D printing, hands-on work, and potentially work through their major.

Future Work

A "conducive environment in which to develop expertise" is a key requirement in creative productivity and a "failure to to nurture early talent, the demands and expectations of society, and the control of entry into many fields and their resources by men has hindered women's accomplishments in virtually all domains"[1]. All users enter a makerspace and see the same 3D printers and tools, but access and methods of supporting users may vary, thereby affecting students' experience in these spaces. In future work, a more detailed study of how users interact with support staff and fellow users while working on a project in the makerspace environment, along with the interactions between the user and the prescriber (ie faculty, club/organization, etc), could provide more insight into any gender differences that may exist in nurturing and supporting users. Future work could also investigate additional factors that may contribute to increased comfort levels in student users in makerspaces or with 3D printing in general.

This work focused primarily on gender differences in 3D printing. Information was collected as part of the survey process on participants' race and ethnicity, but a larger student sample and further examination are needed to understand how 3D printing use, experience, and comfort level differ by race and ethnicity, if at all.

In this work, more men than women reported exposure to 3D printing through high school classes and clubs. Future work could further investigate why women engage less in makerspaces and 3D printing in high school, which may provide a more in-depth understanding of correlations with later engagement and involvement.

Additional work could also include an in-depth analysis of self-assessment. In particular, how do users assess their own 3D printed pieces in the areas of quality, creativity, and function, and what parallel connections do they make between these assessments and their personal level of competence, creativity, and grit? Ultimately, by understanding who uses 3D printing, how and why they use the tool, the support framework they experience, and the assessment methods they apply will provide insight into creating an inclusive and supportive environment. Many of the interviewed participants expressed that the parts they had 3D printed lacked creativity. Self-assessment of creativity should be further explored, specifically studying whether these sentiments differ by demographics. Furthermore, many participants stated in their interviews that they would 3D print more if they had more class assignments that required it. Therefore, it might be beneficial to explore ways to more consistently incorporate 3D printing into the engineering curriculum.

Conclusion

This research aimed to examine how 3D printer use on campus differs by gender. The results indicate that men and women have different habits in this area. These differences are seen in 3D printing frequency, working preferences, and comfortable level with printing on campus. Among the most significant findings: approximately double the percentage of men (33.3% compared to 16.7%) and women (22.2% compared to 11.1%) researched how to solve the problem and tried again to solve their most recent 3D printing problem compared with their first 3D printing problem; undergraduate engineering women begin college with less 3D printing experience; and women are less involved in engineering extracurricular activities. These differences likely contribute to corresponding differences in comfort level, help-seeking behavior, and frequency of 3D printing activities in college.

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Appendix A

Survey

The survey contains 25 questions and was taken by each research subject. It should be noted that these questions were answered referring to pre-COVID 3D printing experiences on the Duke University campus.

1. What is your name (first and last)?
2. What year in school are you?
   (a) First-year
   (b) Sophomore
   (c) Junior
   (d) Senior
   (e) Graduate student
   (f) Non-degree seeking student
3. Are you an [engineering] student?
   (a) Yes
   (b) No
4. (If 3 is Yes) What is your major?
   (a) Mechanical Engineering and Materials Science
   (b) Electrical and Computer Engineering
   (c) Civil Engineering
   (d) Biomedical Engineering
   (e) Environmental Engineering
   (f) Other

5. How would you describe yourself?
   (a) Female
   (b) Male
   (c) Intersex
   (d) Non-binary/Genderqueer
   (e) Trans* (e.g., transgender, transman, transwoman)
   (f) I prefer to self-describe
   (g) I prefer not to answer this question
6. What is your race (select all that apply)?
   (a) Black
   (b) Asian
   (c) White
   (d) American Indian or Alaskan Native
   (e) Native Hawaiian or Pacific Islander
   (f) Middle Eastern or North African
7. Are you of Latinx or Hispanic ethnicity?
   (a) Yes
   (b) No
8. What are your interests and campus involvements (select all that apply)?
   (a) I'm actively involved in at least one hands-on, design-based engineering club (ex. Motorsports, Robotics, AERO, etc.)
   (b) I'm an active member of one or more engineering affinity groups (ex. SWE, NSBE, SHPE)
   (c) I work on independent, engineering-related projects
   (d) I have taken hands-on, design-based engineering courses in addition to those required for my major (ex. EGR 190)
   (e) Other engineering-related interests/involvements
   (f) I'm not active in any engineering-related organizations
9. Which of the following makerspaces have you used most often for 3D printing? Select all that apply.
   (a) Innovation Co-Lab

(b) Lilly Library Co-Lab
(c) Rubenstein Arts Center Co-Lab
(d) The Design Pod
(e) The Foundry
(f) The Smart Home
(g) Departmental Labs

10. How often do you visit a makerspace on campus?
    (a) Once or twice per year
    (b) Once or twice per semester
    (c) A few times per semester
    (d) Once or twice per month
    (e) Once or twice per week
11. When working on a 3D printing project, I prefer to work:
    (a) Alone
    (b) With a partner
    (c) On a team of 5 people or fewer
    (d) On a team of more than 5 people
12. What was your experience with 3D printing before coming to Duke? Select all that apply.
    (a) I 3D printed in a high school class
    (b) I 3D printed in a high school club
    (c) I 3D printed at home
    (d) I 3D printed somewhere else (describe)
    (e) I had never 3D printed before coming to Duke
13. How did you learn how to 3D print at Duke? Select all that apply.
    (a) In a class
    (b) As part of a club
    (c) From another student
    (d) From a staff member
    (e) From a professor outside of class
    (f) By taking an online class

(g) Using an online resource (other than an online class)

(h) I didn’t use any resources at all

Work practices

14. Thinking about everything you have ever 3D printed at Duke, what percent were:
A. For a class?
B. For a club?
C. For fun or for your own interest? [options for each of A, B, C:]

    (a) Less than 10%

    (b) 10% - 25%

    (c) More than 25% but less than 50%

    (d) 50% - 75%

    (e) More than 75%

15. Of all the things you have ever 3D printed at Duke, what percent did you design yourself using CAD?

    (a) Less than 10%

    (b) 10% - 25%

    (c) More than 25% but less than 50%

    (d) 50% - 75%

    (e) More than 75%

16. Now think about all the things you have ever designed at Duke using CAD. How many of those have you 3D printed?

    (a) Less than 10%

    (b) 10% - 25%

    (c) More than 25% but less than 50%

    (d) 50% - 75%

    (e) More than 75%

17. Have you ever 3D printed another person’s file on their behalf?

    (a) Yes

    (b) No

18. Do you have special printing privileges (ability to clear printers, etc.)?

    (a) Yes

    (b) No

19. Do you have an alternate way of 3D printing (ex. non-Duke 3D printer)?
    (a) Yes
    (b) No

    Perceived ability and confidence

20. On a scale of 1-10 (10 being extremely confident and 1 being not confident at all) rate your comfort level with 3D printing on campus.
21. If your print fails, how likely are you to try to print it again?
    (a) Very likely
    (b) Somewhat likely
    (c) Somewhat unlikely
    (d) Very unlikely
22. Have you ever gotten help from the co-lab staff?
    (a) Yes
    (b) No
23. If yes, were they helpful?
    (a) Yes
    (b) No
24. The first time I had a 3D printing problem, I solved it by:
    (a) Researching how to solve the problem and trying again
    (b) Asking for help from a peer
    (c) Asking for help from a Co-Lab staff member
    (d) Asking for help from a professor or TA
    (e) I did not solve it
    (f) I solved it another way
25. The most recent time I had a 3D printing problem, I solved it by:
    (a) Researching how to solve the problem and trying again
    (b) Asking for help from a peer
    (c) Asking for help from a Duke staff member
    (d) Asking for help from a professor or TA
    (e) I did not solve it

(f) I solved it another way

26. Would you be willing to be contacted for an interview about your 3D printing use?
    (a) Yes
    (b) No

Appendix B

Interview

Each willing participant participated in a recorded Zoom interview. During this interview, the participant shared their screen while logged into their online 3D printing project history and answered the following questions for each of their prints:

1. Was this created for a class? Club? Just for fun? (Which class? / Which club? / What was the project?)
2. Was this created individually or on a team? (How large was the team?)
3. Was this personally designed by you using CAD?
4. Was this print successfully printed
5. Was this print able to be put into use?

After going through each of the participants 3D prints, the interview ended with them answering the following three questions:

1. What is the biggest 3D printing challenge you've had?
2. What is the most creative 3D printing project you've created?
3. Complete this sentence: I would 3D print more if ...