# Report on Engineering Design Self-Efficacy and Demographics of Makerspace Participants Across Three Universities

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*University makerspaces have been touted as a possible avenue for improving student learning, engagement, retention, and creativity. As their popularity has increased worldwide, so has the amount of research investigating their establishment, management, and uses. There have, however, been very few studies that use empirical data to evaluate how these spaces are impacting the people using them. This study of three university makerspaces measures engineering design (ED) self-efficacy and how it is correlated with involvement in the makerspaces, along with student demographics. The three university makerspaces include a relatively new makerspace at a Hispanic-serving university in the southwestern US, makerspaces at an eastern liberal arts university with an engineering program that has been created within the last decade, and a makerspace at a large, research university in the southeast often considered to be one of the top programs in the US. Students at all three universities are surveyed to determine their involvement in their university's makerspace and how they perceive their own abilities in engineering design. The findings presented in this paper show a positive correlation between engineering design self-efficacy (EDSE) and involvement in academic makerspaces. Correlations are also seen between certain demographic factors and the percentage of students who choose to use the academic makerspace available to them. These findings provide crucial empirical evidence to the community on the self-efficacy of students who use makerspaces and provide support for universities to continue making these spaces available to their students.*

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## Introduction

Around the world, universities are opening makerspaces on their campuses with the hopes that these spaces will foster student retention, engagement, learning, and creativity, especially for engineering students [1–7]. Though there are many reports published on budding makerspaces, few include empirical data-driven studies [8,9]. We seek to begin to remedy this gap. In this study, measures of engineering design (ED) self-efficacy, involvement in makerspaces, and demographics were collected from students from three universities. University A is a large, Hispanic-serving university in the southwestern US with a makerspace that had been in operation for less than a year at the time of this study. University B is a regional teaching-focused university in the mid-Atlantic US that graduated their inaugural students from the engineering program in 2012. University C is a large, technology-focused research institute in the southern US. The construct of engineering design self-efficacy (EDSE) was used as a way to measure participants' self-concept and confidence in engaging in the design process. Bandura [10,11] defines self-efficacy as an individual's belief in their own ability to complete a task, and his research correlates self-efficacy with effectiveness and success. The literature shows that students with high levels of engineering-related self-efficacy tend to be more engaged in their communities of learning and more likely to persist within their engineering major [12–18]. To discover if makerspaces provide environments that build the self-efficacy of students in an engineering program, this study was conducted to answer the following research questions.

(1) How does the level of involvement in an academic makerspace correlate with students' engineering design self-efficacy?
(2) Are there relationships between students' demographics and their engineering design self-efficacy scores?
(3) Are there relationships between students' demographics and their levels of involvement in an academic makerspace?
(4) What similarities and differences are observed between the three universities?

## Background

The formation of makerspaces has been growing in popularity throughout the US in recent years. Lou and Peek [19] reported that there were approximately 1400 makerspaces worldwide in 2016, which is 14 times more than there were in 2006. *The Maker City* project reports that over 77 colleges and universities have pledged to implement or expand their own campus makerspaces.[1] Though there is not a clear definition of makerspace, Barrett et al. [1] reviewed 40 university makerspaces and reported that the majority of university makerspaces are housed in colleges of engineering, though many of the spaces provide access to non-engineering students. Space tend to include equipment such as 3D printers, laser cutters, wood shops, metal shops, electronics, and textiles.

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[1] http://www.nationofmakers.us

Thomas and Besser [20] state, “There is no authoritative body determining what is or is not‘making,’ and who is or is not a maker. Makers self-identify and …the inclusive nature of the term means that there are innumerable opportunities for inter-/cross-/anti-disciplinary work” (p. 33). Makers within a university makerspace community—regardless if they are majoring in engineering or a non-engineering discipline—can utilize the space to engage with like-minded individuals and engage in design for personal enjoyment, or for a course-related project. Martin identifies three elements of the Maker Movement that are essential to consider in determining potential possible affordances for education: (1) digital tools, including rapid prototyping tools and low-cost microcontroller platforms, that characterize many making projects; (2) community infrastructure, including online resources and in-person spaces and events; and (3) the maker mindset, aesthetic principles, a failure-positive approach, collaboration, and habits of mind that are commonplace within the community [21].

Many approaches for improving engineering idea generation and innovation have been already identified [22–26]. Activities performed in a makerspace may also be akin to hands-on experiences gained through internships, which has been shown to improve students understanding of design documentation [27]. Makerspaces likely improve idea generation and innovation through students learning about other designs and then applying this during design-by-analogy, which has been shown to enhance idea generation [28–30] and multiple approaches along with tools have been developed [31–34]. Learning to fail is another cited benefit of makerspaces [35]. Consistent with this, experimental evidence suggests that when students build and test physical models, often failing, they can overcome design fixation and enhance their mental models of how systems work [24,25,36]. Makerspaces very likely enhance students building and prototyping skills. As they develop these skills in a community of other makers, students could learn systematic prototyping techniques, which have been shown to correlate to more effective prototypes [37,38]. Physical representations, including prototypes, help designers visualize concepts, estimate implicit attributes of designs, validate assumptions, verify functionality of ideas, and enhance communication between disparate design teams and select of the best concept [39–48]. Success in product design can be impacted by several aspects of the prototyping process including the time spent, medium used, and overall strategy employed by the design team [49–52]. Completely functional models may help designers rectify problems in their designs before production [53]. Models often function as vehicles for mutual cognition and help capture information in the design, which are not otherwise available to designers [54], and utilizing quick, low-cost prototypes is an effective method for early-stage design exploration [55]. Camburn and Wood [56] even worked to develop a set of principles behind how quick Do-It-Yourself prototypes often found in makerspaces correlate to the development of design prototyping skills. Unfortunately, while these benefits from prototyping are likely gained through the use of makerspaces, little empirical data support these claims [8,9]. Initial data on learning in makerspace [57] and the impact on teacher’s activities [58] has been done for K-12. In this paper, we choose to evaluate students’ engineering design self-efficacy as an overarching measure that is highly likely affected through the many benefits makerspaces provide.

To date, one of the primary focuses of research regarding academic makerspaces has been on the implementation of these spaces at various universities and the unique aspects of these spaces [8]. Forest et al. [3] described the development of space run primarily by student volunteers and how the culture of this space developed. George-Williams [5] described the process of identifying and establishing faculty partnerships to develop and support an on-campus makerspace. Rogers et al. [59] discussed the aspects of implementing a makerspace in an academic library. Spencer et al. [60] described aspects of developing and maintaining proper safety in a student-led makerspace and the training student volunteers complete. All of these studies provide key insights into how an academic makerspace can be established and well maintained.

Studies have additionally compared multiple universities’ makerspaces in an effort to identify common practices. For example, Barrett et al. [1] searched websites of engineering programs to compare university makerspaces; Wilczynski [61] distributed a survey to several known academic makerspaces to compare aspects such as leadership structure, equipment, and size; Tomko et al. [62] conducted interviews with makerspace leaders in an attempt to establish guiding principles for the development and sustainment of academic makerspaces. While these studies are useful for understanding how makerspaces can be successfully established at a university, they do not provide evidence of the benefits of these spaces for the students who use them. There have been a few data-driven studies attempting to understand these impacts. Galaleldin et al. [63] surveyed students active in an academic makerspace on how well the space helped them improve certain skills. This survey found that the majority of the users of the makerspace felt the space improved their problem-solving skills and design skills. While these findings are helpful for understanding the perceived impact of makerspaces of the students who use them, it does not provide a comparison to students who have not used a makerspace. Lagoudas et al. [64] also surveyed students who used an on-campus makerspace. Their findings included students reporting high confidence and motivation to conduct engineering design tasks; however, that study did not include students who did not use a makerspace for comparison.

There is a lack of research showing how students who use an academic makerspace compare to students who do not, the demographic breakdown of students who use these spaces, and how the impact of using a makerspace varies at different universities. This study seeks to help fill the gap by providing data-driven evidence of user diversity at three university makerspaces and how usage rates correlate with students’ engineering design self-efficacy using data collected through survey instruments.

**Self-Efficacy in Engineering.** Theories about self-efficacy are regarded as important metrics for analyzing confidence and learning because they have proven to be good predictors for achievement and persistence. Bandura’s [11] theory of socio-cultural impacts on self-efficacy examines influences on intrinsic attitudes, motivation, and self-efficacy beliefs in four categories: (1) mastery experience (relating past experiences to the current situation), (2) vicarious experience (observation of exemplars and models), (3) social persuasion (whether or not participants have received encouraging messages or coaching/feedback from others), and (4) physiological state (emotional reactions). From this work, George-Williams concludes that high levels of self-efficacy correlate with being more effective and generally more successful [5].

Self-efficacy toward engineering is an important metric as it has been shown to be positively related to achievement and persistence/retention in undergraduate engineering programs. Hsieh et al. [14] conducted a study with 297 undergraduate engineering students and found that their academic self-efficacy predicted their academic achievement in an algebra course designed for engineering students. Mamaril et al. [16] used a self-efficacy instrument with 728 undergraduate engineering students and found that these students’ intentions to persist in engineering were predicted by their general engineering and engineering skills self-efficacy levels. Concannon and Barrow [12] conducted a study with 493 undergraduate engineering students and found a variance between female and male engineering self-efficacy, which was related to female belief in the importance of getting a good grade (i.e., A or B) and male belief in the importance of their ability to complete the required coursework. In another study conducted with 519 undergraduate engineering students, Concannon and Barrow [13] found that though overall self-reported engineering self-efficacy predicted persistence in engineering, female, and African American participants had lower self-efficacy, which was related to not feeling like they were “part of the group” (p. 169). Marra et al. [17] conducted a multi-year study of female engineering student self-efficacy and found that over time students reported increases in general engineering self-efficacy and decreases in feelings of inclusion with significant changes found in minority female student responses. Similarly, Marra et al. [18] conducted a multi-year retention study by surveying 113 undergraduate students who left the engineering major and found that their decision to leave was influenced by multiple academic factors (curriculum difficulty, poor teaching, and advising) as well as a non-academic factor (lack of belonging in engineering). They also found that these factors were significantly more prominent among minority students. Alternatively, Jordan et al. [15] conducted a study with 394 undergraduate engineering students and found no significant differences in engineering self-efficacy among minority and majority students, which they postulated was due to the majority of those minority students actively participating in related student organization communities (e.g., National Society of Black Engineers, Society of Hispanic Professional Engineers, American Indian Science and Engineering Society, and Society of Women Engineers). This last study highlights the important role that a sense of community can play in student self-efficacy. As academic makerspaces have been speculated to provide a community for engineering students to practice their engineering design skills, this study hopes to show that students in these spaces possess higher self-efficacy for engineering design.

**Theories of Social Integration and Involvement.** Social integration and sense of feeling involved within a community are particularly important factors relating to self-efficacy. Tinto’s [65] academic and social integration model paved the way for a sociological analysis of retention that has been popular for several decades and postulates that persistence occurs when students successfully integrate into the institution academically and socially. Integration, in turn, is influenced by pre-college characteristics and goals, interactions with peers and faculty, out-of-classroom socialization, and personal family dynamics. Similarly, Astin’s [66] theory of involvement, which is based on patterns of behavior exhibited by successful students, asserts that the keys to success and graduation are involvement and connection. Involvement refers to both formal academic or intellectual pursuits as well as co-curricular activities. Among the primary measures of academic involvement is time spent on academic studies and tasks, and the development of higher cognitive skills. Co-curricular involvement includes measures of participation in campus activities and membership in academic/honors associations and social clubs. Connection refers to bonding with peers, faculty, and staff as well as sharing the institution’s values and acculturation factors. Makerspaces provide a place for community involvement in learning from peers as opposed to solely from lectures or textbooks [67,68].

## Methodology

**Spaces Studied.** Data were collected from students at three universities through surveys, herein described as University A, University B, and University C. These data were collected in the spring and fall semesters of 2016 at all three universities. Descriptions of the universities follow. Table 1 provides representative demographics of each university studied.

**Table 1 Demographics of each University**

| | University A | University B | University C |
|---|---|---|---|
| University and department size | | | |
| Total undergraduate | 31,186 | 19,330 | 14,869 |
| Engineering | 883 | 428 | 8200 |
| Engineering technology | 872 | N/A | |
| Gender (undergraduate) | | | |
| Female | 57.1% | 57.9% | 39.7% |
| Male | 42.9% | 42.1% | 58.4% |
| Not reported | N/A | N/A | 1.9% |
| Race/ethnicity (undergraduate) | | | |
| Black, non-Hispanic | 11.0% | 4.9% | 7.5% |
| American Indian or Native Alaskan | 0.3% | 0.1% | 0.0% |
| Asian, Hawaiian, Pacific Islander | 2.6% | 4.8% | 27.4% |
| Hispanic | 35.9% | 6.9% | 8.8% |
| White/Caucasian | 47.5% | 79.3% | 48.7% |
| Two or more races | 2.0% | 4.7% | 4.2% |
| Non-resident international | 0.6% | 2.3% | 11.9% |
| Classification | | | |
| Freshman | 6683 | 5176 | 1671 |
| Sophomore | 6926 | 4992 | 3041 |
| Junior | 7692 | 4559 | 3756 |
| Senior | 9885 | 4603 | 6275 |
| Graduate student | 3655 | 1222 | 11,265 |

*University A* is a Hispanic-serving public research university in the US southwest. University A opened its first university-wide makerspace in the spring of 2016. This 600-sq ft space is housed within a faculty-supported science, technology, engineering, and math (STEM) education and research institute and is physically located in an academic services building. Within the building, the makerspace overlooks the university writing center, which is frequented by students from all majors. This location is geographically closer to the College of Education than to the College of Science and Engineering. The makerspace is staffed by student volunteers, modeled upon University C’s makerspace staffing, where volunteers are given door card access to the makerspace in exchange for three hours per week of staffing the space. The volunteer staff train students as they come in and express interest in learning any of the equipment. Additionally, there are quick start guides posted by every piece of equipment with key reminders and troubleshooting items to assist both new and advanced users. The student volunteers have tremendous ownership of the space, and they have created a social media account to show off the creations made in this makerspace and a promotional video for the space. With nearly all training offered in a peer-to-peer format, student users and volunteers have a culture of helping each other on projects. The volunteers even created a GroupMe account to offer each other assistance when they are not in the makerspace. New student volunteers are recruited from frequent users of the makerspace and from the flyers that both advertise the open use hours and request volunteers. The student staff began with around 3–5 volunteers (at the time of data collection) and the staff have been steadily growing over the first 3 years of operation to 10–15 volunteers. There are two faculty members who co-direct the space. The cross-disciplinary nature of this makerspace is reflected by the co-directors’ home departments: Curriculum and Instruction (College of Education) and Engineering Technology (College of Science and Engineering). The co-directors offer mentoring and training to the student volunteers as well as conducting research and grant administration on and for the makerspace. Equipment available in the space includes 3D printers, sewing machines, an embroidery machine, a laser engraver/cutter, a desktop CNC mill, a digital vinyl and paper cutter, and a heat press. This makerspace is available to students in all majors, however the space is fairly new and advertising has been limited to flyers that are posted predominately in an engineering and science building. Knowledge of the space comes from the flyers, a website, word of mouth, and students in a few courses that utilize the makerspace (honors makerspace course, educational technology master’s course, and a few engineering and engineering technology courses). Use of this makerspace is not pervasive throughout the engineering or engineering technology curriculums, and so while some students come to the space for class projects, many of the users are working on personal projects. Student users frequently bring friends along to socialize while working on a project, but additional research would be needed to see if students who initial come to “just hang out” become makerspace users. The makerspace’s proximity to a food court in the building is also popular with student users, as they ask one other to keep an eye on their 3D print while running out to get food.

*University B* is a public research university in the Atlantic coastal region. The university is historically known for its liberal arts programs but has offered degrees in engineering degrees since 2008. University B integrates design and making throughout the engineering curriculum. Students engage in the makerspaces through required curricular course experiences during their first 2 years and more optionally during their later 2 years due based on personal interests and capstone requirements. All students are trained during their first year to use the tools in fabrication studio through building a catapult with the shop management team; tools available include power and manual hand tools, horizontal band-saw, table saw, panel saw, computer numeric control (CNC) router, and drill press. Following completion of the catapult, students can complete optional welding training in the fabrication studio.

First-year training is assigned through advising and is not coupled to a specific class; rather the students are informed that completion is required for success. Students are provided with instructions through the course management platform (Canvas) which is used to manage sites for each class in the curriculum, for each student cohort in the program, and for all students enrolled in the program. The decoupling is designed to create a culture of independence among a community of learners. Reinforcement of fabrication skills occurs through design-build first-year projects such as building musical instruments for local children with disabilities. Sophomore year, students learn the engineering design process (EDP) through a year-long design project which involves building a human-powered vehicle for a community member with a disability, and as a part of these courses students complete mill and lathe training in the machining studio. Completion of mill and lathe training allows students to apply to join the optional apprentice program run through the machining studio; student apprentices gain additional mill and lathe training through mentored use of machining equipment completing jobs for the university and engineering capstone class projects. Students join their 2-year capstone projects as juniors, and many capstone projects require the use of the making spaces. All first-year, sophomore, and capstone students have studio space (with mobile furniture, whiteboards, and projection systems) dedicated to the academic year in addition to the making spaces.

Beyond the curricular making spaces, students at University B have access to a low fidelity prototyping studio, an ideation studio, a digital communication studio, and a make studio. The low fidelity prototyping studio includes such as pipe cleaners, tongue depressors, cardboard and foam board, and craft knives and is designed to reinforce the idea of communication through prototypes taught during the first 2 years in the program. The ideation studio includes large tables, supplies for brainstorming activities, and a large floor-to-ceiling writable glass wall. The digital communication studio contains six pods, each with a large monitor for sharing designs and communicating ideas within small design teams. While these former spaces are designed to complement the design process education of University B students, the maker studio is meant to complement the fabrication studio and machining studio. The make studio contains 3D printers, a laser cutter, a vinyl cutter, 3D scanners, soldering station, and computer-aided design (CAD) stations. All engineering makerspaces at University B are housed among the teaching spaces with the design studio spaces directly attached to the classroom spaces allowing free flow of students from classroom settings, to design studios, to making spaces, to fabrication spaces. Fabrication spaces are housed on the first floor of the building with the laboratory spaces while design studios and teaching spaces are housed on the second floor.

*University C* is a public research university in the US southeast with globally recognized engineering programs. The largest makerspace at University C, at the time of the study, is housed in the school of mechanical engineering but is open to all of campus. The space is run primarily by students who volunteer their time. In exchange for 3 h per week of leading other students in the use of the space, the volunteers are given 24/7 access. In this way, the students are encouraged to feel a sense of ownership for the space and its upkeep. Students must complete a checklist of mini projects that verify their knowledge of the equipment and safe tool usage to becoming a volunteer in the space. There are typically close to 70 student volunteers at any time compared with only five faculty and staff leaders. The day-to-day operation of the space is handled almost entirely by the students, as the non-student leaders mainly focus on performing complex equipment repairs, ordering supplies, mentoring the student leaders and obtaining funding for the space. At the time of this study, the mechanical engineering makerspace consisted of 2500 sq ft of space with \$600 K of prototyping equipment. Funding has come from students' technology fee-funded proposals along with over 30 industrial sponsors through capstone design projects. Use of the space includes personal projects and required course projects, including a small project for a freshman engineering graphics course, a semester-long sophomore design course. Students often also use the equipment in the makerspace for their senior capstone projects. Even though the makerspace integrates into courses, it is very possible for a student to proceed through the program without becoming a user of the space.

**Survey Instrument.** The survey was web-based, took approximately 15 min to complete, and consisted of three main parts: makerspace usage, design self-efficacy, and demographics. The first portion of the survey consisted of a series of questions developed by Morocz et al. [69] to categorize the students' level of makerspace use. The survey was developed to measure three aspects of usage: exposure, involvement, and participation. The exposure portion of the survey is used to determine whether a participant has ever used the space. The involvement portion aims to capture the frequency of use of the space. The participation portion focused on the types of projects and activities the students carried out in the space. This includes queries about students' involvement in makerspaces prior to starting university, whether their current semester usage was different than their past usage, and the types of projects they completed in the space. The students' responses on what types of projects they had completed in the spaces were used to sort the students into different involvement level groups [70].

The second portion of the survey instrument used in this study was the EDSE instrument [71]. This validated instrument evaluates students' engineering design self-efficacy through four lenses: confidence, motivation, expectation of success, and anxiety. The students are asked to evaluate themselves through each lens on an 11-point Likert scale (0, 10… 100). Each lens contains the same nine statements. The first statement asks about the student's self-evaluation through the lens for conducting engineering design, and the student's response is considered their ED score for that lens (e.g., ranking the student's confidence in their ability to conduct engineering design, or their motivation to conduct engineering design, etc.). The other eight statements in each lens probe different aspects of engineering design, such as prototyping, testing, and redesign. The student's average response to these eight items is considered their EDP score for that lens [71]. This instrument includes the lens of anxiety to assist in screening responses as it is expected that it would have an inverse relationship to the other three lenses.

The third and final portion of the survey asked a variety of demographic questions. These include questions on race, ethnicity, and sex. The students were also questioned on their parents'/guardians' highest earned degrees in order to identify first-generation college students.

**Survey Distribution.** All three universities used the same survey for data collection, with a few small differences. Each University listed its specific makerspaces as choices for questions about involvement. University A included questions about the students' major and year in the program, but these were unnecessary for the other Universities due to their methods of data collection. University A also presented the questions for race and ethnicity questions differently; University B and C inquired into one identifying as Hispanic/Latino separately from race, while University A combined inquiry into one identifying as Hispanic/Latino with race/ethnicity. This difference was inconsequential as the same data was gathered and the participants who identified as an underrepresented minority (URM) were sorted accordingly. Each University had different methods for distributing the survey to its students. For this study, the data were collected during the same calendar year at each University to provide a cross-sectional observation for each University that could also be compared between the Universities to look for common trends.

At University A, students were asked to complete the survey instrument upon initial arrival in the university-wide makerspace examined for this study. Students could choose to decline to have their data used as a part of this research study by choosing the "decline" option in the web-based survey or by leaving the survey blank; declining to participate did not impact students' access to the makerspace. Students were also requested to repeat completion of the survey each semester as long as they were still using the makerspace. Students were allowed to complete the survey prior to arrival at the makerspace.

At University B, students were asked to complete the survey during class. The survey was offered during a sophomore-level engineering design course and a junior level capstone design course. Both classes were surveyed at the end of the semester.

At University C, data were collected from students in two courses. The first was a freshman-level introduction to engineering graphics course, and the second was a sophomore-level engineering design course. Both of these courses were in the mechanical engineering curriculum. For both University B and University C, these data were collected from these courses as part of a longitudinal study. However, this study focuses on a single data collection, so these data can be compared with University A.

**Analytic Procedure.** Before performing analysis on the collected surveys, the data set was checked to make sure students completed the entire survey. Incomplete surveys were excluded. Additionally, the data were evaluated for variation between the answers for each engineering design task. For example, if the respondent marked "90" for all 36 items on the self-efficacy questionnaire, that respondent's survey was excluded. It was assumed that those respondents were simply trying to finish the survey as quickly as possible, and consequently, were not reading the questions.

After screening the data, a Pearson Correlation was conducted to compare the ED and EDP for each lens of the EDSE. The design of the survey was that the eight components of engineering design, which were averaged to calculate the EDP, should correlate to the response for ED [71]. All data analyzed for this study had a Pearson correlation of 0.8 or higher. Once the student's response was validated through this check, then the student's response to the question of ED was used for the remainder of the analysis and reporting of results. Differences in EDSE were investigated based on sex, race/ethnicity, parent's education, and level of makerspace involvement. A student was considered an URM if they indicated they were identified as Hispanic or Latino, African American, American Indian or Alaskan Native, Middle Eastern, or Pacific Islander. Students were considered to be first-generation college students if they indicated the highest level of education of either of their parent/guardians was less than a bachelor's degree.

Analyses of the differences in EDSE scores between various groups were conducted with *t*-tests to compare differences between two groups and with an analysis of variance (ANOVA) with Tukey post hoc comparisons to compare differences between the three groups. These different groupings were compared through each of the four lenses of the EDSE: confidence, motivation, expectation of success, and anxiety in conducting engineering design. Significant differences were evaluated at a threshold of 0.10 for a 90% confidence level to account for the four tests within this survey. Cohen's *d* was used to measure the effect sizes between groups, and Cohen's rule of thumb was used to interpret the effect sizes [72]. Analyses of the proportion of students who use the makerspace between various groups were conducted with Chi-squared tests for three groups or N-1 Chi-squared tests for two groups. Effect sizes were measured using Cramer's $V$ ($\varphi_c$) for three groups and phi coefficients for association ($\varphi$) for two groups. Both Cramer's $V$ and the phi coefficients were interpreted using Cohen's rule of thumb [72].

## Results and Discussion

*RQ #1. How does the level of involvement in an academic makerspace correlate with students' engineering design self-efficacy?*

Students' involvement level was categorized into three levels based on the students' report of the types of projects they had carried out using makerspace equipment. These three involvement levels are: no involvement, class-only involvement, and voluntary involvement, which may be defined as:

*No involvement*: students who self-reported to have never used the equipment in the makerspace.

*Class-only involvement*: students who self-reported to have used the equipment in the makerspace, but only completed course-related projects.

*Voluntary involvement:* students who self-reported using the equipment in the makerspace and completed several types of projects, which can include, but was not limited to, class projects.

Between each of the three study sites, differences in makerspaces and academic programs resulted in different use levels. At University A, where the makerspace had only recently opened at the time of this data collection, very few classes required the use of makerspace equipment. Therefore, all students with involvement were considered to be in the *Voluntary Involvement* groups. At University B, several required courses in the engineering curriculum required the use of makerspace equipment. Therefore, no students at University B were considered to be in the *No Involvement* group. University C has students in all three groups. Correlations between involvement level and students' engineering design self-efficacy for each site follow.

*Correlation of makerspace participation with engineering design self-efficacy for University A.* Of the 109 participants at University A, 27 participants (24.8%) had used an academic makerspace and were labeled as voluntary involvement. A comparison of voluntary involvement and no involvement students is shown in Fig. 1, and the results of *t*-tests along with effect size can be seen in Table 2. Students who voluntarily used an academic makerspace were found to have higher levels of confidence, motivation, and expectation of success when conducting engineering design than students who had not used a makerspace. This difference was statistically significant, with a small-to-medium effect. There was no significant difference for levels of anxiety while conducting engineering design between makerspace users and non-users.

*Correlation of makerspace participation with engineering design self-efficacy for University B.* Of the 140 students analyzed at University B, 41participants (29.3%) were voluntarily involved in the makerspace. Table 3 shows the averages of each EDSE score for the levels of involvement. The *t*-tests comparing the two groups are seen in Table 3. There are no statistically significant differences between the voluntarily involved and class-only involved students for University B.

*Correlation of makerspace involvement with engineering design self-efficacy at University C.* This first analysis conducted for each university sought to determine the impact of being involved in an academic makerspace on engineering design self-efficacy. The average scores are shown in Table 4 with the results of ANOVA and Tukey post hoc tests listed in Table 4. The voluntarily

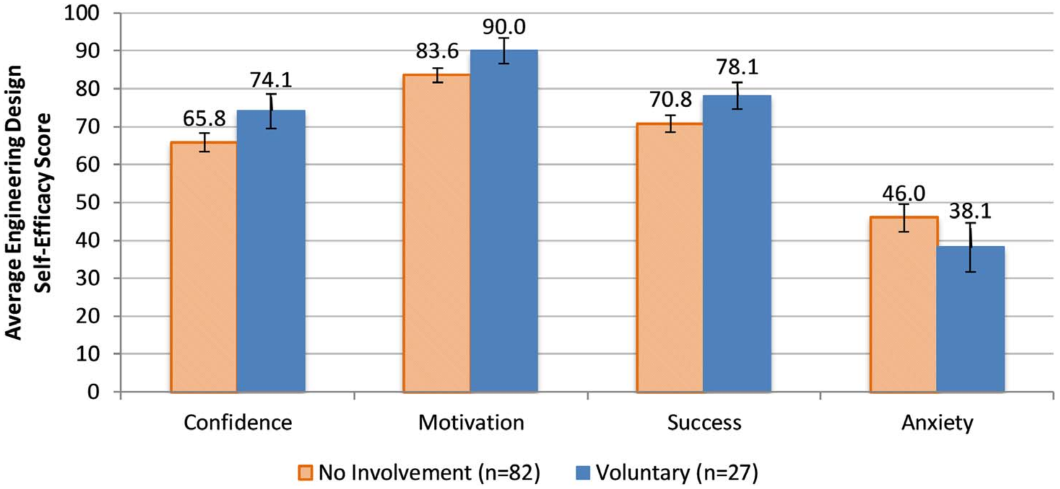

**Fig. 1 Average engineering design self-efficacy scores across involvement types at University A shown with ±1 standard error**

**Table 2 Statistics for EDSE comparisons based on makerspace involvement for University A**

| EDSE | $t$ | df | $p$ | $d$ |
|---|---|---|---|---|
| Confidence | 1.66 | 108 | 0.099[a] | 0.37 |
| Motivation | 1.66 | 108 | 0.100[a] | 0.37 |
| Success | 1.67 | 108 | 0.098[a] | 0.37 |
| Anxiety | −1.07 | 108 | 0.285 | 0.24 |

[a] Significant at $\alpha = 0.10$.

**Table 3 Statistics for EDSE comparisons based on makerspace involvement for University B**

| EDSE | $t$ | df | $p$ | $d$ |
|---|---|---|---|---|
| Confidence | 1.11 | 138 | 0.268 | 0.21 |
| Motivation | 0.31 | 138 | 0.756 | 0.06 |
| Success | 0.10 | 138 | 0.924 | 0.02 |
| Anxiety | −0.55 | 138 | 0.582 | 0.10 |

involved students have significantly higher confidence, motivation, and expectation of success when conducting engineering design tasks when compared with students with no involvement and with students with class only involvement. Voluntarily involved students also have lower anxiety when conducting engineering design.

*RQ #2. Are there relationships between students' demographics and their engineering design self-efficacy scores?*

To identify relationships between students' demographics and their engineering design self-efficacy, students were asked students to identify sex, race/ethnicity, family education history, and their current classification at the university. The demographics of the students whose surveys were analyzed at each university are shown in Table 5. Students who left a demographic question blank (or marked "prefer not to respond") were not analyzed in any group for that demographic but were still analyzed as a part demographic sub-groups for questions they did answer. Percentages are based on the total number of analyzed students at each university. Average EDSE scores were analyzed for three demographic designations: sex, minority status, and family education history, and relationships identified are provided in the following sub-sections.

*University A relationships between demographics and self-efficacy*. The values of $t$-tests and Cohen's effect size can be seen in Table 6. Female students are found to have a statistically significant lower confidence when conducting engineering design tasks than their male counterparts with a medium effect size, but the sample size of females is small. No significant differences were seen between female and male students for motivation, expectation of success, and anxiety while conducting engineering design task. A comparison between students classified as underrepresented minorities (URM) in higher education and students who are not classified as URMs (non-URM) is also presented in Table 6. Students classified as URMs were found to have statistically significant higher levels of anxiety while conducting engineering design with a small-to-medium effect size. There were no statistically significant differences for confidence, motivation, or expectation of success. Further, there are no significant differences between students whose parents did not receive college degrees (1st Gen) and those who are not.

*University B relationships between demographics and self-efficacy*. The average EDSE scores were compared between different groups of students at University B, as seen in Table 7. As with University A, female students were found to have significantly lower confidence than their male counterparts. Unlike University A, underrepresented minorities were found to have lower anxiety than their counterparts, but the sample size of URM students is small at University B.

**Table 4 ANOVA and Tukey tests for EDSE comparisons based on makerspace involvement for University C**

| | ANOVA | | | | Tukey (Vol-None) | | Tukey (CO-None) | | Tukey (Vol-CO) | |
|---|---|---|---|---|---|---|---|---|---|---|
| EDSE | $F$ | df | $p$ | Pool. SD | Diff | $d$ | Diff | $d$ | Diff | $d$ |
| Confidence | 12.07 | 2, 654 | <0.001 | 16.664 | 6.45[a] | 0.39 | −0.06 | 0.004 | 6.51[a] | 0.39 |
| Motivation | 13.84 | 2, 654 | <0.001 | 19.029 | 8.17[a] | 0.43 | 1.07 | 0.06 | 7.10[a] | 0.37 |
| Success | 8.66 | 2, 654 | <0.001 | 17.642 | 5.96[a] | 0.34 | 1.79 | 0.10 | 4.37[b] | 0.25 |
| Anxiety | 6.33 | 2, 654 | 0.002 | 27.21 | −8.08[a] | 0.30 | −2.03 | 0.07 | −6.05 | 0.22 |

[a] Significant at $\alpha = 0.05$.
[b] Significant at $\alpha = 0.10$.

**Table 5 Demographics of participants at each University**

| | University A | | University B | | University C | |
|---|---|---|---|---|---|---|
| | *n* | % | *n* | % | *n* | % |
| Survey question | | | | | | |
| Female | 15 | 13.8% | 32 | 22.9% | 158 | 24.0% |
| Male | 95 | 86.2% | 105 | 75.0% | 490 | 74.6% |
| Prefer not to disclose | 0 | 0% | 2 | 1.4% | 4 | 0.6% |
| Other | 0 | 0% | 1 | 0.7% | 5 | 0.8% |
| What race/ethnicity do you identify with? (select all that apply)[a] | | | | | | |
| African American/Black | 6 | 5.5% | 10 | 7.1% | 32 | 4.9% |
| American Indian or Native Alaskan | 1 | 0.9% | 0 | 0% | 0 | 0% |
| Asian | 3 | 2.8% | 9 | 6.4% | 164 | 25.0% |
| Hawaiian or other Pacific Islander | 0 | 0% | 0 | 0% | 0 | 0% |
| Hispanic, or Latino | 35 | 32.1% | 11 | 7.9% | 56 | 8.5% |
| Middle Eastern | 3 | 2.8% | 1 | 0.9% | 8 | 1.2% |
| White/Caucasian | 62 | 56.9% | 114 | 81.4% | 453 | 68.9% |
| Other | 1 | 0.9% | 3 | 2.1% | 13 | 2.0% |
| I prefer not to answer | 7 | 6.4% | 3 | 2.1% | 12 | 1.8% |
| What is your current classification at [University]?[b] | | | | | | |
| Freshman | 11 | 10.1% | 0 | 0% | 426 | 64.8% |
| Sophomore | 10 | 9.2% | 85 | 60.7% | 231 | 35.2% |
| Junior | 36 | 33.0% | 55 | 39.8% | 0 | 0% |
| Senior | 51 | 46.8% | 0 | 0% | 0 | 0% |
| Graduate student | 1 | 0.9% | 0 | 0% | 0 | 0% |

[a] The race/ethnicity question at University B and University C did not include “Hispanic or Latino” as an option, but rather as a separate question, “Do you identify as Hispanic or Latino?”

[b] The question of classification was not asked on the survey for University B and University C. Instead, this number was determined by the course the survey was administered in.

*University C relationships between demographics and self-efficacy*. The average EDSE scores were compared between different groups of students at University C, as seen in Table 8. Female students were found to have significantly lower expectations of success and higher anxiety than their male counterparts. Underrepresented minorities were found to have lower anxiety than their counterparts. Additionally, 1st-Generation students had higher anxiety than their counterparts. These differences have small-to-medium effect sizes.

*RQ #3. Are there relationships between students’ demographics and their levels of involvement in an academic makerspace?*

**Table 6 Averages and results of *t*-tests between sub-groups’ EDSE for University A**

| Demographic | *n* | Average | SD | *t* | df | *p* | *d* |
|---|---|---|---|---|---|---|---|
| *Confidence* | | | | | | | |
| Female | 15 | 58.00 | 24.26 | −1.82 | 108 | 0.071[a] | 0.51 |
| Male | 94 | 69.37 | 22.16 | | | | |
| URM | 45 | 70.00 | 22.26 | 0.73 | 101 | 0.470 | 0.14 |
| Non-URM | 58 | 66.72 | 22.97 | | | | |
| 1st Gen | 43 | 67.91 | 23.56 | 0.03 | 107 | 0.980 | 0.01 |
| Non-1st Gen | 66 | 68.03 | 22.34 | | | | |
| *Motivation* | | | | | | | |
| Female | 15 | 85.33 | 17.67 | 0.04 | 108 | 0.970 | 0.01 |
| Male | 94 | 85.16 | 17.56 | | | | |
| URM | 45 | 85.33 | 17.14 | 0.00 | 101 | 1.000 | 0.00 |
| Non-URM | 58 | 85.34 | 17.09 | | | | |
| 1st Gen | 43 | 85.81 | 17.35 | −0.28 | 107 | 0.780 | 0.05 |
| Non-1st Gen | 66 | 84.85 | 17.82 | | | | |
| *Expectation of success* | | | | | | | |
| Female | 15 | 70.00 | 20.35 | −0.55 | 108 | 0.580 | 0.15 |
| Male | 94 | 73.05 | 19.95 | | | | |
| URM | 45 | 73.56 | 20.69 | 0.16 | 101 | 0.870 | 0.03 |
| Non-URM | 58 | 72.93 | 19.01 | | | | |
| 1st Gen | 43 | 74.65 | 19.19 | −0.92 | 107 | 0.360 | 0.18 |
| Non-1st Gen | 66 | 71.06 | 20.47 | | | | |
| *Anxiety* | | | | | | | |
| Female | 15 | 36.67 | 27.95 | −0.93 | 108 | 0.350 | 0.26 |
| Male | 94 | 45.26 | 33.86 | | | | |
| URM | 45 | 50.67 | 33.33 | 1.86 | 101 | 0.066[a] | 0.37 |
| Non-URM | 58 | 38.62 | 31.98 | | | | |
| 1st Gen | 43 | 49.77 | 32.77 | 1.57 | 107 | 0.120 | 0.31 |
| Non-1st Gen | 66 | 39.70 | 32.77 | | | | |

[a] Significant at $\alpha = 0.10$.

**Table 7 Averages and results of *t*-tests between sub-groups’ EDSE for University B**

| Demographic | *n* | Average | SD | *t* | df | *p* | *d* |
|---|---|---|---|---|---|---|---|
| *Confidence* | | | | | | | |
| Female | 32 | 80.94 | 12.01 | 2.01 | 135 | 0.046[a] | 0.41 |
| Male | 105 | 86.00 | 12.60 | | | | |
| URM | 21 | 86.19 | 14.31 | 0.59 | 133 | 0.553 | 0.14 |
| Non-URM | 114 | 84.39 | 12.48 | | | | |
| 1st Gen | 17 | 83.53 | 12.72 | 0.31 | 137 | 0.756 | 0.08 |
| Non-1st Gen | 122 | 84.59 | 13.25 | | | | |
| *Motivation* | | | | | | | |
| Female | 32 | 85.63 | 11.90 | 0.24 | 135 | 0.810 | 0.05 |
| Male | 105 | 84.86 | 16.76 | | | | |
| URM | 21 | 88.10 | 11.67 | 0.99 | 133 | 0.326 | 0.23 |
| Non-URM | 114 | 84.39 | 16.46 | | | | |
| 1st Gen | 17 | 83.53 | 14.98 | 0.32 | 137 | 0.753 | 0.08 |
| Non-1st Gen | 122 | 84.84 | 16.12 | | | | |
| *Expectation of success* | | | | | | | |
| Female | 32 | 81.56 | 12.21 | 0.62 | 135 | 0.539 | 0.12 |
| Male | 105 | 83.05 | 11.86 | | | | |
| URM | 21 | 86.19 | 11.61 | 1.47 | 133 | 0.145 | 0.35 |
| Non-URM | 114 | 82.02 | 12.06 | | | | |
| 1st Gen | 17 | 82.94 | 10.47 | 0.23 | 137 | 0.818 | 0.06 |
| Non-1st Gen | 122 | 82.21 | 12.43 | | | | |
| *Anxiety* | | | | | | | |
| Female | 32 | 41.88 | 27.53 | 0.62 | 135 | 0.536 | 0.12 |
| Male | 105 | 38.10 | 30.92 | | | | |
| URM | 21 | 28.57 | 29.71 | 1.80 | 133 | 0.074[b] | 0.43 |
| Non-URM | 114 | 41.32 | 29.82 | | | | |
| 1st Gen | 17 | 38.82 | 29.98 | 0.01 | 137 | 0.995 | 0.00 |
| Non-1st Gen | 122 | 38.77 | 29.97 | | | | |

[a] Significant at $\alpha = 0.05$.

[b] Significant at $\alpha = 0.10$.

**Table 8 Averages and results of *t*-tests between sub-groups' EDSE for University C**

| Demographic | $n$ | Average | SD | $t$ | df | $p$ | $d$ |
|---|---|---|---|---|---|---|---|
| *Confidence* | | | | | | | |
| Female | 158 | 73.29 | 18.28 | 0.67 | 646 | 0.505 | 0.06 |
| Male | 490 | 74.33 | 16.53 | | | | |
| URM | 101 | 76.24 | 16.42 | −1.38 | 646 | 0.167 | 0.15 |
| Non-URM | 547 | 73.69 | 17.08 | | | | |
| 1st Gen | 114 | 71.93 | 18.33 | 1.5 | 652 | 0.133 | 0.16 |
| Non-1st Gen | 540 | 74.56 | 16.64 | | | | |
| *Motivation* | | | | | | | |
| Female | 158 | 77.28 | 20.80 | 1.38 | 646 | 0.168 | 0.07 |
| Male | 490 | 79.73 | 19.02 | | | | |
| URM | 101 | 82.57 | 18.04 | −1.93 | 646 | 0.054[b] | 0.21 |
| Non-URM | 547 | 78.50 | 19.69 | | | | |
| 1st Gen | 114 | 78.51 | 19.47 | 0.37 | 652 | 0.712 | 0.24 |
| Non-1st Gen | 540 | 79.26 | 19.44 | | | | |
| *Expectation of success* | | | | | | | |
| Female | 158 | 70.76 | 18.90 | 1.71 | 646 | 0.088[b] | 0.16 |
| Male | 490 | 73.55 | 17.53 | | | | |
| URM | 101 | 75.15 | 17.53 | −1.37 | 646 | 0.170 | 0.15 |
| Non-URM | 547 | 72.49 | 17.94 | | | | |
| 1st Gen | 114 | 72.02 | 18.73 | 0.56 | 652 | 0.574 | 0.06 |
| Non-1st Gen | 540 | 73.06 | 17.70 | | | | |
| *Anxiety* | | | | | | | |
| Female | 158 | 41.39 | 26.72 | −2.77 | 646 | 0.006[a] | 0.25 |
| Male | 490 | 34.45 | 27.60 | | | | |
| URM | 101 | 38.61 | 30.27 | −0.96 | 646 | 0.338 | 0.10 |
| Non-URM | 547 | 35.76 | 26.94 | | | | |
| 1st Gen | 114 | 41.49 | 28.94 | −2.31 | 652 | 0.021[a] | 0.24 |
| Non-1st Gen | 540 | 34.98 | 27.04 | | | | |

[a] Significant at $\alpha = 0.05$.

[b] Significant at $\alpha = 0.10$.

**Table 9 Involvement level by demographic sub-group**

| Involvement level | Total | Male | Female | URM | Non-URM | 1st Gen | Non-1st Gen |
|---|---|---|---|---|---|---|---|
| Voluntary | 27 | 26 | 1 | 8 | 15 | 7 | 13 |
| No involvement | 82 | 68 | 14 | 37 | 42 | 36 | 46 |
| Total | 109 | 94 | 15 | 45 | 57 | 43 | 59 |

Looking across students' demographics reported in RQ #2 and student involvement reported in RQ #1 provides insight into relationships between students' demographics and academic makerspace involvement. These relationships are reported in the following sub-sections.

*Proportion of demographic sub-groups who are voluntarily involved at University A.* The number of students from each demographic sub-group at University A can be seen in Table 9. Chi-squared tests reveal that men are significantly more likely to be voluntarily involved with a small-to-moderate effect size ($\chi^2 = 3.03$, df = 1, $p = 0.08$, $\varphi = 0.16$). However, there is no significant difference based on minority status ($\chi^2 = 1.04$, df = 1, $p = 0.31$) or based on the students' parents' highest degrees ($\chi^2 = 0.52$, df = 1, $p = 0.47$).

*Proportion of demographic sub-groups who are voluntarily involved at University B.* An analysis of the proportions of each demographic sub-group and their use was conducted (Fig. 2). The proportion of each sub-group who are voluntarily involved can be seen in Table 10. None of the sub-groups are significantly more involved than their counterparts. This includes sex ($\chi^2 = 0.24$, df = 1, $p = 0.621$), minority status ($\chi^2 = 0.31$, df = 1, $p = 0.577$), and parents' education ($\chi^2 = 0.24$, df = 1, $p = 0.626$), but the sample sizes are very small in some cases.

*Proportion of demographic sub-groups who are voluntarily involved at University C.* The proportions of each demographic subgroup at University C can be seen in Table 11. As with University A, female students were found to be significantly less likely to be voluntarily involved than their male counterparts with a moderate-to-large effect ($\chi^2 = 36.93$, df = 1, $p < 0.001$, $\varphi = 0.52$). Neither minority status ($\chi^2 = 1.17$, df = 1, $p = 0.279$) nor parents' education ($\chi^2 = 0.14$, df = 1, $p = 0.705$) were correlated with a significant difference in the proportion of students who were voluntarily involved.

*RQ #4. What similarities and differences are observed between the three universities?*

The data demonstrated some common findings across the three diverse universities as well as some differences as illustrated in Table 12. The possible reasons for the differences will be hypothesized, but future work must test these hypotheses. Note that only University C had students in all three levels of involvement: no involvement, class-only involvement, and voluntary involvement. Across all four categories of the EDSE, no differences appeared between students who used the makerspaces for class only and no involvement groups at University C, but choosing to use the makerspace was correlated with superior EDSE across all four lenses (Fig. 3). Consistent with this, University A also demonstrates higher confidence, motivation, and expectation of success for students involved in the makerspace as compared with those not involved (Fig. 1). At University B, however, there were no statistically significant differences between class-only and voluntary involvement groups. Owing to a curriculum that sends all engineering students to a makerspace as freshmen, there were zero no involvement students surveyed at University B. It is very possible that the design curriculum at University B effectively provides a high degree of involvement in the makerspaces for all students, which therefore provided improvements to their engineering design self-efficacy from class-only involvement at that institution. There may be a threshold at which additional makerspace involvement and design projects do not further increase design self-efficacy (EDSE). Future work should seek to determine this threshold such that all students could be provided with the required level of design opportunities to increase their design self-efficacy.

The differences between no involvement and voluntary involvement groups observed at Universities A and C could be because the makerspaces helped students gain confidence, motivation, and expectation of success. Alternatively, students who already had greater confidence, motivation, or expectation of success may naturally become voluntarily involved in makerspaces. Data from University C suggest that freshmen who were initially more motivated to conduct design tended to become involved in the makerspaces more than did students with initially lower motivation. These same data also indicated students who chose to become involved in the makerspace during their freshman year showed greater confidence and expectation of success at the end of the semester than did students who did not become involved, even though both groups started at similar levels. These trends of students with greater involvement having higher engineering design self-efficacy fits into accepted theories of involvement and social integration that successful students tend to have greater involvement in the university [66,67]. As a strong sense of community may mitigate other traditional factors affecting students' self-efficacy [15], the culture of University B could be the reason there was no significant difference in engineering design self-efficacy among students' makerspace involvement levels.

Females, who are historically underrepresented in engineering fields, were found to have lower engineering design self-efficacy at all three universities, which is consistent with the trends in engineering self-efficacy reported in the literature [12,13,17]. Female students were found to have lower confidence when conducting engineering design than their male counterparts at University A and University B and have lower expectation of success, and higher anxiety at University C. First-generation college students were found to have higher levels of anxiety than non-first-generation students at University C.

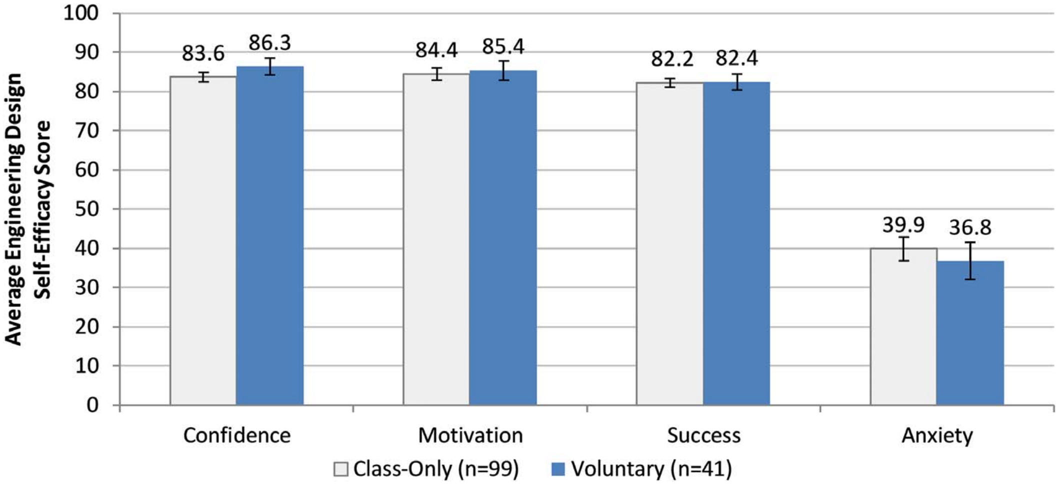

**Fig. 2 Average engineering design self-efficacy scores across involvement types at University B shown with ±1 standard error**

**Table 10 Involvement level by demographic sub-group at University B**

| Involvement level | Total | Male | Female | URM | Non-URM | 1st Gen | Non-1st Gen |
|---|---|---|---|---|---|---|---|
| Voluntary | 41 | 31 | 8 | 7 | 32 | 6 | 35 |
| Class-only | 99 | 74 | 24 | 14 | 82 | 11 | 87 |
| Total | 140 | 105 | 32 | 21 | 114 | 17 | 122 |

**Table 11 Involvement level by demographic sub-group at University C**

| Involvement level | Total | Male | Female | URM | Non-URM | 1st Gen | Non-1st Gen |
|---|---|---|---|---|---|---|---|
| Voluntary | 276 | 218 | 52 | 40 | 230 | 47 | 230 |
| Class-only | 104 | 77 | 26 | 14 | 89 | 16 | 89 |
| No involvement | 277 | 195 | 80 | 47 | 228 | 51 | 226 |
| Total | 657 | 490 | 158 | 101 | 547 | 114 | 545 |

At University C, male students were four times more likely to be a user of a makerspace than women. Based on these findings, as well as a previous study reported in the background demonstrating no significant differences in engineering self-efficacy among minority and majority students likely due to active participation in related student organization communities [15], more effort should be made to increase the participation of these underrepresented groups in academic makerspaces. Previous work describes makerspaces as communities of practice [73], and it is important that students see these makerspaces as *welcoming* communities of practice in order to release the gains in engineering design self-efficacy that, as research is beginning to demonstrate, makerspaces can afford to students.

Another interesting finding is the fact that female students at both University A and University C were significantly less likely to be voluntarily involved than their male counterparts, but the same was not found at University B. Trends from the literature suggest a common lack of belonging in engineering among female students [13,17,18], which can result in lower voluntary participation in an academic makerspace. One hypothesis for University B countering this trend is the amount of required work in the makerspace for class projects, which could be removing the barriers present for female students to feel a sense of belonging in the space. Another contributing factor may be the higher percentage of female faculty at University B. Further studies into how the makerspace at University B seems to be more inclusive for women could lead to significant findings on how this inclusion can be spread to other academic makerspaces or even other extracurricular engineering groups.

Finally, while the data presented in this paper showed a correlation between the use of an academic makerspace and engineering design self-efficacy, it did not prove causation. It is possible that students with higher EDSE were more likely to become involved in a makerspace. Previous studies, however, have found that makerspaces both attracted students with high EDSE and improved the EDSE of students who became involved [74]. In order to truly understand the correlations between EDSE and involvement in

**Table 12 Summary of statistically significant differences observed across the three universities**

| Measure—Group | University A | University B | University C |
|---|---|---|---|
| EDSE—Sex | Females: Lower confidence | Females: Lower confidence | Females: Lower expectation of success<br>Higher anxiety |
| EDSE—URMs | URMs: Higher anxiety | URMs: Small sample size | URMs: Higher motivation |
| EDSE—1st generation | —— | —— | 1st Gen: Higher anxiety |
| Involvement—Sex | Females: Lower involvement | —— | Females: Lower involvement |
| Involvement—URM | —— | —— | —— |
| Involvement—1st Gen | —— | —— | —— |
| EDSE—Involvement | Users: Higher confidence<br>Higher motivation<br>Higher expectation of success | —— | Voluntary users: Higher confidence<br>Higher motivation<br>Higher expectation of success<br>Lower anxiety[a] |

Note: No statistically significant differences.

[a] Voluntary users at University C are only significantly less anxious than students with no involvement (see Fig. 3).

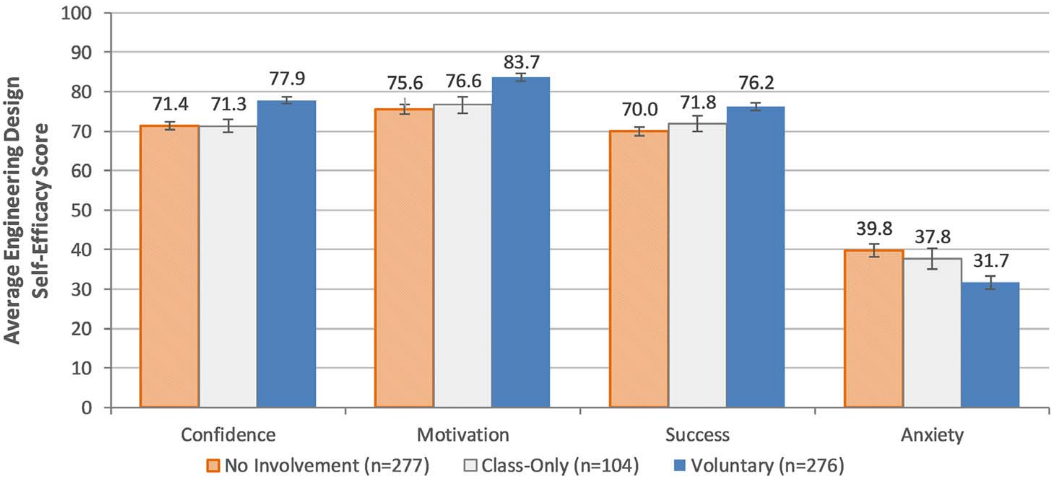

**Fig. 3 Average engineering design self-efficacy scores across involvement types at University C shown with ±1 standard error**

academic makerspaces, especially for students in traditionally underrepresented groups, more work needs to be done.

Regardless of how the makerspace is used, these results appear to demonstrate that there is value in makerspace use, whether as classroom-based use or optional use, toward students' development in terms of design self-efficacy. Consequently, when crafting design-based learning experiences, one might consider makerspaces as a key tool that one couple with design communication, learning, and prototyping activities—each of which have already shown to provide critical benefits toward an engineering students' education in design. Further, when one considers a makerspace, it is important that one considers some best practices to aid in student access, training, learning, and management. While a complete recipe for effective makerspace design does not yet exist, one might consider the following references as starting points for development principles [1,3,6].

## Limitations

Data were taken as a cross section from each university based on the data available during a calendar year of a longitudinal study. This causes a few limitations on how the data can be analyzed and interpreted. First, as stated in the Discussion, these results cannot show causation between makerspace involvement and EDSE. It is possible that students with superior EDSE are themselves more likely to join the space. Second, because each university looks at a different population of students (sophomores and juniors at University B, freshmen and sophomores at University C), it is not feasible to directly compare students between universities without being affected by significant confounding factors. This limitation was mitigated by looking within each institution's data for trends and then comparing these trends among the universities. The data collection method was slightly different at each school, but the minor differences are not expected to affect the results. Finally, the involvement groups used for analysis may be too broad and more information may be gained with more refined groups. Qualitative studies, such as those presented by Tomko et al. [75], have shown that involvement levels vary greatly student to student. Therefore, having only one level of voluntary involvement may result in the neglect of richer data.

## Conclusions and Future Work

As makerspaces have become more and more popular on university campuses, particularly with connections to engineering programs, it is crucial that their impact is measured and understood. This paper has shown empirical evidence that involvement in an academic makerspace is positively correlated with superior engineering design self-efficacy. At University A and University C, students who chose to spend time in an academic makerspace were found to have significantly higher confidence, motivation, and expectation of success than students with no involvement in a makerspace. At University A and University C, it was also seen that the proportionally fewer female students chose to spend time in an academic makerspace than their male counterparts. Female students at all three Universities were found to have lower self-efficacy in at least one lens when compared with their male counterparts. This said, the data begin to shed light on challenges associated with access at different universities, and if we are going to see the noted gains in design self-efficacy across all of our engineering students, processes, procedures, and policies will need to change to ensure equal and equitable access.

Ultimately, the results of this study have shown that students involved in academic makerspaces have a higher self-efficacy for conducting engineering design. This is particularly important due to previous studies showing self-efficacy in a skill being an indicator of success [14]. If we accept the premise that engineering design is the "central or distinguishing activity of engineering" as Dym et al. [76] summarized from Simon [77] and state in the opening of their now famous paper, *Engineering Design Thinking, Teaching, and Learning*, then these results may indicate the revelation of a key method for developing successful engineers. How can we get more students engaged in engineering makerspaces? How can we ensure these spaces are beneficial and inclusive to all students, regardless of gender, ethnicity, or any other demographic?

Of course, as we stated above, these results are just the first step in filling the gap in empirical data-driven literature on makerspaces. While correlation is demonstrated, causation is not. Fortunately, additional studies are being carried out to see how students change with longitudinal studies where their involvement may vary semester to semester. These studies may help to understand causation, as well as what factors may lead students to become more involved in an academic makerspace. All of this work will be crucial in understanding the benefits and drawbacks of the inclusion of academic makerspaces in engineering design curriculum.

## Acknowledgment

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