

Developing a Measure of Engineering Students' Makerspace Learning, Perceptions, and Interactions

Sarah Lanci, Colorado Mesa University

Sarah Lanci is an Assistant Professor of Mechanical Engineering at Colorado Mesa University. She received her B.S. degree in Materials Science and Engineering at Michigan State University and her M.S. degree in Metallurgical Engineering at Colorado School of Mines. Following graduate school, Sarah worked as a part and process engineer at an investment casting facility, PCC Structurals, in Portland, OR for seven years before transitioning to her current position at CMU where she teaches introductory design, materials science, and manufacturing-focused courses. Sarah's research interests include aspects of project-based learning and enhancing 21st century skills in undergraduate engineering students.

Dr. Louis Nadelson, Colorado Mesa University

Louis S. Nadelson has a BS from Colorado State University, a BA from the Evergreen State College, a MEd from Western Washington University, and a PhD in educational psychology from UNLV. His scholarly interests include all areas of STEM teaching and learning, inservice and preservice teacher professional development, program evaluation, multidisciplinary research, and conceptual change. Nadelson uses his over 20 years of high school and college math, science, computer science, and engineering teaching to frame his research on STEM teaching and learning. Nadelson brings a unique perspective of research, bridging experience with practice and theory to explore a range of interests in STEM teaching and learning.

Dr. Idalis Villanueva, Utah State University

Dr. Villanueva is an Assistant Professor in the Engineering Education Department and an Adjunct Professor in the Bioengineering Department in Utah State University. Her multiple roles as an engineer, engineering educator, engineering educational researcher, and professional development mentor for underrepresented populations has aided her in the design and integration of educational and physiological technologies to research 'best practices' for student professional development and training. In addition, she is developing methodologies around hidden curriculum, academic emotions and physiology, and engineering makerspaces.

Dr. Jana Bouwma-Gearhart, Oregon State University

Jana L. Bouwma-Gearhart is an associate professor of STEM education at Oregon State University. Her research widely concerns improving education at research universities. Her earlier research explored enhancements to faculty motivation to improve undergraduate education. Her more recent research concerns organizational change towards postsecondary STEM education improvement at research universities, including the interactions of levers (people, organizations, policy, initiatives) of change and documenting the good, hard work required across disciplinary boundaries to achieve meaningful change in STEM education.

Katherine L. Youmans, Utah State University

Katherine Youmans is a PhD student in the Department of Engineering Education at Utah State University. Kate earned her bachelor's degree in Mechanical Engineering from Worcester Polytechnic Institute and worked in the medical device industry designing surgical instruments before focusing on engineering outreach in MIT's Office of Engineering Outreach Programs. After receiving her master's degree in Science Education from Boston University, Kate helped open the American International School of Utah, a K-12 charter school in Salt Lake City. In her role as STEM Director Kate developed the schools programs in Computer Science, Robotics and Design Thinking.

Dr. Adam Lenz, Oregon State University

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Abstract

Makerspaces have become a rather common structure within engineering education programs. The spaces are used in a wide range of configurations but are typically intended to facilitate student collaboration, communication, creativity, and critical thinking, essentially giving students the opportunity to learn *21st century skills* and develop deeper understanding of the processes of engineering. Makerspace structure, layout, and use has been fairly well researched, yet the impact of makerspaces on student learning is understudied, somewhat per a lack of tools to measure student learning in these spaces. We developed a survey tool to assess undergraduate engineering students' perceptions and learning in makerspaces, considering levels of students' motivation, professional identity, engineering knowledge, and belongingness in the context of makerspaces. Our survey consists of multiple positively-phrased (supporting a condition) and some negatively-phrased (refuting a condition) survey items correlated to each of our four constructs. Our final survey contained 60 selected response items including demographic data. We vetted the instrument with an advisory panel for an additional level of validation and piloted the survey with undergraduate engineering students at two universities collecting completed responses from 196 participants. Our reliability analysis and additional statistical calculations revealed our tool was statistically sound and was effectively gathering the data we designed the instrument to measure.

Introduction

In the United States, multiple reports including the Innovative and Entrepreneurial University Report [1], the Engineer of 2020 [2], and expository papers on the state of engineering education [3]-[5] have indicated that post-secondary engineering education in the U.S. is lagging behind when compared to competitors globally. To be ready to enter the workforce upon graduation, today's engineering students are expected to develop the skills and knowledge that are fundamental to engineering careers in their undergraduate years. The Accreditation Board of Engineering and Technology (ABET) has determined that fundamental skills include social skills, such as how to communicate effectively or function in multidisciplinary teams, as well as proven technical skills, such as an ability to apply knowledge of math, science, and engineering [6], [18]. These skills can be referred to collectively as *21st century skills* as they prepare an engineer for contemporary work [7].

The acquisition of *21st century skills* by undergraduate engineering students may be catalyzed by engaging in certain learning activities such as those offered in makerspaces. Makerspaces are commonly defined by the prototyping and making equipment housed in them and the making processing taking place within the spaces by those using the space. In schools, makerspaces are frequently structured with the intent to facilitate student collaboration, communication, creativity, and critical thinking [8]. The kind of learning activities that take place in makerspaces may promote the development of *21st century skills*, as students may need to work in teams to find solutions and develop prototypes [8]. One of the goals for university-based makerspaces is to provide engineering undergraduates with opportunities for experiential and problem-based projects as well as equitable participation [9]-[12].

Leaders and faculty members at post-secondary institutions have recognized the popularity of university-based makerspaces in the formal undergraduate engineering curriculum [13], [8], [9], [14]-[16]. Resultant actions taken include investing in the resources to develop makerspace facilities and prepare personnel with specific expertise to assure the spaces are staffed and structured with the opportunities to engage students in exploration and experiential learning [4]. The makerspace structure and staffing are critical to assure the spaces foster students' development of *21st century skills* and are supporting their professional preparation [13]. The increased attention makerspaces are receiving in the STEM disciplines, and particularly within engineering education, provides justification to empirically examine the influence of these spaces on undergraduate student development. There is wide speculation that

makerspaces provide a setting to enhance students' undergraduate knowledge and skill development, with the additional assumption that exposing engineering students to extracurricular design activities will enhance students' development as engineers. Yet, there is a lack of empirical support documenting engineering students' involvement in university-affiliated makerspaces and how their experiences and activities might influence their development and knowledge and skills important in the field of engineering.

Collaborative spaces affiliated with academia and their accompanying culture have existed for some time and their structure, layout, and use have been well reviewed [13], [8], [9], [14]-[16]. Spaces vary in size, resources, use patterns, and targeted population. In their review of multiple university-affiliated makerspaces Barrett et al. [9], documented common equipment, staffing models, and models of use by students, staff, and community members. While the work from Barrett and colleagues was not a fully-inclusive study of makerspaces and relied mostly on information available about these spaces published by makerspace personnel online, the report does document the commonalities in makerspace structure, layout, and function.

One area that is relatively underexplored in the makerspace literature, is empirical documentation of how engineering students perceive makerspaces, how they interact with and within the spaces, and what they are learning while using the spaces. We are assuming that the learning in engineering makerspaces is rooted in social interactions and that the community of practice (the idea that learning happens as a community where information and experiences are shared [17]) they are a part of encourages a culture of exploration and shared teaching and learning. However, few empirical studies have been conducted on the impact makerspaces have had on engineering student learning so there is a lack of evidence supporting the assumption of how students learn in these spaces.

Others have identified a gap in empirical evidence related to student learning in and related to makerspaces [10]. Lagoudas et al. [10], conducted a survey study of one makerspace to determine frequency of use, types of resources used, perceived impact on professional and personal growth as a result of using the facility, level of self-confidence in skills supported by the facility, and differences based on gender and ethnicity. Their results suggest that the makerspaces influence student development although the findings did not elaborate more in-depth on how individual elements within a makerspace influence the development of engineering students. Furthermore, we were not able to locate any extant instruments that could be used to assess undergraduate engineering students' perceptions and learning aligned with our constructs in the context of makerspaces.

We developed and tested a survey to explore the impact of makerspaces beyond their structure and layout, instead focusing on the impact of the makerspaces on student perceptions, learning, and knowledge. We considered four constructs to be critical to determine what engineering students experience when working in makerspaces. While our overarching research goal is to determine the impact of student engagement within makerspaces, we began our project by developing a series of tools necessary to gather the desired data which included the combined expertise of our research team. Our report focuses on the development of a survey tool that we designed to gather data from the broader undergraduate engineering community. We intend to use the tool to determine what students think of makerspaces, what their interactions with those spaces look like, and, ultimately, what they're learning within the spaces so use of the spaces can be tailored to more specifically address student acquisition of *21st century skills*

Conceptual Frameworks

Because assessing student learning is complex and multifaceted, we recognized the need to consider student makerspace interactions through the lens of several constructs to work toward an instrument capable of gathering data that would enable a more holistic understanding of student development in a makerspace. We identified four constructs that the research team hypothesized are associated with student makerspace perceptions, interactions, and knowledge. The four constructs we choose are

motivation (related to persistence and a growth mindset), belongingness (including social interactions), engineering competency and knowledge acquisition (related to ABET's program educational outcomes), and professional identity. Each construct is aligned with a corresponding conceptual framework and justification for considering in the context of student engagement in makerspaces.

Motivation

Motivation concerns an individual's determinism around an activity or set of activities. Motivation has been explored extensively with respect to students' engagement and persistence in education-related activities. We can look at the motivation of students interacting in a makerspace through the ideas of engagement and persistence, including consideration of Dweck's [19] conception of growth mindset. When students encounter situations where outcomes are not as expected the first time (or the second or third or fifth), as with an engineering problem, they experience conditions that can be leveraged to promote a growth mindset as opposed to fostering a fixed mindset [19]. A person who approaches learning holding a fixed mindset would perceive a first time failure as evidence of a lack of ability and therefore would disengage from efforts to complete the task. Makerspace activities may lead students to repeatedly explore solutions and continue to engage with failure because of the nature of the level of control the student has in the process of learning. The repeated attempts could be leveraged to promote students' view of failure as part of learning leading to perceptions of learning associated with a growth mindset.

We consider persistence as it entails a propensity for or actual expression of motivation in which students continue to remain engaged and effortful in learning and in educational activities when they encounter or perceive challenges, barriers, failure, and/or adversity. There are several extant surveys designed to assess student persistence in learning [20] however, these instruments are not aligned with learning engineering or engagement in makerspaces. Further, while the items of the extant surveys may be aligned with a range of persistence concepts, the context of the makerspace is rather unique for learning making the adoption or adaptation an extant survey unlikely for meeting our research goals. Therefore, we maintain we had warrant for creating a new set of persistence and motivation in learning items for a survey framed in terms of learning engineering and contextualized for engaging in makerspaces. Exploring persistence as it relates to the influence of makerspaces on undergraduate engineering students provides us with a framework for delving into how and why makerspace engagement may influence students' propensity to remain engaged in studying engineering despite facing academic challenges and barriers. Again, the nature of the projects in makerspaces that may include the requirement for modifications and multiple iterations emphasize student persistence.

We also considered motivation through the framework of self-determination theory (SDT) [21]. We considered SDT due to the focus on intrinsic and extrinsic motives related to learning. The motive for learning is critical in the makerspace environment where students are usually provided with an assignment to complete providing a level of extrinsic motive, but the extent to which they engage in the makerspace to complete the assignment is primarily an intrinsic motive. The focus on source of motivation afforded us the opportunity to design survey items to determine if students engaging in makerspace projects are more likely to be intrinsically motivated regarding makerspace activities (satisfied with completing the project because the project was interesting and the student want to learn), or extrinsically motivated (completed the project just to get it done because it is required).

Belongingness

Given that students are most likely using makerspaces in groups [13], [8], [9], [14]-[16], we considered Vygotsky's sociocultural theory [23], which maintains that learning is based in social interactions. However, there is a lack of empirical evidence detailing how students are interacting in the makerspaces and how the interactions are influencing their learning. Thus, there is further support for measuring social interactions and the culture of the spaces to determine if there are relationship to student learning. Thus,

there is justification for the creation of an assessment tool that can gather data associated with levels of comfort in these spaces, feeling of belonging in the spaces, and the nature of their social interactions within the spaces.

A student's level of comfort in a learning environment may have an impact on their learning. Maslow's [22] hierarchy of needs states that human beings are motivated by a need to belong. It is possible that a student's engagement in a makerspace, and their levels of learning, is associated with their sense of belonging or a sense of being valued by others in the space or around an activity. By using Maslow's theory as a foundation for assessing student belongingness, we created a series of survey items that could be used to determine if students feel like they belong in a makerspace and if they feel accepted in the space and with respect to activities within that space. Our goal was to assess students' sense of belongingness in the context of makerspaces to determine if there are shifts over time and if the sense of belonging is actually associated with the learning taking place in the space.

Knowledge of Engineering

While many universities have incorporated makerspaces into their engineering programs, few empirical studies have been conducted on the impact makerspaces have on student learning of engineering concepts and processes [10]. Most university makerspace research has focused on identifying the characteristics of the spaces [9], [12] or recommended best practices to successfully run a makerspace such as staffing, resources, facilities [10]. However, makerspaces potentially provide a setting for fostering student development of critical engineering concepts and processes ranging from leadership characteristics to understanding and application of the design cycle [24]. We were able to locate few empirical published studies based on empirical evidence for the learning engineering processes, such as 21st century skills, through interactions in makerspaces [24]. Yet, 21st century skills are part of the ABET outcomes for engineering programs indicating that there is a need to assess student learning in makerspaces in relationship to a wide range of engineering skills and knowledge. Thus, we determined there is a need to design research tools to empirically assess to what extent university makerspaces actually foster student develop of the competencies that ABET requires.

Professional Identity

Identity in a profession is influenced substantially by the level to which an individual has developed his/her professional identity [25], [26]. We posit that engineering students' development of perceptions of their professional ability, belonging, capacity, and propensity for success within a profession is aligned with culture or setting where their learning is taking place. For example, if students look, sound, and act differently than the predominant culture then they may perceive a low sense of belonging and fail to develop and internalize an identity for the profession. The opposite is true as well, if students sense a culture and people aligned with their personal identity, they are most likely to develop and internalize an identity for the profession. Similarly, if students feel uncomfortable in a setting, such as a makerspace (perhaps they don't understand how to use the tools), they are unlikely to develop a professional identity through interaction in the space [27]. The converse may be true as well.

In makerspaces, there is an expectation that individuals take ownership of their space and learning [27]. Ownership of learning is likely to be associated with acceptance of the norms and practices in the space which are indicators of professional identity development [25], [26]. Given the high potential for an association between professional identity development and engagement in makerspaces, we maintain there is justification for developing research tools for assessing professional identity in the context of makerspaces. Measuring students' perceptions of their professional identity in a makerspace will allow us to determine whether these spaces are impacting students learning and development as professionals within the space.

Methods

Research Questions

Our overarching research goal is to determine the outcomes of the integration of makerspaces in undergraduate engineering education. Our first step in our research process was to develop a tool that could be used to effectively assess student knowledge and perceptions associated with their makerspace engagement. To provide a conceptual foundation for instrument we considered four constructs that have been documented to be associated with learning. Used the following guiding research questions to funnel our efforts to develop a valid and reliable measure of student engagement in makerspaces:

RQ1: To what degree does our survey tool capture student perceptions, learning or knowledge, and interactions with makerspaces?

RQ2: How do students respond to our survey items in relationship to their professional experience, knowledge, and demographics?

Participants

We recruited participants from two universities in the western United States with undergraduate student engineering preparation programs and affiliated makerspaces. One of the universities was a primarily undergraduate institution and the other was a research university with extensive graduate programs. We had 196 participants fully complete our survey. The participants were 86.2% male and 10.7% female with the remainder choosing not to answer. The average age of the participants was 22.63 years ($S = 3.73$), and they had completed an average of 3.69 years of college ($S = 1.56$). Participants on average were in their 2.79 year in their engineering programs ($S = .96$). They were taking an average load of 13.79 credits, with 85.2% majoring in mechanical engineering, 4.1% in civil engineering, 7.1% in biological engineering, 2.6% in electrical engineering, and 1.0% in computer engineering.

Survey Development

We were not able to locate any extant instruments that could be used to assess undergraduate engineering students' perceptions and learning aligned with our constructs in the context of makerspaces. Therefore, we needed to create a survey that would allow us to meet our research goals. We relied on team expertise in engineering education, integration of makerspaces for learning, psychometrics, research design, survey design, motivation, professional identity, engineering, engineering education research, and social cultural influences on learning and persistence. Thus, our team had the knowledge and experience necessary to create a valid survey to assess multiple facets of learning in the context of makerspaces and learning engineering.

We began our instrument development with an exploration of the extant research selecting an aligned conceptual framework for each of our major constructs. As a team we discussed the frameworks' limitations and affordances, and explored the possibility of other options. Upon agreement of the four constructs, we searched the literature for possible extant instruments that used the frameworks to assess students along these constructs. We were able to locate some extant instruments that were aligned with the constructs and framework that we used as models for our item development.

As we created our survey we sought to include approximately the same number of items for each construct. We developed our items to be in the context of makerspace interactions and learning engineering so that students would consider their answers in relationship to the context and not learning in general. For example, to assess level of performance goal orientation as an aspect of motivation, we reworded the item stating "It is important that I perform better than others" to contextualize the item transforming it into, "It is important my makerspace projects are better than the projects produced by

others.” Thus, we retained the general focus on performance orientation but framed the item in terms of projects and makerspace activities. To increase participation and reduce participant cognitive load, we designed the items to be answered using a Likert scale with “1” representing “Strongly Disagree” and “5” representing “Strongly Agree.” We reversed phrased approximately one third of the items in our survey. For example, to determine if student feel welcome in the makerspace we reversed phrased an item to state, “I feel disconnected to fellow students in the makerspace.”

We went through multiple iterations of analysis of items and the survey as a whole. We eliminated items that seemed to be overly redundant and rephrased items to make the stem shorter or easier to comprehend. Once all members of the research team were satisfied with the survey we shared our product with our project advisory board members. The members reviewed the survey and indicated that the contents were appropriate for assessing various aspects of college student development in makerspaces. The review by the advisory board members, researchers and educators engaged in makerspace education, provided an additional level of validity for our instrument.

Our final survey contained 60 selected-response items. We attempted to design items specific to our four major research constructs. However, through the process of contextualizing the survey stems through the lens of engagement in makerspaces and learning in engineering, many of the items could be interpreted to align with more than one construct. Thus, through the process of contextualizing our items for makerspaces, we made the items more malleable increasing the ability for the items to assess the impact of students working in maker spaces along multiple constructs. For example, one of our items states, “I participate in makerspaces because others think badly of me if I don’t” is aligned with motivation and goal orientation but also with professional identity due to the consideration of others for engagement in professional activities. We considered the ramifications of certain items being aligned with two or more constructs following the rewriting for makerspace context. We determined that given the exploratory nature of our work we would continue to include the items in our survey and as we gather data we would decide if there was a realistic possibility of creating items for a single construct that are effectively contextualized for makerspaces.

In addition to the makerspace and engineering learning items, we developed a series of demographic items, which included measures of traditional parameters such as sex, age, major, year in school, and ethnicity. We also included several other items related to individual differences such as employment as an engineer, relationship to an engineer, perceived knowledge of makerspaces, and reason for wanting to be an engineer. Our demographic survey included 23 items.

Data Collection

We recruited undergraduate students from the two institutions enrolled in engineering preparation programs to complete the survey. We notified the students that their participation in completing the survey was purely voluntary and informed them about our research on the first page of the instrument by a letter of information (and IRB approved a non-signed consent form). We distributed the link to the online version of the survey via course management systems.

Results

Our first research question asked, “To what degree does our survey tool capture student perceptions, learning or knowledge, and interactions with makerspaces?” We began answering this question with the determination of the reliability of the instrument as a whole and the four construct subscales (see Table 1). The reliability for the instrument as a whole was calculated to be a Cronbach’s alpha of .91 which is interpreted to be an acceptable level of reliability. We calculated the reliability for the four subscales to have a Cronbach’s alpha between .74 and .89 which also indicates an acceptable level of reliability.

Table 1. For Each Construct Stems of Representative Survey Items, Number of Items and the Cronbach's Alpha

Construct	Stems of Representative Survey Items	Number of Items	Cronbach's Alpha
Persistence, growth mindset, & motivation	• Most of my engineering coursework is boring. • I prefer to work on makerspace projects that have no clear answer. • My goal in the makerspace is to complete the assigned project	32	.78
Belongingness & social interactions	• I don't feel respected by my peers in the makerspace • I want to interact with students in the makerspace more often.	24	.89
Learning in Engineering	• I frequently search online for more information when I work on engineering course projects. • I find ways to apply what I learn in the makerspace to what I learn in my engineering courses. • Peer collaboration in the makerspace helps me develop my problem solving skills.	20	.74
Professional Identity	• Makerspaces help me understand engineering is about helping society • I work to expand my knowledge of engineering because it is a challenge to really understand how to solve engineering problems • A solid understanding of engineering is important to my intellectual growth	24	.87
Whole Instrument		60	.91

We continued our analysis by creating a composite score for each of our four subscales by calculating the average response to the items within the scale. We then calculated the bivariate correlations of the composite scores to determine the level of consistency in the responses. We found the construct subscale composite scores were all significantly correlated (see Table 2), which indicates additional consistency of the measurements gathered using our survey.

Table 2. Bivariate Correlations among the Four Subscales

	Persistence/Motivation Subscale Composite	Belongingness Subscale Composite	Learning in Engineering Subscale Composite	Professional Identity Subscale Composite
Persistence/Motivation Subscale Composite	-	.635**	.916**	.734**
Belongingness Subscale Composite		-	.593**	.852**
Learning in Engineering Subscale Composite			-	.713**

** . Correlation is significant at the 0.01 level (2-tailed).

Our second research question asked, “How do students respond to our survey items in relationship to their professional experience, knowledge, and demographics?” To answer this question we proceeded with our analysis to determine the correlation of the subscales with various demographic measures, such as age, years in program, perceived knowledge of makerspaces, perceived knowledge of engineering. Our analysis revealed significant correlations between answers on the four subscales and students’ perceived knowledge of makerspaces (see Table 3). Our analysis suggests that as students gain deeper understanding of makerspaces they are likely to answer the items differently than those who have low perceived knowledge of makerspaces. The results indicate that our survey appears to be measuring student perceptions, learning or knowledge, and interactions with makerspaces, which is the goal for the instrument.

Table 3. Correlations among Perceptions and Demographics and the Four Subscales

	Age	Year in College	Credits Enrolled	Makerspace Knowledge	Knowledge of Engineering Profession
Persistence/Motivation Subscale Composite	.053	-.029	-.074	.287**	.096
Belongingness Subscale Composite	.112	.077	-.134	.226**	.139
Learning in Engineering Subscale Composite	.055	-.070	-.107	.344**	.088
Professional Identity Subscale Composite	.060	.007	-.137	.207**	.139

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

To determine if there were differences by sex, engineering work experience, and relationship with an engineer we conducted a series of independent sample t-tests. Our analysis revealed no significant differences by sex, experience working in engineering, or knowing an engineer personally. Our results indicate that our survey is likely capturing makerspace experiences rather than some other facet of perceptions and engagement in engineering.

Discussion and Implications

The goal of this project was to create a survey tool that could be used to assess undergraduate engineering students’ perceptions, interactions and learning that takes place through their engagement in makerspaces. We considered four constructs associated with makerspace engagement: motivation and persistence, belongingness and social interactions, knowledge of the processes of engineering, and professional identity. We designed the items in our survey to align with the constructs and framed the items in the context of learning and engagement in a makerspace environment.

Our analysis revealed the instrument had acceptable levels of reliability (above .65 and below .95), which we maintain makes the instrument suitable for assessing student perceptions and engagement in makerspaces. Further, the acceptable reliability indicates students are answering the items consistently which further reflects alignment of the items to our four constructs of interest.

We were able to provide an additional level of assurance that our instrument is aligned with our assessment goals through our analysis of the students' responses in conjunction with their individual characteristics. The only association with student individual characteristics we found to be predictive of the survey outcome was students' perceived knowledge of makerspaces. This finding indicates that student perceived knowledge level of makerspaces is associated with how the students responded to the survey items. We maintain that the association between perceived knowledge of makerspaces and responses to the items contextualized for makerspace engagement provides additional evidence that we have achieved our goal of designing an instrument to assess facets of student engagement in makerspaces.

The primary implication of our work is we now have a valid reliable tool available for educators and researchers to use to determine the impact of student engagement in makerspaces. We have also laid groundwork for developing additional instruments to study other facets of engineering education in which context is critical to understanding the associated student learning.

Limitations

The first limitation of our research was the limited scope of students who participated in our study. We recruited undergraduate students majoring in engineering from two different kind of institutions in the same region of the United States which may have limited the potential scope of responses and lead to a constrained data set. We might obtain a greater diversity of data if we included students from other regions in the United States or from a greater diversity of institutions. We will be gathering data from students in a diversity of institutions in our future research.

The second limitation of our research was the potential that students refer to makerspace settings using a different title such as "innovation center" or "Fab Lab" and therefore may not be fully aware of what the term makerspace was referring too. Because students' perceptions of what a makerspace is may differ from our perceptions there is a possibility that they answered the questions differently than they would have if they shared the same understanding we hold. Our finding of the association between perceived makerspace knowledge and composite scores of subscales further supports the need to assure students have the same understanding of what a makerspace is as we hold. Regardless, makerspaces were associated with the engineering preparation programs at both schools and most of the students had spent time in the spaces making prototypes as part of their degree programs. The experience in the spaces and the common community adoption and support for makerspaces suggests that most students hold at least some awareness of the structure and function of the spaces that would allow them to respond to the survey from an informed perspective. In the future, we may include a more detailed introduction in the survey to assure students share a similar understanding of the spaces that we hold.

Conclusion

The integration of makerspaces into undergraduate engineering programs led us to wonder what do students learn in the spaces, but also how is their engagement in the spaces associated with their motivation and persistence, knowledge of engineering, belongingness and social interactions, and their professional identity. To gather the desired data required us to develop a survey tool. Our analysis of our survey pilot indicates that our validated tool is also reliable, and appears to be effective at gathering the desired data. With our instrument filling a notable gap in engineering education and makerspace research, we hope others will use our tool and provide us feedback so that we can continue to refine the instrument to make it as effective as possible.

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