Relating Student Participation in University Maker Spaces to their Engineering Design Self-Efficacy

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Abstract

For new engineers to succeed in today’s competitive global economy, engineering education has to foster innovation and creativity in students. The rapid growth of university maker spaces across the country has created an opportunity to combine textbook with hands-on engineering education. With their culture of collaboration, multidisciplinary acceptance, and hands-on learning, we believe that these spaces provide the perfect environment for students to develop their design self-efficacy, ability to innovate, and creativity in design.

This paper focuses on characterizing university maker space’s users and non-users in terms of their engineering design self-efficacy. The results presented in this paper are part of a longitudinal study and will be used to measure the impact of these unique learning environments on the students’ engineering design self-efficacy over time. To have a clear definition between maker space users and non-users, a survey was developed and implemented to capture a student’s level of participation. Concurrently, a survey instrument designed by Carberry et al. (2010) was used to gather the student’s engineering design self-efficacy scores. Both surveys were used to collect data from a freshman level engineering design course during the spring and fall semesters of 2015. The participants were classified in two groups according to their level of participation, and were compared in terms of their engineering design self-efficacy scores. The results from this comparison show that the students with higher participation are more motivated and less anxious to perform engineering design related tasks.

Based on these results, we theorize that academic institutions and introductory engineering design courses could play a key role in stimulating students to participate in university maker spaces. Since anxiety to perform engineering design tasks could be considered a significant barrier preventing students from participating, instructors should highlight the non-threatening and collaborative nature of maker spaces. We postulate that as this barrier is reduced, more students will begin to participate, which ultimately will result in higher number of students taking advantage of maker spaces as hands-on learning environments and gaining design experience.

Introduction

In an effort to educate engineers capable of solving the most challenging problems and excel in an increasingly competitive job market, it is important that academic institutions make an effort to nurture creativity and innovation in their students.1 Since university maker spaces create a unique learning environment where students can freely design, build, and test their idea, they could play a key role in helping academic institutions develop engineers with these traits. As a complementary part of the engineering curriculum, university maker spaces have the opportunity to foster creativity through implementation of open environments that promote designing, building, and collaborating outside of the classroom. Due to the potential, but not documented educational benefits associated with maker spaces, many academic institutions have developed or are in the process of establishing their own university maker spaces.2-5 This movement has
sparked the interest of scholars and other enthusiasts to study the process for developing an effective university maker space.\textsuperscript{6-10} To accurately measure the impact of effective maker spaces in academic institutions, it is important to understand the effects this new environment has on students in terms of metrics like GPA, engagement, self-efficacy, idea generation, and retention.

The data and results presented in this paper form part of a multi-university, four-year longitudinal study that began in Fall of 2014.\textsuperscript{11} This paper will focus on defining users in terms of their participation level as well as identifying the relationship between levels of participation and the student’s engineering design self-efficacy. These findings will be used to further support the motivation for measuring the impact of university maker spaces on the student population and engineering education as well as provide the foundational basis for comparison studies between the different universities participating in this study.

Background

The maker movement was born as the DIY culture got access to affordable digital design software and desktop fabrication tools. The movement gave rise to a community of practice that was significantly different from the older tinkerer and hobby communities. Defined as the maker community, this fast growing group has been characterized by the use of computer software to design products and digital prototypes, and the sharing of ideas, designs, products, and processes physically and digitally.\textsuperscript{12} Maker spaces are the locations where the members of the maker community have access to the tools and workspaces necessary to design, build, prototype, collaborate, and share their work.\textsuperscript{13} Maker spaces are non-traditional machine shops with a focus on rapid prototyping (e.g., 3D printers and laser cutters) and other more typical manufacturing equipment (e.g., lathes, mills, and hand tools).\textsuperscript{14} In addition, these spaces are known for fostering a culture of collaboration, openness, and hands-on learning. Due to the perceived educational benefits associated with maker spaces and the promising future of the maker movement in education,\textsuperscript{3,4,6,10,15,16} the development of these environments has rapidly gained commitment from many academic institutions\textsuperscript{2} and other learning environments (e.g., libraries and museums) around the world.\textsuperscript{13} Figure 1 shows one example of a well-developed university maker space developed at the Georgia Institute of Technology.

\textbf{Figure 1: Well developed maker space at Georgia Tech}
Maker spaces have been identified as the community of practice for makers. The individual’s regular participation in the activities that are considered important by the community helps them identify themselves as part of it. For these users, maker spaces foster a culture of collaboration. These users often come from different disciplines and are united by their common interest in making. These users learn from each other informally through constructionism, where failing is considered a motivator and learning mechanism. Successful maker spaces adapt to the user’s interests, and users are encouraged to drive their own learning. For these users, maker spaces provide an environment for learning, teaching, mentoring, and advising; designing, building, and fixing; collaborating; and participating.

In recent years, there has been growing interest in understanding the impact of maker spaces in education and the best practices for developing new maker spaces. In particular, a reoccurring topic of discussion in engineering education revolves around the need to increase retention and improve recruitment of students, especially women, minorities, and first generations, into engineering related fields. While the difficulty of the engineering curriculum and poor teaching have been recognized as factors influencing attrition, other issues like the lack of belonging in engineering have a great impact on the decision to leave. In other studies, the lack of belonging is identified as one of the main obstacles for women and minorities to persist in engineering related fields. In these studies, lower involvement or participation in college and male-oriented curricula are thought to be causes for the lack of belonging. Due to the open and collaborative nature of university maker spaces, they could help individuals to become more involved at their college and increase their feeling of belonging.

Further, university maker spaces have the potential to assist engineering education in nurturing the student’s self-efficacy and other valuable qualities outside of the classroom. Developing students to have strong self-efficacy, or the confidence an individual has in his or her ability to perform a task, can be valuable in engineering and science related fields for multiple reasons. A study by Marra et al. showed that the lack of self-efficacy negatively affected the student’s feeling of belonging in engineering. By strengthening the student’s confidence in their engineering abilities it is possible to enhance their feeling of belonging in the field. Bandura argues that through the development of strong self-efficacy, individuals can persevere even when facing adversity and failure. Other studies have shown a positive relation between student self-efficacy and their academic performance and persistence. Due to the challenging nature of engineering, it can be argued that confident students are more likely to persevere in their field regardless of the difficulty.

Bandura identifies three characteristics that can positively influence students self-efficacy: 1) observation of others successfully performing a task, 2) social persuasion due to the culture of the space, and 3) repetition of tasks with positive reinforcing results. Observing others successfully perform a task will have a strong positive influence on the observer’s self-efficacy. Positive vicarious experiences will generate the feeling and expectation that, through enough effort, the observer can also be successful. Since a part of the learning process in university maker spaces is through vicarious experiences, there is an opportunity for these environments to positive influence the user’s confidence. As users gain experience performing a task, they become teachers or role models for other individuals trying to work on the same type of tasks.
Similarly, university maker spaces could have positive impact on the user’s self-efficacy through social persuasion. According to Bandura,\textsuperscript{25} social persuasion is the positive or negative influence that others can have on an individual’s self-efficacy. Through the culture of collaboration and the previously mentioned student to teacher mechanic,\textsuperscript{25} maker spaces could take advantage of social persuasion to reduce anxiety and strengthen self-efficacy. Through their failure-positive learning environment,\textsuperscript{16} university maker spaces could also have a positive effect on self-efficacy. In the maker culture, failure is considered a learning mechanism.\textsuperscript{10} Through failure, individuals gain the experience and knowledge to successfully achieve the desired results. According to Bandura,\textsuperscript{25} being capable of performing a task successfully and repeatedly will have a positive impact on self-efficacy, while failing to perform the task multiple times will have a negative impact. Bandura\textsuperscript{25} mentions, however, that as individuals gain experience in a situation where they overcome failure through enough effort, their persistence when facing adversity becomes stronger.\textsuperscript{25} By reducing the negative connotation of failure as part of the learning process, university maker spaces can help individuals to keep working on a task even when facing an obstacle. This will have a positive impact on the individual’s self-efficacy by helping the individual persevere and achieves the desired results.

**Survey Instruments**

Two survey instruments were used in this study: 1) an instrument designed and validated by Carberry et al.\textsuperscript{28} was implemented to measure the participant’s engineering design self-efficacy and 2) an instrument designed and developed by the research team was implemented to measure levels of student involvement in maker spaces. The following two subsections discuss these instruments.

**Engineering Design Self-efficacy**

The engineering design self-efficacy instrument designed and developed by Carberry et al.\textsuperscript{28} measures the respondent’s confidence to perform engineering design tasks, and it requires the participant to rate themselves in four self-concepts (self-efficacy or self-confidence, motivation, expectancy of success, and anxiety). Each one of the four self-concepts is composed of nine identical items (conduct engineering design, identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, evaluate and test a design, communicate a design, and redesign). The first item from each self-concept was used to calculate the engineering design (ED) score, and the subsequent eight items were used to calculate the engineering design process (EDP) score. The ED score is described by Carberry et al.\textsuperscript{28} as the participant’s confidence, motivation, expectancy of success and anxiety when “conducting engineering design,”\textsuperscript{28} while the EDP represents the participant’s self-conception in different types of engineering design tasks. According to Carberry et al.\textsuperscript{28} tasks associated with the EDP were implemented in the survey instrument to capture the overall engineering design process, and when averaged, they have to correlate to the participant’s ED score.

The data gathered using the engineering design self-efficacy instrument is used to compare the high and low participation populations.

**Student Maker Space Involvement**
The student maker space involvement was developed to measure three aspects of involvement: exposure, involvement, and participation, and the survey is divided into three corresponding sections. The exposure section was used to quickly determine if the participant has ever used the university maker space, while the involvement section mainly focused on measuring the frequency of use and the amount of time participants were spending while using the university maker space. The participation section measures the type and purpose of a student’s participation in a maker space.

The survey went through three iterations during the first two semesters of data collection. Due to the variations in the involvement questions from semester to semester, this paper will focus on the relation between levels of participation and engineering design self-efficacy. To separate students based on their level of participation, a criteria for participation had to be defined. For the remainder of this paper, low participation students are defined as the students that have never used a university maker space, while high participation students are defined as having the following two characteristics: 1) they have used the university maker space for multiple types of activities, and 2) the purpose of their participation is not limited to class related projects. Participating in multiple types of meaningful activities is important for students to become part of the community of practice. The second requirement was included to differentiate the students that self-select to use the maker space to those that are instructed to use it, since many courses at this university require the use of the maker space as part of the learning objectives.

**Data Collection**

To better understand the impact of university maker spaces in engineering education, there is a need to track students as they progress through their college career. Data was collected from three courses that have an emphasis on engineering design and promote the use of university maker spaces as part of the curriculum: Intro to Engineering Graphics, Creative Decisions and Design, and Capstone Design. These courses are tailored to students from the freshmen, sophomore, and senior year, respectively. Since the courses cannot be taken simultaneously, they ensure that we can track the same students throughout their undergraduate education. The methodology for collecting the data will change when the approaching junior year as there are no engineering design courses that can be taken only by juniors. Therefore, participants will have to be tracked via email.

The data was collected from the freshman level course (Intro to Engineering Graphics) at the end of the spring and fall semesters in 2015. This allowed us to capture the group of students that take the class during their first fall semester and those that wait until spring to take it. Between both courses, data was collected from a total of 518 participants, 146 participants in spring of 2015, and 372 in fall of 2015. The sample size will ensure that the results are representative for the entire population of freshmen.

One of the main concerns of the longitudinal study is to gather diverse data in terms of gender, race, and ethnicity. Table 1 shows the population distribution in terms of the participant’s self-reported demographics for the freshman level course.
Table 1: Participant responses to the questions about demography in the freshmen level course

<table>
<thead>
<tr>
<th>Survey Questions</th>
<th>Number of Participants</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spring 2015</td>
<td>Fall 2015</td>
<td>Total</td>
</tr>
<tr>
<td>What is your gender?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td>108</td>
<td>258</td>
<td>366</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td>25</td>
<td>76</td>
<td>101</td>
</tr>
<tr>
<td>What is your race/ethnicity?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White/Caucasian</td>
<td></td>
<td>81</td>
<td>234</td>
<td>315</td>
</tr>
<tr>
<td>Black or African American</td>
<td></td>
<td>6</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>American Indian or Alaskan Native</td>
<td></td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific Islander</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Middle Eastern</td>
<td></td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Asian</td>
<td></td>
<td>32</td>
<td>90</td>
<td>92</td>
</tr>
<tr>
<td>Prefer not to disclose</td>
<td></td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Do you consider yourself to be of Hispanic, Latino or Spanish origin?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>119</td>
<td>297</td>
<td>416</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td>8</td>
<td>35</td>
<td>43</td>
</tr>
<tr>
<td>Prefer not to disclose</td>
<td></td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

There were several reasons for excluding participants from the data analysis and the reported results. If participants failed to complete all components of the design self-efficacy questionnaire, their data was not analyzed. Participants were also excluded if they answered every item of the instrument with the same score, disregarding the expected flip when reporting their anxiety to perform engineering design. This criterion was included to reject the data from the participants that tried to finish the survey as fast as possible without reading the actual questions. For both freshman level courses, a total of 20 participants were excluded from the final results.

Data Analysis & Results

As previously stated, the engineering design self-efficacy instrument is divided into four areas: self-confidence (CONF), motivation (MOT), expectancy of success (SUCC), and anxiety (ANX). First, a Pearson Correlation between ED and EDP scores was calculated for the four self-concepts as a validation mechanism to ensure the correct behavior of the instrument. The results from the Pearson Correlation test show high correlation between the ED and EDP scores for both semesters and the correlation values can be seen in Table 2.

Table 2: Pearson Correlation between ED and EDP scores for the two freshman courses.

** Correlations are significant at the 0.01 level.

<table>
<thead>
<tr>
<th>Courses</th>
<th>N</th>
<th>CONF</th>
<th>MOT</th>
<th>SUCC</th>
<th>ANX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2015</td>
<td>138</td>
<td>.83**</td>
<td>.83**</td>
<td>.83**</td>
<td>.86**</td>
</tr>
<tr>
<td>Fall 2015</td>
<td>356</td>
<td>.84**</td>
<td>.80**</td>
<td>.88**</td>
<td>.88**</td>
</tr>
</tbody>
</table>
Comparison between Spring and Fall Semester Sample Populations

First we wanted to determine if there were any differences between the spring and fall participants. This was done by comparing them in terms of the four engineering design self-concepts. The score distribution for both groups was found to be non-normal and equivariant. In terms of ED scores (Figure 2), only the difference in confidence was found to be statistically significant (Independent Samples T-Test, $t=-2.89$, df= 492, $p=0.004$) (Mann-Whitney U, $U=20271$, $p=0.002$). The results from the EDP scores show the same trend as the ED scores. Only the difference in confidence was found to be statistically significant (Independent Samples T-Test, $t=-2.93$, df= 492, $p=0.004$) (Mann-Whitney U, $U=19919$, $p=0.001$).

![Figure 2: Comparison between spring and fall semesters in terms of ED Scores for the freshman level course](image)

Comparison between High and Low Participation for the Combined Population

Since only the confidence score was found to be different, we combined the sample populations from both semesters. We then grouped the students in terms of participation levels, and we compared their engineering design self-efficacy scores. The data was found to be not normal, and mostly equivariant. The results showed that there was statistical significant difference between the high and low participation groups in two self-concepts for the ED scores (Figure 3): motivation (Mann-Whitney U, $U=13010$, $p=0.002$), and anxiety (Independent Samples T-Test, $t=3.29$, df= 388, $p<0.001$) (Mann-Whitney U, $U=12636$, $p<0.001$). The result from the EDP scores show the same trend as in the ED scores: motivation (Independent Samples T-Test, $t=-2.92$, df= 388, $p=0.004$) (Mann-Whitney U, $U=13271$, $p=0.004$), and anxiety (Independent Samples T-Test, $t=2.06$, df= 388, $p=0.04$) (Mann-Whitney U, $U=13804$, $p=0.02$).
Identifying Differences between the Two Semesters

To identify the reason for the semester differences we compared the high participation students from spring semester to the high participation group from fall. Both the Independent Samples T-Test and the Mann-Whitney U revealed that there was no statistically significant difference for any of the four self-concepts. Figure 4 shows the ED scores for the high participation groups in spring and fall.

On the other hand, when we compared the low participation groups from spring and fall semester we discovered that there was a significant difference between the two. Statistical significant difference between the semesters was found in two self-concepts for the ED scores (Figure 4): confidence (Independent Samples T-Test, t = -2.84, df= 268, p=0.005) (Mann-Whitney U, U=4599, p=0.002), and motivation (Independent Samples T-Test, t = -1.96, df= 268, p=0.05) (Mann-Whitney U, U=4826, p=0.007). The results from the EDP scores show the same trend as in the ED scores, but only the difference in confidence was found to be statistically significant (Independent Samples T-Test, t = -2.35, df= 268, p=0.02) (Mann-Whitney U, U=4717, p=0.004).


Discussion

The results presented in this paper show a positive correlation between levels of participation in university maker spaces during freshman year and two engineering design self-concepts. Students that participate in university maker spaces tend to be more motivated and less anxious about performing engineering design tasks. This result suggests that anxiety might be a significant barrier for students to start participating in university maker spaces. Finding approaches to reduce student anxiety surrounding design activities may also lead to greater participation in maker spaces where students have the opportunity to build knowledge and skills.

We also see that students who are scored as high performers have a higher motivation and a lower level of anxiety about using the maker space. This result, while not surprising, provides an indicator that perhaps those students with a natural inclination to use the space have a propensity to seek out opportunities to engage in the maker space. So again, the question becomes, how can we reduce the anxiety surrounding design activities requiring the maker space?

Due to the trends shown in Figure 4, it can be argued that the low participation students in spring and fall semesters might come from two distinct populations. We believe that during the fall semester, highly confident freshman students have not had the opportunity to participate in the university maker space. This theory can be supported through the results seen in Figure 5. This graph shows that there is a higher percentage of high participation students and a lower percentage of low participation students in the spring semester when compared to the fall semester. Throughout the spring semester, highly confident students will have more opportunities to participate in university maker space related activities. By the end of spring semester, originally low participation students will be considered to be part of the high participation group. The migration from low to high participation might be the cause of the differences between low participation group from spring and fall. This also indicates that there are existing processes in place that help students make this transition from low participator to high participator. Additional studies will need to focus on the learning in the wild that is occurring to help students with this transition.

![Figure 5: Percentage of high and low participation students in both of the two freshman level courses](image-url)
The current results are only correlation at this point and do not show causality, but the longitudinal results should be able to start to discern if students with more motivation and less anxiety about design tend to join maker spaces. These two factors in combination could indicate that university maker spaces must be very easy for students to engage with and minimize many barriers in order to be successful. If only the students with very high levels of motivation to do design related activity participate, they may leave these spaces under-utilized.

Future Work

This paper correlates participation in university maker spaces to the individual’s engineering design self-efficacy. In future papers we will also take into consideration involvement as a factor to differentiate between university maker space users and non-users. We believe that analyzing the data in terms of both involvement and participation will allow us to create a clearer differentiation between users and non-users. We will take advantage of multivariate analysis to determine which questions or set of questions will have a stronger effect on engineering design self-efficacy and other metrics. Furthermore, future studies will analyze the relationship between involvement and participation, and the impact they have on GPA, innovation self-efficacy, idea generation ability, and retention.

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