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IMPACTS ON DESIGN SELF-EFFICACY FOR STUDENTS CHOOSING TO PARTICIPATE IN A UNIVERSITY MAKERSPACE

E. C. Hilton[1], M. Tomko[1], A. Murphy[1], R. Nagel[2] and J. S. Linsey[1]

[1]Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA
[2]Engineering, James Madison University, Harrisonburg, USA

Abstract: Engineering design courses can take advantage of makerspaces on university campuses. Makerspaces are built with a diverse set of equipment thought to inspire creativity and design confidence among the student population; however, the impact that these makerspaces have toward these constructs remains an ongoing research question. In Spring 2016, students in a first-year engineering design course were surveyed at the beginning and end of the semester for a longitudinal study tracking student makerspace involvement and its use on design self-efficacy. This freshmen engineering course introduces students to the makerspace. Students were evaluated based on their level of involvement pre- and post-semester. Findings show that highly motivated students tend to join makerspaces and that students who chose to become involved have increased confidence in their design ability and expect more success.

Keywords: *makerspaces, curriculum, design self-efficacy*

1. Introduction

Introducing makerspaces into the university environment sparked new and unpredictable opportunities for engineering educators. Makerspaces are unconventional environments that house numerous and various equipment, tools, machinery, and other resources that allow students to pursue and peruse creativity through hands-on building projects at their respective universities. With these nontraditional spaces growing in popularity at the university setting, engineering educators may find that their curricula often do not support these makerspaces. As might be expected, the integration of makerspaces into engineering curricula varies across universities as universities have different curricula, physical spaces, requirements, visions, and cultures (Barrett et al., 2015; Wilczynski, 2015). All of this factors into how a university builds up, around, and with a makerspace.

In this work, we introduced students to the makerspace at a large (~27,000 students with about ~15,500 enrolled as undergraduates), public, Southwestern, Research 1, technology-focused university in a first-year, cornerstone engineering design course. Cornerstone design, as opposed to capstone design, is meant to give students an early introduction to the engineering design process and engineering design tools whereas capstone design is usually incorporated near the end of an engineering degree program. The emphasis is on building student interest in design by demonstrating that design is the essence of engineering. The popularity of cornerstone design courses has been growing steadily in universities across the United States.

By introducing first-year students to the engineering makerspace at their home institution, the authors hope to develop a culture of community-building among the students and improve retention through an increased sense of belonging as increasing a students' sense of belonging has been shown to be a factor in improving retention (Marra, Rodgers, Shen, & Bogue, 2012). In essence, we strive to plug first-year students into an existing community of practice, where a community of practice is a place that facilitates the quest for knowledge, learning, and identity through experience and social interaction in which members work side-by-side generating a circular operation of participants guiding and receiving guidance from one another (Kriner, Coffman, Adkisson, Putman, & Monaghan, 2015). It is believed that student engagement in this university's large, open, and student-run makerspace will improve retention, engagement, and community among students. It will also provide an avenue of independent exploration of engineering design and creativity through the sophomore and junior years when there is minimal curricular engineering design opportunity.

The students in the course who provided consent to participate in this research study completed a self-efficacy survey instrument and a makerspace involvement survey instrument twice—once at the beginning and again at the end of the course. Comparing these two surveys allows us to assess how the engineering design course impacted students' involvement in the space and their self-efficacy in completing engineering design tasks (Carberry, et al., 2010). This paper presents the findings from one semester of integrating the makerspace with this cornerstone course and compares students' responses from the beginning to the end of the semester.

2. Background

Self-efficacy, or "the beliefs in one's capacity to organize and execute the courses of action required to produce given attainments" (Bandura, 1977), has been found to contribute to students' decisions to persist in difficult courses of study (Bettinger & Long, 2005; Downing, Crosby, & Blake-Beard, 2005)—one of our aforementioned overarching goals in introducing first-year students to makerspaces. Further, it has been shown that increasing confidence and self-efficacy has been found to be one of the keys for increasing retention within a program, particularly for women (Fisher & Margolis, 2002).

Through participation in a makerspace, we believe that students may discover (1) mastery experiences, (2) social persuasion, (3) physiological states, and (4) vicarious experiences—Bandura's theorized four main sources of self-efficacy (Bandura, 1977). Mastery is the sense that one has the knowledge and skills to achieve a goal, a sense that can develop in a makerspace by working with more experienced students and mastering the use of equipment. Social persuasion is the positive or negative impact others can have on one's sense of self-efficacy. Negative social persuasion can induce the physiological state of anxiety, potentially inflaming stereotype threats (Steele & Aronson, 1995), whereas positive persuasion can be a significant motivator. In a makerspace, we postulate that a sense of belonging and community can potentially reduce anxiety and induce a growing sense of confidence which can allow for more creative exploration. Finally, having the vicarious experience of observing someone else (a model) engage in a task can positively affect one's self-efficacy, dependent upon the similarity of the model to one's own abilities and circumstances (Bandura, 1977). To assess self-efficacy, this work uses the design self-efficacy instrument developed by Carberry, Lee, and Ohland (2010). This instrument assesses students across four constructs: anxiety, motivation, belief toward success, and confidence.

Some approaches have shown to positively impact students' retention such as providing more supportive educational environments, role models, mentors, and demonstrating that students can be successful in their work lives while also having a personal life (Fisher & Margolis, 2002; Milgram, 2011). Emphasis on the positive impact that engineers can have in the world as creative problem solvers has also been shown to have a positive impact on retention (*The engineer of 2020: Visions of engineering in the new century*, 2004). An open, student-run makerspace, as a community of practice, is likely to have many of these characteristics built in for the purposes of support and safety such as being a supportive educational environment with a well-trained cadre of student role models and mentors. Actively engaged members in communities of practice are demonstrated to cultivate identity and connection to both their work and other members of the community (Wenger, 1998).

A mixed method study on a highly reputed competition team (e.g., Formula SAE) shows that the team possesses unwritten conditions on the required time commitment, dedication, and personal sacrifices, and that these unwritten conditions create an unwelcoming atmosphere for many, especially under-represented groups, (Foor, Walden, Trytten, & Shehab, 2013). This unwelcoming atmosphere results in poor retention of impacted members. In contrast, makerspaces are open to all students and do not possess any conditions for inclusion and acceptance to the space. The faculty and students in a makerspace continuously monitor the culture and work hard to maintain a welcoming, open environment. Makerspaces also do not demand any significant time commitment from students. Students in makerspaces work on projects of their choosing, including humanitarian projects for organizations like Engineers without Borders. Makerspaces should provide opportunities for students to be creative, to see engineering as a highly creative field, to work on projects that impact society, and to increase their design skills. These factors are likely to increase retention, self-efficacy, and idea generation, which is particularly important for retention of females in engineering (Morocz, 2016).

What is the impact of a makerspace on the student experience? The anecdotal evidence supports the potential for these spaces to have tremendous impact on engineering (Brown, Collins, & Duguid, 1989; Forest et al., 2014; Knight, Carlson, & Sullivan, 2007; Morocz et al., 2016; Julian Weinmann, 2014; J. Weinmann, Farzaneh, Lindemann, & Forest, 2016), yet research in an academic setting is still sparse. Research circles are investigating the impact of makerspaces in terms of K-12 outreach, maker identity, longitudinal impact, and successful practices. While university makerspaces are one area of study, makerspaces are becoming more common in libraries, museums, and even in mobile vehicles (Burke, 2015; *Makeology: Makerspaces as Learning Environments*, 2016). Makerspaces are capturing and facilitating to a wide audience. Yet, for these academic makerspaces, the risk for building and integrating a makerspace into the curriculum begins to impact a greater audience, where students, faculty, parents, stakeholders, and administrators are all impacted.

Ultimately, this points to questions for how beneficial these spaces are and what will make them successful. Hartnett (2016) discusses the benefits of makerspaces as perceived by users. In this work, makerspaces are identified to have a variety of benefits for both the community and the individuals. Makerspaces allow students to not only develop hands-on problem-solving skills and collaboration experience, but also to socialize and learn from their peers and mentors within these spaces. In makerspaces, the culture is critical to the success of the space, and one study identified student ownership as a crucial cultural element for encouraging individual exploration and creative problem solving (Kurti, Kurti, & Fleming, 2014). This type of creative problem solving inspires more than just a design approach, but also inspires creative confidence through design thinking—an open-ended method of thinking combined with 21st century skills such as technology and transmedia navigation (Bowler, 2014).

These makerspaces have supported the ability for students to gain skills that were neglected in the traditional classroom setting, yet strongly advocated for in reports such as the Engineer of 2020 (*The engineer of 2020: Visions of engineering in the new century*, 2004). Almost in response to *The Engineer of 2020*'s call, the makerspace has opened opportunities for students to gain a wide skillset. Makerspace users reported that working in the space improves their communication skills and gives them more confidence for communicating engineering principles to non-engineers, a crucial skill to have in the workforce (Galaleldin, 2016). While encouraging students to communicate their ideas, makerspaces allow students to practice their design skills by fabricating the ideas and becoming acquainted with design process through trial and error (Wilczynski & Adrezin, 2016). Even more so, makerspaces support students in their independent projects, where working independently on projects encourages them to take initiative in their education and learn the skills necessary to complete the project (Harnett, Tretter, & Philipp, 2014).

3. Methodology

This study involves students in a first-year engineering design course at a large public, Southwestern, Research 1, technology-focused university. Approximately 350 students enroll in the course per semester. The course is included in the undergraduate requirements for both mechanical engineering and aerospace engineering students. In the beginning and at the end of the course, all students were given a survey and were provided an opportunity to participate in the study. Students' responses to the survey were deleted for any student who refrained from participating in the study. This resulted in a total of 330 students participating in the study.

The surveys for this study included a design self-efficacy survey, an involvement (or engagement) survey, and a demographics survey. The self-efficacy survey follows that of Carberry et al. (2010) and asks students questions in regards to their confidence, motivation, expectancy of success, and anxiety in completing different engineering design tasks. In conjunction with this survey, students were also presented with questions regarding their use and involvement with the university makerspace. Questions asked how often students worked in the space and what they used the space for (if applicable) in order to sort them into three categories based on their involvement: Low, Medium, and High involvement. Low involvement students self-reported to have never used the equipment in the makerspace. Medium involvement students self-reported to have used the equipment in the makerspace, but only completed one type of project. The High involvement students self-reported using the equipment in the makerspace and completed several type of projects. Additional information about the students was collected through a demographic survey, which helps to uncover if underrepresented minorities and women are using the space as much as other students.

While this study is limited by a lack of a control group without makerspace contact, student engagement in the space, measured through the engagement survey, provides a measure for students' use of the makerspace. The students who self-reported to have never used the makerspace provide a reasonable proxy for the control group

4. Results

The data collection resulted in responses from 330 students. As only true freshmen were of interest to this portion of the study, 56 students who were not in their first year at a university were excluded. Additionally, 4 students were excluded for not finishing the survey, leaving 270 students as viable data points. These students were sorted into groups based on their involvement levels as dictated in the Methodology section. The following three groups were analyzed to help determine the impact of involvement on design self-efficacy:

- LowLow: Students who had Low involvement at the beginning and end of the semester
- LowHigh: Students who had Low involvement at the beginning of the semester and moved to High involvement at the end of the semester.
- HighHigh: Students who had High involvement at the beginning and end of the semester

Using these definitions, 147 students were determined as LowLow, 39 students were determined as LowHigh, and 27 students were determined as HighHigh. The remaining 57 students were determined to have medium involvement in the makerspace at either the beginning or end of the semester and not included in further analysis. This exclusion was due to the uncertain boundaries between low and medium involvement and between medium and high involvement. Comparing only low and high involvement participants ensures we are measuring the impacts of involvement. There were no students who moved from high involvement to low involvement (HighLow). This was expected based on our definitions as low involvement students have never used the equipment in the makerspace. Therefore, a change from high to low involvement should not be possible. Figures Figure 1 through Figure 3 show the pre-to-post comparison of the average engineering design self-efficacy ratings for each group along with the standard error of each average.

The within-subject comparison of engineering design self-efficacy ratings for the students beginning and ending the semester with low involvement in the makerspace can be seen in Figure 1. A paired t-test was run to determine significant changes in the group's self-efficacy. The group's confidence and expectation of success both significantly increased with t-values of $t = 13.87$ ($df = 146$, $p < 0.001$) and $t = 10.14$ ($df = 146$, $p < 0.001$), respectively. Anxiety was found to significantly decrease with a t-value of $t = 4.81$ ($df = 146$, $p < 0.001$). There was no significant change in motivation with a t-value of $t = 1.53$ ($df = 146$, $p = 0.129$).

Figure 2 shows the within-subject comparison of engineering design self-efficacy ratings for the students who began the semester with low involvement in the Makerspace but moved to high involvement by the end of the semester. A paired t-test was run to determine significant changes in the group's self-efficacy. The group's confidence and expectation of success significantly increased with t-values of $t = 8.58$ ($df = 38$, $p < 0.001$) and $t = 6.74$ ($df = 38$, $p < 0.001$), respectively. Anxiety decreased at a significant rate if $\alpha = 10\%$ with a t-value of $t = 1.82$ ($df = 38$, $p = 0.077$). Motivation did not significantly change with a t-value of $t = 0.23$ ($df = 38$, $p = 0.82$).

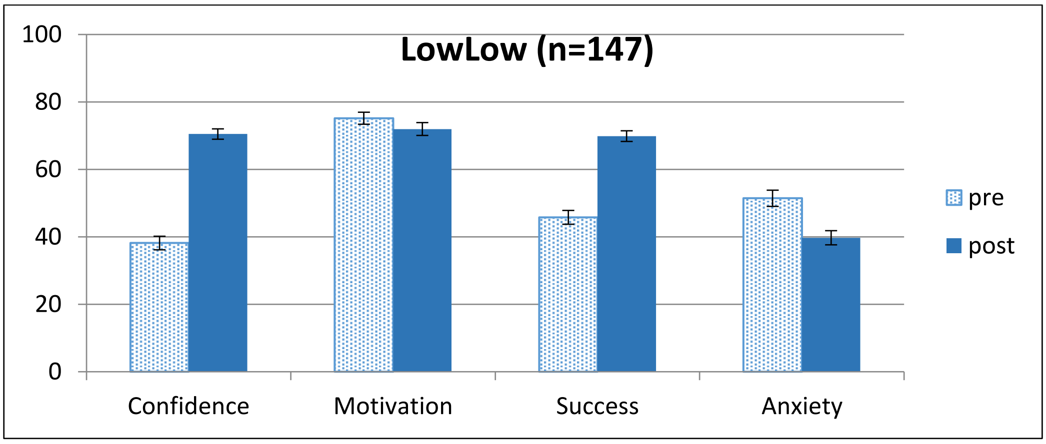

Figure 1. Pre v. Post Engr. Design Self-Efficacy Ratings for students in beginning and ending with Low Involvement

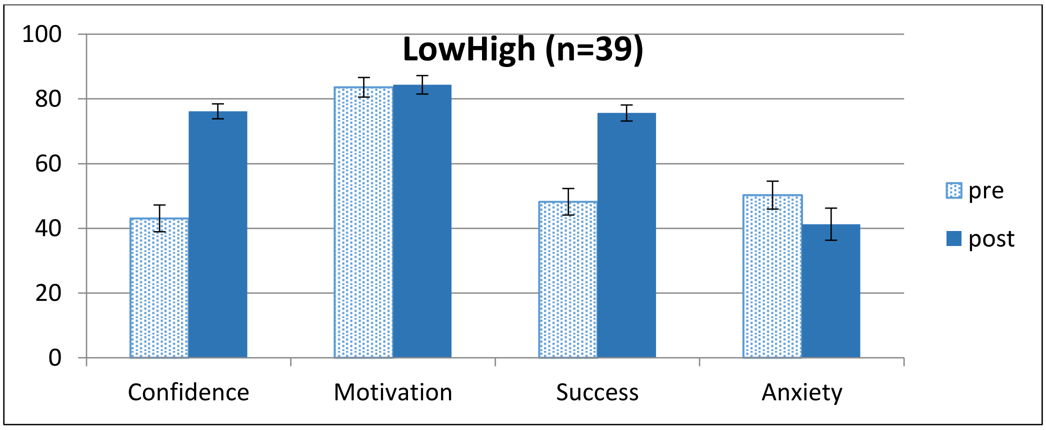

Figure 2. Pre v. Post Engr. Des. Self-Efficacy Ratings for students moving from Low to High Involvement

Figure 3Figure 2 shows the within-subject comparison of engineering design self-efficacy ratings for the students who began the semester with high involvement in the Makerspace. A paired t-test was run to determine significant changes in the group's self-efficacy. The group's confidence and expectation of success significantly increased with t-values of t = 3.84 (df = 26, $p < 0.001$) and t = 3.05 (df = 26, p = 0.0052), respectively. Anxiety and motivation did not significantly change with a t-values of t = 0.22 (df = 26, p = 0.83) and t = 0.20 (df = 26, p = 0.84), respectively.

Between-subject analysis was also conducted using two-sample t-test assuming equal variances. Figure 4 shows the comparison between the three groups' engineering design self-efficacy at the beginning of the semester. Table 1 shows the results of the two-sample t-tests between each of the three groups. The HighHigh group was significantly higher than both of the other groups in confidence and expectation of success and significantly lower in anxiety. The LowLow group was also shown to have significantly lower motivation than the other two groups.

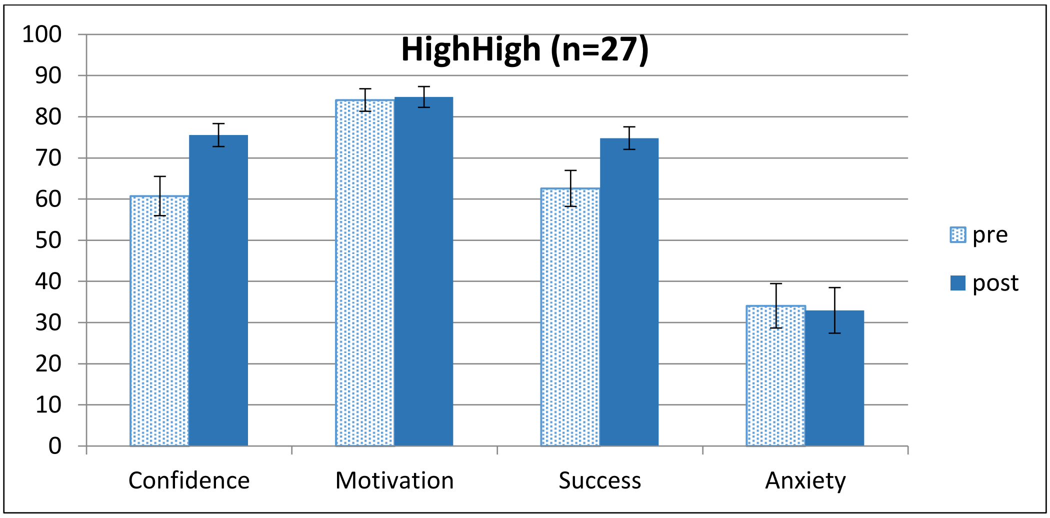

Figure 3. Pre v. Post Engr. Design Self-Efficacy Ratings for students beginning and ending with High Involvement

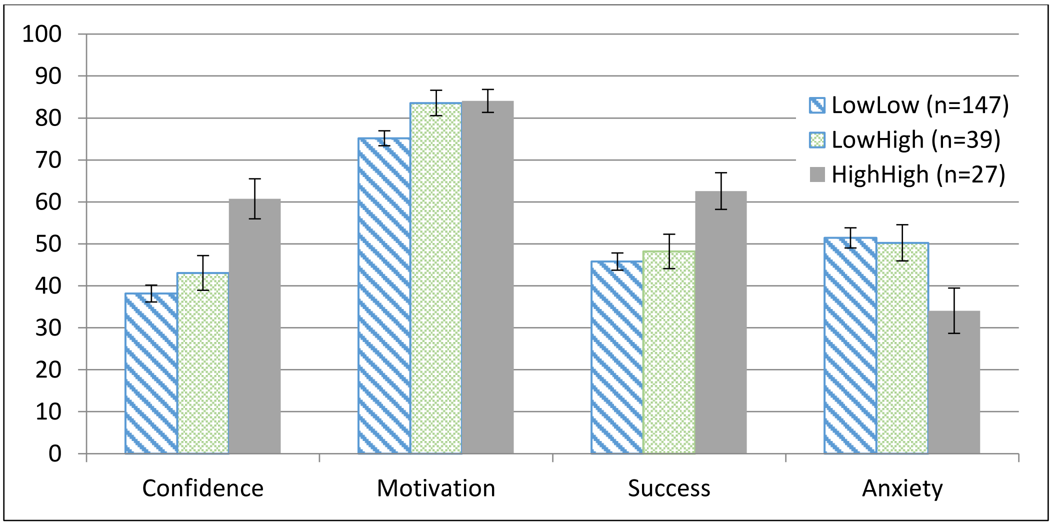

Figure 4. Between Subject Comparison of Engr. Design Self-Efficacy at the Beginning of the Semester

Table 1. Statistics from two-sample t-test assuming equal variances of Pre data

Comparison and df		Confidence	Motivation	Success	Anxiety
LowLow vs LowHigh	t	1.1	2.21	0.53	0.23
df = 184	p	0.27	0.03*	0.59	0.82
LowHigh vs HighHigh	t	2.73	0.11	2.31	2.32
df = 64	p	0.008*	0.91	0.02*	0.02*
LowLow vs HighHigh	t	4.39	2.05	3.25	2.84
df = 172	p	< 0.001*	0.04*	0.001*	0.005*
p-value Color Key:		*Statistically Significant at α = 5%			

Figure 5 shows the comparison between the three groups' engineering design self-efficacy at the end of the semester. Table 2 shows the results of the two-sample t-tests between each of the three groups. The LowLow group has significantly lower motivation than the other two groups at the α = 5% level. The LowLow group also has significantly lower confidence and expectation of success that the LowHigh group at the α = 10% level.

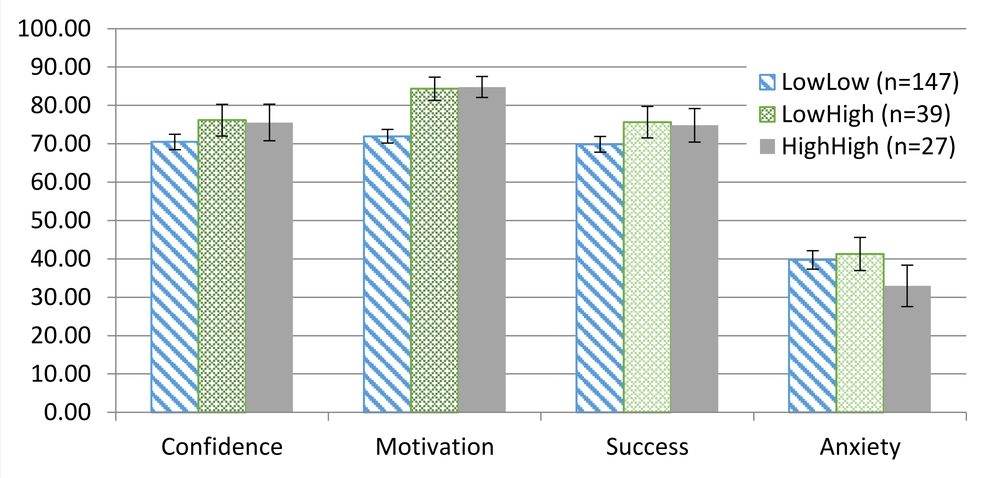

Figure 5. Between Subject Comparison of Engr. Design Self-Efficacy at the End of the Semester

Table 2. Statistics from two-sample t-test assuming equal variances of Post data

Comparison and df		Confidence	Motivation	Success	Anxiety
LowLow vs LowHigh	t	1.76	3.1	1.73	0.32
df = 184	p	0.08**	0.002*	0.09**	0.75
LowHigh vs HighHigh	t	0.16	0.11	0.22	1.09
df = 64	p	0.87	0.91	0.83	0.28
LowLow vs HighHigh	t	4.39	2.05	3.25	2.84
df = 172	p	0.18	0.006*	0.21	0.22
p-value Color Key:		*Statistically Significant at α = 5%		**Significantly at α = 10%	

5. Discussion

Makerspaces are inherently creative spaces where students can explore, create, design, and make. Previous studies (Morocz et al., 2016) have shown there is a correlation between makerspace involvement, higher confidence, and lower anxiety for engineering design tasks, indicating that student involvement in a space geared toward open creativity allows students to have more creative freedom. In turn, students are more confident and less anxious in their ability to conduct engineering design, interact with these spaces, and explore creative avenues. While these previous studies could not show definite causality between involvement and design self-efficacy, the results presented in this paper suggest there may be causality in these two categories.

Students who began the semester with low involvement in the makerspace but ended with high involvement (LowHigh) were found to have initially higher motivation to conduct engineering design than students who remained in the low involvement group throughout the semester (LowLow). This suggests that having high motivation to conduct engineering design will lead students to become involved in the makerspace.

Students who began the semester highly involved in the makerspace had significantly lower anxiety when conducting engineering design than students who initially had low involvement in the makerspace. By the end of the semester, there were no significant differences between any of the groups in anxiety caused by conducting engineering design. This may suggest that involvement in a makerspace reduces anxiety caused by conducting engineering design as effectively as taking a course that introduces some basic engineering design methods. It may be that the course is causing the changes —further work is needed.

Students in the LowHigh group and students in the LowLow group initially showed no significant difference in confidence or expectation of success in conducting engineering design. At the end of the semester, however, the LowHigh group was significantly higher in both categories. This suggests that becoming highly involved in a makerspace may improve confidence and expectation of success for conducting engineering design. With a larger sample size, significance may be found at a higher confidence level.

6. Conclusion and Future Work

University makerspaces may be an avenue for further enhancing engineering students' design experience since these spaces and student engagement in these spaces can allow for opportunities through learning opportunities beyond the current curriculum and through design creativity as students build, test, and explore. At the end of the semester, students who chose to become involved in makerspaces had more confidence in their design ability and a greater expectation for success than students do did not become involved. This is true even though these two groups of students started the semester at similar levels for these two measures. This work also indicates that students who have higher motivation to do engineering design tend to become involved in makerspaces. This study does not completely separate the effects of the engineering design course from student involvement in makerspaces or other effects that may be occurring simultaneously. Current data collection and analysis are beginning to evaluate this.

This is part of an on-going longitudinal study following a cohort of students from the first-year until senior year. An ethnographic study of student learning in makerspaces is also under way. Future work will evaluate the correlation between engineering idea generation scores, design self-efficacy, and makerspace involvement. The current paper presents data from a single university and continuing work collects data from two additional university makerspaces.

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