

## **Understanding Academic Makerspaces through a Longitudinal Study at Three Universities**

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# Understanding Academic Makerspaces through a Longitudinal Study at Three Universities

## Abstract

Academic makerspaces continue to grow in popularity nationally and internationally, but the empirical data of how students are impacted is limited. To engage students in these spaces, some curricula require the use of the space for certain design courses (such as the program studied herein), while other schools have kept space use as an optional perk for students. This leads to several questions about what impacts these spaces are making on the students, what kind of students are choosing to partake in makerspaces use, what factors drive students to initially and continually participate in makerspaces, and what is the impact that involvement has on the development of design skills. In an effort to better understand the impact of involvement in academic makerspaces, a longitudinal study on students at three different universities has been carried out over the last four years. Data were collected from students through the use of surveys and collection of GPA and retention data. Students were tracked throughout their respective programs to observe how changes in involvement correlated to changes in factors such as retention and engineering design self-efficacy. This paper gives an overview of the entire study and presents results including trends in voluntary involvement in academic makerspaces over the course of each program and how these trends correlate to other measured factors.

## Introduction

Makerspaces are becoming increasingly prevalent on college campuses due to their perceived pedagogical benefits for students. On many college campuses, makerspaces have become a hub of creativity and innovation. Those working in these spaces may gain skills crucial for developing engineers.

Creative design, prototyping, building, and communicating ideas are important skills to foster within students in engineering. Makerspaces are an ideal place for students to develop the aforementioned skills and more. Universities usually have machine shops for making parts for projects and prototypes, but the shops are run by professionals, and extensive training is required for students to use equipment themselves [1]. Makerspaces, on the other hand, utilize a variety of tools and materials housed in a single location to provide community space that acts as a hub of creativity and is accessible to anyone. An essential aspect of a successful makerspace is its welcoming atmosphere, which allows those who participate to feel a sense of community with other makers and invites them to continue using the space.

The longitudinal study aims to illustrate the impacts of makerspace involvement on students. Surveys were given to students to collect demographic data, determine involvement levels, and gauge engineering design self-efficacy (EDSE). Makerspace involvement can give students hands-on experiences not obtained in the classroom. This can improve the students' EDSE, which is based on confidence, motivation, expectation of success, and anxiety when conducting engineering design tasks.

Preliminary data was collected from engineering students at three different universities during their first and second years. The results of preliminary data analysis are summarized in this paper, and

expected results for longitudinal comparisons are reported. These findings contribute to the understanding of students' engineering design self-efficacy as they relate to makerspace involvement, engineering curricula, and demographic groups.

## **Background**

Previous work on self-efficacy by Bandura describes self-efficacy as a self-reported measure of a person's perceived capability to organize and carry out the processes and tasks required for the subject in question [2]. Students with higher self-efficacy scores have been found to have greater likelihood of retention within challenging programs of study [3, 4]. This relates to the work on makerspaces and engineering design self-efficacy, which found a positive association between makerspace involvement and two aspects of engineering design self-efficacy: motivation and anxiety [5,6]. This shows that students involved in makerspaces have more motivation on average and have less anxiety surrounding engineering design tasks. However, the study could not provide evidence for causation between these factors.

A review of several academic makerspaces throughout US universities by Wilczynski provided observations on the differences and similarities between various academic makerspaces in order to create guidelines for other universities wishing to implement a makerspace of their own [7]. These guidelines suggest practices that will continue to attract new users, as well as retain and grow existing users. User involvement is crucial to help understand the extent of the educational impacts makerspaces have on students who participate in them.

## **Methodology**

Collection involved administering surveys to students in engineering and engineering technology programs of study at three universities [8]. Preliminary data has been collected and analyzed for all three universities, but final collection for the longitudinal study is still in progress as of spring 2019. The longitudinal collection of data will provide a clear picture of how mechanical engineering students develop as they progress through the curriculum. Changes in their makerspace involvement levels and self-efficacy assessments can be tracked to draw conclusions on the relationship between these two metrics and the curriculum itself.

The surveys focused on three things: involvement level in makerspaces, engineering design self-efficacy, and demographic information [9]. The participants were divided into three makerspace involvement level groups [9] based on the survey questions regarding the extents and purposes of the students' use of makerspaces [5].

- No Involvement - students who self-reported no experience using makerspace equipment
- Class-Only Involvement - students who self-reported only using makerspace equipment as required for class projects
- Voluntary Involvement - students who self-reported using makerspace equipment for projects not required for class, such as personal projects

The engineering design self-efficacy (hereafter EDSE or self-efficacy) questions on the survey, developed by Carberry, Lee, and Ohland [10], sought to understand student perceptions regarding their abilities to conduct engineering design tasks. From the scores reported by students on these

questions, we were able to get a quantitative measurement for their confidence, motivation, expectation of success, and anxiety surrounding engineering design tasks. The scores were analyzed across different comparison groups to see existing trends.

### ***University A***

University A is a large, Hispanic-Serving institution located in the Southwestern United States [8] with a relatively small to moderate proportion of students in engineering or engineering technology majors. During preliminary data collection, the makerspace on this campus was a recent addition, which had less than a year of previous operating time. Students were not required to use the makerspace for class projects, so only the ‘No Involvement’ and ‘Voluntary Involvement’ groups were possible here. A total of 205 students took the survey, 58 of which were not in engineering or engineering technology majors.

The survey was initially given to students when they visited the makerspace for the first time. For subsequent collections, participants were asked to complete the survey again at the beginning of each semester if they were still using the makerspace. Final data collection from the spring 2019 semester is in progress. The participants could choose not to have their survey data disclosed as part of the research study, or they could choose not to answer the survey questions. Choosing not to disclose data or participate had no effect on whether the student would be allowed to access the space in the future.

### ***University B***

University B is a regional teaching-focused university in the Mid-Atlantic US; the engineering program, which began in 2008, offers a single Bachelor’s of Science degree with no specific concentrations, and the inaugural class of students graduated in 2014 [8]. Students were required to use makerspace equipment starting in freshman-level courses, so the ‘No Involvement’ group was not possible here.

At this university, the survey was administered to participants during class time. Initial data collection occurred simultaneously for both a sophomore-level engineering design course and a junior-level capstone design course. Final collection at the senior-level is in progress as the students near completion of their capstone project.

### ***University C***

University C is a large, technology-focused research institute in the Southern US [8]. There are multiple makerspaces at this university, with the main one being an openly available student-run space that started in 2009. Students were only required to use makerspace equipment if the specific instructor required it for the course, so all three involvement groups were possible here.

At this university, preliminary data were collected from two courses. First, the survey was given to freshmen in an introductory engineering graphics design (CAD) course at both the beginning and end of the semester. Next, data were collected from a sophomore level creative decisions and design course. Final collection from seniors enrolled in a capstone design course is in progress.

### ***Statistical Analysis***

For comparisons of EDSE score differences, t-tests were used for two group comparisons, and ANOVA analysis for three group comparisons, with Tukey post-hoc comparisons to compare differences between two groups within those three groups. A 90% confidence level was used to determine significant differences between average EDSE scores of various comparison groups. The effect sizes between groups were evaluated using Cohen's  $d$  and described using Cohen's rule of thumb [11].

To analyze the proportion of students voluntarily involved in makerspaces for demographic group comparison, Chi-squared tests with Cramer's  $V$  ( $\phi_c$ ) effect sizes were used for three-group comparisons.  $N-1$  Chi-squared tests with Phi coefficients for association ( $\phi$ ) effect sizes were used for two-group comparisons. Cohen's rule of thumb was also used here to interpret effect sizes [11].

### ***Exclusion Criteria***

Surveys that were incomplete were not included in the sample for analysis. Furthermore, participants from University A that were not enrolled in engineering or engineering technology majors were excluded since data collected from Universities B and C surveyed only engineering and engineering technology majors. Finally, the question regarding anxiety surrounding engineering design tasks acted as a screening check because participants who reported higher confidence, motivation, and expectation of success are expected to report lower anxiety. Therefore, students who reported the same scores for all metrics were excluded from data analysis because it was assumed that they did not fully read the questions and rushed completion of the survey.

In order to ensure accurate representation within the sample data, surveys were removed from the data set if they met any of the above defined aforementioned exclusion criteria. After exclusions, preliminary data analysis used 109 surveys from University A, 140 from University B, and 657 from University C. The figures below show EDSE scores from the surveys at each university as they compare to levels of makerspace involvement among participants.

### **Results**

The results presented herein were summarized from previous work, and only represent the preliminary data analysis from all three universities [8].

## Engineering Design Self-Efficacy Findings

Table 1: Significant EDSE Differences in Demographic Groups

* = superior EDSE score	n	$\bar{x}$	$\sigma^2$	p	d	t	df
<b>University A</b>							
<i>Confidence</i>							
Male*	15	69.37	22.16	0.071	0.51	-1.82	108
Female	94	58.00	24.16				
<i>Anxiety</i>							
URM	45	50.67	33.33	0.066	0.37	1.86	101
non-URM*	58	38.62	31.98				
<b>University B</b>							
<i>Confidence</i>							
Male*	105	86.00	12.60	0.046	0.406	2.01	135
Female	32	80.94	12.01				
<i>Anxiety</i>							
URM*	21	28.57	29.71	0.074	0.427	1.80	133
non-URM	114	41.32	29.82				
<b>University C</b>							
<i>Motivation</i>							
URM*	101	82.57	18.04	0.054	0.21	-1.93	646
non-URM	547	78.5	19.69				
<i>Expectation of Success</i>							
Male*	490	73.55	17.53	0.088	0.16	1.71	646
Female	158	70.76	18.9				
<i>Anxiety</i>							
Male*	490	34.45	27.6	0.006	0.25	-2.77	646
Female	158	41.39	26.72				
1st Gen	114	41.49	28.94	0.021	0.24	-2.31	652
non-1st Gen*	540	34.98	27.04				

Table 1 summarizes all of the significant ( $p < 0.10$ ) differences in EDSE scores among demographic groups at each university and lists statistical data for each. The demographic groups with the higher (or lower for anxiety) average EDSE scores are highlighted. University A showed higher confidence among males than females, and lower anxiety among non-underrepresented minority (non-URM) students. University B showed higher confidence among males as well. However, contrary to University A, University B students of minority status (URM) showed lower anxiety. University C showed higher confidence among URM students, higher expectation among male students, and lower anxiety among males and non-first generation college students.



Figure 1: EDSE vs Makerspace Involvement at University A

At University A, the average EDSE scores (Figure 1) for voluntarily involved students were significantly higher for confidence, motivation, and expectation of success than the no-involvement group (significance at  $\alpha=0.10$ ).

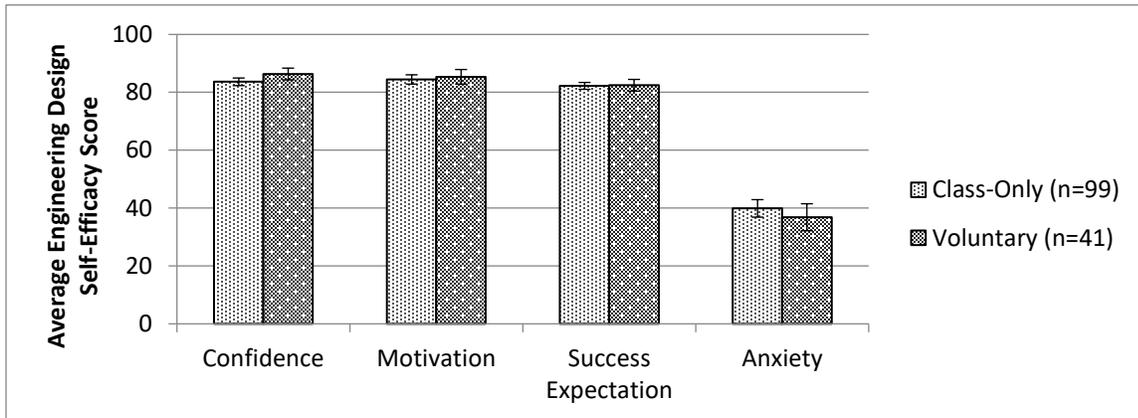


Figure 2: EDSE vs Makerspace Involvement at University B

University B had no significant differences in EDSE scores (Figure 2) between the class-only and voluntary involvement groups. Since University B requires a significant amount of makerspace involvement in its curriculum, the amount of exposure from class-only involvement could be sufficient for increasing design self-efficacy, such that extra voluntary involvement beyond class requirements provides no further improvement.



Figure 3: EDSE vs Makerspace Involvement at University C

The findings from University C agree with University A for the first three metrics (Figure 3) between the voluntary involvement and no involvement groups, for which a Tukey test with significance at  $\alpha=0.05$  was run. Furthermore, voluntarily involved students from University C also reported lower average EDSE scores for anxiety than students with no involvement (significance at  $\alpha=0.05$ ). While this cannot provide sufficient evidence for causation, the existing correlation suggests either: 1) students who become voluntarily involved in makerspaces have improved EDSE, or 2) students with greater EDSE scores are more likely to become voluntarily involved.

### ***Factors Influencing Involvement***

At University A, a significant difference was found in voluntary involvement between men and women from the Chi-squared test, with the proportion of voluntarily involved males being significantly higher at small-to-moderate effect size ( $\chi^2=3.03$ ,  $df=1$ ,  $p=0.08$ ,  $\phi=0.16$ ). University B had no significant differences in voluntary involvement levels for any comparison group. University C showed the same trend between males and females but with a moderate-to-large effect size ( $\chi^2=36.93$ ,  $df=1$ ,  $p<0.001$ ,  $\phi=0.52$ ). No significant differences were found for voluntary involvement level based on minority status or participants' parents' highest education level for these universities.

Figure 4 shows the proportion of students from University C who became voluntarily involved at the end of the freshman-level engineering graphics course, which was categorized based on the 3D printing requirement for the final project assigned by the instructor [12]. The self-print group was required to 3D print their project models by using the makerspace equipment themselves, while the group-print group was required to submit their 3D model file to the instructor to be batch-printed, and the no print group was not required to have 3D printed models at all.

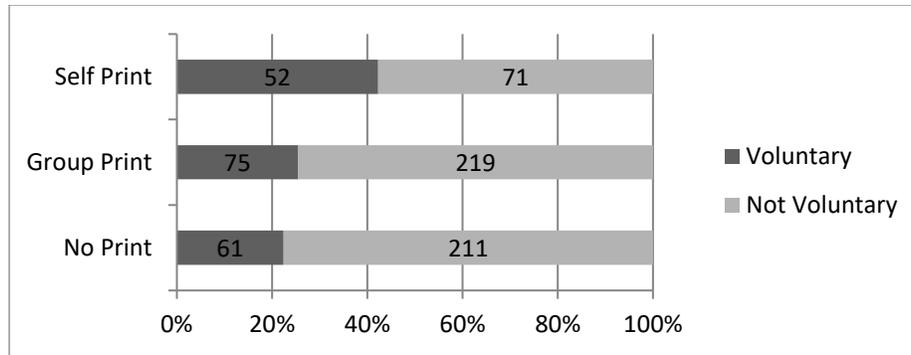


Figure 4: Makerspace Involvement vs. Magnitude of Required Equipment Use for Class Project [12]

The proportion of self-print students who became voluntarily involved was 42.3%, while the group-print and no-print proportions for voluntary involvement were 25.5% and 22.4% respectively. The N-1 Chi-squared test for two-group comparisons described in the previous section was used to determine statistical significance. No significant difference was seen between the group-print and no-print groups. However, the proportion of self-print students who became voluntarily involved was significantly higher than both the group-print ( $\chi^2=11.5$ ,  $N=417$ ,  $df=1$ ,  $p<0.01$ ) and no-print ( $\chi^2=16.3$ ,  $N=395$ ,  $df=1$ ,  $p<0.01$ ) sections.

## Discussion

Demographic trends in makerspace involvement showed a significantly larger proportion of males who became voluntarily involved than females at both University A and C, but no demographic trends at University B. Furthermore, at University C, the results described from Figure 4 showed that a significantly larger proportion of students who were required to use the space became voluntarily involved. This suggests that requiring students to use makerspace equipment independently will have a positive impact on their likelihood to become voluntarily involved in the space. Longitudinally, it is expected to see the proportion of voluntarily involved students to increase due to further exposure to the space throughout the program.

Based on the preliminary results, it is evident that involvement and self-efficacy are positively correlated. Aside from University B, voluntarily involved students had significantly better scores in confidence, motivation, and expectation of success. Since University B requires a great degree of makerspace involvement as part of its curriculum, and no significant differences were seen between the class-only and voluntary groups, it appears that there is a threshold at which the degree of involvement no longer affects self-efficacy scores. This suggests that higher EDSE scores could be seen in students who frequent makerspaces, even if it is only for required course-work. More work must be done to determine the thresholds for how much makerspace use is required in order to observe significant increases in self-efficacy.

Longitudinally, it is expected that EDSE scores will remain relatively the same for students who were highly involved in makerspaces during the preliminary data collection. For students who had no involvement or a small amount of class-only involvement, it is expected that EDSE scores will increase longitudinally, but the increase could be due to either the students' progress through the engineering curriculum at the university or from becoming more involved in makerspaces after the time of preliminary data collection.

## **Conclusion**

This paper presents the current results from the five-year longitudinal study of the impacts of makerspaces on students. The correlations found suggest a positive relationship between makerspace involvement and self-reported EDSE according to the results from Universities A and C. Since the data is only correlational, the current results from this study do not prove that makerspace involvement causes improvements in engineering design self-efficacy.

For men and women at Universities A and C, the proportion of voluntarily involved men is higher than that of women. University B had no significant differences in makerspace involvement between men and women or other demographic groups, but the curriculum at University B demands heavy involvement in the makerspace. This suggests that the extensive amount of makerspace involvement required at University B may effectively remove the barrier to entry experienced by the demographic groups at the other two universities. Another piece of the overall project at University C illustrates approaches to increasing early participation in makerspaces through projects that require the use of the makerspace. When students were required to print parts themselves, a significantly larger proportion became voluntarily involved students in the makerspace as compared to students who did not print their designs or for whom a technician printed one design for the entire group. The findings from all three universities suggest that students required to use makerspace equipment are positively influenced to become voluntarily involved in the makerspace.

## **Future Work**

Future work involves final data collection and longitudinal analysis for EDSE, retention, GPA, and idea generation ability, which are in progress during spring 2019. Final results are expected in summer 2019. Results will be compared longitudinally for each university to draw conclusions about how EDSE and makerspace involvement levels change over time. Data on student GPA and major retention is also being collected for analysis to search for any relationships that exist in those categories with EDSE or makerspace involvement. Additionally, data collection for idea generation in the senior-level capstone course at University C is still in progress. Future work will investigate the impact of makerspace involvement and EDSE on idea generation ability.

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## **References**

- [1] Forest, C. R., Moore, R. A., Fasse, B. B., Linsey, J., Newstetter, W., Ngo, P., & Quintero, C. (2014). The invention studio: A university maker space and culture. *Advances in Engineering Education*, 4(2), 1-32.
- [2] Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavior change *Psychological Review*, 84(2), 191-215.

- [3] Bettinger, E., & Long, T. L. (2005). Help or hinder? Adjunct professors and student outcomes. Ithaca, NY: Cornell University.
- [4] Downing, R. A., Crosby, F. J., & Blake-Beard, S. (2005). The perceived important of developmental relationships on women undergraduates' pursuit of science. *Psychology of Women Quarterly*, 29(4), 419-426.
- [5] Morocz, R., Levy, B., Forest, C., Nagel, R., Newstetter, W., Talley, K., and Linsey, J., "Relating Student Participation in University Maker Spaces to their Engineering Design Self-Efficacy," Proc. American Society for Engineering Education Annual Conference Proceedings 2016.
- [6] Hilton, E. C., Tomko, M., Murphy, A., Nagel, R. L., and Linsey, J., 2018, "Impacts on Design Self-efficacy for Students Choosing to Participate in a University Makerspace," The Fifth International Conference on Design Creativity (ICDC)Bath, UK.
- [7] Wilczynski V., "Academic Maker Spaces and Engineering Design," in 122nd ASEE Annual Conference & Exposition, Seattle, Washington, 2015.
- [8] Hilton, E. C., Talley, K. G., Smith, S. F., Nagel, R. L., and Linsey J., 2019, "Is 'Making' Making a Difference? Investigating Student Makerspace Involvement and Engineering Design Self-Efficacy Through a Multi-Institutional Study," ASME Journal of Mechanical Design, In Review.
- [9] Hilton E. C., Forest C. R., Linsey J., "Slaying Dragons: An Empirical Look at the Impact of Academic Makerspaces," in Proc. of the 2018 International Symposium on Academic Makerspaces (ISAM) Stanford, CA[10] Carberry, A. R., Lee, H. S., and Ohland, M. W., 2010, "Measuring engineering design self-efficacy," *Journal of Engineering Education*, 99(1), pp. 71-79.
- [11] Cohen, J., 1988, "Statistical Power Analysis for the Behavioral Sciences. 2nd edn. Hillsdale, New Jersey: L," Erlbaum.
- [12] Hilton, E. C., Tomko, M. E., Nagel, R. L., Newstetter, W. C., & Linsey, J. S., "Investigating why students choose to become involved in a university makerspace through a mixed-methods study." Proc. *American Society of Engineering Education Annual Conference (ASEE)-DEED Proceedings* 2018.