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Engineering Faculty Members' Perceptions of University Makerspaces: Potential Affordances for Curriculum, Instructional Practices, and Student Learning

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We detail an exploratory study of faculty members' perceptions of activities associated with undergraduate engineering programs in university-based makerspaces. Our study examines the affordances and constraints faculty perceive regarding teaching and learning in these spaces and, specifically, how makerspaces support engineering faculty members in accomplishing the goals and expectations they have for undergraduate students' learning and development. We found that makerspaces inspired faculty members' curricular and instructional innovations, including design of new courses and implementation of practices meant to result in more team-based and active learning. Faculty perceived student activities in makerspaces as fostering of student agency and development of engineering skills, knowledge, and affect. Faculty also identified concerns related to the teaching of engineering in these spaces, including the need to change their instructional practices to more fully engage students and to balance the sophisticated tools and resources with the rigor of completing complex engineering tasks. We use structuration theory to illuminate how faculty act, rationalize, and reflect on their teaching practices and goals in relation to structures present in university-based makerspace. Our study is intended to inform faculty and administrators working to engage students through interactions in makerspaces or similar innovations, and to consider how access to and impact of these structures support undergraduate engineering education.

Keywords: makerspaces; engineering education; undergraduate; faculty perceptions; diverse populations

1. Introduction

The use of makerspaces is a growing trend in university engineering programs. Makerspaces can include a range of cutting-edge design and fabrication tools, such as 3D printers, laser cutters, and modeling software, as well as more "traditional" building implements like hand tools, sewing equipment, and welding equipment [1]. University-based makerspaces unite the designs of machine shops or fabrication labs with project areas that are found in libraries and community makerspaces. These spaces provide more open access to tools and making supplies and opportunities to work with other makers and are intended to support a community of learners and individuals that apply their learning with hands-on activities and projects [2]. While community and K-12 education-based makerspaces have existed and been researched for decades, the use of makerspaces in university engineering programs is still a relatively unexplored phenomenon [3, 4]. Emerging research suggests that makerspaces can enhance engineering students' undergraduate experiences [5], by exposing students to designing and prototyping activities that can enhance their development of engineering skills, motivation, and competence [6]. Limited past research also suggests that work in university-based makerspaces supports peer-to-peer interactions and activity [5]; promotes students' project-oriented collaborations across engineering, science, and other fields [1]; and positively influences students' confidence, motivation, and expectations for successful engineering design activities [6, 7].

Makerspaces have been proposed as welcoming and democratizing environments for women's and

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underrepresented racial/ethnic groups' STEM participation [3, 8]. Desires to foster more inclusive and welcoming engineering environments has spurred the overall use of makerspaces in undergraduate programming [9]. Calls for more inclusion and diversity – such as increasing the number and percentages of women and people of color – in STEM fields have been numerous for several decades [10]. With disproportionately low enrollments and retention rates for these populations in many postsecondary STEM programs, educators and leaders are motivated to examine and innovate relevant structures and practices [11]. Proponents of the use of university makerspaces point to evidence of enhanced engagement and success of underrepresented student groups (e.g., women) in engineering projects in these spaces that cater to their interests (e.g., socially conscious designs) [12].

Other scholars have critiqued what they feel are unfounded egalitarian assumptions associated with university-based makerspaces, noting problems of access and equity issues for groups historically marginalized or underrepresented in engineering [13]. Vossoughi et al., argues that the inclusion of makerspaces in formal educational settings (like the one in the study detailed in this paper) may not address the historical inequities of marginalized groups, specifically in higher education in STEM fields; makerspaces may, in fact, reproduce a white, male ideology [14]. Ultimately, while there is optimism with regards to embracing makerspaces as a place where students can work in teams, develop creativity and innovation, and engage with diverse others [8], research exploring relevant issues of equity and inclusion is limited. Research further signals that postsecondary engineering education programs and faculty members' uses of makerspaces may vary widely in aims and associated pedagogical approaches in these spaces [7]. More research is needed documenting how engineering faculty perceive and use makerspaces to support student development and persistence in engineering to better support both students' and faculty members' uses of such spaces.

Our paper explores engineering faculty members' (hereafter, just faculty) perceptions of university-based makerspaces, specifically affordances for undergraduate teaching and learning. We document the goals and expectations faculty have for undergraduate students' learning and development and their thoughts about makerspaces helping to meet these outcomes. We describe how makerspaces influence faculties' curricular and instructional innovations, including those meant to foster more team-based and active learning. Additionally, we discuss faculty concerns related to teaching engineering in these open access spaces, including those more practical implementation issues, and those concerning students' understanding of engineering practice. We present implications for faculty and administrators working to engage students as engineers through interactions in makerspaces, and to consider how access to and impact of these structures may support undergraduate engineering education. Finally, we suggest future research regarding makerspaces and the confluence with undergraduate professional preparation programs.

1.1 Brief Description of University-based Makerspaces

Historically, makerspaces have functioned as community-based spaces, where members have access (sometimes per a fee) to technology and tools to work individually or collaboratively on a design problem of interest [9]. Makerspaces have also existed in public and academic libraries, in K-12 schools, and on college and university campuses, accessible via certain permissions or functioning more as open-spaces, with more open access to the tools and resources in a less controlled environment [15]. In the last decade, the number of university-based makerspaces has increased dramatically, especially those associated with engineering programs, whose leaders have begun to realize the value of uniting traditional labs and machine shops into less redundant and more open-access and inclusive spaces [5, 16]. University makerspaces can be differentiated from community-based makerspaces by the commitment of postsecondary faculty, staff, and students that have specific goals, responsibilities, and activities associated with the spaces [2], and high potential for alignment with formal academic programming.

2. Theoretical Frameworks

2.1 Structure-Agency Dialectic Theory

Structure-agency dialectic theory allows for exploration of the affordances and constraints of individuals' perceptions and potential for action in formal and informal teaching and learning environments and systems, including in relation to curriculum, practices, and policies [17]. This framework has rooted recent scholarship in science education, notably concerning K-12 settings, providing rich exploration of the complexity of the confluence of social structures and human agency, which can involve educators' pedagogical practices that form structures and students' agentic actions that may shape and reshape those structures [18, 19], including the identity development of marginalized groups [20]. A structure-agency lens can steer researchers focus away from viewing instructors and students from a deficit perspective [21], instead allowing researchers to consider how learning is shaped by structural and social factors that are present in learning environments [22]. Varelas et al. [17] have argued that, in educational settings, interactions between and among individuals (e.g., students, educators, and staff) and structures in these settings (e.g., syllabi, expectations related to assignments and grades, and physical spaces) reflect and create complex systems where individuals and groups may (or may not) feel empowered or enabled to make sense of complex tasks, create, and thrive.

We build on a structure-agency dialectic framework in utilizing Gidden's theory of structuration [23] to explore the complexities of one makerspace and its interaction with formal engineering programs at one university. Gidden [23] posits social systems are comprised of *agents*, individuals engaged in activities within that context (e.g., faculty and students), and *structures*, the physical and psychological (human and nonhuman) elements that make up the social systems in which agents operate (e.g., teaching and learning environments). *Agency* refers to what one knows or believes about a situation (an agent's *knowledgeability*), and their potential for action within the structures of that system [23]. A duality exists between structure and agency, where structures can constrain and enable agents, and agents' knowledgeability and actions can reproduce, disrupt, and transform structures (Fig. 1). Structure refers not only to the physical and psychological resources that exist within social systems (e.g., instructional technologies in a classroom), but also to the "rules implicated in the production and reproduction of social systems," rules that encompass the collective thoughts (actions) of agents in the production and reproduction of structures [23, p. 23]. Agents share social "schemas" as rules [24], reflected as routines (e.g., end-of-term grading) that are embedded and reproduced in social structures and systems, including as policies and procedural norms. Social systems, like the structures and agents comprising them, are fluid and resist remaining in a static state.

Individuals display agency in creating and developing new ideas, achieving outcomes, and producing artifacts [17]. As individuals interact with structures and other agents in social systems, they routinely assess and rationalize theirs and others' actions. This *reflective monitoring of actions* [25] occurs against a backdrop of the individual's knowledgeability of the situation, including the larger socio-historical context of a social system, related structures, and interactions. When agents engage in reflective monitoring, they rely on their mental schemas constructed via relevant past experiences, or what Gidden [23] terms *memory traces*. Memory traces are called forth as *modalities*, allowing individuals to assess and rationalize actions, per their determination of the level of significance and legitimacy of those actions, and their power within a social system. *Signification* concerns the degree to which an individual deems an action relevant and appropriate for a goal (e.g., assigning a group versus individual assignment). *Legitimation* concerns the degree to which an individual deems an action is aligned with the rules or norms of a social system (e.g., providing a syllabus at the beginning of class, using exams or presentations to assess knowledge/skill), including clusters of rules (*frames)* as well as organizational *routines* (e.g., lectures versus active learning strategies). Recognizing action as aligned with system norms provides individuals a sense of security via reiteration and maintenance of structures. An individual's felt power within a system, or their *domination*, concerns the degree to which an individual's "capacity to achieve outcomes" is exercised through the utilization of resources (e.g., designing and prototyping a new artifact) and the capacity to influence other agents regarding actions (e.g., influencing teammates in group activities) [23, p. 257]. As individuals gain access to resources and related actions, their competence and power in navigating a system grows [23].

While largely interested in the reproduction of social systems, Gidden [23] also provides basic

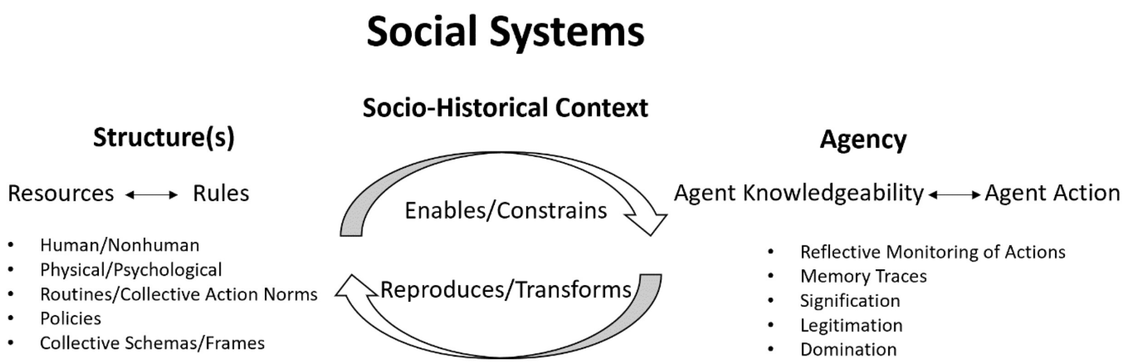

Fig. 1. Interpretation of Structure-Agency Theoretical Framework.

insight regarding the power of the dialectic to change social systems. Sewell [24] elaborated on the potential for change by pointing out that change happens, in part, due to a multiplicity of (potentially interacting) structures and the transposable nature of agents' schemas. We draw on structuration theory to illuminate the ways engineering faculty act, assess, and rationalize teaching-related actions, and to explore the related potentials for pedagogical and programmatic change.

3. Research Design

3.1 Setting

This study is part of a larger, three-year, NSF-funded project, focused on delivering rich accounts of the experiences of faculty, students, and staff regarding undergraduate engineering programs' interactions in six university makerspaces, ultimately towards promoting strategies for more equitable access, success, and persistence of diverse undergraduate populations in engineering programs. This paper presents the intentions and experiences of faculty teaching in a relatively new (under 5 years old) university makerspace at a public research university located in a western state. The university makerspace's large area (over 20,000 square feet) was technically accessible to all campus affiliates, including faculty, staff, and students who paid a fee based on the level of access requested. Although housed in its own building, the makerspace was operated by the College of Engineering; however, faculty from other disciplines and departments were invited and encouraged to apply to teach courses within the makerspace, and students of any major could utilize the space. Faculty secured time and space for their courses through an application process facilitated by a committee of faculty and makerspace staff. All makerspace users were required to complete safety training workshops.

3.2 Research Questions

Our paper attends to the following specific research questions:

1. What do engineering faculty, at one research university in the US, perceive university-based makerspaces affording undergraduate teaching and learning?
   (a) What are engineering faculty members' uses of and goals for makerspaces with respect to their undergraduate engineering students' agency and competence?
   (b) How do engineering faculty perceive makerspaces as helping to foster their goals for students?
   (c) In what ways are engineering faculty members' pedagogy influenced by makerspaces?

3.3 Methods

Our larger study utilizes a phenomenological approach, allowing rich exploration of complex phenomena within natural environments at six university sites. This paper presents results from one data source, faculty interviews, that we feel provide rich descriptions of how faculty are utilizing makerspaces, their goals for such spaces, and their perceptions of impact to teaching and learning. We conducted our semi-structured interviews with twelve faculty teaching various courses involving undergraduate engineering-major students within the makerspace. Interview questions sought to elicit faculty perceptions of how they supported their students in makerspaces, what they wanted students to learn through their use of makerspaces, and to what extent faculty felt makerspaces promoted the skills and practices essential to engineering principles. Two-thirds of faculty who participated in the interviews were from mechanical, electrical, and computer engineering fields with the remaining in related sciences, performing, and visual arts. Courses taught ranged from introductory courses in manufacturing, fabrication, design, or computational engineering, to capstones in mechanical engineering and advanced manufacturing.

Interviews were transcribed verbatim and transferred to Dedoose coding software for qualitative analysis. Coding was done in two phases, an inductive followed by a deductive phase. The first author initially created inductive codes from a first read of the verbatim transcripts, drawing perspectives from interviewees' own words towards grounded interpretations of answers to interview questions [26]. This stage was followed by a second, deductive round of analysis. During both rounds of coding and analysis, theoretical memos [27] were created to provide a record of developing ideas and interconnections. The second author reviewed 20% of the transcripts to ensure reliability and consistency of coding and provided ongoing contributions to the emerging codebook. In both phases the two analysts discussed emerging concepts and themes based on their critical reflections on the data [28]. All findings we report in this paper were made by at least two of the twelve interviewees.

3.4 Limitations

We realize two distinct limitations based on the data that was used in this study. First, the data reported here were collected at one university and concerning one associated campus makerspace. Thus, we assume the perceptions, experiences, and expectations of faculty who were interviewed are not generalizable to other universities. A second limitation concerns faculty members' self-reports and perceptions, including their unconfirmed perceptions of student impact. We recognize that this may tell only "half the story" [29], although other researchers have argued that postsecondary STEM faculty self-reports do reliably convey teaching practices and related phenomena [e.g., 30, 31]. Nevertheless, we contend that our exploratory study may still enlighten the emerging field of research in university-based makerspaces and the interactions of faculty and students in such teaching and learning spaces. Our future presentations of research will explore student impact gathered through interviews and surveys with students.

4. Findings

4.1 Faculty Perceived the Makerspace as Affording Access to Additional Technologies and Personnel for Designing and Prototyping

Even at this comparatively well-funded university (and especially with respect to its engineering programs), faculty perceived the new makerspace as alleviating access constraints to tools, equipment, resources, and concerns for student training and safety regarding their use. Recognizing the constraints of typical campus engineering workshops, faculty acknowledged the value of bringing together highly specialized tools and equipment that are sometimes absent from campuses or that otherwise reside behind locked doors with limited access, both in days and times, to most students. The makerspace allowed faculty to create new learning opportunities and activities for their students as stated here by one faculty:

> "With the opening of the [makerspace], it dramatically increased the capacity and the quality of the equipment that these students had available to them . . . . Things that are very, very heavy in the prototyping process, that were not possible because of lack of machinery, now became possible and for existing classes. It actually made the prototyping better because there were different types of machines that were available, different types of fidelity and the capacity of the [makerspace] made it possible to actually offer more sophisticated and more in-depth projects in existing classes."

The enhanced prototyping technology, coupled with lower safety risks (when compared to more prototyping tools and environments) were key affordances of the makerspace, as noted in this faculty member's comments:

> "[In comparison to] many types of design classes, your types of prototypes that can be manufactured with a makerspace available is quite a bit more sophisticated than without that particular space, and also a lot safer and faster as well."

Makerspace staff provided training for use of the equipment and were available to support students in using the tools. The combination of accessible space and equipment, with trained personnel to help students learn how to use equipment, was credited by faculty as resources for teaching of skills, via activities and classes, that faculty felt valuable for engineering students, particularly earlier in their academic programs.

4.2 Faculty Perceived the Makerspace as Affording Enhanced Student Engagement and Competency in Authentic and Important Practices and Processes in the Field of Engineering

With access to the makerspace, faculty perceived themselves as able to (re)design curriculum and instruction to be more applicable to students' discipline- and profession-related development. By having a space that simulated relevant engineering situations, faculty envisioned their students engaging in the kinds of experiences that students could expect in an engineering profession; faculty believed this allowed for students' development of specific skills, knowledge, and competence concerning creative and critical thinking, innovative design, iterative prototyping, and production of complex models. Said one faculty member:

> "I think it's great if the students can have an experience that gets as close as possible to what they might experience in a real industrial design environment."

Through these more realistic interactions, faculty saw students being able to develop skills (e.g., communication, designing and testing, and rapid prototyping) to levels that were not possible in other learning environments and course activities. Some of these activities involved working with clients or industry partners in prototyping or collecting data, as demonstrated by this professor's statement:

> "Some of the skills that I think are essential that I've been able to incorporate is working with a client, redesigning [the student's] idea with [the client's] needs and not your wants. Testing it, because a lot of times in college and not in college, in education, you have an assignment, you turn it in, you get a grade and that's it, you're done. With these projects, they really do see that it's an iterative process, it's not just one and done."

The potential for students to produce something that was relevant to a larger and more "diverse society" by utilizing the makerspace was also mentioned by faculty at this institution, one with a notable societal impact mission.

> "And so very early . . . being able to create something they get to see the relevance of what they do early and the connection and the confidence it gives them to ultimately realize that what they're learning could

actually produce something in whatever way they choose. It's a whole different experience that I think is absolutely necessary for the kind of diverse society that we will have."

Faculty perceived early-program design activities as especially critical for students' understanding and participation in engineering processes. They viewed makerspaces, specifically, as affording students earlier and easier access to opportunities (in comparison to other university spaces) for knowledge construction and participation in engineering processes, even students with no prior engineering experience or skills.

"With the opening of the makerspace, it dramatically increased the capacity and also the quality of the equipment that these students had available to them. So, the first thing it did was it made certain types of classes just possible."

Faculty were especially appreciative of what makerspaces afforded regarding prototyping, including the potential for rapid creation of three-dimensional objects and related iterative design, that could foster students' creative and critical thinking. Conversely, faculty expressed a related concern that students "needed more than just technical skills" and might perceive rapid prototyping, afforded by 3D printers that were prevalent and accessible in the makerspace, as the crux of design. Faculty viewed this growing "demand [by students] to learn by design, by making," and especially those pursuits "taken up as creative activities in more and more K-12 schools" as potentially negating the importance of understanding engineering design concepts such as geometric dimensioning and tolerancing (GD&T), or how to work through a feasibility analysis towards understanding the constraints and primary requirements of their engineering design (prior to building a prototype). Overall, while engineering faculty favorably viewed the design experiences afforded by makerspaces, they were concerned that students could develop a mindset of engineering as predominantly comprised of the quick and successful fabrication of products using fancy, cutting-edge machinery. This concern seemed somewhat negated per faculty perception that activities in makerspaces could help students become "better at critical thinking and problem solving" and "engage in creative thinking around different technologies, people, and communities." Other critical attributes included communication and collaboration skills. Described by one faculty as "projects that are worked on by teams and that helps to develop the communication aspect of the ABET requirement." (ABET is the Accreditation Board for Engineering and Technology.)

4.3 Faculty Perceived the Makerspace as Creating Opportunities for Students to Develop their Creative Ideas, Listen to Diverse Perspectives, and Experience a Sense of Belonging

Faculty perceived the makerspace environment as affording students new opportunities in their courses and programs. For instance, faculty spoke of the makerspace as providing students with the experience of working in teams that they claimed encouraged collective discovery and collaboration and helped to create a sense of community with both diverse individuals and ideas. Working in such communities, faculty perceived students influenced in their future designs as they observed their peers' designing and making. The monitoring of other students' activities and designs as well as the creation of one's own ideas were seen by faculty as generating greater student agency and sense of capacity and power concerning one's own ideas and actions. Faculty overall perceived makerspace interactions as leading students to develop more creative designs, artifacts, and prototypes as stated here:

"I think just an exposure to the environment, to seeing what other people are doing, other people's designs, what type of things can be fabricated. For example, I've seen a lot of very, very interesting 3–dimensional structures that are being produced in the machines in the makerspace that I never thought of doing myself. So . . . it's an opportunity to actually participate in a community, to be exposed to an environment, to see what other people are doing, what other ideas are being generated, what other types of structures or products are being produced. It helps a person become a more creative person, just by seeing what has been done out there and what is possible with certain types of machines."

Through team-based activities, faculty facilitated opportunities for students to experience the power in listening to the diverse perspectives of their teammates, in expressing their own ideas, and in collaborating to produce a new concept or design. Faculty described successful students working in makerspaces as those who realized their potential strengths as well as their weaknesses, were engaged in the collaborative learning process, and were excited about what they were creating. Students were also encouraged to "feel that their voice is heard and they each can contribute something different" as stated here by two faculty members:

"So, if you can get that mix of engaging people and what they're passionate about, care about what they wanna learn about in a mix, then what we argue is that the collective discovery is beyond what any single person could do, that's successful."

"The whole idea is that in a team, if you're successful, then every student feels that their voice is heard and they each can contribute something completely differ-

> ent and the goal is to find out what that is in every person, to do the best project possible, and it's the same sort of approach we use in research, we try to achieve it with teams."

Developing and supporting an emerging agency and belongingness were both part of faculties' goals for and perceptions of the influence of makerspaces on students' learning and development. Faculty conceptualized emerging student development as "learning about self," gaining knowledge, as well as being able to express knowledge and to communicate within engineering-focused groups around project-based assignments, lab classes, and classroom-based assignments. According to faculty, these characteristics afforded students an opportunity to progressively participate more in a community of learners comprised of other future engineers and to see themselves ever more a member of this community. These elements of emerging student development are seen in the below excerpts from faculty. One faculty even noted that a course inspired by the availability of the makerspace served as a novel structure to allow for students' sense of identity and belonging.

> "I think it's a unique class though in that you've experienced a good deal of knowledge of self. You learn about yourself. You express yourself. You articulate yourself. You touch upon things about yourself. And you're also working within a structure that has groups, that has projects, that has systems, that has activities. I don't really know of another structure that you do that with."

> "When they [students] come in a classroom like this and they realize 'well my knowledge, my way of knowing is valuable' and all of a sudden they feel value themselves and can find a major that supports that or equally could contribute to their identity and that Imposter Syndrome can fall away. 'I'm not an outsider, I actually bring information in, I don't need to perform, my knowledge is important.' I think that's what this class is doing in these groups . . . saying my knowledge is important."

Faculty's perceptions of student agency seemed largely attributed to students' enhanced feelings of identity and belonging in makerspaces. Through group interactions and collaborations where students learned to express and value themselves, the experiences in makerspaces allowed students to realize the valuable contributions they and others can make.

4.4 *Faculty Perceived the Makerspace as Affording their Pedagogical Innovations*

Faculty claimed that access to the makerspace inspired their curricular innovations, both the development and offering of more project – and group-based activities in existing courses as well as entirely new courses. One faculty member summed this up more generally with "the space lends itself to a lot of possibilities." Another faculty linked their pedagogical innovations to the prototyping that makerspaces afforded, with "I mean, there's really nowhere else where they [students] could prototype things in such a flexible way." Faculty developed new courses that took advantage of the benefits that makerspaces provided, "in order to support, generate, and create an atmosphere of collaborative learning and thinking and experiencing together" for their students.

Seeing the opportunities that makerspaces afforded students also motivated faculty to revise their instructional practices. With the availability of tools and equipment, trained staff to assist, accessibility of the space, and the realization that students' creative and innovative talents in groups flourished in the makerspace environment, faculty adapted their teaching practices to be more group or team oriented and to allow for more student autonomy in their design processes and products. Faculty attributed the shift in pedagogical and content choices to the structures of the makerspace as explained by this faculty member:

> "So, it [instructional practice] did change from a homework assignment, individual homework assignment to group projects. ... just giving them [students] that freedom, you [instructor] really get a lot back, and then you realize where you can actually go with this. It was definitely a learning process. The very first time I taught in [makerspace], I had in my mind mostly lectures. Then the first day I gave a lecture where they're all sitting at these tables and people are walking through. I was like, 'This is not going to work.' I had to really change it. I tried to change it a little bit my first semester to making it more activities during class and more so the second time around, when I taught the course. There were more in-class activities that I figured out like, 'How can I change this from straight lecture to lecture new material for maybe 10 minutes and then have an activity and go back and forth?' That's something that I'm still iterating and working on."

Faculty linked these changes to larger efforts and desires to improve programming for students well beyond their own courses.

> "We're challenging . . . pedagogy, the structure of our University. We're saying this kind of space, and this type of pedagogy is essential and important for students to come away with this knowledge of experience."

However, faculty also noted that they received no professional development concerning how to teach in makerspaces. It was a learn-by-doing process for faculty, both for new faculty and more seasoned faculty, resulting in changes to how they taught, the activities they assigned, their expectations for students, and the freedom they allowed students. The unique nature of makerspaces compelled faculty, largely on their own, to rethink and redesign their courses towards better empowering students to engage with engineering principles and norms often in collaborative learning activities. Furthermore, faculty reflected on how to pedagogically navigate an open space that contained potentially disruptive, unrelated activities and other individuals.

5. Discussion

Our goal in this exploratory study was to examine the potential affordances and constraints that engineering faculty perceive with respect to teaching and learning in a university-based makerspace. We now consider our findings in light of structuration theory to illuminate how faculty act and rationalize teaching practices that are informed by their professional experiences and frames, particularly those inherent to engineering programs and in the novel structure of a university-based makerspace.

Faculty perceived the makerspace as a compilation of structures of varying types (e.g., physical, processes, norms and rules) that fostered enhanced student engagement, competency development, and agency in authentic and important engineering practices. Relevant physical structures included physical equipment, technology, and resources situated in the makerspace that allowed for more student interactions and engagements. Engineering processes and programmatic norms and rules involved the social systems and structures faculty thought necessary to understanding engineering concepts and principles that are essential to engineering practices. Noted more than any other feature, faculty perceived the makerspace as containing physical structures that afforded resources for students' designing and prototyping (e.g., cutting-edge technologies, open work areas, and staffing). Faculty also appreciated the larger and more accessible space to work on projects in collaborative teams, space not afforded them in traditional machine labs and classrooms. The availability of high-tech and modern tools and machines, and trained staff available to assist students in their interactions with such, allowed faculty to concentrate their instruction and curriculum towards growing students' knowledge and conceptual development essential in engineering (e.g., what are the processes and importance of prototyping and design). These features, as a whole, were mentioned by faculty as not always available for non-makerspace-affiliated courses and students.

Faculty situated their descriptions of teaching in the makerspace as discipline-based outcomes for students, outcomes they believed could be achieved by students interacting in the space. Faculty planned curriculum and instruction that they deemed significant and legitimate, at the intersection of disciplinary norms and aims (largely noted above), as well as the rules or requirements of formal undergraduate engineering programs and around noteworthy features in makerspaces. As well, overall, we postulate that faculty teaching in the makerspace may have been challenging the sociohistorical norms and rules of engineering classes and programs per the new curriculum and instruction inspired by their availability. Faculty made sense of their teaching practices through historically established norms and rules including those related to physical spaces normally used by engineering programs and their instructors (e.g., machine shops and fabrication labs), their typical teaching practices (that often occurred in isolated classrooms), and ontologies associated with how to support learning and knowledge development in students in the disciplines of engineering. In light of these, faculty seemed to be modifying curriculum and instruction to allow for the better technological and more open and expansive space and staffing support afforded by the makerspace.

Faculty claimed enhanced agency and engagement in innovating curriculum and instruction in light of the makerspace. We attribute this increased faculty agency to anticipation of future teaching in the makerspace as well as the students' results, particularly in engaging diverse students in engineering processes, programmatic norms, and physical resources. Of particular note was the recognition by faculty that students brought their own diversity of experiences, interests, and contributions to the activities. Our findings sync with research on K-12 science education that has documented that access to novel teaching-related structures can increase educators' innovations in curriculum and instruction and the potential for their students' learning [17, 18]. In turn, as educators are positioned as change agents in transforming structures and norms, they further their students' learning gains, and specifically those of female and other marginalized students [32, 33]. For faculty in our study, the makerspace allowed for engaging more students, including those early in their academic career, in authentic engineering activities and the related development of skills and knowledge, thus, fostering diverse students' developing a sense of belonging in an engineering community and motivations for increasing engagement with the community.

While faculty were excited and motivated to use the space given the affordances for their students and themselves, they also noted tradeoffs regarding their capabilities to realize their intended outcomes at the intersection of the unique resources of the makerspace and the norms and rules of their professional preparation and discipline. One tradeoff involved shifting from more private teaching environments to one more open and less fostering of lecture. Faculty realized that the newness of makerspaces as teaching environments and the development of certain types of classes within these spaces meant that many of their teaching practices were going to change. This shift was a novel experience for some faculty, and they highlighted a need for more professional development related to how to more effectively teach in these open and collaborative spaces. A second tradeoff involved faculty concerns about students developing the misguided perception that engineering is simply the making of objects via sophisticated equipment, overlooking the time-intensive, complex reasoning and iterative process work actually required. On the whole, faculty favored giving greater agency to students. In return, they saw the potential for richer learning outcomes from students, but they also realized the need to adjust their practices to more fully engage students, many of whom entered with prior experience designing and making in K-12 and community makerspaces. Faculty members' recognition of these tradeoffs, however, did not negate the overall benefits they perceived the makerspace offering their teaching or their students' learning.

The unique qualities of makerspace environments as teaching spaces provides an opportunity for faculty innovations and experimentation in delivery and creation of new and revised versions of engineering curriculum and courses. Engineering program administrators and lead faculty can, and should, support teaching faculty members' professional development with respect to makerspaces. We propose that faculty who are teaching in the spaces may be the best resources for what is working or not with respect to students' development of conceptual and experiential learning; we base this thinking on past research that suggests that promotion of effective teaching practices may best be accomplished via faculty communities of practice [34] where interested faculty can learn from each other's experiences. Topic coverage within these professional development opportunities should include best instructional practices for teaching critical content and skills within the nuance of these spaces, including strategies to help students understand the affordances and limitations of makerspace resources in relation to the complexity of engineering practice.

5.1 Future Research

Further study is needed to better understand and support teaching and learning in makerspaces, including university makerspaces' impact on student development, their formation as engineering professionals, as well as faculty members' practice, and revisions to practice, in light of these spaces. Research in our larger study of six makerspace sites will seek to confirm or contradict the perceptions of faculty in this exploratory study to determine the overall themes and trends that provide greater insight into how faculty exercise agency and utilize structures in makerspaces. Our larger study will also explicate the perceptions of students and other staff interacting in makerspaces, to examine trends or themes that provide greater insight into affordances they experience in makerspaces. While makerspaces, in general, have shown capacity to serve as a basis for active, equitable learning communities [12, 2], future research is also needed to determine the extent to which university-based makerspaces are democratizing spaces, and how, specifically, faculty might utilize or modify these environments to foster a more diverse undergraduate student population in engineering.

6. Conclusions and Implications for Engineering Education

It has been argued that makerspaces, including those university-based, promote accessible, inclusive, egalitarian, and democratizing environments for those working within them. As students engage in "making," – designing an idea and constructing it into a physical or digital representation or object – they may get to participate in active learning communities, where participants work with or alongside each other on projects of interest. Concurrently, as formal postsecondary engineering programs are designed to deliver discipline-and profession-based curriculum and instruction, programming may, at times, be in conflict with characteristics of makerspaces per socio-historical norms and rules that drive faculty teaching and student learning. These tensions raise questions regarding the intersection of makerspace resources and disciplinary, professional, and programmatic rules towards faculty professional development, enhanced programmatic issues, and creating environments that support diverse students' success. Implications for how to more effectively incorporate makerspaces into formal curriculum can be furthered by learning from the experiences of these faculty to better support other faculty and students' efforts in university-based makerspaces. As well, attention to the needs, interests, and experiences of diverse students will keep professional development activities, program planning, and strategic goals focused on cultivating makerspaces as inclusive learning environments.

In this study, we found that makerspaces provided access to additional technologies and personnel that enhanced the quality and access for designing and prototyping activities. In addition, makerspaces encouraged faculties' curricular and instructional innovations, including the creation and design of new courses and implementation of teaching practices meant to foster more team-based and active learning for students. Faculty perceived student activities in makerspaces as promoting student agency and development of engineering skills, knowledge, and affect. Although faculty identified challenges related to the teaching of engineering in these spaces, including the need to adapt their instructional practices and to balance access to sophisticated tools and resources with the rigor of completing complex engineering tasks, faculty were energized by the possibility makerspaces provided to more fully engage students early in their engineering programs.

Balancing the needs of the different stakeholders operating in makerspaces requires collaboration, communication, and strategic planning across key stakeholders. Working collaboratively with teaching faculty and academic departments, makerspace administrators can better ensure that makerspaces retain their unique and welcoming structures and continue to provide a place where disciplinary innovation can thrive. Makerspace administrators can support the needs of engineering faculty and their students by supporting faculty professional development, as well as helping to limit unnecessary distractions in the spaces. Efforts that take into account the needs of faculty and students in these unique spaces has the potential to better meet the evolving demands of the field. A collective and concerted effort may be required of engineering departments, teaching faculty, program developers, and administrators to fully take advantage of the potential of makerspaces to engage students early and often in meaningful engineering practices and to foster an environment of inclusivity that attracts and retains women and underrepresented student populations into engineering programs and careers.

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