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Participation pathways for women into university makerspaces

Megan Tomko[1] | **Melissa W. Alemán**[2] | **Wendy Newstetter**[3] | **Robert L. Nagel**[4] | **Julie Linsey**[1]

[1]George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia

[2]School of Communication Studies, James Madison University, Harrisonburg, Virginia

[3]College of Engineering, Georgia Institute of Technology, Atlanta, Georgia

[4]Department of Engineering, James Madison University, Harrisonburg, Virginia

Correspondence
Julie Linsey, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, 801 Ferst Drive, Atlanta, GA 30332.
Email: julie.linsey@me.gatech.edu

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Abstract

Background: Engineering education has observed considerable growth in academic makerspaces with initial data indicating significant potential for makerspaces to support learning.

Purpose/Hypothesis: Given gender disparities in engineering as a professional community of practice (CoP) and indications for makerspaces as sites for learning, educational researchers need to forge a better understanding of women's pathways into makerspaces, including the barriers that inhibit and the catalysts that broaden participation.

Design/Method: This study employed qualitative interviews with 20 women students who were identified as makers in order to gain insights into the characteristics of their pathways into university makerspaces.

Results: Using grounded theory development, four major aspects of students' pathways emerged: (1) early forms of apprenticeship through mentors; (2) overcoming and resisting limiting gendered expectations imposed by others in early experiences in unfamiliar makerspace CoPs, resulting in failed articulations of related communities; (3) successful articulations of community grounded in making-centered coursework and personal passions; and (4) relationships in college that expanded access, leadership, and visibility toward fuller participation in makerspace CoPs.

Conclusion: Educational interventions to broaden women's participation in makerspaces must be multipronged and attend to early childhood experiences, include supportive opportunities for women to participate in making in K-12 and university curricula, expand definitions of making to legitimize the arts and crafts as part of design, and create apprenticeship opportunities for women to mentor women in makerspaces. We must change the narrative of who makers are, what making is, and who belongs in makerspaces to reduce barriers and create inclusive making communities.

KEYWORDS
apprenticeship, community of practice, gender, inclusivity, makerspace

1 | INTRODUCTION

The prevalence of academic makerspaces has generated interest among engineering educators in understanding how to engage students in makerspaces and identify the impact of those spaces on student learning and development. Yet 81% of the demographic participating in the maker movement identify as men (Make/Intel, 2012), signaling societal constructions that assign gender to tools, designing, and making (A. Meyer, 2018). These gendered constructions are not particularly surprising as women are an underrepresented group both in engineering (Labor, 2017) and as participants in makerspaces (Bean et al., 2015). Given the gender disparities in engineering as a professional community of practice (CoP) and indications for makerspaces as sites for learning, it is essential that educational researchers explore the pathways of women into makerspaces, including both the barriers that inhibit their participation and the catalysts that broaden their participation.

Understanding women's entry into makerspaces requires investigating key situational factors, such as family, schooling, and gender ideologies, that are not necessarily captured in typical pathway models. It is necessary to look at the entire ecosystem (Lord et al., 2019) in which women engineering students learn and work in order to understand their successful entry into makerspaces as CoPs. Indeed, Allendoerfer et al. (2012) demonstrate the importance of looking at the influences of multiple communities toward understanding students' academic trajectories and success. Undoubtedly, girls and women makers come to making via a variety of different opportunities, thus warranting closer study (Intel & HarrisPoll, 2014). The qualitative interview study presented in this paper examines how women move through various overlapping ecosystems in their pathways toward participating in an academic makerspace CoP such as those found on many campuses today. Specifically, we recruited women students who identify themselves as makers to participate in in-depth reflective interviews about how they came to be involved in the makerspace and their experiences therein. Using grounded theory, we identified themes that provide critical insight into understanding women students' forays into university makerspace CoPs, and from which, we offer implications toward creating a more inclusive engineering professional CoP by opening up greater opportunities for girls and women in making and makerspaces.

2 | BACKGROUND

To explore the pathways of women students into an academic makerspace CoP, it is necessary to set the context of women in engineering and science, technology, engineering, and math (STEM) as well as the conceptual framework of a CoP with the related learning affordances of legitimate peripheral participation (LPP) and apprenticeship and its application to engineering. While we embrace the ecosystem metaphor for understanding participation patterns of women in engineering practices, we are also interested in the evolution over time of changing and growing participation experiences. Thus, we use the word "pathway" to capture this temporal aspect of their learning trajectories as they move through various ecosystems.

2.1 | Women in engineering and makerspaces

Women continue to be underrepresented in the engineering field (Labor, 2017), which is heavily influenced and driven by a culture of masculinity (Hatmaker, 2013; Herman et al., 2013; Hewlett et al., 2008; Miller, 2004; Sharp et al., 2012), and in fact, as a profession, engineering itself is gendered masculine (Cockburn, 1985; Hatmaker, 2013). As a result of the associated gender stereotypes, men continue to be viewed as most suited for engineering work (Ely & Padavic, 2007; C. L. Williams, 1995). Indeed, the engineering profession is seen as among the most male-dominated professions in the United States (Fox, 2006).

This masculine culture of engineering has impacted women in the profession in a variety of ways. For example, women engineers have taken masculine attributes and behaviors, particularly in their interactions with others (W. Faulkner, 2000; Jorgenson, 2002; Kvande, 1999; McIlwee & Robinson, 1992) or ignored potential gender differences by describing the workplace as neutral while considering themselves to be just like the men (Jorgenson, 2002; Kvande, 1999; Ranson, 2005). Women have historically adopted such strategies and mindsets as a result of exclusionary practices (W. Faulkner, 2009a; Miller, 2004), particularly as they face resistance from co-workers, as perceived anomalies to the profession (W. Faulkner, 2009b; Miller, 2004). Women struggle to develop a sense of belonging or to adopt an engineering identity in a profession that is seemingly incompatible with their gender identities (Eisenhart & Finkel, 1998; W. Faulkner, 2000, 2009a, 2009b; Jorgenson, 2002; Kvande, 1999; Tonso, 2007). More importantly, women's competence is contested by gender ideologies that equate "engineer" with "masculinity," as one's

> competence as an engineer is a function of how well one presents an image of an aggressive, competitive, technically oriented person. ... To be taken as an engineer is to look like an engineer, talk like an engineer, and act like an engineer. Of particular importance in this presentation of self is the image of hands-on competence. (McIlwee & Robinson, 1992, pp. 20–21)

Despite women's competence in the technical aspects of engineering, gendered expectations create barriers (Sharp et al., 2012) and may lead to situational practices that preclude and exclude women from developing hands-on competence. Women face daily barriers (Miller, 2004; Powell et al., 2009; Rhoton, 2011), including microaggressions (Camacho & Lord, 2011) and forms of hostile and benevolent sexism such as spotlighting (McLoughlin, 2005).

Further, women of color experience a double bind in engineering spaces, confronted by the intersections of sexism and racism (Cross et al., 2017). As a result, women engage in both coping strategies (Jorgenson, 2002; Khilji & Pumroy, 2019; Miller, 2004; Watts, 2009) and impression management (Goffman, 1959) as a means to experience validating interactions that create a sense of belonging (Hatmaker, 2013). For women of color, the creation of counter spaces, "safe social spaces ... which offer support and enhance feelings of belonging" (Ong et al., 2018, p. 207) is of further importance toward their persistence and success in STEM-related fields.

Unfortunately, while makerspaces are touted as open, collaborative learning environments, legitimacy in the form of prior hands-on experience and competence may place many women at a disadvantage. For example, Nordbrock, a maker, volunteer, and board member of Xerocraft, is quoted by Reed (2018) as saying:

> There's some unspoken societal rules that have to do with makerspaces, and it ends up being why there are more men in engineering, or why there are more men showing up to a makerspace. These unspoken rules assign gender to the use of tools or the ability to make and design things. (para 5)

While these tacit understandings assign gender to tools and designing, crafts, often the purview of women, frequently are not acknowledged as "making" (S. Faulkner & McClard, 2014). Further, gendered associations with makerspaces can cause women to avoid makerspaces as they are generally dominated by men (S. Faulkner & McClard, 2014). In an effort to understand women's making experience, Intel and HarrisPoll (2014) conducted a mixed-methods study of girls and women makers worldwide. They found that women makers are more likely than men to come to making through multiple pathways, including engineering, computer science, arts, and design (Intel & HarrisPoll, 2014). Further, through encouragement and support from community members in their projects, women can come to participate in makerspaces in order to be able to present their work and collaborate with others (Bean et al., 2015). While these studies have focused on a variety of different settings, there remains little understanding of women students' pathways into the burgeoning number of academic engineering-oriented makerspaces.

2.2 | Legitimate peripheral participation and apprenticeship in communities of practice

A makerspace, an engineering academic department, or engineering as a profession are all CoPs. Such communities comprise members who share a common set of competencies learned through opportunities independently sought or offered to them for recurring shared social interactions that constitute learning (Lave & Wenger, 1991). Members in the CoP engage in both apprenticing and receiving apprenticeship in collaborative social activities (Kriner et al., 2015). Membership in a CoP is achieved through LPP in activities offered to newcomers and mediated by apprenticeship interactions with expert members. As noted by Lave and Wenger (1991), "peripherality, when it is enabled, suggests an opening, a way of gaining access to sources for understanding, through gaining involvement" (p. 37). When a newcomer to a CoP is offered this opening, it can serve as the start of a pathway toward increasing community membership achieved through repeated apprenticeship interactions in activities valued by the community that leads to learned competencies. This study is particularly interested in how women successfully enter a CoP, specifically an academic makerspace that has been historically gendered masculine, via situated learning interactions prior to and during engagement with these CoPs.

In particular, the CoP framework allows for insights into engineering such as in the mastery or acquisition of knowledge and pathways into the field more generally. Although little work has examined pathways into engineering makerspaces, researchers have sought to understand student pathways into engineering. Of particular interest has been students' persistence in engineering. For example, it has been shown that the persistence of engineering undergraduate

students is threatened by insufficient preparation and feeling overwhelmed by the engineering workload, feelings of self-doubt or disappointment, poor advising, or misconceptions of what engineering entails (Adelman, 1998; Cruz & Kellam, 2018; Haag et al., 2007; Hutchison-Green et al., 2008; Koenig et al., 2012; M. Meyer & Marx, 2014; Ohland et al., 2008; Seymour & Hewitt, 1997; Tseng et al., 2011). Overall, students come into engineering with little understanding of what the program requires of them, yet the students are able to come to understand how to persist in their coursework and their own engineering journey through interacting with advisors, teachers, and peers (Cruz & Kellam, 2018). Not discussed in these prior studies are the kinds of participatory learning interactions offered or denied that could ease entry and assimilation into full membership.

Recently, Lord et al. (2019) reframed the examination of persistence in engineering education by expanding the pipeline and pathway metaphor into an ecosystem approach. While pipelines suggest that students "leak" out of the system, pathways focus on the multiple entry points into a system. Meanwhile, the ecosystem approach suggests more complex aspects of a system be recognized by offering a holistic understanding of educational experiences. Lord et al. (2019) argue that the ecosystem approach offers insights into contextual factors such as multiple influential actors, gatekeepers, power relations, tacit knowledge, knowledge transmission, and disciplinary cultures. To offer more robust insights into these factors, we argue for the use of qualitative research methods that allow for rich understandings of students' contextualized experiences—each of which we refer to as one's participation pathway. Such a research approach can reveal the forms of peripherality that are offered or denied to girls in their homes, in school, and in communities as well as the variety of apprenticeship activities foundational to learning. Given that gender is a dominant construction and social identity, combining the metaphor of ecosystem with that of a pathway enables us to look at the pervasive character of gender in the lives of women pursuing engineering generally and a makerspace community specifically. At the same time, we can notice the internal resources of that ecosystem that precipitate or cut off pathways to making.

3 | RESEARCH QUESTIONS

By providing access to a variety of resources and hands-on outlets, makerspaces offer opportunities for innovative thought by providing a platform for engineering students to create a CoP centered around making (Galaleldin & Anis, 2017; Halverson & Sheridan, 2014; Pernia-Espinoza et al., 2017). Overall, this study seeks to understand women's pathways into an academic makerspace CoP, as described through the following research questions:

RQ1: What kinds of activities and forms of participation characterize women's pathways to and in academic makerspaces?
RQ2: In what ways do gender expectations and stereotypes impact opportunities offered and taken up?

As a means to further narrow the scope for analysis, we examine how women are coming into the academic makerspace CoP by investigating access to forms of LPP and the barriers they encounter. In an effort to answer the research questions, we drew upon in-depth phenomenologically based interviewing (Seidman, 2006) although we do not conceive of this study as grounded in phenomenology. Rather, such an interview protocol enabled us to deeply explore three life phases of the study participants: experiences prior to college, experiences in the academic makerspaces on campus, and future expectations and aspirations regarding being a member of this CoP. Through this process, we interviewed 20 women students who are actively involved in various makerspaces at an engineering and technology-based public research university. The interview data were analyzed using grounded theory techniques and coding processes as a means to identify themes of women's pathways within the data.

4 | METHODS

4.1 | Recruitment and participants

Participants were recruited using a combination of purposeful maximum variation sampling and snowball sampling. Through purposeful maximum variation sampling, we sought a group of women who were described as active members of a university makerspace at a predominantly White institution (PWI), moving toward or considered full members of the CoP, and had the potential to provide the most insight into involvement and pathways in

makerspaces (Palinkas et al., 2015; Patton, 2002; Seidman, 2006; Tagg, 1985). A wide range of experiences and perspectives (e.g., academic standing, membership/role in CoP, backgrounds/upbringings) were sought to reflect those of the larger population. We went to three main makerspaces and talked with the student workers or staff regarding potential women who were active members of the makerspace CoP and would be interested in the study. Through emails, word of mouth, and referrals, we continued recruiting until theoretical saturation was achieved in the data analysis process.

Twenty women participated in the study: five for an in-depth three-series interview process and 15 for single, targeted interviews. These women ranged from undergraduate freshmen to graduate students, from US residents to international students, from those with little to substantial making background, and included women involved in five different makerspaces: Aerospace Engineering (AE) Makerspace, Biomedical Engineering (BME) Makerspace, Graduate Research Makerspace, Industrial Design Makerspace, and Mechanical Engineering (ME) Makerspace. Unless offered by the participants themselves, demographic data were not collected as a part of the interview protocol. Similar to the demographics of the predominantly White university from which participants were recruited, the majority of interviewees were White, while others included Asian American students and international students from nations such as India and Egypt, and regions such as Southeast Asia and the Middle East; no Black women were interviewed for this study. Transcripts of interviews were not coded to the racial, ethnic, or national demographics of participants.

4.2 | Interview procedure

4.2.1 | In-depth three-series interviews

Phenomenological interviewing is a specific process of reflective open-ended interviews that seek to answer the question, "What is the meaning of X?" (Seidman, 2006). Five women makers participated in three consecutive 90-minute interviews designed to evoke an in-depth inquiry into their lived experiences, or narrative, through an open-ended, semi-structured protocol. The first interview concentrated on the participants' life histories and was centered on *how* the participant became involved in making as opposed to *why* they became involved. In the second interview, participants described the details of their current lived experiences of making and were asked to bring to the interview an artifact that they had made. The interview focused on asking participants to reconstruct their experiences around the artifact, which then became the gateway into an expanded discussion on their current lived experiences making. Finally, in the third interview, participants reflected on the *meaning* of their lived experiences. To focus on the third interview contextually, participants were asked to draw a timeline on paper related to their making experiences. This physical timeline created a starting point to springboard the conversation while also helping the participants to reiterate their lived experiences, to potentially fill in gaps that may not be noticeable in a verbal narrative, and to then have a tangible timeline that they could reflect on throughout the interview.

This in-depth interview process with five women was implemented to gain a comprehensive understanding of women's pathways into makerspace CoPs by exploring the participants' reflective, detailed descriptions of their past and current experiences relevant to their pathway into the makerspace CoP. The analysis of these interviews resulted in creating a condensed, single interview protocol as a means to increase the participation as well as provided a shorter time commitment for the participant. For a detailed description of this methodology, see the study by Tomko (2019).

4.2.2 | Targeted interviews

Fifteen women makers participated in the single, targeted interviews that occurred after the initial in-depth three-series interviews were coded and analyzed for emergent themes. From this analysis, it was determined that following up on a limited number of specific themes with additional participants would serve to both elaborate on these themes and better verify initial findings. The targeted interviews condensed the protocols from the three-series interviews into a 1-hour in-depth interview. Participants were asked to draw a timeline of their life history related to their involvement in making, to clarify and elaborate upon their experiences around making at each point in that timeline, and to reflect on their own development and learning throughout each experience.

4.3 | Data cleaning and analysis

Each interview was audio-recorded and transcribed. The transcriptions were edited to revise for missed jargon and to remove any confidential information such as the names of the participants. The transcriptions were also reviewed for any words that may have been missed or misheard. Following data cleaning, the data were 868 pages of single-spaced transcriptions.

After the data were transcribed, the interviewer, the first author, read the transcripts several times and then began examining the data for initial recurring themes and patterns. Throughout the initial data immersion phase, the interviewer developed analytic memos (Tracy, 2020), noting points of interest, which became useful later on in interpreting the data. The data were then analyzed through multiple iterative phases. First, during open coding (Charmaz, 2014; Glaser & Strauss, 1967), the first author used methods of constant comparison to move through the data line-by-line to identify central attributes of the participants' stories related to their experiences becoming makers. The first author continued collecting interviews and coding the data until theoretical saturation was reached, or no new themes appeared in the data. Second, the data were then analyzed through axial coding in which open codes were organized and positioned in relation to one another to identify the significant pathways through which women made meaning of their lived experiences as makers. Repeating themes were identified based upon the criteria of recurrence, repetition, and forcefulness (Owen, 1984). Finally, those themes were interpreted using CoPs as a heuristic framework (Lave & Wenger, 1991).

5 | FINDINGS

In the construction of their timelines and their more in-depth recounting of experiences on the boundaries of the maker movement, we see a variety of unique points of departure. While there was not a uniform set of learning activities offered to the women students, we did identify recurring themes that cut across their timelines. These themes capture childhood relationships and apprenticeship activities, along with experiences of building self-confidence as they practice new and different forms of LPP toward the construction of their identities as women makers.

5.1 | "My background of making": Early apprenticeship opportunities in family and school

In explaining their timelines, women shared how their homes and family served as early participation sites where hands-on work was valued and practiced. These narratives suggest the origins of women's pathways through what one participant called "my background of making." In these narratives, three elements emerge as essential to early forms of apprenticeship: mentors who offer entry, guidance, and encouragement; materials to act with and upon; and space to work. One participant shared how her mother and father both modeled and encouraged her hands-on activities:

> My family is very into hands-on crafts stuff. I grew up with a lot of like art supplies and art materials and tools in my house. So, my mom is really into scrapbooking. So, there's always a lot of papercrafts. And sewing supplies. And then my dad ... does some construction work. He's a contractor. But then, he is also into building small projects. There were always a small amount of woodworking tools where we lived. ... I guess my first makerspace was our house and like our dining room. And I often get a lot of flak from my family about, like putting stuff all over the dining room, like totally taking over, like making my sewing empire. ... And so, my family is always very encouraging of learning by doing.

This excerpt illuminates the situational elements supportive of early-making activities. Arts and crafts emerge as powerful catalysts for increasing participation in hands-on work and growing confidence. The family dining room has been consigned not to dining but to sewing, scrapbooking, and woodworking. In this space, materials of all kinds are readily available from art supplies, papercrafts, fabric and thread, woodworking tools, and a sewing machine. Interestingly, here we find an amalgam of traditional women's craft, sewing (Stalp, 2015), as well as those associated with more masculine forms of crafting, woodworking, co-existing in a shared family space. One form of making is not privileged over another, so multiple entry points for hands-on activities were present and encouraged.

Other stories of hands-on activity integrated into family life highlight the importance of older siblings where, in one case, a participant's brother served as an entry point for making:

> I started playing with wood a lot, mostly because of my older brother, ... and we had saws, a ton of saws. ... I would just be playing around, and I would like cut out shapes with the wood and paint them and stuff and make like monkey stuff. I just like making like art out of wood I guess so I just start there. Well I don't know if it's considered making things, but I would also break apart a ton of things.

Strikingly, we see how the desire to make personal artistic creations can lead to positive collisions between the world of saws and playful art expressions. In this excerpt, she wonders whether "breaking apart a ton of things" is considered making, an important question. Another participant also recalls taking things apart:

> And then at home at my grandma's, we have like a shed and a bunch of tractors, and I was always around my cousin, Paul. He's like 50 now. So, but when I was younger, he would – we'd end up like when he was taking apart something, I'd be like, oh, does that work? And I ended up just like following him around whenever he was like working on stuff around the house.

This practice of taking things apart or fixing served as early opportunities to dissect as means to understand or perhaps to redo toward improvement. This kind of "playing around" with no worry of perfection, just enjoyment of the material, and hands-on exploration toward understanding seems an important peripheral activity leading to other such activities where pleasure is derived from serendipitous play. In a continuation of sibling apprenticeship, the first participant later attends the same university as her brother, where he again eases her entry into hands-on work in the academic makerspace by providing participation opportunities to learn new tools there.

Home renovation offered apprenticeship opportunities for another participant. "I did do a lot of renovation and construction stuff with my dad and my brother on our house. So that's kind of where I learned how to use most of the tools that I knew how to use before I got to the [makerspace]." This knowing-in-advance is not inconsequential. Membership in academic maker communities is contingent on and mediated by tool knowledge and skills. Those who come having some knowledge and skill of the tools are at an advantage, one that may be tied to socioeconomic class that enables access to material resources, tools, and spaces for making. Thus, for women students, arriving having had prior opportunities for legitimate participation can potentially impact whether they take advantage of this campus resource.

In another case, sewing as a form of LPP was a requirement for daughters and sons alike: "I had always known how to sew because my mom had taught me like this is what you need to know, like hem your pants and sew buttons back on your shirt. ... And she taught it to my brothers as well, 'believing' you just need to know this stuff." In college, this passion for sewing led this participant to the makerspace. As observed by Lave and Wenger (1991), "peripherality suggests that there are multiple, varied, more—or less-engaged and—inclusive ways of being located in the fields of participation defined by a community" (p. 36). For these women, wood, art, home renovation, and sewing all served as forms of peripherality toward changing and growing forms of participation.

Research suggests that parents play an influential role in the gendered messages regarding the value and appropriateness of toys and childhood play (Kane, 2006). It is not surprising, then, that one way that participants moved toward making was the result of the parents' influence on the toys. In one case, we heard of a parent intentionally shifting the gender narrative in a way that moved a daughter toward making:

> I liked Barbie dolls a lot. ... I did a lot of fashion shows for my parents. ... My father was kind of concerned. He used to tell me, ... "You can, when you grow up, either be the doll, or be the boss of the dolls." That's what he used to tell me. I internalized that but ignored it a little bit. I continued along my way. Then one day, I came back home, and all of them were gone. He had given them to my neighbor. ... He replaced it with a Lego set. ... I built all these houses and got addicted to it a little bit. I guess all the way to the age of 11, and from there onwards still, I just built a lot of Lego sets.

This recalled childhood event seems an extreme instance of redirected LPP where one CoP (building/creating structures) is privileged by a parent over another (dressing dolls, fashioning hairstyles). By controlling the materials available for play, the father replaces, actually discredits, one activity type (dressing dolls) and forcefully replaces it with another (building structures) to cultivate in his daughter practices of a different and, from his hegemonic masculine perspective,

more valuable CoP. This classed expectation that his daughter should aspire to be "the boss" rather than the "doll" points to assumptions about valued skills and pathways to success. With this redirection, this woman's pathway takes a turn. She transitions from play mediated by dolls to play achieved through blocks. It could be easily argued that this abrupt redirection of interest and activity by physically removing favorite play materials reduces the girl's agency in choosing her pastimes and future directions. Girls' and women's CoP and the feminine activities therein are viewed by the father, in a position of power, as less valued ones that need to be stopped and replaced with materials and activities fostering different activities that will lead to a "better" outcome. Indeed, this illuminates how gender is constructed via both processes of interaction and stratification, elevating masculine forms of play as superior to feminine forms (Lorber, 1994). Yet in the interview, the woman student expresses gratitude toward her father's measures to expose her to another activity, demonstrating that it often takes inviting, or in this case redirecting, a girl's activities away from gender-stereotypical play to allow exposure to and engagement in making activities. In this woman's narrative, her father ends up recognizing the value of allowing his daughter's and his own interests to coincide, that is, not one (dolls) or the other (blocks), as he lets her get an American Girl Doll, to which she ends up making "a makeshift doll zip line thing," and in turn, "the concept of building things without an instruction manual started to take root, or get seeded in [her] mind."

Similar to the midwives in the Yucatan that Lave and Wenger (1991) discuss as a case study of apprenticeship, apprenticeship as shown in these cases is not separate from, but instead integrated into, daily family life and enacted through the immediacy of materials, play activities that those materials afford, and familial mentoring. Young women offered early apprenticing opportunities by siblings and parents can gain awareness of the pleasures of building, working with different kinds of materials, and the confidence to create with their hands.

Schools and their associated extracurricular clubs also presented opportunities for LPP that were instrumental to gaining the confidence and knowledge preemptory to taking advantage of academic makerspaces. In several cases, participants had experiences in a school setting that significantly influenced their pathways into a makerspace. While at least five participants discussed engaging in high school robotics, one woman's interest started because of a teacher offering her extra credit:

> My teacher says, "I'll give you extra credit if you join the robotics team because we need one girl to be able to qualify for the competition." And I was like, "Sure, okay." Extra credit is extra credit. I joined robotics. ... I fell in love with robotics very quickly. Became president, and then I served as president for three years. Won some awards, and just was receiving a lot of positive reinforcement for getting involved in STEM. Tinkering, physics, robotics ... and then we went to the world championship, which was just awesome.

This story is revelatory of the gendered nature of certain high school clubs and the ways in which interventions to redress gender inequities can be simultaneously tokenizing and transformative. She was recruited not for her skills or knowledge, but because of her sex, female, sometimes linked to forms of spotlighting that communicates that girls and women are the exception rather than at the center of the community (McLoughlin, 2005). The team needed just one female to compete. The student's motive was pragmatic—extra credit, but something changed. She discovered something compelling and rewarding at the intersection of tinkering, physics, and robotics. We surmise that activities offered and taken up propelled her from a marginal position as the female to increasing and deepening forms of participation in this CoP. Important to note here is that once engaged with this CoP, she was not denied increasing forms of participation because of her gender. In fact, she became a central member of this community most certainly moving from periphery to fuller participation, demonstrating the importance of ensuring gender diversity of the participants in school-related clubs such as these.

For another participant, her brother was the catalyst for joining the robotics CoP in middle school: "Back in elementary school, I wanted to be an artist. Then in sixth grade, I get involved with my older brother's LEGO robotics team on the condition that I don't have to touch the robot. By eighth grade, I am captain of the team and fixing everyone else's programs." She later helped to start the robotics team at her high school.

In contrast to these positive participation stories, some women's educational experiences posed more barriers than openings. Teachers' and peers' gendered expectations and presumptions created conditions adverse for peripheral participation. For instance, one participant had a mentor on the high school robotics team whom she characterized as

> very old-fashioned, like, "Girls can't do anything." And so, like, I had a really hard time getting started because he, like, didn't trust me in the lab. So, when I became the head of the build team, like, my second

> year, he was like, "Ugh." I guess. Like, he wasn't very happy about it. So, my experience there wasn't super positive.

Hostile sexism from teachers such as this one creates unwelcoming educational environments for girls and women who shape their participation in makerspaces and showcase what J. C. Williams et al. (2016) describe as the demand for women in STEM to "prove it again" to demonstrate their competency and belonging in masculine-governed CoPs. For some, such as the student above, hostile sexism creates what is called reactance, increasing motivation to perform in the face of a restrictive environment (Dardenne et al., 2007). Another woman had negative experiences in her high school robotics team, which led her to seek an alternative hands-on outlet through her school's Science Olympiad team. She reflected, "For the first time, I saw a bunch of females in my club that were doing hardcore engineering stuff, hardcore biology, hardcore chemistry. Everybody had a supportive environment." These examples echo the kinds of learning constraints chronicled in Marshall's ethnographic study of apprenticeship of meat cutters where pathways to gaining skills were either intentionally or inadvertently thwarted (Marshall, 1972). As observed by Lave and Wenger (1991) in their analysis of that study utilizing the LPP framework, "Gaining legitimacy is also a problem when the masters prevent learning by acting in effect as pedagogical authoritarians, viewing apprentices as novices who 'should be instructed' rather than as peripheral participants in a community engaged in its own reproductions" (p. 76). When members of a CoP position newcomers as "XX who can't do anything," a position commonly ascribed to female students on engineering design teams (Meadows et al., 2015), this positioning constructs newcomers as outsiders not worthy of participation activities rather than as future community members seeking legitimate peripheral experiences toward learning and full participation. The challenge, of course, is to shift that perspective of insider/outsider to that of an expanding community open to all willing and wanting to be members.

5.2 | "Self-confidence to be the Expert": Pitfalls and pathways to full participation in the sociocultural practices of academic makerspaces

5.2.1 | Early failed articulations of related communities

Prior learning opportunities including renovating, building, sewing, and creating artwork in their homes or schools served as openings for our participants to a larger CoP; thus, in transitioning to college, our participants were poised to explore the related communities offered in the five academic makerspaces on campus. These related communities held the possibility that "legitimate peripherality can be a position at the articulation of related communities" (Lave & Wenger, 1991, p. 36). If we conceive of the larger community of makers, we can understand how homes, schools, libraries, and university-based shops that all value hands-on work with tools and a variety of materials are all related communities.

Transit between these, however, is not always fluid as we see in the recollections of two participants in particular. For them, this possible articulation did not come easily or early. At the time of the study, there was one makerspace of the many on-campus that was so well-equipped and renovated that it served as a stopping point for campus tours and, thus, seemed a likely place for both participants to start. For one participant, though, her first encounter with this community was unsettling enough to preclude future use. She recalls:

> Yeah, I think I've only done 3D printing at the (makerspace), I never ended up – because I was like a freshman and I was like ... I don't know how to use any of these things. And it's kind of like daunting to be like ... because when I was a freshman ... the ratio was a little bit higher, so there were more guys. So, like I remember my freshman year is like me going in there and a bunch of guys 3D printing stuff and it was like they all really stared at me. Or like ... because they're like "a girl is here," or they like assume I know nothing, and then they're like trying to help me. And I'm like, no, like I just need to load this and leave, like I don't need you to teach me how to use this thing, like I know how to use this thing.

This encounter with the men who were overseers of the 3D printing room was both daunting and aggravating. She felt outnumbered as the lone woman and also categorically assigned the role of know-nothing woman needing help—a deficit role she was unwilling to embrace. This experience of being treated as the helpless woman by the makerspace males arose repeatedly in the interviews. Another woman maker described her initial experiences there as a "turn-off":

> It was pretty intimidating - the water jet was scary. I was worried I was going to break things ... and, then often times I would come in, and it would be too busy, and so I kind of got turned off by the fact that it was busy ... it took me coming with [my friend] after hours, and him being like, "let me teach you individually how to use these tools and how to make something cool" and how to really experience the studio rather than just being thrown in.

While these two first encounters with the makerspaces are recalled differently, both women experienced them as "daunting" or "intimidating," limiting initial possibilities for positive or generative forms of peripherality. The tools themselves with which they have little or no experience are the first barrier that both acknowledge, so for one, the water jet is scary, and for the other, the sheer number of new tools is daunting. These two recollections demonstrate the importance of affective and psychological responses to the physical design of makerspaces and their equipment as first participation opportunities in unfamiliar spaces might be a disincentive to further engagement with that CoP, particularly when those experiences are not successfully mediated by full members. The second participant is able to overcome her intimidation by returning after hours with a friend who offers apprenticeship by using the tools to make something cool. For the other, she found another makerspace where LPP was mediated differently as will be discussed later.

Returning to the first participant, we cannot miss how the gendered experience with unbalanced ratios and gendered assumptions precipitated an unpleasant but memorable experience for her. She feels singled out as a woman in a space full of men who seem to assign incompetency to her and then try to help when she is neither seeking nor wanting help. Such unwanted help further showcases protective paternalism (Glick & Fiske, 2001), a form of benevolent sexism, that may pervade masculine-defined spaces such as this one, where "helping women" may be perceived as one's "duty" as a "good man" protecting women from "dangerous machines." While this was not the case in this instance, it is important to note that Dardenne et al. (2007) found that benevolent sexism such as this is shown to have the most damaging impact on women's performance in an activity. As such, it is important for help to be offered, but not imposed, and such approaches to help avoid gendered assumptions of an individual's competency. Further, Lave and Wenger (1991) observe:

> Legitimate peripherality is a complex notion, implicated in social structures involving relations of power. As a place in which one moves toward more-intensive participation, peripherality is an empowering position. As a place in which one is kept from participating more fully—often legitimately, from the broader perspective of society at large—it is a disempowering position. (p. 36)

A social order that fails to situate women as qualified makers places women students in disempowering positions within the university makerspace CoP, creating a disadvantage in moving toward more intensive participation. This participant rejects the disempowering positioning in telling the men offering her help, "No. I don't need your help." and leaving, resisting the gendered social order. Still, this interaction is complex. Assuredly, the men in this instance (as may also be women), as community members and possibly designated mentors in the space, were trying to be helpful, but by taking over and trying to do it for her, she is kept from participating more fully; this is how benevolent sexism operates. She rejects their assignment to her as occupying the "helpless woman" role in which they have assumed her (in)competency in using a tool valued in the community, the 3D printer. These early episodes of gendered assumptions as woman makers on campus are certainly not unique. In both cases, LPP seeking moves in the academic makerspace did not feel welcoming or smooth. Yet women's *resistance* of this gendered social order and the associated role expectations ("helpless woman") within the community pervaded their accounts, leaving openings for participation and, thus, their persistence as makers.

Importantly, the practices of benevolent sexism and protective paternalism are historically tied to the legacies of racism that construct differential stereotypes of White and Black women (McMahon & Kah, 2016) and have implications for the nature of both the helping practices and the targets of benevolent sexism in makerspaces. McMahon and Kah (2016), for example, found that White women were more likely to be the targets of benevolent sexism and viewed as requiring help and protection (e.g., protective paternalism). Understanding the racialization of benevolent sexism and protective paternalism is critical to locating women's differential experiences in makerspace CoPs as well as the possibilities of varied responses to forms of sexism and (in)visibility tied to their social locations.

5.2.2 | Successful articulations of related communities

While it is important to unearth and try to understand these kinds of failed articulations, it is equally important to understand the successful transitions to these academic makerspaces in terms of the precipitants, the mediators, and the user intents. As Lave and Wenger observe about apprenticeship, "Learning itself is an improvised practice: A learning curriculum unfolds in opportunities for engagement in practice. It is not specified as a set of dictates for proper practice" (p. 92). One of the participants in explaining her growing engagement with academic makerspaces enumerates two catalysts that we find among other women: "I would say it definitely centered around, like, figuring out how I could use a lot of that stuff for my passions, I guess, like, — and for school." This reflection clarifies the challenge of mapping the tools—"that stuff"—in these spaces to the personal productions that create satisfaction or fulfill a class requirement. This mapping did not come naturally. She had to figure it out, and while a class assignment was the catalyst for using the laser cutter, 3D printing was her tool for gift giving and fun.

> Like, I took an English class where we had to laser cut a medallion. So, like, out of wood. Like, it was a 1101 base English class. ... So, like, using it for that and I'm like, "Oh, this is really cool. Like, this is the thing that I drew. (Shows interviewer) And so. I'm, like, 3D printing, like, a coffee cup holder, or like—for—so my mom—this is totally irrelevant. My mom donated her kidney to, like, my aunt, like, six years ago, so I like 3D printed her a kidney Christmas ornament and, like, painted it all cute. It was really funny. But and stuff like that. And then my neighbor, like, had a kidney removed for cancer, so he saw that, he asked for one. So, I 3D printed him one and stuff like that. So, like, completely irrelevant to anything educational, but, like, just fun projects.

Design classes, which require prototyping and thereby legitimize the use of these makerspaces for the learners, were cited by several of our participants. After taking a design course, one woman engaged in a more entrepreneurial pathway into using the makerspace, and then she reported that during her capstone class, she "was in the basement [makerspace] for 133 hours of the 150 hours leading up to expo. I literally lived there." Her immersion in the space throughout college allowed her to feel that "all the things I am most proud of that I did at [University] were because I used these makerspaces." These kinds of empowering experiences can work to combat the negative disempowering experiences that we have seen our participants face both initially and continuously as they challenge the maker as male construction.

The nature of the class and the organization of activities, however, can produce different motivations for further engagement. For biomedical engineering students, their early design class requires student teams to find a biomedical device of interest and spend the semester redesigning it in some way based on in-depth analysis of use, function, and users. "I think that the earlier you take that [prototyping] class, the more it jumpstarts you if you enjoy it, to go to the shop and do stuff." Second year ME students, in contrast, all work on the same design challenge and then compete against one another at the end of the term. For one participant who chose to work with other women on a team, this competition took on a significant gendered dynamic:

> Boys just snickered because they thought it was just hilarious that girls would band together like that thinking they had a chance in the big competition. It was just so frustrating. By the end of the summer we had put in so much work, so much more work than the guys, because they've just been relying on all the experience that their dads had taught them, and just boys being boys they knew how to do things. They were just not even putting in extra effort. With all the extra effort, we ended up tying for sixth in the competition, and it was the best moment ever.

As earlier examples of hostile sexism and gendered assumptions reported in this paper, the students in the above team experienced reactance that motivated them to prove themselves. In support of J. C. Williams et al.'s (2016) argument that women in STEM have to "prove it again" to be perceived as competent, women in this study routinely reflected on instances in which they were left to be the "documentation girl" on a hands-on team or where they had to prove themselves in every aspect of their work. Undoubtedly, this all-woman team was challenging societal gender norms in ME, which usually dictated a mostly male team with the single woman who did little of the technical work and most of the organizational and communication work. And this visual reminder of this challenge resulted in pushback in the form of ridicule by the keepers of the norm. Indeed, as Lave and Wenger (1991) argue, "Granting legitimate participation to

newcomers with their own viewpoints introduces into any CoP all the tensions of the continuity-displacement contradiction. These may be muted, though not extinguished, by the differences of power between old-timers and newcomers" (p. 116). For this participant, however, beating the men at their own game started her growing engagement with the makerspace and with the larger CoP, serving as yet another example of the ways in which women can both resist limiting definitions of their roles in makerspaces and cultivate empowering experiences.

Returning to the "irrelevant to anything educational" comment regarding Christmas ornaments cited earlier, the practice of creating things that others will enjoy was a common catalyst for many of the women. In fact, personal creations designed to please others were probably the most common precipitant for seeking increasing forms of engagement in these CoPs.

> I like making gifts a lot, so I really like being able to make something that somebody else enjoys. I like it—I like the validation of them being like, "Oh my goodness, I love it so much. It's so cool." And, I'm like yeah. I made that. I put my effort into that and then you like it. It's pretty cool. And, so it's really cool when I'm able to like put new skills into something and then someone sees it and they're like, "Wow, you did this thing and it's cool. I couldn't do that, and you could do that, and you made a cool thing."

For another woman maker who wanted to give her friend living in another state a birthday cake, she made one in Solidworks, which was the start of increasing her engagement.

> So I like for my friend's birthday I printed her, I designed a cake in like Solidworks and then printed it out. So, I sent her a cake, because it was like she lives in Tennessee so I sent it to her, because I was like, oh, I can't send her a real cake. I was being sweet. [laughter] And then so I started doing little things like that.

The significance of creating gifts for others as opposed to following the requirements for a job or even a class was explained by one of the participants:

> If I'm just creating something as a job, like someone's handed me something and is like, "Make this," I'm not going to be as invested in it as if I'm making something for my grandma who's going to put it on her mantle for three years.

It is important to note that none of these women experienced restrictions as to what the tools could be used for in these makerspaces. Personal projects, as well as school assignments, were viewed by the community as valid uses. There may have been tighter restrictions at certain times of the semester when capstone projects were due, but other than that, these makerspaces seem to welcome all projects.

5.2.3 | Near peers, boyfriends, and role models

For almost every woman we interviewed, first engagements with makerspaces were facilitated through social acquaintances. For one, a friend called and said: "I'm getting bored. Do you want to come visit me? ... I actually work in the [Aerospace Makerspace]. It's for aerospace students. It's free. Do you want to come make things?" As Lave and Wenger (1991) observe,

> It seems typical of apprenticeship that apprentices learn mostly in relation with other apprentices. There is anecdotal evidence (Butler personal communication; Hass n.d.) that where the circulation of knowledge among peers and near peers is possible, it spreads exceedingly rapidly and effectively. (p.93)

As a result, engagement in makerspaces is infused with affect for participants. One participant, for example, had one of her first dates with her eventual boyfriend in another makerspace on campus. Later when he graduated, this space reminded her of all the happy times they spent there hanging out:

> One of the first times we hung out we went down there like with friends because we had a friend running for Miss (school name). So, like helping her build her project for stuff like that. So, it was more like a friendly hang out space, where we would build projects whether together with friends.

Or in another case, friendship eventually led to becoming a mentor in the makerspace or full community member:

> One of my friends showed me the [makerspace] and showed me how to [3D] print things. The [name of another makerspace], I didn't hear about until like sophomore year. But then I had to laser cut some stuff [in the summer for research], and then my friend started working as a [student worker] there, and then I ended up spending a lot more time there and I really liked it. So, then I started getting trained on all the machines, and then decided I wanted to be a [mentor].

Moving beyond the role of a user, women who have the opportunity to assume meaningful responsibilities in the space can gain more legitimacy as they continue on a making pathway. In taking on more responsibilities, women were able to "ma[k]e the most change" and gain respect from peers, faculty, and staff, such as this student who reflected: "So I had like a lot of respect from the faculty and staff, and I think that got represented in how the students saw me, like other students. I realized that people had a lot of confidence in me." Such confidence helps to further one's investment and enjoyment in the makerspace. For instance, when asked how the experience of being a mentor in the makerspace impacted her life, one participant responded, "It gives me a lot of self-confidence to be an expert in an area of something I'm really interested in, and that not a ton of people are an expert in." If women maker-mentors are visible in these spaces, women on the fringes, curious but intimidated, are given a visual of new opportunities and horizons:

> It was cool coming into the studio and seeing these like women who were like super involved in like making stuff and like super powerful, like willing to do things and these authoritative figures. Because like, I—like, my mom was kind of, but she really wasn't like that strong. She wasn't the same type of person I was, which is a sometimes overly authoritative woman in engineering who likes to get things done and likes to make things. And, it was really cool to have that role model to look up to, because that wasn't something—like as a kid, there weren't many strong engineering women in my life.

The rapid spread of building and making among women on university campuses or any marginalized community will be enhanced when peers, significant others, and role models are available to visually signal inclusion and interactively invite and create apprenticeship opportunities.

6 | DISCUSSION

The narratives examined in this study highlight the importance of elevating women's voices in educational research on makerspaces and engineering in order to examine more closely the locations for cultivating inclusive educational and professional environments and combatting both overt and tacit gendered assumptions. Because CoPs are rooted in sociocultural contexts, "the cultural richness of this broader context generates a fluidity and heterogeneity within and beyond communities" (Handley et al., 2006, p. 641). For example, while a woman student navigates a high school robotics club and gains legitimacy, this does not guarantee the same level of membership and legitimacy in a university makerspace where the culture and rules for legitimacy are different. As found in two studies of professional CoPs (Fuller et al., 2005; Hong & Fiona, 2009), community members can choose to exclude or disenfranchise potential members seeking access or delegitimize previous participation experiences. A woman's previous experience, though, still creates the possibility for movement into the university makerspace and for articulation across communities. Regardless of previous experiences, women students are coming to the makerspace. Their experiences are wide and varied, yet they are navigating their way through a making ecosystem in a recurring cycle of catalysts and barriers.

Catalysts and barriers occur throughout women's life narratives related to making. Importantly, our study demonstrated that girls and women may experience contradictory messages about making from the same sources, confirming that implicit biases and gendered practices that connect masculinity with making run deep. It is not surprising, then, that most of the participants described apprenticeship experiences with fathers, brothers, male peers, and boyfriends. Despite this, the *recurring* catalyzing events and apprenticeship experienced by the women

in this study speak to the importance of continuing to create gender-targeted making curricula for youth, to actively change the discourse of making to be more gender-inclusive, and to create openings for later articulations of communities once in college. Yet the findings also point to the affective consequences of programs that tokenize and result in spotlighting, leaving girls and women feeling like outsiders to the community, simultaneously hypervisible and invisible (McLoughlin, 2005).

At the university level, friends, classes, and campus jobs afford access and legitimacy for using the makerspace, where women encounter opportunities to further engage themselves in the different equipment and design activities giving them the "self-confidence to be the expert." Women take on new roles that help them encounter creative outlets through making and innovating. Through the makerspace, women can gain support and respect that validates the work that they are doing, despite the gender biases that at times manifest themselves in demeaning and disempowering encounters and structures that might otherwise serve to limit legitimate participation. Indeed, our study joins others in supporting J. C. Williams et al.'s (2016) research that describes the ways that implicit gender biases are manifested in STEM fields, while simultaneously heeding their call to create mechanisms for change.

Our research on women's pathways into makerspaces suggests that a single intervention is inadequate for shifting the narrative and opening doors for women to participate in makerspaces. Instead, multipronged approaches that look at creating and supporting early life making experiences, legitimizing arts and crafts as important contributions to the CoP, and creating opportunities for leadership in makerspaces at both the K-12 and university levels are critical to continuing to challenge the narrative "think maker, think man." In summary, using the interpretive lens of CoP and LPP, we can see how intersecting ecologies of family, friends, after-school clubs, and on-campus makerspaces, if connected and coordinated in a more coherent and supportive fashion, create onramps at different times into the maker movement.

Finally, studying trailblazing women students' pathways, such as those shared in this study, is an important part of changing the narrative for women in design. The diverse entry and pathways through making demonstrate that people can come into the makerspace with a little or no background in making but can still become a member of the community and build a repertoire of making skills. Importantly, we saw the critical role of apprenticeship through both formal and informal mentoring and support by and for women in their narratives, suggesting the importance of women's presence in makerspaces toward drawing in more women. Such early shifts in the socializing messages about making and engineering along with cultural shifts in academic disciplines characterize the hopefulness that the participants in this study communicated. As one participant hoped, "It's really important to know that if a woman comes into the space, then she's still welcome there. She's allowed to be there; she's allowed to make things in there. To also know that even if a woman messes up in that space, or makes a mistake, then it's just another learning experience and has nothing to do with gender."

7 | LIMITATIONS

The most significant limitation of this study is our failure to collect and code demographic data from participants that would have enabled a more robust intersectional analysis of the role of systemic oppression in shaping women's experiences in a makerspace CoP. Specifically, this limitation constrained our understanding of how the varied social locations of the women interviewed were impacted by interlocking systems of oppression, thus essentializing the experiences of women and risking painting a portrait of women as a homogeneous group. Yet, research consistently demonstrates that Black, indigenous, and other women of color (BIPOC) face significantly greater barriers to participation in STEM than White women (Ong et al., 2011), are likely to experience microaggressions that couple race and gender (Wilkins-Yel et al., 2019), and experience racial battle fatigue as a result (McGee & Bentley, 2017). Indeed, existing scholarship demonstrates that persistence in STEM for BIPOC women, particularly Black women, is greatly impacted by scientific preparation in youth that privileges White students as well as patterns of isolation in STEM communities during undergraduate education (Charleston et al., 2015). Our interpretations, for example, failed to articulate the manner in which the barriers the participants faced as youth may be connected to educational practices that privilege whiteness, not recognizing that exposure to making is not only gendered but raced and classed as well. This study, thus, is a springboard for future research that must untangle and interrogate the nuanced ways that systemic institutional oppression is at work in shaping women's pathways into makerspaces, particularly at predominantly White institutions such as the one studied here.

8 | CONCLUSIONS

In this paper, we explored the making narratives of 20 women students toward understanding the characteristics of women's pathways into university makerspace CoPs. To do so, we conducted in-depth interviewing to gain insights into the complex, lived experiences of women students who identify themselves as makers. Examining the making ecosystem and using grounded theory development, we identified four major aspects of their pathways: (1) early forms of apprenticeship through mentors who offer entry, guidance and encouragement, materials to act with and upon, and space to work; (2) overcoming and resisting limiting gendered expectations imposed by others in early experiences in unfamiliar makerspace CoPs that result in failed articulations of related communities; (3) successful articulations of community grounded in making-centered coursework and personal passions; and (4) relationships in college that expanded access, leadership, and visibility toward fuller participation in makerspace CoPs. The insights from these characteristics demonstrate that the entry points into makerspaces are neither linear nor are they without obstacles for women. It is important to ensure that initiatives for women in engineering education show value toward arts and crafts, provide support and appropriate mentorship for women, and allow for diverse interests and pathways in order to change the narrative toward one that is more inclusive of women makers.

Findings draw attention to the need for creating making-related catalyst opportunities and providing consistent and meaningful affirmation for girls and women at home during their K-12 education as well as in our colleges and universities. The findings of this research can be summarized as demonstrating the importance of early apprenticeship relationships in families and schools, building immersive educational experiences in K-12 and colleges in which making is integrated into the curriculum, and dismantling overt and tacit gendered assumptions in makerspaces that erect barriers for women's articulation of community. Indeed, the importance of relationships cuts across all of the women's narratives as mentors—whether family, friends, or teachers—cultivated apprenticeship opportunities that created openings for them to view themselves as makers and, thus, as central to makerspace CoPs. Perhaps most importantly, providing women with leadership opportunities in makerspaces expanded opportunities for participation while simultaneously increasing the visibility of women in makerspaces, disrupting the bias "think maker, think man." Thus, we demonstrate an imperative for scholars and educators to change the narrative on who is a maker, what making is, and who belongs in makerspaces in order to reduce barriers and create inclusive and welcoming university makerspaces.

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ORCID

Megan Tomko https://orcid.org/0000-0003-0276-2140
Melissa W. Alemán https://orcid.org/0000-0002-1979-6964
Wendy Newstetter https://orcid.org/0000-0001-5693-4265
Julie Linsey https://orcid.org/0000-0003-3030-7399

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AUTHOR BIOGRAPHIES

Megan Tomko completed her PhD in the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology, 801 Ferst Drive, Atlanta, GA 30332; megan.e.tomko@gmail.com.

Melissa W. Alemán is a Professor in the School of Communication Studies at James Madison University, 54 Bluestone Drive, MSC 2106, Harrisonburg, VA 22807; alemanmc@jmu.edu.

Wendy Newstetter is the Assistant Dean for Educational Research and Innovation in the College of Engineering at the Georgia Institute of Technology, 225 North Avenue, Atlanta, GA 30332; newstetter@gatech.edu.

Robert L. Nagel is an Associate Professor in the Department of Engineering at James Madison University, 801 Carrier Drive, MSC 4113, Harrisonburg, VA 22807; nagelrl@jmu.edu.

Julie Linsey is an Associate Professor in the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology, 801 Ferst Drive, Atlanta, GA 30332; julie.linsey@me.gatech.edu.

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