Innovation, Design, and Self-Efficacy: The Impact of Makerspaces

Roxana Maria Carbonell, University of Texas, Austin

Roxana Carbonell is a current graduate student in mechanical engineering at the University of Texas at Austin. Her primary research interests are prosthetics, additive manufacturing, makerspaces, and engineering education.

Madison E. Andrews, University of Texas, Austin

Madison Andrews is a STEM Education doctoral student and Graduate Research Assistant in the Department of Mechanical Engineering at the University of Texas at Austin. She received her B.S. in Mechanical Engineering from Clemson University in 2017.

Audrey Boklage, University of Texas, Austin

Audrey Boklage is research assistant in the Cockrell School of Engineering at the University of Texas at Austin. She is particularly interested in improving the culture and environment of undergraduate education experience for all students, particularly those from underrepresented groups. Audrey has expertise in qualitative research methods including exploratory case studies and narrative inquiry.

Dr. Maura Borrego, University of Texas, Austin

Maura Borrego is Director of the Center for Engineering Education and Professor of Mechanical Engineering and STEM Education at the University of Texas at Austin. She previously served as a Program Director at the National Science Foundation, on the board of the American Society for Engineering Education, and as an associate dean and director of interdisciplinary graduate programs. Her research awards include U.S. Presidential Early Career Award for Scientists and Engineers (PECASE), a National Science Foundation CAREER award, and two outstanding publication awards from the American Educational Research Association for her journal articles. Dr. Borrego is Deputy Editor for Journal of Engineering Education. All of Dr. Borrego’s degrees are in Materials Science and Engineering. Her M.S. and Ph.D. are from Stanford University, and her B.S. is from University of Wisconsin-Madison.
Abstract

In recent years, makerspaces have become an increasingly common feature in the engineering buildings of academic institutions. Through the creation and continued funding of these spaces, access to rapid prototyping technology has allowed for fast, straightforward project development across the engineering disciplines. While many hypothesize that students’ participation within these facilities has a positive impact on their educational experiences and outcomes, there is little empirical data that describes how and to what extent individuals are impacted by exposure to a makerspace.

In this paper, we seek to understand how the use of a university makerspace in a course project impacts students’ engineering attitudes and skillsets as they relate to the makerspace. Our research team surveyed 172 undergraduate students in 6 unique courses that incorporate a makerspace based project into their curriculum. These courses varied by student year, department, subject matter, and project complexity. Each student was surveyed at the beginning and end of the semester, before and after they had completed a course project in the makerspace.

The survey measured students’ affect towards design, design self-efficacy, technology self-efficacy, innovation orientation, and sense of belonging within the makerspace. Survey items were validated through exploratory and confirmatory factor analysis. Subsequently, paired t-tests were used to analyze if, and how, these metrics changed within individual students over the course of one semester using the makerspace. By surveying this broad pool of students and exploring the ways in which students’ attitudes change after completing a makerspace project, we can better understand how incorporating these assignments into a class impacts students’ affect towards engineering and perception of their engineering efficacy.

Introduction

A Review of Makerspaces

Celebrated as cradles of innovation, creativity, and entrepreneurship, makerspaces are among the most compelling engineering facilities, highly desired by both faculty and students. These spaces, driven by the maker movement and dedicated to the process of making, are becoming increasingly popular as their potential is unveiled.

While makerspaces are a relatively recent development in engineering education, a 2014 survey of 127 highly ranked colleges and universities in the United States found that 40 have documentation of their institution’s makerspace on their website (Barret et al., 2015). Makerspaces and the cultures that surround them have the potential to impact engineering, education, and society by enhancing the relationship between informal and formal learning; changing our methods for teaching, evaluation, and assessment; developing diversity, accessibility, and inclusion; and leading to new technologies and innovations (American Society for Engineering Education [ASEE], 2016).

In addition to having the potential to create these largescale systemic changes, these spaces – and the process of making – have a profound impact on individual students. Makerspaces are often characterized not only by possibilities for design and innovation, but also by unique cultures that
profoundly shape the education of students (Forest et al., 2014). Makerspaces have been shown to increase confidence, creativity, and entrepreneurial thinking (Longo et al., 2017). Making experiences in education also increase practical skills that are key to a comprehensive engineering education (Foster et al., 2015).

These spaces impact student educational experiences by improving the quality of individual projects. Prototyping, an engineering practice that is among the primary functions of these facilities, has been shown to result in better final project outcomes (Forest et al., 2014). Additionally, the prototyping process activates student engineers’ ability to connect their education to real world and industry applications (Kim & Maher, 2008). As a result, these students hone their design skills through the creation of physical projects. This process has been shown to expose design flaws that student engineers would otherwise miss (Forest, 2014). Existing research clearly indicates that the ability to create physical, tangible models is an important element of a robust engineering education.

Prior to the technological advancements and rise of the Do It Yourself (DIY) mentality that typifies makerspaces, students’ ability to experience the making process in their education was sometimes hindered or halted by the steep learning curve that characterizes more traditional machine shops. The addition of rapid prototyping tools has increased accessibility, opening the making process to more students (Forest, 2014). While there is no breakdown of the necessary equipment or specific facilities that compose a makerspace, the majority of engineering departments are adopting rapid prototyping tools, such as additive manufacturing machines (3D printers) and laser cutters (Barrett et al. 2015; Wilczynsky, 2018). Many makerspaces also include hand tools, such as handsaws or wire strippers, that require minimal training and can easily create low resolution prototypes (Wong & Partridge, 2016). These tools give students impressive prototyping capabilities without extensive training or sophisticated craftsmanship.

Purpose

As these spaces become more commonplace, the broad strokes of research and empirical understanding to support makerspaces are coming into view. Engineering departments have a growing understanding of what makerspaces look like, what equipment they typically contain, and what impacts they may have on engineering education. There is also clear evidence that makerspaces and hands on learning experiences have a positive effect on individual students, but our understanding of how makerspaces impact individuals is far from complete (ASEE, 2016).

To further the case for makerspaces, it is paramount that we learn how, and to what extent, student beliefs and engineering skills are affected by completing makerspace-based projects. With this foundation, our research team endeavored to analyze how makerspace usage in a course project impacts students’ attitudes and self-efficacy as they relate to design and technology.

Context

The students we studied would develop their projects in the recently redesigned Texas Inventionworks. This new facility is two floors with over 30,000 square feet of available
workspace. It is brightly lit with floor to ceiling widows that look out onto the atrium of a large, recently constructed, engineering building. As students walk between classes, they can see their peers gathered around tables with whiteboards and watch the nozzles of 3D printers zip back and forth. The space feels inviting and, in that same spirit, it is available to all University of Texas at Austin (UT) undergraduate engineering students, graduate engineering students, and engineering faculty. The space is supervised by a knowledgeable staff and a cohort of undergraduate student workers who provide support to their peers.

More than 30 courses use the makerspace as a component of their curriculum. Our research team found that the space had over 4,000 unique users from August to December of 2018. Texas Inventionworks is used for a diverse range of engineering endeavors and houses a variety of tools to accommodate these projects. There are several rows of desktop additive manufacturing machines, computer driven subtractive processes such as laser cutters and CNCs, a variety of hand tools, stockpiles of electronic components, and soldering stations. Some of the equipment requires special training but, for the most part, it is easily accessible and elaborate prototypes can be made with entry level knowledge of the machines. While the space has no dues or fees, some materials are sold at cost onsite, but the filament for the 3D printers is free to anyone regardless of the nature of their project – personal or academic.

In addition to providing equipment and tooling, the space also serves as a dynamic physical meeting place where students can collaborate on projects of all kinds. Organizations that use the space include Tau Beta Pi, the Society of Women Engineers, and the Society of Automotive Engineers who hold chapter meetings and special events in the makerspace.

**Methodology**

*Instrument Administration and Participants*

To understand the impact that makerspace use has on students, we selected a target population of undergraduate engineering students enrolled in UT courses that incorporate the university’s makerspace into their curriculum. Surveys were administered to students in the fall 2018 semester in a strategic selection of courses that varied by department, student level, and complexity of the course assignments within the facility. Of the six courses in which the survey was administered, three were offered by the Mechanical Engineering Department, one by the Electrical Engineering Department, one by Interdepartmental Engineering Studies, and one by the School of Undergraduate Studies. Four of these courses targeted lower-division students and two targeted upper-division students.

The survey asked participants to respond to a series of Likert-scale, multiple choice, and open-ended questions about their attitudes towards design and technology. The online survey took approximately fifteen minutes to complete and was administered in class during the first weeks of the fall 2018 semester, and again during the last weeks of the fall 2018 semester. A total of 382 participants consented to take the survey. A sample of n=172 was examined, as only participants with complete data on all factors of interest from both the pre- and post- surveys were included in the final analytical sample.

*Instrument Development*
The survey had a total of 14 questions measuring a variety of factors, including: technology self-efficacy, innovation orientation, design self-efficacy, affect towards design, and sense of belonging to the UT makerspace. Students’ technology self-efficacy was measured through four 10-point, Likert scale items that asked students to rate their confidence in their ability to perform a skill at that time (Lucas et al., 2009). Students’ innovation orientation, borrowed from the Young Entrepreneurs Survey, was measured through six 5-point, Likert scale items that asked students to rate the extent to which they partook in a series of innovative behaviors (Jin et al., 2014). Design, indicated by seven 5-point, Likert scale items, measured students’ affect towards creative elements of engineering professional practice (Patrick et al., 2017).

Students were asked to rate their confidence in their ability to perform a series of tasks in order to measure their design self-efficacy. For this factor, the research team followed the item generation, refinement and instrument validation procedure required for new survey measures. The four, 5-point Likert scale items for this factor were selected from the items used to measure students’ affect for design. The wording for each item was matched between factors, but the design self-efficacy items were rooted to a question stem that asked students to evaluate their ability rather than their interest in each task. Confirmatory and exploratory factor analyses were then conducted to validate this theorized construct.

Students’ sense of belonging was measured through the adaptation of a previously validated scale that analyzed students’ perceptions of the campus climate and its impact on their sense of belonging (Hurtado & Carter, 1997). The original scale asked students to evaluate their sense of belonging to their institution; this survey modified the item wording to ask students about the makerspace rather than campus. For instance, instead of being asked to what extent students saw themselves as part of the campus community, students were asked to rate the extent to which they saw themselves as a part of the Texas Inventionworks. An exploratory factor analysis was then conducted to validate this construct.

Construct reliability for the five factors of interest was 0.87 for technology self-efficacy, 0.83 for innovation orientation, 0.85 for design, 0.83 for design self-efficacy and 0.95 for belonging. Factors are listed by item in the appendix.

Findings

Table 1 provides an overview of the analytical sample. All data analyses were conducted using StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP. From the initial pool of n=372, responses were removed by listwise deletion if they were missing values for any of the five factors of interest. The sample was then further narrowed to only include students who had complete responses for both all factors of the pre- and post- survey. These students were matched using unique UT student ID numbers. This left an analytical sample of n=172. The majority of these students were lowerclassmen and about 90% of students were enrolled in the college of engineering. Table 1 shows a breakdown by major.

Table 1: Overview of analytical sample

<table>
<thead>
<tr>
<th>College</th>
<th>Responses</th>
<th>%</th>
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<tbody>
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</table>
Exploratory and Confirmatory Factor Analyses
An exploratory factor analysis was conducted on a subsample (n=86) on the new design self-efficacy items. Of the 4 items hypothesized to characterize design self-efficacy, all items were retained, but we found they load onto two separate factors. The latter two items relate to a construct we referred to as innovation self-efficacy. An exploratory factor analysis (n=86) was then conducted on the students’ sense of belonging to the makerspace. This analysis showed that all three items loaded onto the same factor.

Subsequently, confirmatory factor analyses were conducted for the new design self-efficacy, innovation self-efficacy and sense of belonging factors. First, the 4 theorized design self-efficacy items were examined by conducting structural equation modeling on a holdout subsample (n=86). Results indicated that the items loaded onto two distinct factors, henceforth referred to as design self-efficacy and innovation self-efficacy. The model fit indices indicated a perfect fit (RMSEA = 0.000, CFI = 1.000, TFI = 1.054, and X²= 0.145; df= 1; p= 0.70). The two factors were then examined for internal consistency: the new design self-efficacy and innovation self-efficacy have Cronbach’s alpha of 0.77 and 0.69, respectively. Then, an additional confirmatory factor analysis was conducted on the three sense of belonging items, which indicated a perfect fit (RMSEA = 0.000, CFI = 1.000, TFI = 1.000, and X²= 0.00; df= 0; p=undefined). The factor has a Cronbach’s alpha of 0.96.

Longitudinal Analysis
Matched t-tests were conducted on the sample of n=172 for each of the five factors of interest. Over a one semester period, each of the five factors showed statistically significant increases within persons. A Bonferroni correction of p<0.008 was used to account for the number of t-tests conducted on the sample. Table 2 details the results of the matched t-tests, as well as the effect size for each factor.
Table 2: Matched t-test results and effect size for each factor

<table>
<thead>
<tr>
<th>Factor</th>
<th>α</th>
<th>Scale Range</th>
<th>Pre</th>
<th>Post</th>
<th>P-Value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Self-Efficacy</td>
<td>0.87</td>
<td>0-10</td>
<td>6.07</td>
<td>7.39</td>
<td>0.000</td>
<td>0.73</td>
</tr>
<tr>
<td>Innovation Orientation</td>
<td>0.83</td>
<td>1-5</td>
<td>3.34</td>
<td>3.69</td>
<td>0.000</td>
<td>0.46</td>
</tr>
<tr>
<td>Affect Towards Design</td>
<td>0.85</td>
<td>1-5</td>
<td>4.21</td>
<td>4.39</td>
<td>0.006</td>
<td>0.28</td>
</tr>
<tr>
<td>Design Self-Efficacy</td>
<td>0.82</td>
<td>1-5</td>
<td>3.31</td>
<td>4.02</td>
<td>0.000</td>
<td>0.81</td>
</tr>
<tr>
<td>Innovation Self-Efficacy</td>
<td>0.77</td>
<td>1-5</td>
<td>3.63</td>
<td>3.94</td>
<td>0.005</td>
<td>0.38</td>
</tr>
<tr>
<td>Belonging to Makerspace</td>
<td>0.96</td>
<td>0-10</td>
<td>4.53</td>
<td>6.05</td>
<td>0.000</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Conclusions

In a short period of time, makerspace use impacts students’ affect towards engineering and perception of their own engineering efficacy. As makerspaces become standard facilities in engineering institutions, it is important to understand what impact these spaces have on the individuals who use them. Prior research has suggested that makerspaces are catalysts to innovation, confidence, and design (Longo et al., 2017). In addition to this, we have further broken-down what areas are impacted in students who complete a makerspace project as part of their coursework. By surveying students involved in makerspace projects, we found that, over the course of a four-month semester, there were significant changes within individuals who took part in a course that made use of the makerspace for a class project. Technology self-efficacy, innovation orientation, affect towards design, design self-efficacy, and belonging to the makerspace were all positively and significantly impacted within individuals who completed projects in the makerspace. Our research team has identified these skills as necessary to engineering education, and our analysis shows that makerspace projects can significantly impact proficiency in these areas. This suggests benefits of makerspace use throughout the undergraduate experience and across the engineering disciplines. Such large effect sizes over this short period of time are shocking and imply a great deal of potential for student development through the incorporation the makerspace into engineering curriculum.

Of particular interest is the impact on belonging. Students’ sense of belonging to the makerspace increased by over half a standard deviation during the course of one semester. In the past, it has been suggested that the face of the maker movement may alienate specific groups of students from the makerspace (Vossoughi et al., 2014). While our team is interested in further breaking down our survey results demographically, by class, and by major to analyze any trends, the substantial growth in a sense of belonging suggests that having a course that requires the makerspace as a part of the curriculum increases a sense of belonging in students as a whole. A prior study found that students who were required to use the makerspace in a class were significantly more likely to become involved in the makerspace later on in their education (Hilton et al., 2008). This sense of belonging is a potential component of this trend. It is our hope that a sense of belonging to Texas Inventionworks will increase individual students’ use of the space throughout their academic career. After completing course projects, many students may grow to feel a sense of belonging in the makerspace and, as Hilton and colleagues suggest, seek further involvement in the makerspace community.
Additionally, we found that engineering skills and perception of those skills were improved both in terms of technology self-efficacy and design self-efficacy. While prior work has shown that confidence on the whole is improved by makerspace use, we now see that confidence in design and technological capability specifically are significantly impacted (Longo et al., 2017). Growth in both softer engineering skills, such as creativity, and more technical engineering skills, such as experimental design indicates the multifaceted impact that makerspaces have on the educational experience. In both cases our team is most impressed by the speed at which these attitudes dramatically shift. These increases reinforce Foster and colleagues’ (2015) findings that makerspace use increases numerous practical skills and add that these capabilities can be significantly changed over the course of three months.

Our survey findings also reiterated past findings that makerspaces foster an interest in design and innovation (Longo et al., 2017). These skills are important elements of problem solving as students progress as engineers through academia and industry, being able to improve these metrics within a semester shows the great potential of makerspaces (Foster et al., 2015).

Limitations and Future Work
One of our most limiting factors was our small sample size although 383 students consented to take the survey, we were only able to use data from the 172 who had completely filled out all the data from the pre and post surveys. As these surveys become more standard practice, and with the increase in courses using the makerspace, we hope to sample a larger segment of the target population in future studies.

After such a brief period, it is exciting to see any facets of student affect and engineering capability change; however, it is likely that additional surveys, after further makerspace use, will tell us more about the significance of these changes and potentially reveal more factors of engineering education that benefit from makerspace projects. As we continue to survey students in makerspaces, we hypothesize that our results will adjust to give us a richer view of the impact makerspace use has on individual’s education throughout their undergraduate studies.

References


doi:10.1080/00048623.2016.1228163
# Appendix A: Factors by Item

<table>
<thead>
<tr>
<th>Factor</th>
<th>Question Stem</th>
<th>Range</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Self-Efficacy</td>
<td>Indicate how confident are you that you could perform that skill now</td>
<td>0-10</td>
<td>Convert a useful scientific advance into a practical application&lt;br&gt;Develop your own original hypothesis and a research plan to test it&lt;br&gt;Grasp the concept and limits of a technology well enough to see the best ways to use it&lt;br&gt;Design and build something new that performs very close to your design specifications</td>
</tr>
<tr>
<td>Innovation Orientation</td>
<td>Rate the extent to which you partake in the following behaviors</td>
<td>1-5</td>
<td>Search out new technologies, processes, techniques, and/or product ideas&lt;br&gt;Generate creative ideas&lt;br&gt;Promote and champion ideas to others&lt;br&gt;Investigate and secure funds needed to implement new ideas&lt;br&gt;Develop adequate plans and schedules for the implementation of new ideas&lt;br&gt;Are innovative</td>
</tr>
<tr>
<td>Affect towards Design</td>
<td>To what extent would you enjoy a profession or career that usually requires each of the following?</td>
<td>1-5</td>
<td>Identifying technical solutions that are as simple as possible&lt;br&gt;Designing and conducting experiments to test an idea&lt;br&gt;Improving a design to make it more efficient (faster, better, cheaper)&lt;br&gt;Searching for innovative ways to do things&lt;br&gt;Using technology to solve environmental problems&lt;br&gt;Creating prototypes to test an idea&lt;br&gt;Designing a system, a part/component of a system, or a process based on realistic constraints</td>
</tr>
<tr>
<td>Design Self-Efficacy</td>
<td>How confident are you in your ability to do the following?</td>
<td>1-5</td>
<td>Designing a system, a part/component of a system, or a process based on realistic constraints&lt;br&gt;Creating prototypes to test an idea&lt;br&gt;Searching for innovative ways to do things&lt;br&gt;Improving a design to make it more efficient (faster, better, cheaper)</td>
</tr>
<tr>
<td>Belonging to Texas Inventionworks</td>
<td>To what extent do you disagree or agree with the following statements?</td>
<td>0-10</td>
<td>I see myself as a part of Texas Inventionworks&lt;br&gt;I feel that I am a member of Texas Inventionworks&lt;br&gt;I feel a sense of belonging to Texas Inventionworks</td>
</tr>
</tbody>
</table>
Appendix B: Item Loadings

Table 3: EFA Item Loadings for Efficacy Factors

<table>
<thead>
<tr>
<th>Construct</th>
<th>Item</th>
<th>Factor Loading</th>
<th>Uniqueness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Self-Efficacy (α=0.77)</td>
<td>Designing a system, a part/component of a system, or a process based on realistic constraints</td>
<td>0.76</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Creating prototypes to test an idea</td>
<td>0.75</td>
<td>0.28</td>
</tr>
<tr>
<td>Innovation Self-Efficacy (α=0.69)</td>
<td>Searching for innovative ways to do things</td>
<td>0.73</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Improving a design to make it more efficient (faster, better, cheaper)</td>
<td>0.70</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Table 4: EFA Item Loadings for Sense of Belonging

<table>
<thead>
<tr>
<th>Construct</th>
<th>Item</th>
<th>Factor Loading</th>
<th>Uniqueness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sense of Belonging (α=0.96)</td>
<td>I see myself as a part of Texas Inventionworks</td>
<td>0.90</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>I feel that I am a member of Texas Inventionworks</td>
<td>0.95</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>I feel a sense of belonging to Texas Inventionworks</td>
<td>0.96</td>
<td>0.07</td>
</tr>
</tbody>
</table>