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A Typology for Learning: Examining How Academic Makerspaces Support Learning for Students

While advances have been made in studying engineering design learning in the classroom, to date, such advances have not addressed hands-on, real-world learning experiences in university makerspaces. Our particular interest was how such spaces support women engineers as designers, learners, makers, and community members. To investigate this, we initially completed two qualitative interview studies: (1) a three-series in-depth phenomenologically based interview methodology with five women students and (2) a targeted, single interview protocol with 15 women students. The in-depth interviews were analyzed using grounded theory techniques and coding methods as a means to develop a typology. To explore the broader applicability of the findings, 19 additional interviews (five women and five men at Big City U.; four women and five men at Comprehensive U.) were also completed. Overall, makerspaces are confirmed to help provide women students with a diverse skillset that engages design, manufacturing, cultural knowledge, failure, collaboration, confidence, resilience, communication management, and ingenuity.

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1 Introduction

While advances have been made in studying engineering design experiences in the classroom, challenges persist when trying to study hands-on, real-world experiences occurring in academic makerspaces. Overcoming these challenges to understand the learning which occurs through engagement is important to the mechanical engineering design community due to factors such as the prevalence of hands-on learning experiences in engineering design education (e.g., product dissection [1–6], design methods [7–10], sketching [11], prototyping [12–16], and design competitions [17–19]). Another important factor is the estimated proliferation of makerspaces on America's college campuses. One such estimate cites more than 150 academic makerspaces ranging in size from 100 to over 1000 active student members [20]. Past research demonstrates significant benefits from classroom use of makerspaces on design and innovation self-efficacy, belonging in the makerspace and engineering, and innovation orientation, but also notes gender and racial gaps in the impacts [21]. As engineering educators, we can be sure that our students are using these spaces, but what are they learning through this experience?

Studying student learning in makerspaces is challenging. The very characteristics which make makerspaces unique: exploratory, interactive, collaborative, self-paced, and open [22–24], also limit their study. Some studies have looked into learning in makerspaces [23,25–37], yet there remains minimal evidence demonstrating the value of academic makerspaces in STEM fields. In a recent review of literature conducted by Weiner et al. [38], just five out of 68 papers "made explicit and repeated references to learning sciences concepts, terminology, or theoretical frameworks" (pp 9–10).

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What we have learned, though, is that makerspaces offer opportunities for self-driven learning, and creative thinking from building models, creating art, and visualizing ideas [39], providing students with a means to develop creativity, curiosity, independence, determination, and grit [24,40–42]. There is also a correlation between engineering design self-efficacy and makerspace use [43]. Makerspaces provide opportunities for collaboration, discovery, and innovation [44], where ideas, tools, machines, and knowledge are shared amidst the use of advanced technologies and the making of projects [45,46].

These learning opportunities, though, do not appear to be equitably distributed among all engineering students. National trends report a gender bias in makerspace participation, with 81% of participants identifying as men [47] and women being considered an underrepresented group [48]. For those women who do engage in makerspaces, immersive educational experiences and supportive interactions with others are necessary for the development of their identities as makers [49], yet when makerspaces use is not a requirement of the curriculum, women students choose to participate at lower rates [50–52]. In a study of three university makerspaces, statistically significant lower confidence in design skills was observed for women in two of the spaces along with under-represented minorities (URMs) reporting higher anxiety about doing design [43]. Studies do show women experience gender bias in makerspaces, most often seen when males doubt their ability and offer unwanted advice or training. However, having access to a space that allows creativity and the freedom to create also helps build confidence [53]. One study of six engineering makerspaces identified ways a culture of belonging for engineering students was being influenced [54]. They found the cultures of the makerspaces tended to unfortunately be extensions of the normative cultures traditionally found in engineering, and also make recommendations for improving belonging in engineering makerspaces. Additionally, the presence of female role models plays a large roll in how welcome women feel in makerspaces. There appear to be unspoken societal rules attaching gender making and design [55], and in fact, it is argued that the entire maker movement is gendered White, male and based solely on a Eurocentric view of making—a fact propagated through popular media including Make: magazine [56].

With women being a minority user of academic makerspaces in the United States, we choose to first examine how makerspaces support learning for the women students who do choose to engage in making and academic makerspaces to develop a typology of learning. To accomplish this, we first implemented a phenomenologically based interview approach adapted from Seidman [57] with 20 women students to develop the initial typology, five of which were conducted over a series of three 90-min interviews and 15 were targeted single interviews. To confirm broader applicability of our findings, we followed these initial interviews with 19 additional interviews (five women and five men at Big City U.; four women and five men at Comprehensive U). The interview data were analyzed as a means to develop a typology of learning: *The Learning through Making Typology*. This typology showcases the breadth and arrangement of categories associated with students' experiences learning in the makerspace.

2 Background

Makerspaces engage the type of learning that is social, hands-on, and contextualized, where constructs pertaining to traditional learning styles are incompatible for understanding the nuances of learning and knowledge-building within a makerspace. The type of learning within a makerspace invites the theoretical concepts associated with constructivism [58], sociocultural development [59], constructionism [60], and situated learning [61].

Constructivism is an epistemological stance that "describes knowledge not as truths to be transmitted or discovered, but as emergent, developmental, nonobjective, viable constructed explanations by humans engaged in meaning-making in cultural social communities of discourse" [62]. Constructivist learning theories focus on how individuals make meaning and construct knowledge through experience [58]. Piaget's constructivism characterizes learning as a process where an individual's knowledge structures are confirmed or reconciled through experiences and interactions with one's environment [58,63]. An individual reconciles their knowledge structure when the information generated from an experience fails to conform to the individual's existing framework; the reconfiguration does not occur in response to simply receiving information; rather, there is an emphasis on individual learning from an experience [64]. Embodied in the Maker Movement, the constructivist approach offers an opportunity to reform the educational system [65].

Developing a sociocultural perspective on learning, Vygotsky [59] emphasizes that social interaction embedded in cultural practices is the means for learning to occur and knowledge to be constructed. An individual learns from being enculturated into a community and thereby acquires knowledge via directly interacting with the learning environment [66]; as such, learning is modeled as a situational and contextualized activity [67–69].

Similarly, constructionism focuses on how knowledge is constructed in context; however, constructionism is a theory for learning [70], where an individual elicits meaning and engages in learning through the act of making a meaningful, tangible artifact [29,71]. Learning occurs in the process of transforming one's inner feelings and ideas into a physical medium that can be analyzed and admired [23,71]; the making of the artifact helps to then inform, shape, and communicate ideas, as expressed within particular contexts [72]. While constructionism may seemingly be simplified to learning through making, Papert and Harel [57] argue that the implication of this simplification negates the depth, richness, and versatility ingrained within the essence of constructionism, where learning-rich activities (i.e., building sandcastles, creating houses of Legos, or playing with a collection of cards) go beyond featuring a narrow skillset [57]. Centered around this expansive form of making, learning in constructionism offers a foundation for learning makerspaces, which are centered around the act of making in all its forms [45]. Even more so, Papert [70] argues that there is an undoubtable link between the process of learning and the content from learning, reinforcing the need to study both how and what individuals are learning in the makerspace.

In situated learning, the emphasis shifts toward the context in which learning is occurring. Situated learning acknowledges that learning occurs from social interactions within the cultural constructs of authentic, real-world environments [61]. The acquisition of knowledge extends from the apprenticeship process that an individual undergoes in order to grow in experience and further membership into a community of practice. Prior to the onset of the concept of situated learning, "apprenticeship" was without a theoretical foundation for meaning, for impact on learning, nor for differences from cognitive learning forms, despite the term being widely used in learning studies [73]. With situated learning, apprenticeship extended beyond the simple master-apprenticeship mode into a well-formed theory that accentuates the mastery of knowledge through contextualized experiences [73]. Similarly, makerspaces act as communities of practice by situating learning within a community of people who offer access to the tools, equipment, and an environment that provide a catalyst for innovative thought and resourcefulness [24,46].

Studies that are specific to investigating the Maker Movement in education can be considered of three different forms: understanding makerspaces as learning environments, understanding makers as learners, or understanding making as a designed learning activity [24,28]. Of interest in this work is understanding makerspaces as learning environments, where the research spans a variety of settings, including K-12 and higher education [25–28], libraries and museums [23,29–35], and mobile and online communities [23,28,36]. For example, in a children's museum's makerspace, the learning and engagement of families and children are assisted by the presence and interaction with available tools and materials

[30]. In investigations on K-12 and informal learning, individuals engaging in making activities are stated to have learned engineering, design, electronics, art, and computer programming [24,25]. For studying academic library spaces at a mid-sized university, Bieraugel and Neill [35] examined student perceptions of how different types of makerspaces supported certain behaviors and learning that would forward creativity and innovation; this study contextualized the survey in the form of Bloom's taxonomy and showcased how the students perceived learning to be supported in different makerspaces. Further, the engineering education literature on maker education does not make considerable use of learning science concepts and literature despite regularly alluding to the potential learning outcomes of maker education [74]. So, while prior work has investigated learning in makerspaces, there remains a need to gain insights into the learning that occurs toward the professional development of STEM students in higher education makerspaces.

3 Research Questions

In order to approach the study of learning in makerspaces, we aimed to investigate the breadth of learning and the interaction of competencies that occur in a makerspace for students. Our research question follows:

> *What types of learning are students experiencing in academic makerspaces?*

In order to answer this research question, we iterated several phases of qualitative interviewing, specifically phenomenologically based interviewing, to construct a typology of learning based on students' sensemaking of their experiences with making. Adopting a phased approach to the development of the typology enabled us to both refine and validate the categories of learning across a diverse population of students at two different universities.

4 Methodology

In this study, we adopted and adapted the interviewing process of in-depth phenomenologically based interviewing [75]. This methodology is grounded in the principles of life history interviewing [76] and in-depth interviewing based on the phenomenology of Alfred Schutz [77]. In the methodological process described by Seidman [75], participants engage in a set of three consecutive interviews over an approximately two-to-three-week period, in which each interview is 90 min in duration. The process focuses each interview on a different topic as a means to understand the participant's lived experiences of a phenomenon of interest (in this case learning in makerspaces). The first interview in the set seeks to understand the participant's past experiences associated with learning through making. The second interview seeks to understand the details of the participant's experiences making in the makerspace(s). The third interview seeks to understand the meaning of the participant's involvement in the makerspace(s).

Since engineering design focuses on creating a design through a process, we adapted Seidman's methodology in two ways: (1) for the second interview, participants were asked to bring an artifact with them—a project that they made, and (2) for the third interview, participants were asked to draw out a timeline of their making experiences leading up to their involvement in the makerspace. For the second interview, the artifact provided a starting point for the conversation and allowed participants a tangible way to talk through their design process, and this artifact-based approach has been used in another study on makerspaces [78]. In the adaptation for the third interview, the student's constructed timeline provided both a reflective starting point providing structure for the reflection of the participants.

Following an initial set of three-series interviews with five women makers at Big City U., a large research university, the researchers used inductive methods of qualitative data analysis to identify the modes and types of learning described in students' accounts. After developing an initial typology, we sought to further refine the categories and fill potential gaps. Thus, we conducted targeted interviews modeled after the original three-series interview protocol with a larger sample. To do this, researchers designed a targeted, focused, single interview protocol, 60–90 min in duration. The interview questions for this targeted protocol were developed from the early learning typology. In this phase, the targeted interviews with 15 women makers at the same university were used to further refine definitions and better distinguish differences across categories of learning in the typology.

The third phase of data collection and analysis involved broadening the data set to include both women and men makers across two different universities to refine the definitions and coding rules in the learning typology such that they could be used to train coders to reliably code qualitative data. The third phase also served to validate the typology across a more diverse population. In this phase, nine three-series interviews (five men, four women) were conducted at a large regional comprehensive university (Comprehensive U.), and five targeted interviews with men were conducted at a large research university (Big City U.). In this phase, two coders were trained in using the learning typology to code the remaining data set until they reached an acceptable level of intercoder reliability. This research study was approved by the Institutional Review Boards at all associated universities.

4.1 The Participants.

Overall, 24 women and 10 men participated in the study across two different universities. Big City U. is a large technical research university, and Comprehensive U. is a large comprehensive university with an undergraduate focus. Five women participated in the three-series interviews, 15 women participated in the targeted interviews, and five men participated in the targeted interviews at university one. Four women and five men participated in the three-series interviews at university two. Participants at both universities were recruited via purposive maximum variation sampling and snowball sampling [79]. By implementing purposive sampling, we recruited students based on their potential to provide detailed and thorough information toward learning in makerspaces due to their high levels of involvement in university makerspaces [80,81]. Additionally, we sought to recruit a diverse population that reflected the range of student makers at both universities, thus coupling purposive with maximum variation sampling [75,82]. Through maximum variation sampling, a wide range of perspectives and experiences are sought as a means to construct a typology that is transferable across a wider population. For this study, purposive sampling recruited students who were highly involved in a makerspace on campus so as to provide the most insight into learning in makerspaces. The introduction to these involved makers was facilitated by referrals by campus makers (snowball sampling). To ensure maximum variation, we sought makers using all of the main makerspaces at Big City U., which led to recruiting women of various majors, academic levels, and backgrounds. Students interviewed reflected a variety of racial, ethnic, and nationalities—and included domestic and international students—yet were still reflective of the broader populations at these two predominantly white universities.

4.2 Author and Interviewer Positionality.

The type of interview used in this study is characterized by delving into the lived experiences of students through a dialogue between the interviewer and the participant. The interviewer's avowed and ascribed identities impact the dialogue and thus the data. In this study, the interviewer was a cisgender white woman graduate student in her mid-twenties studying mechanical engineering at a public university in the South. Her undergraduate degree was also in mechanical engineering, and she had a youthful self-presentation that left many interacting with her as if she were an undergraduate student, creating a level of comfort in the interviews. She had 3 years of studying qualitative methods and utilizes an interpretive lens due to the need to engage students' interpretations of making in makerspaces.

The remaining authors, three cisgender white women, and one cisgender white man comprise the multidisciplinary team collaborating on methodological design, data analysis, and interpretation. Two of the authors, both women, have expertise in qualitative methodologies in different fields of study—one in communication studies and the other in cognition and learning sciences, both bringing their methodological and theoretical backgrounds to the study of learning in engineering environments. Two of the authors are trained in mechanical engineering, with expertise in design, making and makerspaces, innovation, and engineering education.

4.3 The Interview Procedure. The interview questions in both the three-series interviews were based on the themes of life history, details of experience, and meaning of making (for a detailed description of the methodology and the contents of each of the interviews [83]). After each interview, the interviewer uploaded the audio recording to a computer, removed superfluous banter, outsourced the audio file to be transcribed, and then edited transcriptions for missed jargon and for removing confidential information. This resulted in a total of 868 pages of single-spaced transcriptions.

4.4 The Data Analysis. Once the first interview was completed and transcribed, we began the qualitative data analysis process, which is iterative and includes multiple phases. First, during the data immersion phase, a phase that was repeated after each interview was completed, the interviewer read the transcripts several times, making analytic memos to note her early observations about the data in relation to the research question. Second, she began the process of primary cycle coding using methods of constant comparison to interpret "what's going on" in the data [84,85]. Through constant comparison, the interviewer examined, compared, and labeled units of analysis (typically an utterance or several utterances) within each interview. Third, the interviewer, working with the coauthors, began to group the first-level codes into broader categories based upon the research question, thus beginning the process of constructing the learning typology. Constructing a typology is not a linear process but instead is an analytical process of moving back and forth between larger categories (second-level codes) in which smaller pieces of data "fit" and the micro-moments in the data (first-level codes initially created during the primary cycle coding) that helps the researchers to understand the nuanced features of those categories. We explain the processes of typology construction in greater detail in previous work [83]. The interviewer continued conducting interviews until reaching theoretical saturation, or no new themes were emerging from the data [86–88], resulting in an initial typology for learning in makerspaces.

The initial typology was constructed through interviews with 20 women occupying diverse making-related undergraduate majors and racial and ethnic backgrounds at Big City U. In order to confirm the learning typologies across genders and in different university contexts and demonstrate its reliability and validity, additional data were collected and coded using the typology. In this next phase, nine three-series interview sets were conducted at Comprehensive U. (five men and four women), and five targeted interviews with men were conducted at Big City U., resulting in 974 pages of single-spaced interview transcripts.

Two coders, one at each university, were trained in using Learning Typology to code the second set of interview data. During the training of the coders, each wrote analytic memos during the data immersion phase, in which they were reading and re-reading each of the interview transcripts as we coded them. During the process of training the coders, one additional sub-category ("Components," a type of "Content Skill and Knowledge") was added to the typology to account for a more nuanced understanding of knowledge and skills present in the additional data set.

In order to train coders to utilize the learning typology, a codebook was created that included a label, a definition of the code, coding rules, and examples from the data for each category. The typology itself is divided into two major categories: (1) Modes of Learning; and (2) Products of Learning. For each mode and product, there are subcategories that showcase the nuanced "types" within each major mode and product. For example, "learning by doing" was a primary type of "mode of learning" and features numerous sub-types such as "failing," "struggling," "practicing," "iterating," and "exploring" were all "types of learning by doing" (see Table 1 for an excerpt of the codebook for Learning by Doing).

To ensure the rigor of the typology, efforts were made to attain intercoder reliability on the typology of the primary categories. First, the interviewer randomly selected a participant's data set and had another researcher read through the entire participant's data set. Then, using the primary categories, the interviewer coded and unitized 10% of the overall data corpus (meaning only

Table 1 Excerpt of codebook

ID	Code	Description	Coding rules	Example
1	*LEARNING BY DOING*	Discussion of learning by doing—learning through experiences as a direct result of one's own actions	Code when participant uses words such as "hands-on" or "hands-on learning," "need to do it," "need to make it." Reflects the concept "If I do it, I know it." *This code can be by itself or paired with the codes below. "Trial-and-error" is also a cue and could be a cue for any code below*	Like I'm very hands-on. I have—to learn something, I have to do it
1.1	Failing	Discussion of failing, making mistakes, falling short in succeeding to achieve a goal, or error in one's action or judgment	Code when participant points to specific mistakes or failures they made that required them to rethink *how* they were making. Mistakes might be related to the choice of machine, the speed, the steps, or the materials	And so I went in and I'm like, "Okay, so let me just take this wood and cut it down." And I cracked a piece of wood. And I'm like, "Shoot, okay, I can't do it this fast."
1.2	Struggling	Discussion of working through a task or contending with a task while having uncertainties	Code when participant says things like "I didn't know how" or "I didn't understand at first," as well as "overcome," "struggle," "difficulty." This is distinct from 1.1 in that there is a focus on obstacles such as lack of knowledge that must be worked through, whereas 1.1 points to specific failures and mistakes that needed correction	But in you struggling through like, "Let me try this formula. Seems like the units work out." … Versus me accidentally picking the right equation and plugging it in, it working, I might not be able to recreate that on the test, you know. That same idea or concept is how like I think I've learned through design

Note: The first row is the overall category and others are the corresponding subcategories.

the in-depth interviewing data at this point) using NVIVO Software. The interviewer then trained the other researcher in using the typology to code the data. The interviewer and other researcher went through a few excerpts in the data; this was in an effort to confirm that the other researcher had an understanding of the process and would use the same interpretive lens for analyzing the data. Once the other researcher seemed to have a handle on the typology and the data, the training session ended, and the other researcher coded 10% of the data. After the other researcher finished analyzing the 10%, the interviewer calculated intercoder reliability on the 10% that the other researcher coded after the training session. Using Cohen's Kappa analysis, the intercoder reliability resulted in an agreement of 0.70, with a percent agreement of 75.8.

Then, the interviewer discussed discrepancies with the other researcher and calculated intercoder agreement. Through reconciling discrepancies and discussing the data, the interviewer and other researcher came to agree on all the unitized data, resulting in an interrater agreement value of 1.0 Cohen's Kappa and 100% agreement. This demonstrates the credibility and rigor of the typology.

5 Findings: The Learning Typology

The typology showcases the breadth and arrangement of categories associated with students' experiences of learning in the makerspace for the spaces and students we studied. Collectively, the typology captures both *how* and *what* students learn in and from makerspaces as two broad areas: modes of learning and products of learning (see Table 2). Modes of learning refer to the ways students account for *how* they are learning. Products of learning describe *what* students are learning from their involvement in the makerspace. Products of learning in makerspaces demonstrate cognitive competencies, interpersonal competencies, and intrapersonal competencies, cognitive competencies and are the types of knowledge that students gain. Interpersonal competencies correspond to the social skills that students acquire from their involvement in the makerspace. Intrapersonal competencies are the students' internal skills and awareness that evolve from the activities and social interactions within making and the makerspace.

5.1 Modes of Learning. The learning modalities fall into two primary categories: learning by doing and learning through others. The primary difference that distinguishes these two modes is that *learning by doing* is a physical activity while *learning through others* is a social activity. Importantly, these two modes of learning are not mutually exclusive. Instead, students would often describe both modes as they reflected on their experiences of learning through making, such as in the following account:

> I had to be in shops and makerspaces and talking with people who work with their hands and messing up projects and then getting them right in physical spaces before I could understand how to use those same rapid prototyping for research and empathy approaches to solve problems kind of like in ethereal, conceptual spaces that you can't touch.

In this example, the student describes the importance of both the social interactions with other makers (learning through others) and the importance of being able to be in tangible environments where she could touch things (learning through doing).

5.1.1 Learning by Doing. Learning by doing is characterized by students' accounts of learning through tangible experiences making and needing to learn by working with one's hands. Students used phrases such as "hands-on," "doing," "tangible," and "making things" to describe how they learn best. For example, the following student described her own learning as experiential: "I actually learn the best by making things or seeing things happen, or like, actually doing it."

There are five different ways that students express *learning by doing*: failing, struggling, practicing, iterating, and exploring. Importantly, all of these subcategories are tightly linked and often appear together in a student's account of learning. Still, these subcategories express distinct features that help us understand the nuanced experiences of learning by doing. For example, while failing and struggling involve contention in the learning process, "failing" refers to when mistakes are made or when one falls short of succeeding in a task, such as expressed in the following student's account:

> That's how I usually learn. I'm like, oh, that's cool, let me see if I can do that, and then I try it. And then I'm like, okay, I can't do it this way, but then I figure out a way around it to do what I want it to do.

Distinct but similar, "struggling" focuses on the instances when a participant endures frustrations or challenges when trying to complete a task as illustrated in the following account:

> I did think the motor assist was fun even though it didn't, it decided to break last minute, but that was fun because I think I went through like 10 iterations of that. Five of it being the day before that beta was due. Which finally, once I got it, and I strapped it on, and we rode it once, and it worked; that was the most exciting part about that bike. Because it was like, there's just one thing I couldn't figure out and finally started working, even though it was down to 3:00 AM the night before the beta was due, we got it done and working.

Learning by struggling is characterized by experiences in which a maker confronts a series of barriers or problems through which they work to accomplish a task and develop skills.

In contrast, the other three categories involve an experimentation process. "Practicing" involves a participant seeking to gain proficiency in a task; "iterating" corresponds to intentional experimenting toward making a design "right." "Exploring" focuses on the experimenting process associated with figuring out a solution. These distinctions are made in order to showcase the unique differences in how a participant learns by doing:

> It was a MIG welder. So yeah, we're just welding, uh, we were just doing Phillip welds to two pieces of steel perpendicular to each other. We weren't really making anything; it was just practicing a common type of weld.

It was common for students to describe their experiences working on a particular skill or piece of equipment with no particular outcome in mind other than for the purpose of learning, as highlighted in the above example.

5.1.2 Learning Through Others. Learning through others refers to the instances when a participant discusses learning from other individuals, whether by just watching or by interacting with them. Students' accounts, like the following from a woman maker, point to the importance of their social relationships toward learning in makerspaces.

> Like, when I go in, I'll look for my friends, and we'll just, like, have a conversation, just like, what are you making, what are you working on? It's like, having the environment where it seems like people are, like, happy to be there and enthusiastic, and, like, want to talk about what they're doing and share what they're doing.

This student highlights the ways that social relationships create a learning culture and community of practice in which one becomes a member. Another student pointed to the helping character of makerspaces as important to his learning.:

> To me, it's almost like a no-worries space. I'm able to ask questions or ask around for advice, and it's very open, so it's also a familiar environment to me, seeing people that are also working on similar projects or similar classes as me. It's also—we go there to help each other on certain things.

Across the students interviewed, relationships and interactions with others in the makerspaces played an instrumental role in student learning, creating spaces that were familiar and open for their exploration.

Table 2 Learning typology

Modes of learning	
1. Learning by Doing	Discussion of learning by doing—learning through experiences as a direct result of one's own actions
1.1 Failing	Discussion of failing, making mistakes, falling short in succeeding to achieve a goal, or to error in one's action or judgment
1.2 Struggling	Discussion of working through a task or contending with a task while having uncertainties
1.3 Practicing	Discussion of experimenting in order to gain proficiency. Participant is practicing with tools, machines, software, or material; making projects in order to get the hang of how a tool, machine, etc., works or how to make something
1.4 Iterating	Discussion of intentionally experimenting to get something right; making something over again or repeatedly
1.5 Exploring	Discussion of experimenting to figure out a solution or something that works through exploring, tinkering, playing around, or fixing; not having a direct plan
2. Learning through Others/ Communicating & Managing	Discussion of seeing what other people are doing or interacting with other people as a way to beget more understanding of something
2.1 Observing and listening	Discussion of watching what someone is doing or saying and then realizing how one can use those insights in their own work
2.2 Collaborating—working with others	Discussion of the two or more people who do not fully understand but are working toward understanding or achieving a goal, whether through brainstorming, thinking of new concepts and ideas together, talking to understand together, and working together
2.3 Receiving or soliciting help or training	Discussion of receiving help in order to learn a tool or figure out what to do. In this process, a person with knowledge (or understanding) giving assistance to a person without the knowledge so as to help them understand conceptually; training can also be seen as when a person uses tutorials or training manuals in order to figure out how to do something
2.4 Giving help or instruction	Discussion on training, teaching, or providing direct instruction for someone in order to help them with a task or to make them proficient on some equipment
2.5 Leading, managing, and administering	Discussion on caring for or taking on responsibilities in the community along with recognizing social nuances to help with leading in the space
Products of learning	
3. Content Knowledge and Skills	Discussion on the knowledge, skills, and technical jargon acquired in various subject areas
3.1 Design	Discussion on the formal conceptual, ideation, problem-solving, or prototyping processes/techniques that are used to create a design or to perform a task
3.2 Manufacturing and tools	Discussion on the physical tools, machines, devices, or apparatuses that perform a task
3.3 Computational tools	Discussion on computer-based software that is used to perform a task
3.4 Materials	Discussion on the materials that are used in order to carry out a task, such as understanding of the material's properties
3.5 Components	Discussion on commonly used parts and elements within a domain
4. Cultural Knowledge and Skills	Discussion on navigating a community [in this case, the makerspace community] along with the physical space and what the person comes to understand about that community
4.1 Access conventions and protocols	Discussion on the ability to access the different aspects to a community and the community's resources
4.2 Roles and structure of participation	Discussion on the roles and responsibilities of the people involved in the community
4.3 Rules of the community	Discussion on the way the community works, the rules (both implicit and explicit) that are in place or have changed—includes rules on safety and how safety is handled
4.4 Gender associations	Discussion on the way that gender is perceived in the community or experiences seemingly associated with gender
5. Ingenuity	Discussion on an informal seeking out solutions or being aware of strategies to use in performing a task
5.1 Improvisation	Discussion on figuring out how to accomplish a task without previous preparation or knowledge
5.2 Opportunism	Discussion on being cognizant, aware of, or open to other ideas within one's surroundings and what could be used for a project, or vice versa
5.3 Resourcefulness	Discussion on using available resources and finding strategic ways to achieve a goal or complete a task
6. Self-Awareness	Discussion on the motivating factors toward one's attitude along with one's personal attributes/characteristics
6.1 Confidence	Discussion on developing confidence, acquiring comfort, and overcoming fear
6.2 Patience	Discussion on the value of time, taking the time to perform a task, and allowing oneself to be engrossed by working on a project
6.3 Resilience	Discussion on messing up or struggling but continuing to keep going with a task
6.4 Reflection	Discussion on sharing one's perspective about what they've learned about themselves or the community

There are five subcategories of activities that characterize the sociality of learning through others: observing, collaborating, receiving help or training, giving help, and leading. The interviews demonstrated that student social interactions are different depending on their role in the space. For example, students who had more formal roles in the space would more often find themselves in positions in which they were helping others learn a variety of skills, such as using a laser cutter. Student leaders in these cases would describe how these instructional moments were important to solidifying and enhancing their own knowledge and skills.

> I feel like a lot of people just haven't spent a lot of time in those spaces. The bike prototype that I was talking about, with group members not being familiar with the different machines and processes, I would teach them, and then once they got comfortable with it, then like they were able to be more self-sufficient.

For many students in administrative or leadership roles, helping others, such as the student's description above, was important to their own sense of identity as makers.

In contrast, students would often describe how soliciting help from others in the makerspaces was important to early successes as novice makers, as they developed the confidence they needed to persist in the makerspace. While at first glance these subcategories seem to have clear distinctions, there are some important characterizations to take into consideration. First, observing can sometimes be intentional and associated with the training process, as a participant watches how to do an activity in order to gain experience. Alternatively, observing can emerge from the participant sitting in the space and seeing what other people are doing:

> So, they start by teaching us, just like a professor teaching the class. So, this is just a friend teaching us. And then memorize, observe how they do it, and what to do. What not to do. Try to look around because safety is very important for the makerspace. We have to keep ourselves safe, and someone else too, right? So, more like tips and tricks. How to use the machine, how to operate it. And then have to try to use it. And I learn from YouTube, too.

Students are actively observing others as a means to learn particular skills in making. In this example, the student recognizes that observing others in a makerspace is not much different from students observing their teachers. In this case, they highlight the necessity of observing others as a means to learn how to stay safe in makerspaces.

Collaborating is associated with two or more people working together to figure out how to achieve a task. Collaborative interactions and the collaborative culture found in makerspaces were a recurring description, such as the one described in the following account of a woman maker:

> It wasn't just one person making it because he had an idea; it's like a very big community effort thing. Yeah, I feel like that's a big part of it. Just like you meet more like-minded people, you learn how to brainstorm and actually get things done. Also, feel like it helps you stay less in your dream zone and more in your "do" zone. "Cause like you—a lot of times, people will have these ideas in their head, and they're like, What if we did this? And this?"

In the above account, the student captures how ideas are moved from one's "dream zone" into one's "do zone" as a product of collaborating with others and piggybacking solutions until an idea becomes a physical project. In the makerspace setting, the collaboration process can quickly evolve into a helping process or vice versa. Here, the distinction lies in the fact that collaborating is occurring when two people are both not understanding, and together, they work to develop an understanding, whereas helping is when one person is in the role of a helper (having supposedly more knowledge than another). Later, it became clear that receiving help and giving help were two distinct entities. The process and humility in asking for help permitted a different understanding and gaining of knowledge than the act of giving help. One participant supports this notion by saying, "The best way that I can learn all this stuff is by teaching it." As a final category for learning through others, leading caters to the acquiring of knowledge through having more managerial responsibilities facilitated by one's involvement in the space:

> And my biggest thing is I'm going to be like, You have to sit everybody in the cohort down and tell them everything and how you meant to be and how you are meant to be communicated with and what the consequences are because it's nice and all to have an autonomous group of people that can read your mind, but it's not what everybody is, and it's not always going to work out, and sometimes it's going to blow up like it did. So you should have a meeting and tell people your expectations and how the timeline needs to work and the consequences of not meeting that timeline.

For example, when a participant becomes a student worker or even a member of the executive board, they have to engage leadership skills so as to ensure that they abide by their given responsibilities.

5.2 Products of Learning

5.2.1 Content Knowledge and Skills. Content knowledge and skills pertain to when the participant gains an understanding or skills associated with various subject areas. In the narratives, the students talked primarily of four main categories: design, manufacturing and tools, computational tools, and materials.

In the "design category," participants discuss the formal processes involved in creating a design or performing a task. This includes, but is not limited to, problem identification, ideation, and prototyping. The techniques that a participant may use in the design process, such as interviewing the population for design insights or branding the design, are also included in the design category:

> I know why I'm actually doing things now. Because you learn techniques when you're making things, but all of the courses and classes that you take here are giving you the ability to understand the decisions that you're making from a maker perspective. You can see the fundamental underlying mechanics of how those decisions impact your design and impact the functionality of what you're making.

Importantly, as we see in this student's reflection, design knowledge also reflects a holistic understanding of the decision-making that goes into all aspects of making.

Often seen with design are the participant's manufacturing and tool knowledge. This refers to the physical tools, machines, devices, and apparatuses that a participant learns how to use, when to use, or how it works.

> I guess a lot of time it's accounting for things you didn't expect. There is no one process; there isn't necessarily a right way to do anything, so however you set something up, you need to be aware of what implications that has on how you cut things with what tools you're going to use, what speed you're going to run the machine at, uh, what orientation you're going to cut it and what order you're going to cut it and that kind of thing. It's just important to be aware of all the nuances and implications certain decisions you make have.

Unfortunately, this category does not capture the depth of a person's knowledge of tools and manufacturing. This is due to the fact that participants' discussion of tool or manufacturing knowledge is not always specific, such as "I learned the 3D printer," which we did not probe further because the research questions prioritized an understanding of the breadth of learning. As such, a participant's knowing how to 3D print is categorized the same as a participant knowing how to fix an advanced 3D printer. The research team discussed ways in which to further evaluate for depth of knowledge but made decisions to table analysis for depth of knowledge for future work and focused on simply capturing the breadth of knowledge for the current endeavor.

Coupled well with the aforementioned content knowledge categories are the final two categories of computational tools and materials. Computational tools are a participant's knowledge of computer-based software.

> So, I started relying more on doing all the upfront front iterations in SolidWorks. So, I was wasting a lot of time changing the part and then making a new one. I'll make another one instead of just using the software to tell me if it's actually going to work or not. So, with this motorcycle, there's so many parts that are interacting with each other that have to change if something goes wrong. So, instead of wasting time, which is like months, months-worth of time, to try to make the actual bike and see what happens. I'm relying on the software instead, which saves you time and a lot of money.

Students often commented on the importance of learning computational tools for both efficiency of their making, as well as saving money, as they recognized its important role in shaping an overall design and the materials included:

> I think that's also why SOLIDWORKS is used so much in prototyping because you could just change one thing and have the entire prototype change around that instead of if you were to make the physical model instead of the CAD model and then have to change something, you would have to completely either tear it apart and start over again or cut pieces and waste material, and that wastes a lot of money and time.

Computational skills were thus often mentioned in concert with materials. The materials category is students' understanding of material properties and what certain materials are appropriate for a design. Students describe choices they are making based upon the properties of the material and the tools they plan to use, such in the following example of a student describing soldering:

> We're going to use an industrial solder, so it's like these joints but on a much larger scale. So, the braided copper is going to go between both of them, but where it meets up here, it's going to be solid because it's going to have a solder in it. So, a solder is like a really low melting metal that kind of just fits in between all the nooks and crannies of the braid. So that's how we're going to make them.

While the "content knowledge and skills" categories are distinct from one another, they often appear together in the data.

Finally, components reflect specific knowledge relating to common "mechanisms" in a field, like differentiating between or discovering commonly used parts and elements in a domain that expands their design knowledge, for example, gears, bearings, specific operations in code, or electrical components. In the following, the participant accounts for the different component knowledge generated in a robotics-making experience:

> I got experience with gears. We tried to make treads, but it didn't work. But it was super cool. It was super fun. I had my first experience with sensors, so we were using an ultrasound sensor for distance detection. I got experience with servos. I had some experience with motors, but I had more experience with servos, so that was very interesting to see what the difference was actually between a motor and a servo. Didn't know that before. There was another interesting thing about it. I said motors, servos, linear actuators, all those mechatronic stuff. It was my first time dealing with solenoids, first time dealing with those, so that was great. Because those are… implemented some amount of code… or Arduino, that's what it was. I had never used Arduino before.

5.2.2 Cultural Knowledge and Skills. The "cultural knowledge and skills" category organizes the data that talks about navigating the makerspace community, whether that be through access conventions and protocols, roles, and structure of participation, rules of the community, or gendered experiences. Through cultural knowledge and skills, the participant comes to understand the nuances and rules of the community. Participants discuss experiences on how they gained access to the space, their perceptions of accessibility before and after involvement, and what they know to be available for them to use. This type of learning is critical in showcasing how university makerspaces are succeeding or failing at providing access to students.

Access is characterized by students' reflections on their rights to be in the makerspace and the ease and barriers to entry and use of the tools in a makerspace. For example, the student leader in the following example recognizes students' frustrations with their lack of access to using tools themselves:

> Sometimes I think it's like students are frustrated that they can't use the things [3d printer] themselves and especially because we can use them ourselves at IT, it's frustrating to have to, yeah, give your file off to someone and have them print it for you or whatever. I know some people have just sometimes been frustrated because basically they felt like people were messing up their stuff, and they were like, "I know how to do this properly." It's frustrating that I'm having to go through this other student who is messing it up.

Often, access was discussed in terms of training and safety features of makerspaces. For student leaders in the makerspaces, tests ensured that they could adequately help those who entered the spaces:

> You have to get trained on all the machines. They're called rooms. You get trained on the laser cutting room. You have to take a test that tests sets of knowledge. It's really simple. You don't really make anything crazy. They ask you to take this picture and turn it into this. Cut parts of it away, but you have to do it all in the program. … The idea of the tests are all to test and see, if you were working, could you help someone else who needed troubleshooting.

Indeed, it is the responsibility of the makerspace community, including student leaders, to decrease barriers to entry and provide clarity on access for both insiders and outsiders.

Furthermore, cultural knowledge and skills include both roles and rules of the community. The participants learn the hierarchical structure of the makerspace community, the responsibilities of the different members, and their own personal roles in the community. For many makerspaces in our study, student leaders and makerspace staff serve both a helping and gatekeeping function, and student makers learn who can help them when using the makerspaces:

> It's in the [makerspace], and it's a little closed off for safety purposes, or like, so other people don't get blinded by the light. But also, it's limited to only, like, one or two people at a time, as there's limited gear there. You don't have to constantly be working on welding. You can come back to it or ask advice from the TAs, or if there's a problem, you could ask the lab manager. Very interesting to do that. Then as an apprentice, my job is to basically learn a lot from it, learn a lot from it and eventually become a master myself, so I get an in-depth knowledge in a specific room.

Students' comfort in entering and using the makerspaces is understood in relation to not only comfortable with the tools themselves but with an understanding of the roles within those spaces. Thus, the cultural knowledge associated with the roles is connected to student access to makerspaces.

Leveraging their understanding of the different roles, the participants also come to know the rules for working and interacting with the social community and the materials in the community. Rules include more explicitly defined processes, such as safety procedures, or more implicitly known processes, such as it being okay to fail, as revealed in the following account:

> It's just like, you have to pass the test to become a PI because you have to know all the safety procedures. If you cannot do everything that's required on that checklist, then you have to take the test again. We're allowed to take the test again, so failing a test doesn't mean anything. You can just come back. It just means that you need to work harder on that.

Lastly, the "gendered experiences" category showcases makerspaces as gendered environments and cultures and highlights women's reflexive awareness of makerspaces as masculine. For example, the following student reflected on how the masculine culture of makerspaces impacts the interactions with others in those spaces:

> The culture of the [makerspace] is very male. It's like male students who work there who really think they're the smartest and the best, and especially as a girl working in there, I would not be taken seriously, so even if I do know how to use all these things because I absolutely use them at the College of Design, I would be assumed to not know what I'm talking about. Again, a little bit of sexism, but I think the machine shops are—there's not always a lot of females in there just because of, like, norms, I guess. But there's a lot of females I know that like building, but they usually tend to take—I don't want to say a submissive role, but like, letting the guy do it when it's—sometimes I'll be in the shop, and there will be someone that's like, "Can you do this for me?" I'm like, "No, I'll show you how to do it, and you can do it, but do it yourself," and it's usually females that are like that. "Can you just do it for me?" "No. Do it yourself."

Further, women participants highlighted how important it is to have women role models in and around makerspaces, such as women professors and women in leadership roles: "I definitely feel more confident now, obviously. There are a lot of really powerful women at the [makerspace], which is really special. It's normalized the idea of women in STEM for me. Why wouldn't women be in STEM? They're just as good."

5.2.3 Ingenuity. Ingenuity aims to capture the instances when a participant informally uses innovative means or strategies to pursue a solution. Attributes of ingenuity include the subcategories of improvisation, opportunism, and resourcefulness. Students' narratives generally engaged more than one of these subcategories of ingenuity in a given account. Improvisation is characterized when a participant works to figure out how to accomplish a task despite a lack of previous preparation or knowledge. Students used improvisation when there was an unexpected need that arose, such as in the following example:

> I remember sophomore year apartment, it had like a weird hole in the desk, so I couldn't put my lamp somewhere. So, I 3D printed something that would fill in that gap and then extend out a bit, so it wouldn't take up space on my desk. It snapped instantly, and I thought I should make it out of wood instead. That worked a lot better.

Perhaps not surprisingly, improvisation was quite common when a participant has a project that fell apart the night before it was due, and they have to figure out a quick solution. When figuring out a quick solution, the participant's behavior may be characterized by opportunism. Opportunism, described in the entrepreneurship literature [89], refers to when a participant recognizes and exploits opportunities to the ways in which other solutions in their surroundings may be applicable to a design task. For participants, that often meant scanning the information landscape to pull from diverse resources to tackle a task or see a design in their everyday life as something they can make, as did this participant: "So I was at a friend's, like looking at their coat hanger, and I was like, why don't I just do that with my hats?" Thus, this can take shape when makers begin to be aware of design in the world around them and perhaps build a collection of designs that they see as transferrable to other design tasks. This category may be seen as a means for acquiring inspiration in design and improving upon it.

In the third category of resourcefulness, the participant strategically uses available resources as a way to achieve a goal or complete a task.

> I've been a mountain biker. The first time that I actually broke something on my bike, I went to the bike shop to get it fixed and noticed how expensive it was to get things repaired. So, then I would just Google how to fix something and then buy the tools and do it myself. And it would be much cheaper. Then I got to the point where I was able to fully disassemble my bike, fix everything, reassemble it, know my way around it. And then I ended up getting a job at a bike shop, too. That was during the school year here. That was during freshman year, summer.

Participants may find that they want to make something in the shop, so they look to what machines, tools, and materials are available for them to use. These types of categories, characterized under ingenuity, are linked to the participant's ability to adapt to given situations.

5.2.4 Self-Awareness. Self-awareness reflects the motivating factors toward one's attitude and personal characteristics. While this category could easily have an abundance of secondary categories, we highlight four underlying main areas that emerge in the data: confidence, patience, resilience, and reflective. To reiterate, we recognize that there is an abundance of categories that could characterize the nuances in the data; however, we focus on four that are able to capture instances of self-awareness that permeate the data. As a participant learns in the makerspace, they become more confident and comfortable while also overcoming their fears or facing their anxieties associated with the space:

> Well, knowledge brings confidence, you know. So, just knowing how to use a tool more, using it more brings confidence. So, just getting out there and not being afraid to try something, even if you don't know how to use it. Also, the people. With the right people they bring you up, so that can increase confidence too.

Confidence was expressed in a variety of ways, such as in relation to simply entering the space or using the machines.

Patience is characterized by the participant taking the time to perform a task or allowing themselves to be engrossed in the task, as this participant reflects:

> You have a lot more control, and that's something that I had to learn over time. So, I think the biggest thing that I've really picked up on through makerspaces, and it also sort of plays into fencing, is that the more patience and respect that you have for a process, the more you understand why that process is better if it takes a little longer.

Few participants articulate acquiring patience, but there are numerous instances of them discussing the patient's endeavors for creating a design or achieving a goal.

In a similar vein is resilience. Participants do not refer to gaining resilience, but rather they talk about instances where they fight through a task or bounce back from failure.

> So, it means if I come up against a challenge, I know with enough dedication, I can probably overcome that challenge. You can see it happen over and over again. How the snowmobile was invented. This guy lived in the Arctic, and his kid got sick. He had to take him to the doctor, but the roads weren't good enough, and they didn't have machines that could travel fast enough in the snow, so his child died. So, then he engineered a better vehicle to actually help more people. You can see it happen over and over again.

Evidently, resilience is closely related to the "failing" and "struggling" categories within the "learning by doing" category. Also, it is necessary to address that the "patience" and "resilience" categories have an overlap when it comes to perseverance. While perseverance is not granted its' own label, the instances where perseverance is evident must be carefully identified as patience, resilience, or both. Then, holding the position of the last category in the typology is the reflective category.

While the very nature of the interviews is characterized by reflective considerations of their experiences making, the "reflective" category aims to capture when the participant shares their perspective about what they have learned about themselves or the community. This is highlighted when the participants realize that their involvement in the makerspace has changed their lives or when the participants see how important it is to have a "toolbox of design." In the following account, the participant showcases her awareness of her identity as an engineer, how that identity is related to characteristics like creativity and esthetics, and the role of makerspaces in providing her with an outlet for fostering self-expression:

> The [makerspace is] great to have for classwork and stuff, but just as like a mode for being able to make products and express yourself, it is so nice to have that resource there. It is so nice. I feel like engineers aren't always able to express themselves in a creative way, and I feel like this is like an *engineery* way to be able to do that. I feel like in our classes; there's not a lot of creative freedom for a lot of stuff. And I feel like engineers are like, oh, I can't have hobbies. … But this is a really cool way that lets you use your skills that you learn in class to create something, and you use that engineering mindset in an artistic way.

This category demonstrates that participants are acquiring skills in reflection from being involved in the makerspace, which given the work on the need for reflection in engineering design [90,91], showcases a means for students to become reflective that is neither imposed nor forced.

5.3 The Breadth of Learning. Through developing a thorough typology, we have been able to show the breadth of learning that makerspaces have the potential to provide. As evidenced, this learning is more than just manufacturing and tool knowledge. Students are engaging in both content and culture knowledge and skills along with communication, management, ingenuity, and self-awareness. With this expansive typology, we are then able to extract the main claims for learning that emerge from the data as a means to craft a model for how the types of learning develop and interact.

6 Discussion

In 2004, the National Academy of Engineering (NAE) emphasized that the Engineer of 2020 should have strong analytical skills, practical ingenuity, creativity, communication, business and management knowledge, leadership, high ethical standards and professionalism, dynamism, agility, resilience, flexibility, and the habit of lifelong learning [92], which is evidently a high aim to achieve. In the meantime, the number of makerspaces experienced a worldwide increase from 100 in 2006 to 1400 in 2016 [93]. Makerspaces are seen to provide a means for individuals to acquire certain twenty-first-century skills [94] and offer opportunities for students to engage in more innovative thinking and produce creative solutions [31]. Through investigating how university makerspaces support how and what students are learning, along with how they are engaging in engineering design, we articulate the types of learning (both modes of learning and products of learning) in which students engage.

The typology of learning demonstrates that students can engage diverse skillset through involvement in an academic makerspace. For modes of learning, the makerspace primarily supports two modalities: learning by doing and learning through others. For products of learning, the makerspace encourages the learning of cognitive competencies (content knowledge/skills and cultural knowledge/skills), intrapersonal competencies (ingenuity and self-awareness), and interpersonal competencies (communication and management). This shatters the notion that makerspaces are only helping students to gain manufacturing and tool knowledge. Students are learning how to collaborate, how to design, how to reflect, how to problem solve, and how to produce creative solutions.

7 Limitations

While data were collected at two distinctly different types of universities, they were both predominantly White universities, and the population interviewed reflected the racial and ethnic demographics at both universities. Similar to our prior work, the data set lacks articulation of the varied social and cultural identities beyond gender/sex, of those who use makerspaces [49]. Our analysis would have been enhanced by using an intersectional lens that attended to the convergent and divergent making experiences of individuals who experience different sets of unearned privileges and disadvantages due to their identities and social locations.

The research team occupies relatively privileged positions as White cisgendered individuals, and as such, we recognize that our identities not only implicate the kinds of questions that we asked about making, but also the interpretations of the data itself. Further, our approach to the study of making and makerspaces is grounded in a Eurocentric framework that guides most inquiry in this area [56]. We believe that future applications and extensions of the learning typology presented here would be benefitted from using both an intersectional lens and challenging Eurocentric frameworks of making in the interviews themselves.

8 Conclusions

In effort to understand how makerspaces support student learning, this paper presents a qualitative approach for gaining insights into both how and what students are learning from these makerspaces. Using two different interview processes, we developed a typology of learning that characterizes different types of learning emerging from lived experiences of students in the makerspace; the typology articulates both modes of learning and products of learning. The typology showcases how students are learning a variety of skills and competencies through engaging in academic makerspaces. The makerspaces help to support the learning of content knowledge in design, manufacturing, tools, and computational tools; of cultural knowledge in access conventions, roles, and rules of the maker communities, and gendered experiences; of ingenuity through resourcefulness, opportunism, and improvisation; of self-awareness through patience, resilience, confidence, and reflectivity; of communication and management skills; and of hands-on learning via failure, iterating, exploring, and practicing.

While this work gives more focus on women student learning in university makerspaces, it is expected that these findings transfer to students of all ages or genders and of makerspaces of all kinds. Evidently, we are continuing our exploration of learning in makerspaces which will be presented in future publications. Nevertheless, the findings and work presented in this paper help to forward the conversation of learning in academic makerspaces in the university setting. Thereby, makerspaces are confirmed to help provide women students with diverse skillset that engages design, manufacturing, cultural knowledge, failure, collaboration, confidence, resilience, communication, management, and ingenuity.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The data sets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request.

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