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# The Makeup of a Makerspace: The Impact of Stereotyping, Self-Efficacy, and Physical Design on Women's Interactions with an Academic Makerspace

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**ABSTRACT**

This article applies a qualitative ethnographic research approach to explore the perceptions of highly-skilled makers of gender and its role in their makerspace. It explores two research topics – common problems impacting makerspaces and the role of gender in makerspaces – and then analyses the results in the context of their impact on women's sense of self-efficacy. Various factors relating to the overall makerspace culture contribute to women's lowered sense of self-efficacy. In the makerspace under study in this work, a feminine-stereotyped Craft Area had been integrated among the more 'traditional' makerspace equipment, affecting women's participation in the space. Ergonomic and accessibility problems in the masculine-stereotyped areas of the makerspace were more likely to negatively impact women's use of the space. We discuss potential solutions to common problems in the makerspace and share recommendations to create a more universally accessible makerspace and impart the benefits of experiential learning more equitably.

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Makerspaces; heuristics; self-efficacy; gender stereotyping

## Introduction

Academic makerspaces provide an invaluable opportunity for hands-on experiential learning. Similar to 'fablabs' or hackerspaces, makerspaces are places where people can work together to build knowledge and physical or digital projects.[1] Makerspaces, often located in libraries, universities, community spaces, or museums, commonly provide access to woodworking, electronics, robotics, and fabrication equipment.[2] Academic makerspaces provide opportunities to integrate impactful active and experiential learning activities[3] into interdisciplinary curricula.[4] The open-source culture of makerspaces means that knowledge and equipment previously available only to experts is now accessible to the wider public. In the *Maker Movement Manifesto*, Mark Hatch[5] emphasizes the power of the maker movement: 'almost anyone can innovate,' 'almost anyone can make,' and 'anyone can change the world.' However, the use of the word 'almost' is telling in this context; makerspaces have been criticized for failing to attract and retain diverse users,[6] especially

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those coming from diverse socioeconomic, gender identity, racial, disability, and sexual orientation backgrounds.[7] As a result, it is mostly affluent, white, well-educated men who reap the personal benefits of makerspace usage,[8] which include building useful technical skills[9] as well as improved self-confidence in their abilities.[10] As a result, women face disproportionately strong barriers to building technical skills and self-confidence in makerspaces, which is critical because previous research has connected women's feelings of self-confidence to their likelihood of entering and remaining in STEM fields.[11] Women are already under-represented in STEM education and in the STEM workforce, with only 24% of U.S. engineering bachelor's degrees awarded in 2020 going to women.[12] In 2022, only 17.4% of all U.S. architecture and engineering employees were women.[13] Finally, in a study following women in the workforce over 30 years, there was only a 50% retention rate among women in STEM fields, compared to 80% for women overall.[14] In order to address the issues that exclude women from making and from engineering as a whole, it is first necessary to understand the context and causes for these problems.

From a physical design standpoint, makerspaces may enforce stereotypes and possess features that discourage women from fully interacting with them. Because many academic makerspaces are student-run, training procedures may benefit from peer-to-peer learning,[15] but suffer from a lack of experience in equitable management practices.[16] Previous qualitative research on the role of gender in makerspaces describes women feeling unwelcome and experiencing sexual harassment in makerspaces.[17] In makerspaces, women also face problems with reduced self-efficacy, which refers to one's belief in their own capabilities to perform a task.[18] Psychologist Albert Bandura originally proposed the concept of self-efficacy and identified four main factors that contribute towards building self-efficacy: master experiences, vicarious experiences, verbal persuasion, and physiological feedback, which are defined and explored further in the Background section of this article.[19] The contributing factors towards women's poor retention in makerspaces will be better understood through analysing the impact of each of these mechanisms on women's sense of self-efficacy.

Through a series of observations and ethnographic interviews with eight highly-skilled student makers (referred to in the makerspace as 'Masters'), the following research questions will be investigated in this article:

RQ 1) How does the perception and usage of a makerspace vary between two sub-areas with oppositely-gendered stereotypes attached?

RQ 2) What are common problems that impact makerspaces? Are they more likely to disproportionately impact some makerspace users over others?

RQ 3) How does gender play a role in makerspace self-efficacy?

The following section of this article will explore related background literature, and discuss how gaps in existing research informed the development of the research questions.

## Background and research questions

The makerspace under investigation in this article is a free-to-use, student-run makerspace at a major Southeastern U.S. institution of higher education. After opening a dedicated Craft Area of the makerspace in 2017, this makerspace experienced an increase in women users and makerspace employees. By integrating equipment that is less traditionally found in a makerspace, such as vinyl cutters, sewing machines, and button makers, the makerspace was able to attract users that may not have entered the studio otherwise – a finding that is critical given many makerspaces' struggle to attract and retain diverse users.[20] In a study where makerspace users were asked to indicate which gender identity they associated with various pieces of makerspace equipment, Marijel Melo found that sewing machines, electronic textiles, and craft supplies were all associated with women makers, while more common makerspace tools such as 3D printers, laser cutters, and hand tools were associated with men.[21]

The presence of gender stereotyping in engineering is well-established; for decades, technical expertise has been connected to masculinity, resulting in the overrepresentation of men in engineering higher education.[22] However, Amy Bix asserts that the presence of home economics training – a feminine-stereotyped area of technical training – in higher education is indicative of a link between femininity and technical skills.[23] Wendy Faulkner further explored nuances of stereotyping within engineering through ethnographic observation, describing engineering as containing aspects of both 'the technical' and 'the social,' with the former being associated with masculinity and the latter with femininity.[24] Reframing making with feminine stereotypes can help women feel welcomed, but there is a fine line to walk, as focusing too closely on women makers' identity as *women* rather than as *makers* can appear condescending and tokenizing.

The makerspace under study in this work provides a unique opportunity to study feminine-stereotyped and masculine-stereotyped making in the same physical space. In order to better understand stereotyping within makerspaces, and particularly trends that may arise when makerspaces integrate feminine-stereotyped making tools, the first research question that will be investigated in this article is:

> **RQ 1)** How does the perception and usage of a makerspace vary between two sub-areas associated with masculine and feminine stereotypes?

The goal of this research question is to explore the similarities and differences in the usage of the Craft Area, a feminine-stereotyped space, and the Wood Shop, a masculine-stereotyped space. We evaluate the physical environment of each of the spaces in order to better understand the signals that the space communicates to the users, and how this impacts their perceptions. The authors acknowledge that the wording of this question reinforces the erroneous interpretation of gender as a binary, rather than the proper interpretation of gender as a spectrum,[25] and emphasize that the gender diversity problem in makerspaces goes beyond just men and women. However, because each of the Masters in the Craft Area and Wood Shop identified as either a man or a woman, the conclusions of this article are limited to the perspectives of men and women. Additionally, stereotyping and views of the makerspace and its users were limited to a gender binary, reinforcing this research question's focus on masculine and feminine stereotypes.

Stereotype threat is the phenomenon that subverts the achievement of people when they feel that others may apply negative stereotypes to them when interpreting their behavior or their performance of a task.[26] Simply being a woman in a man-dominated environment can be enough to trigger stereotype threat, reducing women's comfort levels[27] and even their spatial reasoning performance.[28] Sarah Thébaud and Maria Charles identified two main forms of stereotypes that harm women's interest in STEM: stereotypes that depict women as intrinsically ill-suited for STEM work, and stereotypes that depict STEM work as ill-suited for women due to its solitary, uncreative, and masculine nature.[29] When men and women's STEM abilities are identical, STEM faculty members[30] and even their own parents[31] assess women as less competent in STEM-related skills.

These stereotyped perceptions of women influence the way they are treated by their peers. In collaborative technical work environments such as makerspaces, women are impacted by a group-work dynamic that pressures women into being less active group participants[32] and assuming non-technical group roles, such as note-taking and report writing, while men assume more technical roles.[33] In addition to more obvious hostile sexism, women are negatively affected by benevolent sexism, which often manifests in STEM fields as 'protective paternalism,' or the treatment of women as if they are weaker or need more assistance than men,[34] thereby undermining women's confidence and motivation.[35]

Physical cues, such as classroom decorations that carry a masculine stereotype, have also been found to decrease women's sense of belonging in an environment, causing them to be less interested in joining and more likely to leave the space.[36] This presents a particular problem for makerspaces, which commonly contain tools such as 3D printers, laser cutters, and hand tools, all of which are associated with a masculine stereotype.[37] In fact, machine log data has confirmed that men use 3D printers and CNC milling machines in makerspaces more often than women.[38]

In addition to facing the same common barriers to making as men do, such as access to tools, information, and funding, women especially struggle to find time for making.[39] One woman told Faulkner[40] that, 'to be a maker, you don't need an engineering degree, you need childcare' – a sentiment that is supported by the worldwide imbalance in unpaid labor and household work performed by men and women.[41] In addition to familial obligations, women also cite fear of failure, fear of the unknown, the loud and disorganized environment, and the gender imbalance as barriers to women's entry in makerspaces.[42] In order to understand problems that are inherent to the physical design of makerspaces (and thus can be solved by more empathic design), this article will answer the following research question:

**RQ 2)** What are common problems that impact makerspaces? Are they more likely to disproportionately impact some makerspace users over others?

The goal of this research question is to understand the problems that arise when users interact with the space, and whether users of different genders experience different problems. The crowd-sourced compilation of makerspace problems will inform the development of future studies, as well as being a valuable resource for people operating or starting a makerspace. After identifying these problems, we will propose solutions to these problems in the form of heuristics, which Katherine Fu et al. define as 'a context-dependent directive, based on intuition, tacit knowledge, or experiential understanding, which provides design process direction to increase the chance of reaching a satisfactory but not necessarily optimal solution.'[43] Extraction of mechanical design heuristics often suffers from uncertainty when researchers extrapolate heuristics based on their observations of designers at work[44] or products created by designers,[45] but the use of interviews as a heuristic extraction technique has been previously applied and validated by Kenton Fillingim et al.[46] We selected this heuristic format due to its success in communicating information in other subfields of mechanical design; designs that are developed with the aid of heuristic tools are of higher quality and function more effectively than those developed without heuristics.[47]

In addition to potentially impacting physical interactions with makerspaces, there is evidence that gender impacts the way users interact socially with makerspaces. Within the maker community, men are more likely than women to prefer solitary work with less interaction with other makers, while women are more likely than men to gravitate towards building an in-person maker community by attending maker events, fairs, clubs, or social groups.[48] Despite this, women who turn to online maker communities find themselves once again outnumbered and excluded on sites such as Instructables.com, which feature sets of instructions for DIY projects.[49] On Instructables.com, the only project categories with women posters exceeding men were related to sewing, jewelry crafting, and decorating, which correspond to the feminine-stereotyping of the analogous areas in some makerspaces.[50]

These differences in the way men and women interact with making has resulted in the role of women in makerspaces being viewed as less technical and therefore less deserving of respect.[51] In makerspaces, there is a division between 'crafting' and 'making,'[52] with women who use makerspaces self-identifying more strongly with terms such as 'creator', 'crafter', 'artist', and 'designer', while men identify more with 'hobbyist', 'engineer', and 'builder.'[53] Accordingly, men in makerspaces are more likely to have a STEM or technical background, while women who use makerspaces are more likely to come from a humanities background.[54] Women have been described as being drawn to making by the aesthetic aspect, influenced by platforms and communities such as Pinterest and Instagram.[55]

Researchers have made efforts to host workshops and develop makerspace environments where women feel comfortable engaging with spaces and methods from which they have, until recently, been excluded.[56] Part of this effort includes exposure to women as role models,[57] which are currently lacking in makerspace environments.[58] Seeing women as role models demonstrates to women users that women are not just given access to makerspaces, but are recognized and made visible.[59] The student-run format of many academic makerspaces means that equipment training is conducted by students, providing opportunities for new users to build self-efficacy. Watching other women be successful in a makerspace environment supplies users with a vicarious experience – an important contributor to self-efficacy,[60] which is especially critical for women in makerspaces as their self-efficacy levels are generally lower than men.[61] High self-efficacy results in higher persistence, resilience, motivation, commitment towards goals, and better mental health,[62] in addition to being correlated with a higher likelihood of both entering and becoming successful in STEM fields.[63]

In addition to the aforementioned vicarious experiences, Bandura identified three additional sources of self-efficacy.[64] The strongest is performance accomplishments, which refers to personal mastery experiences. In other words, successfully performing a task increases a person's self-efficacy. After vicarious experiences, the next strongest sources of self-efficacy are verbal persuasion, such as social encouragement and affirmation, and physiological feedback, which is related to a person's emotional state. Involvement in academic makerspaces increases students' self-efficacy by providing personal mastery experience, particularly boosting self-efficacy in the design abilities that are critical for engineers.[65] As a result, the barriers for women in makerspaces may be preventing them from building valuable engineering self-efficacy. In order to better understand this phenomenon and move towards a solution, this article will answer the final research question:

RQ 3) How does gender play a role in makerspace self-efficacy?

The goal of this research question is to explore how gender affects users' experiences in the makerspace. The intimidation some women feel upon entering a men-dominated makerspace results in low self-efficacy. This article will present an analysis of the factors that may contribute to this self-efficacy problem.

## Methods

The researchers used a qualitative, ethnographic approach consisting of both an observational and an interview portion to investigate the above research questions. We conducted this work in the context and environment of a free-to-use, student-run makerspace at a major Southeastern U.S. institution of higher education. Student 'Mastersï£¡ï£¡ï£¡ conduct the more intensive equipment maintenance, complex training, and safety procedures after undergoing months or years of training to specialize in a particular area of the makerspace, such as the 3D printers, laser cutters, or wood shop. We selected the Masters as the participants for this study due to their knowledge and experience in the makerspace. Four Masters from the Craft Area (previously identified as a feminine-stereotyped space) and four masters from the Wood Shop (previously identified as a masculine-stereotyped space) agreed to participate in this research. The researchers introduced themselves to the participants via email, and each participant provided consent for the researchers to observe their 'Master Hours', or time when they were staffing their respective space and answering users' questions in the makerspace. The Institutional Review Board at the Georgia Institute of Technology oversaw and provided guidance throughout the entire study protocol, including the consent procedure. During this observation time, the researchers recorded how users were utilizing the makerspace, how the Masters interacted with the users, and the types of problems that were observed. In addition to providing the researchers with a deeper understanding of the Craft Area and Wood Shop areas of the makerspace, these observations also served as a basis for the interview questions.

We developed the interview questions using guidance from Johnny Saldaña et al.[66] For example, we asked questions that were as open-ended as possible in order to encourage thorough responses from interviewees. Additionally, we piloted the interview questions to ensure that responses would sufficiently aid us in answering the research questions. The finalized interview protocol began by collecting more general background information,[67] then narrowed in on questions directly relating to the research questions, based on feedback from piloting. The chosen interview site was a comfortable, casual environment in order to build a positive, balanced relationship between the researchers and participants, and so that participants would feel comfortable expressing their views and experiences.

The research questions, observations from the makerspace, and prior investigations into makerspace usage[68] informed the development of the interview questions. Interviews followed a semi-structured format of 1) background on the makerspace and the Master's involvement with it, 2) details on a project the Master made recently in the makerspace, 3) how the Master witnesses students interacting with the space, and 4) problems that are encountered in the makerspace. The researchers added questions within the sections based on their observations during each interviewee's Master Hours. For example, one Master spent much of the observation session helping a user who was struggling with the table saw, so the researchers asked questions during the interview to better understand the problems associated with using the table saw. Throughout the interview, researchers also asked follow-up questions as needed. The second author of this article recorded audio and video of the interviews, while the first author took notes while interviewing each participant. The second author was present for all interviews and independently recorded a second, more thorough set of notes during the interviews. Participants also filled out a brief demographic survey, including their gender, age, major, and degree progress. The Masters interviewed represented both men and women, undergraduate and graduate students, and mechanical engineering and industrial design majors. Participants received $20 as compensation for participating in the one-hour interview session.

The researchers used the notes that they took during the interviews, as well as transcripts of the audio recordings, to translate information from the interviews onto virtual sticky notes. Similar to the technique utilized by Christian Voigt et al.,[69] they then used three primary codes, established based on the research questions, to sort and code the virtual sticky notes into an affinity diagram using the online tool Miro.[70] Finally, the researchers used the affinity diagram to perform a thematic analysis to identify the sub-themes from the interview results.[71] The following section of this article, Results & Discussion, will be broken down into subsections based on these three primary codes: Environment and Usage, Gender and Self-Efficacy, and Problems and Solutions.

## Results & discussion

### *Makerspace environment and usage*

This section will report data from the observation portion of the study to give context for the makerspace, and then tie these observations in to results from the interviews. Upon entering the Wood Shop, one got the sense of an industrial machine shop, as shown in Figure 1.

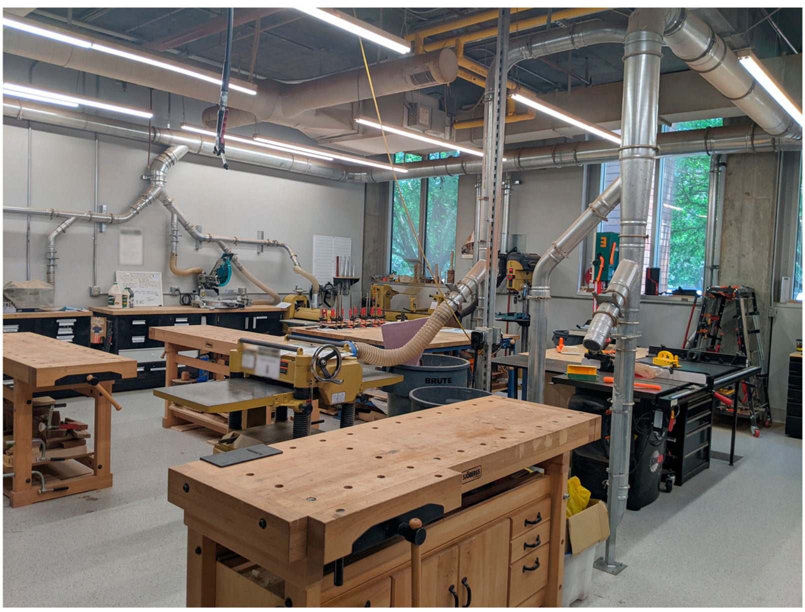

**Figure 1.** Photo of the Wood Shop, with worktables in the front and left, storage cabinets along the back wall, and the table saw visible to the right.

The walls and floors were gray, along with the plentiful ductwork throughout the room for ventilation. Tabletops and pieces of furniture were made of natural wood, and most pieces of equipment were black or yellow, which, along with some safety orange, made up most of the color in the room. Tabletops and counters were high, between 36″ and 40″, as all of the tools in the Wood Shop must be used while standing rather than sitting. The walls were undecorated except for some signs with safety instructions, although the Masters talked about plans to put up shelving to hold tools and display example products. Generally, while the aesthetic design of each space leaned towards a masculine stereotype, the appearance of the Wood Shop adhered more strictly to the masculine design stereotypes laid out by Miriam van Tilburg et al., with its robust materials, bulky furnishings, and straight lines.[72] Accordingly, the Masters were in agreement that men were the dominant users of the Wood Shop.

In the Craft Area, shown in Figure 2, the walls were adorned with sample projects that were made on the machines. A rainbow of sewing thread and yarn were on display on the walls, along with a collection of Polaroid photos of users enjoying the makerspace. The table and counter heights in the Craft Area were much lower, between 30″ and 34″, as the equipment can be used while sitting down, and the Masters encouraged the use of the Craft Area as a space for makers to socialize and share ideas. Often, users came to the Craft Area without a project in mind, but get inspired and start making once they're in the space, while Wood Shop projects typically require more prior planning. Although the Masters disagreed on whether more women actually use the Craft Area than men, there was a consensus that compared to other areas of the makerspace, especially the Wood Shop, more women can be found in the Craft Area, with one Master speculating that this may be due to 'societal pressures.' At the time this study was conducted, the makerspace's website used a picture

**Figure 2.** Photo of the Craft Area, with vinyl cutters off-screen to the left, sewing machines in the center of the photo, and more specialized equipment and materials along the wall to the right.

of the Pinterest logo to advertise the Craft Area, rather than a picture of the tools in the area as it did for the other areas of the makerspace, including the Wood Shop. This observation aligned with the findings of Jennifer Eckhart et al. regarding the social-media-aesthetic component of feminine-stereotyped making.[73]

In the Craft Area, each piece of equipment was named after a '90s hip-hop artist, with its name displayed with a colorful vinyl sticker. The Craft Area Masters explained that they were in the process of renaming each piece of equipment after a type of bird, in order to make them more 'feminine.' The tradition of naming and labeling tools extended to the laser cutting and 3D printing areas of the makerspace as well, and some Masters explained how naming the tools made the makerspace feel less intimidating and more approachable. In the Wood Shop, tools were not named or labeled except for the vacuum cleaners, for the purpose of clear communication between the different Masters when discussing which of the identical machines needs maintenance. The Wood Shop Masters explained that there was no need to name the tools since there was, for the most part, only one of each piece of equipment (compared to the Craft Area where there were multiple vinyl cutters and sewing machines), and they wished for the users to refer to each tool by the proper name. Some of them also believed that naming the tools would detract from the 'serious' atmosphere of the Wood Shop. Although the tool naming seems like a fun tradition on the surface, it is one indicator of the 'fun' vs 'serious' divide between the Craft Area and Wood Shop.

Through the interviews with the Masters, a difference in perceptions of the Craft Area and Wood Shop by users and employees quickly became apparent to the researchers, as summarized in Table 1. Generally, Masters viewed the Wood Shop as a more 'serious' area of the makerspace, with one woman Master describing its 'hard equipment, something you need to concentrate more on.' The same Master described her view of the Craft Area as casual: 'a bit more playing around, a bit more creative.' Part of this may be due to the inherent danger of the spaces: the Wood Shop carried 'a lot more potential for injury' than the Craft Area does, and had safety systems in place accordingly. In addition to the safety risks associated with making a mistake, the Wood Shop inherently held higher time and financial consequences. Shorter-term projects were more common in the Craft Area, while Wood

**Table 1.** Summary of contrast between the Craft Area and Wood Shop areas of the makerspace based on Masters' interview responses.

| Craft Area | Wood Shop |
|---|---|
| 'More art-focused,' 'cute,' 'decorative,' 'aesthetics,' 'finishing touch' projects | 'Functional,' 'not specifically aesthetic' projects |
| 'More accessible' | 'Big scary tools' are intimidating |
| 'Art for the sake of art' | 'Also artsy, but in a more technical way' |
| Shorter-term projects: 'projects are pretty quick and simple' | Longer-term projects: 'a little bit more gravity and seriousness to it' |
| 'Fun', 'casual,' 'People used to dismiss it, kind of,' '[Craft Area] is not a real section' | Danger: 'a lot more potential for injury,' 'Hard equipment, something you need to concentrate more on' |
| 'I actually just really enjoy [Craft Area], and I just love [Craft Area]' | 'I thought it would look better on my resume' |
| More casual, less academic usage: 'a lot more recreational users' | Projects for classes as well as personal projects: '[Robot-building course] devours the space' |
| Hobby, crafting, 'not as engineering' | Manufacturing, engineering |
| Makerspace supplies materials | Users provide their own materials |
| More women users | More men users |
| 'More diversity of majors and diversity of people' | 'Most of the people who come in to use our space are mechanical engineers' |

Shop projects were often longer-term, meaning that mistakes throughout the woodworking process were more likely to result in wasted time. Materials for Wood Shop projects were typically more expensive, so there was also a concern about wasting expensive material, as summarized by one of the Wood Shop Masters:

> So, fabric, like you just grab it, but, wood – like if I've spent like two hours, milling it down four square, ripping it down to a certain thickness, like, there's a lot of work that goes into before you actually start your project. And so that is also stressful. And then like, also, it's expensive, you know.

The makerspace provided funding for the Craft Area to keep materials in stock for any users to take, while the users of the Wood Shop must provide their own materials, further raising the stakes for woodworking mistakes. The typical use case of the Wood Shop and Craft Area also differ; for example, according to the Masters, one of the most common projects seen in the Wood Shop was a wood-frame robot required for one of the university's core classes in the Mechanical Engineering curriculum, a class which they say sometimes 'devours the space.' Near the end of each semester, when the robots were mostly complete, students often used the Craft Area equipment to add finishing decorative touches or 'make it nicer.' However, despite the Craft Area's reputation as a fun spot to bedazzle your belongings, Craft Area Masters said the area is underestimated – it even features 'one of the biggest, advanced tools' in the makerspace, the embroidery machine.

However, another factor in the perception of the Wood Shop and Craft Area may be differences in the way that work performed by men and women has been viewed and credited; industries that begin to attract women also attract a downward trend in pay and prestige.[74] The first computer programmers were mainly women who used a punch-card system, notably utilized during the early Apollo missions, that was adapted from weaving-loom technology. Originally, this field carried a stereotype associated with administrative work, however, the field rapidly increased in pay and prestige as it became dominated by men in the late 1900s.[75] Relatedly, when women make creative innovations, such as in fashion or composing, it is viewed as a fun hobby, while men make prestigious careers of it.[76] Perhaps this historical trend is partially behind the reason for the different levels of respect associated with the Wood Shop, a masculine-stereotyped space, and the Craft Area, a feminine-stereotyped space. When discussing common Craft Area projects, Masters focused mostly on discussing personal projects such as vinyl stickers, jewelry, pieces of clothing, and cloth masks. However, the Craft Area was also conducive to important academic projects, such as car airbags, surgical gowns, wearable electronics, parachutes, and cold-weather camping gear. The Craft Area also attracted many users who want to use the sewing equipment to repair a piece of clothing. Even among men who use the Craft Area, Masters reported that men tend towards more utilitarian uses of the space, such as mending clothes, working on research projects, or adding logos to existing garments rather than 'literally making the garment' from scratch, as they more often saw women doing. One Craft Area Master observed that men who use the Craft Area sometimes felt self-conscious about using the sewing machines, suggesting that this might be tied to cultural views on masculinity.

### *Gender and self-efficacy in the makerspace*

Throughout the interviews, responses related to women's self-efficacy in makerspaces addressed Bandura's four sources of self-efficacy.[77] This section of the article presents a breakdown of how factors in the makerspace impact each of the four main self-efficacy sources for women.

1. Performance Accomplishments: One woman Master described how women users of the makerspace are 'treated like they don't know as much.' Masters of both genders described observing that in general, women in the makerspace were less likely than men to have previous experience with performing makerspace-related tasks, reinforcing decades of marketing and social stereotypes assigning tools and hardware as a masculine domain.[78] One man Master speculated how societal expectations may have caused users' backgrounds with tools to differ: 'women aren't as called upon to be learning these tasks, you know, helping dad fix the roof, as a man might.' As a result, women's self-efficacy may have been impacted by a lack of performance accomplishments. Some women Masters described new women users as appearing intimidated and hesitant in the space, describing themselves as new users being 'very intimidated' and 'scared from afar.' One woman described the perspective of a new woman user of the makerspace: 'when you just walk in, and you see almost no girls in the space, you kind of feel awkward.' Conversely, Masters observed how men who were new to the space 'overestimate how their skills apply to our space,' or expressing overconfidence in their woodworking skills and knowledge based on previous experience in a different environment.
2. Vicarious Experience: Because makerspace employee training was performed by other student employees, the training system promoted a collaborative environment that is conducive to vicarious experiences. The positive impact of having a role model for women is stronger when the role model is also a woman,[79] so the lack of women in leadership positions – 'somewhere between 10 and 20%' in the makerspace under study – may be damaging for new women users' vicarious experience of self-efficacy. Ensuring that women are involved in training as student employees will further strengthen the benefit of vicarious experiences for women in the makerspace.
3. Verbal Persuasion: Many of the Masters spoke favorably of the collaborative and friendly environment of the makerspace, resulting in positive verbal persuasion experiences for many users. Student employees often encouraged users to go through training and become makerspace employees as well, which motivated users to believe that they could be successful. However, many women in the makerspace had encounters that may negatively affect their verbal persuasion, resulting in them feeling 'not as worthy of the space.' One woman Master felt that 'sometimes men don't come to me on purpose, or they will, like, dismiss me.' Women were addressed in ways that cause them to question whether they belong in the makerspace – such as users acting surprised when they discover that a woman is a Master in a masculine-stereotyped makerspace area, or when their peers address a question to other men rather than a more qualified woman Master in a conversation. Both benevolent sexism, such as men being overly helpful or assuming that a woman doesn't know what she's doing ('sometimes we have some awkward dude PIs who are a little too helpful to the female users'), and outright hostile sexism, such as degrading the competence of women makerspace employees, are discouraging for women and serve to lessen their self-efficacy.
4. Physiological Feedback: Women in the makerspace encountered stress and emotional situations that men in makerspaces simply do not have to deal with. Upon entering

the makerspace, they are confronted with stereotype threat.[80] One Master discussed an internal conflict between wanting to dress fashionably and not being taken seriously as a woman in a man-dominated space ('I feel scared to dress cute, because I'm like, "I'm not going to be taken as seriously if I dress cute."'). Although she brushed this off as a frivolous concern, this conflict was not without merit – stereotypically feminine appearance decreases women's likelihood of being perceived as a scientist.[81] The instances of sexism addressed under Verbal Persuasion also result in increased stress and taxing negative emotions.

One additional theme that does not fit easily under Bandura's categorizations, but is nevertheless important to the development of self-efficacy, is women's sense of fitting in to the physical environment.[82] Prior work has shown that properly fitting personal protective equipment (PPE) is positively correlated with women's self-efficacy.[83] PPE in the makerspace is provided on a 'one size fits all' basis, which disadvantages women and jeopardizes their physical safety.[84] Women's self-efficacy and safety would be improved by providing properly-fitting PPE for all body types, as well as ensuring that makerspace equipment is physically accommodating of their body types, which will be discussed in detail in the next section on makerspace problems.

Masters report women users appearing intimidated by the makerspace, and women Masters described feeling 'really intimidated' and 'scared' when first starting out as users of the makerspace. Societal norms and stereotyping in childhood promote construction and building activities, which stimulate spatial abilities important for makerspace success, for boys.[85] Potentially due to women's lack of prior experience with the activities in the Wood Shop, Masters observe women in the makerspace 'self-selecting' to the Craft Area. One Wood Shop Master also noted that users who lacked self-confidence were especially hesitant to start using Wood Shop tools. In order to make all areas of the makerspace feel accessible to everyone, one Master discussed the importance of having positive interactions with new users, especially women, in order to encourage them to return to the makerspace. Another woman Master attempted to help her friends overcome this intimidation by organizing social events for women to go to the makerspace as a group and work on a project together ('I'll invite all my girlfriends, be like, "hey, let's go make stickers."'). One woman Master also helped create and sell 'more girly' makerspace merchandise, such as shirts for student employees to wear, since she perceived the shirts with the default makerspace branding as too masculine.

### *Problems and solutions in the makerspace*

Throughout the interviews, the Masters made it clear that the main problem plaguing the makerspace was employee training. Although, as discussed previously, student-led trainings may positively impact self-efficacy in addition to being financially and logistically efficient, any poorly-trained students can 'slip through the cracks' and propagate the poor training. This issue will be expanded upon further in the Conclusions section of this article, as the authors chose to focus on physical and ergonomic problems existing in the makerspace, rather than on administrative and training issues. In addition to discussing problems that they observed in the makerspace, the Masters also suggested solutions for the problems, when possible. Table 2 summarizes a set of guidelines for developing and maintaining a makerspace derived from these problems and solutions.

**Table 2.** Summary list of common makerspace problems, identified by Masters, and solutions presented in heuristic form.

| Problem | Solution in Heuristic Form |
|---|---|
| There is not enough room for all tools and users in the makerspace | When planning the layout of a makerspace, account for future expansion and utilize wall space |
| It can be difficult to find the tool or component you need | To ensure that components are easy to find, label all drawers and cabinets clearly |
| Components in the makerspace are often overtightened by the previous user | To prevent users from struggling with overtightened components, provide force multipliers or lever extensions for additional torque |
| Users struggle to transport heavy work pieces and overweight trash bins | To easily transport heavy loads, provide wheeled transportation, such as dollies or carts |
| Some tools are too high or low off the ground, making them uncomfortable/dangerous to use | To accommodate all users, install adjustable-height work surfaces whenever possible |
| The provided 'one-size-fits-all' personal protective equipment does not fit all users | To accommodate a wider range of body types, provide a range of/adjustable PPE sizes |
| Users slip on the floor, especially when using their body to apply force to a workpiece | To prevent slipping, provide non-slip mats or install non-slip textured flooring |
| Some power drills are too large to be used with one hand for some users | To ensure that tools are accessible for users, conduct research before purchasing power tools and provide a range of sizes |
| Craft Area users with large hands struggle to manipulate small parts on sewing machine | To replace tedious and difficult manual tasks, provide automatic or assistive tools such as an automatic needle threader for a sewing machine |
| Users move all over the space when performing a task | To allow users to utilize a space more efficiently, group related tools and materials together |
| Scrap containers not organized or used appropriately | To keep scrap containers neat and free of trash, provide scrap containers clearly labeled by size of material |
| Users with mobility issues cannot navigate narrow walkways | To make every area of the makerspace accessible, maintain a 32″ wide path to each tool in accordance with the Americans with Disabilities Act |

For standardization, these guidelines are presented as heuristics. The flexibility of the interview structure of this present work permitted the researchers to gain clarity and ask explicit follow-up questions about heuristics, although this format also meant that researchers were only able to consider heuristics that the Masters were consciously aware of. While some of these heuristics have been validated by their implementation into, and subsequent improvement of, the makerspace, others are derived only from the Masters' experiences; although these remain unvalidated, this method of heuristic derivation is well-supported and common.[86] Future research should work to validate these heuristics prior to implementing them in practice.

For problems that generally impact most users equally, the heuristic solution was typically quite clear, as the Masters had already implemented or conceived of a solution. Many of these problems were solvable through a relatively simple single solution. For example, throughout the eight interviews, the lack of space was a problem that the Masters constantly brought up in both the Craft Area and Wood Shop. In addition to contributing to an overall feeling of crowdedness, the lack of room in a makerspace may cause safety hazards from users bumping into each other, the inability for two users to use adjacent tools at the same time, or a movable tool being inoperable at the edges of its range of motion. When designing a makerspace, care should be taken to ensure that the space not only adheres to the Americans with Disabilities Act accommodates the presently-existing tools and users, but also permits future expansion.[87] In the Wood Shop, a considerable amount of floor space was occupied by tool storage, and Masters noted plans to utilize wall-mounted storage instead to save space, which would also make tools more visible and alleviate new users' struggles to find tools.

When many people are using the same space, differences in physical abilities can become apparent. Considering the difference between men and women in physical strength, particularly mean height and upper body strength, this may pose a problem for women or people with lower-than-average physical strength in makerspaces.[88] For makerspace problems with a gendered/accessibility slant, a range of solutions may be required to accommodate users rather than a single solution as discussed above. For example, some tools in the Wood Shop, such as a spindle sander and miter saw, were permanently fixed at a height that was too high for shorter users, who are often women, to use comfortably and safely. This layout had been selected by a person who did not consider the range of body types that the equipment would need to accommodate. The Masters provided a step stool as a temporary workaround, but this poses its own risks, and some women said that they simply avoided using those tools. In the Craft Area, the inverse problem occurs, where the table height is uncomfortably low for taller users, who are often men.

## Conclusions

Makerspace Masters perceived the masculine-stereotyped Wood Shop as a serious, high-stakes area of the makerspace. Conversely, they viewed the less-traditional, feminine-stereotyped Craft Area as a place to have fun and work on casual projects. This may be related to the relative levels of danger among the spaces, as well as historical trends painting stereotypically feminine work as less valuable. The physical design of the two spaces also contributes to these perceptions. Although this work identified distinct trends in the stereotyping and perceptions of the Wood Shop and Craft Area, the exact mechanisms that caused these biases are not understood. Of the accessibility problems discussed in the previous section, many of them disproportionately impacted women in the Wood Shop or men in the Craft Area. Would adjusting inequitable physical factors such as the heights of some worktables and providing various sizes of tools diminish this stereotyping, or is stereotyping in the makerspace more due to social and cultural factors? Implementation of the identified solution heuristics would not only validate the heuristics, but also provide more insight into how makerspace accessibility problems can be solved.

This work compiled a list of common problems in makerspaces and a set of heuristics for makerspace design. These heuristics may serve as a helpful resource for people starting a makerspace or improving an existing makerspace, serving as a reminder to proactively tackle accessibility problems that are often overlooked until they are first encountered. Problems encountered in the Wood Shop were more likely to negatively impact women on the basis of body size and strength.

In addition to problems related to the physical design of makerspaces, Masters acknowledged problems with general makerspace employee training as one of the greatest impediments to makerspace access. Although this work focused mainly on solutions that will be most relevant to future work in mechanical design, and particularly future studies on the impact of implicit gender bias on the design of physical products and environments, the importance of effective and equitable training in makerspaces cannot be overstated. Especially considering the issue of women's lower self-efficacy, training should be viewed as an opportunity to provide vicarious experiences to underrepresented users of makerspaces by showcasing women and other underrepresented users as people with authority in the space. Additionally, while many student employees, such as teaching and research assistants, are required to undergo diversity or anti-bias training, many makerspace employees are volunteers, and thus not subject to the same requirements. Bias training for all makerspace employees has the potential to help employees recognize and prevent the instances of both benevolent and hostile sexism previously discussed. However, further exploration must be conducted before implementing either of these strategies to avoid common pitfalls such as adding additional unpaid labor to the workload of tokenized minorities,[89] or the consequences of ineffective diversity training.[90]

Although the Masters interviewed in this study identified trends on gender breakdown in the makerspace based on their combined years of observations and experiences, more robust conclusions could be drawn from long-term tool usage tracking. For example, data on makerspace users and employees broken down by gender before and after introduction of more feminine-stereotyped tools would allow these trends to be quantified.

This article applied Bandura's theory of self-efficacy as a framework to evaluate the lowered self-efficacy of women in makerspaces.[91] Although makerspace usage has been proven to benefit engineering students, the culture and background of men-dominated makerspaces present barriers for women to achieve positive performance accomplishments, vicarious experiences, verbal persuasion, and physiological feedback.[92] Now that these detracting factors have been laid out in detail, makerspaces can begin the task of tackling the cultural issues that allow these disparities to persist. It should be noted that the diversity problem in makerspaces is by no means limited to gender, or the gender binary, and this work could be expanded into intersectionality by exploring the makerspace experience as a function of race, class, sexuality, and more.[93]

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