The Engineering Education Maker Identity Project: A Look at the First Year

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Abstract

The LBJ Institute for STEM Education & Research at Texas State University launched a three-year research study to examine how university Maker Spaces might affect student identity formation and self-efficacy, and how these experiences can be leveraged to serve as a potential pathway to engineering. The primary experimental work for this research aims to: 1) discover key concepts and principles that particularly enable a more diverse group of students to leverage creativity and innovation toward success in engineering careers; 2) discover specific learning models that involve both STEM university students and pre-service teachers in order to develop teamwork, self-efficacy, communication, and identity formation in the Maker environment; 3) pilot instruments to measure the impact of such programs on students' self-efficacy, communication, and identity formation and 4) understand to what extent students who use the maker space for a class project become regular users of the space. This paper reports on the progress and findings from the first year of implementation. Maker Space user log in data will be analyzed as will preliminary results of student surveys. Further, the paper will describe the integration of making-based projects into engineering design and educational technology courses.

Introduction

Makerspaces are a recent addition to the list of what Blikstein refers to as that "new set of skills and intellectual activities that are crucial for work, conviviality, and citizenship and that often democratizes tasks and skills which were previously accessible only to experts" [1]. Of late, the makerspaces concept, which originated in the do-it-yourself community (DIY), has received the attention of universities, schools and public libraries as a means of facilitating learning, especially in STEM disciplines. However, the effect of makerspaces on student learning in STEM and STEM Education has not been thoroughly researched. Closely related to the application of makerspaces in engineering education is the notion that engineering design is in itself an educational pedagogy. Resnick and Silverman suggest that the "best learning experiences come when learners are actively engaged in designing and creating things, especially things that are meaningful to them or others around them" [2]. However, engineering design, a major part of which is rooted in engineering sciences, is almost always a highly constrained, analytical activity. This aspect of design pedagogy, in addition to disenfranchising several types of learners, also does not facilitate creativity and inventiveness (which abilities are fostered by exposure to "shop work"). Some researchers [3] have suggested that design, as a mechanism for learning, is accessible to many types of learners. The Maker Faire report [4] describes making as not only personally motivating and socially engaging, but as accessible to diverse audiences. Makerspaces encourage safe experimentation where learners make mistakes but still retain their confidence and identity to pursue their interests. In other words, the organizers of makerspaces value the prior life experiences of learners.

Research in Making and Engineering Design as Pedagogy

There is a growing national recognition of the maker movement's potential to transform how and what people learn in STEM and arts disciplines [5]. Many researchers see in "making" the prospects for expanding participation in STEM fields and in STEM workforce development by leveraging the strengths of interest-driven, multi-disciplinary STEM learning communities. These efforts generally engage high school and university students in engineering and design projects.

A close relationship exists between the engineering design process and making. The relationship between making, design and learning in engineering is strong and historic. At the very root of the practice of engineering are the iterative processes of design, test, respond to feedback and redesign [6]. Implicit in the iterative process is the inclusion of making and tinkering processes. Without these processes, designs cannot transform into products and systems and without products and systems there can be no testing. However, engineering's strong ties to making and tinkering which dominated the discipline during the first half of the 20th century was undermined by the dominance of engineering science that is so essential to design in the age of Apollo. This resulted in a significant push towards analysis and mathematics, and away from traditional "shop work". The 'professional engineer' of the first half of the 20th century was replaced by the 'scientific engineer' of the second half [1]. Over time, this shift resulted in the removal of the engineering design experience (and the concomitant processes of making and tinkering) from not only college curriculum, but also from K-12 education. Shop class became "vocational education" for those who supposedly could not handle 'serious' math or science [1].

These changes in engineering education had some very serious consequences. While the Engineer of 2020 [7] recognizes that creativity, invention, and innovation are indispensable qualities for engineering, this shift from professional engineer to scientific engineer resulted in a loss of experiences that were critical to the development of skills such as creativity and innovation.

Theoretical Framework

Despite the resurgence of fabrication labs and making in formal and informal settings, the driving theoretical ideas behind this movement are at least a century old. Digital fabrication and making are based on the following theoretical and pedagogical pillars: experiential education, constructionism, and critical pedagogy [1]. John Dewey [8] who is most commonly associated with the theory of experiential learning described this learning approach as simply 'learning by doing". This echos Confucius's famous quote that states the following: I hear and I forgot, I see and I remember, I do and I understand. Critical pedagogy is a philosophy of education and social movement. Critical pedagogy includes relationships between teaching and learning. Its proponents claim that it is a continuous process of what they call "unlearning", "learning", and "relearning", "reflection", "evaluation", and the impact that these actions have on the students, in particular students whom they believe have been historically and continue to be disenfranchised by what they call "traditional schooling" [9]. The most notable scholar of this school is Paulo Freire, who introduced the idea of culturally meaningful curriculum construction and also advocated education as a form of empowerment. Others [10,11] have extended his theories to logically imply that students' projects should be deeply connected with meaningful problems, either at a personal or community level, and designing solutions to those problems would become both educational and empowering. Seymour Papert developed the theory of learning called constructionism [1]. Papert was influenced by both Freire and Jean Piaget. To Piaget and his version of constructivism [1], knowledge is not information to be delivered at one end, and encoded, memorized, retrieved, and applied at the other end. Instead, knowledge is experience that is acquired through interaction with the world, people and things and built on a student's prior knowledge. Constructionism builds upon Piaget's constructivism and claims that the construction of knowledge happens remarkably well when students build, make, and publicly share objects [1]. His theory is at the very core of what "making" and digital fabrication means for education, and underlie what many enthusiasts of the "maker movement" propose – even if many are not aware of it [1].

Makerspaces as novel learning environments in engineering

In 2011 and 2012 alone countless museums, schools, community centers, and libraries announced plans to build digital fabrication and 'making' facilities – it became mainstream [12]. The implementation of makerspaces into the university community, just like the maker movement itself, is a relatively recent one. Within the past decade multiple makerspaces were opened at large universities world-wide. Some examples include: Arizona State University, Georgia Tech and TU, Berlin. However, there has been little research on the effects of these spaces on engineering education [11].

The key relevance of makerspaces in engineering education is their potential to bring hands-on learning into the curriculum and enable project-centered classes. Based on a review of the literature, the following ideas have guided this project:

1. Learning is an active, constructive process. Students use information they know to acquire more knowledge.
2. Construction of knowledge happens remarkably well when students build, make, and publicly share objects.
3. Education should be experiential and connected to real-world objects preferably drawn from the students' personal or community background. Such hands-on, project centered learning positively impacts many aspects of the engineering learning process.
4. Design is an engineering pedagogical method that is accessible to many types of learners.

Integrating "Making" in the Engineering/Education Technology Curriculum

This research program consists of restructuring three freshman and sophomore level engineering technology courses that have an engineering/design focus. Such restructuring is aimed at rendering "traditional" design courses more welcoming to students with diverse learning styles, life history and prior experiences. A key aspect of the first year of restructuring has integrated hands-on projects and student work in the makerspace.

The targeted engineering courses are US 1100, TECH 1311, and TECH 2310, two at freshman level and one at sophomore level. The courses for pre-service STEM teachers are EDTC 5310 and EDTC 5330. Two of the courses were impacted in year one, as described below:

1. U.S. 1100 – University Seminar – This course prepares freshman to be successful in the university. Multiple generic versions of this course are offered each semester. However, a limited number of discipline specific versions of this course are also offered for those majors who have made a choice of major early in their college tenure. One such discipline specific offering is in engineering. It is in such a discipline specific section of US 1100 that our effort has been focused. Amongst many themes that are explored in U.S. 1100 are career exploration, team work, diversity and professionalism. This team created an engineering and engineering technology focused version of this course in which a term project was assigned to require the use of the maker space for project completion. Teams of students worked together on "product realization" bringing their prior school, work and life experiences to bear on their designs. This iterative process of brainstorming and making challenged the students' ingenuity and fostered the development of creativity.

2. TECH 1311 – Engineering Design Graphics – This course introduces students to the process of spatial visualization of engineered products and their documentation through the use of computer graphics using a program such as AutoCAD. Topics covered included orthographic projections, descriptive geometry, cross sectional views, dimensioning and tolerancing and design problem solving. While these topics are important for the future engineer, a class that consists only of these topics and employs classroom based pedagogies has the following issues: it discourages students who in spite of their real world prior experiences with tangible engineered products feel inadequate in this rather abstract visualization oriented course and it does not expose students to the actual design of a product. Thus, the traditional approach undervalues students' prior experiences and life history on the one hand and by focusing on abstract and sometimes detail oriented, tedious design documentation procedures may turn both a committed and prospective engineering/engineering technology major away from these majors. The intervention the research team carried out included three maker space design projects where teams of students were asked to come up with progressively challenging designs to meet certain pre-specified functional requirements. The process of making and tinkering facilitated the students' mental spatial manipulation skills as physical manipulation of objects and things in the makerspace correlated with the counterpart mental manipulations. These design projects affected a good balance between those pedagogical elements that are abstract in nature and those that are experiential and thereby synergistically boost learning for students with all kinds of prior knowledge and backgrounds.

3. ***TECH 2310 – Computer Aided Design and Drafting*** – This sophomore level course builds upon TECH 1313 and covers the basics of mechanical design using parametric CAD software such as ProENGINEER. Students are exposed to topics such as geometric dimensioning and tolerancing, fits and clearances, surface finish, geometric modeling, assembly modeling and the design of mechanical elements such as gears, fasteners, screw threads etc. Here again considerable amount of essential technical design material is covered in the traditional offering of this course. The intervention intended calls for three team based term projects of increasing complexity, which would incrementally develop both the creative and technical aspects of a student's design abilities. The projects would be accomplished in the makerspace. In this class the projects would be more advanced than those in ENGR 1313 involving the consideration of decision factors such as tolerance stacks, assembly constraints, material choices and the use of design standards such as those from ASME. The making and tinkering activities complement the theoretical technical content covered in the class and foster creativity. In addition, this course marks a transition in the course sequence from design to manufacturing. Thus, the makerspace-based activities prepare the students for future manufacturing processes oriented courses.

Program participants

Texas State University is an Hispanic-Serving Institution, so it was expected that approximately one-third of the students in these targeted courses would self-identify as Hispanic. Unfortunately, the low response rates during the first year of students who completed both the pre- and post-survey does not support extensive conclusions for any one class. Student responses to survey questions on gender and race or ethnicity are presented in Table 1. The enrollments for these courses ranged from 20 to 25 students. Despite the small number of respondents per class, nearly thirty percent of the students who completed both pre- and post-surveys did self-identify as Hispanic, which approaches the university's student profile of 35% Hispanic undergraduate students. Two-thirds of the students participating in both the pre- and post-surveys for this first year of the study are white, which oversamples that population at Texas State University, where white students make up 49% of the undergraduate student population. Female students made up approximately 15% of the respondents to this survey versus 57% for the university, but this population is in line with the student demographics for the Department of Engineering Technology.

Table 1: Demographics of Students Who Completed Both the Pre- and Post-Semester Survey in the Targeted Classes

Survey Question	TECH 1311 Spr. '16	TECH 2310 Spr. '16	TECH 2310 Fall '16	US 1100 Fall '16
What is your gender?				
Female	**3**	**1**	**0**	**0**
Male	**5**	**10**	**3**	**5**
What is your race/ethnicity? (select all that apply)				
African American/Black	**0**	**2**	**0**	**1**
American Indian or Alaska Native	**0**	**1**	**0**	**0**
Asian	**1**	**0**	**0**	**0**
Hawaiian or other Pacific Islander	**0**	**0**	**0**	**0**
Hispanic, Mexican, Mexican-American, Puerto Rican, or Latino	**1**	**4**	**0**	**3**
Middle Eastern	**0**	**0**	**0**	**0**
White	**6**	**7**	**3**	**2**

Year One Research Agenda

Research in Identity Development

This team proposed to investigate the effect of makerspaces on engineering education by seeking answers to the following specific research questions.

> Q1. What engineering instructional approaches can value, build upon, and render meaningful students' prior making and life experiences and thereby boost student success?
>
> Q2. To what extent does involvement in a makerspace affect student learning and STEM professional identity development?
>
> Q3. To what extent does involvement in a makerspace, as a recruitment and retention tool, serve as a pathway to and through engineering?

In year one, instructors have focused on designing the course interventions in such a way that the maker space design experiences are integrated to a degree sufficient enough to affect change while maintaining time to meet expected course goals. Preliminary feedback from instructors has been collected. In addition, a focus on question 2 has been initiated by developing a survey for students that aims to collect student insight into how their learning and professional identity may have been affected by these Maker space experiences. The survey design and preliminary findings are described in the next section.

Pilot of a Survey Instrument- Maker Identity Development

The survey instrument used to collect student opinions, self-perceptions and knowledge of making for this project contained two validated measures within it: the Engineering Design Self-Efficacy tool [13] and the Metacognitive Awareness Inventory [14]. Self-efficacy is defined as an individual's belief in their own ability to complete a certain task [15]. The research team also included some additional statements that were modeled upon statements in the Metacognitive Awareness Inventory, but utilized wording to tie the identity constructs to the making movement. Following these measures and the additional making-based statements, there were questions to ascertain each students' familiarity with making and the on-campus maker space, Bobcat Made, as well as some demographics questions. The demographics questions were purposefully placed at the end of the survey in order to minimize effects of stereotype threat [16].

The Survey

<u>Element 1 Questions:</u>

After students agree to the informed consent, the first element of the survey is the Engineering Design Self-Efficacy tool [13]. This survey assesses the students' self-efficacy in completing engineering design through four lenses: confidence, motivation, expectation of success, and anxiety. The fourth lens, anxiety, is intended to have responses contrary to the other lenses. As such, it is additional useful as a screening tool to look for students who gave exactly the same response in all four categories, which implies they did not read the questions. This instrument has students evaluate their confidence, motivation, expectation of success, and anxiety in completing engineering design using an eleven-point scale (0, 10, …, 100).

Element 2 Questions:

The second element is the Metacognitive Awareness Inventory [14]. This instrument asks students to evaluate a series of statements about their problem solving approaches, habits, and preferences using a five-point Likert scale (Very true of me, True of me, …, Very untrue of me).

Element 3 Questions:

Based upon the language and phrasing of the second element, the research team developed some additional statements about students' making approaches, habits, and preferences. These statements were evaluated using the same Likert scale as the preceding section.

Element 4 Questions

The final section of the survey asked participants to describe themselves, their definition of making and designing, and to state how much they view themselves as makers and/or designers. These questions were a mixture of open-ended responses and drop-down menus to categorize some responses. This conclusion of the survey also inquired about students' familiarity with and use of maker spaces in general, the university's maker space, Bobcat Made, specifically, and finally with a brief group of demographics questions.

Survey Procedures

The survey was created in an online survey hosting platform, in order to allow students to take the survey by clicking a link provided to them by their instructor of the targeted class. During the first semester of implementation, some instructors requested paper surveys for their courses. As such, in the first semester pre-surveys were completed online while post-surveys were completed on a paper survey form. During the second semester paper surveys were used for both pre- and post-surveys. The survey was administered pre and post the respective course, each requiring approximately twenty minutes each to take the survey.

Preliminary Data

The responses rates were lower than desired during this first year. For instance, in Fall 2016 only five students in US 1100 and three students in TECH 1311 took both the pre and post surveys. These responses were out of 19 and 21 students registered for these classes, respectively. The average student response for the four areas of engineering design self-confidence are shown pre- and post- semester for the special Introduction to Engineering section of US 1100: Figure 1. This preliminary data is the average of only those students who took both the pre-and post-semester survey. This early data suggests that the engineering design and making project boosted the student's self-efficacy regarding their confidence and expectation of success in conducting engineering design. The shifts seen in motivation and anxiety are within standard error for the pre- and post-semester results and thus are not considered significant. These large increases in student confidence and expectation of success measured with the

Engineering Design Self-Efficacy tool reflect the results observed by Talley et al [17] with a similar student population and freshman design experience.

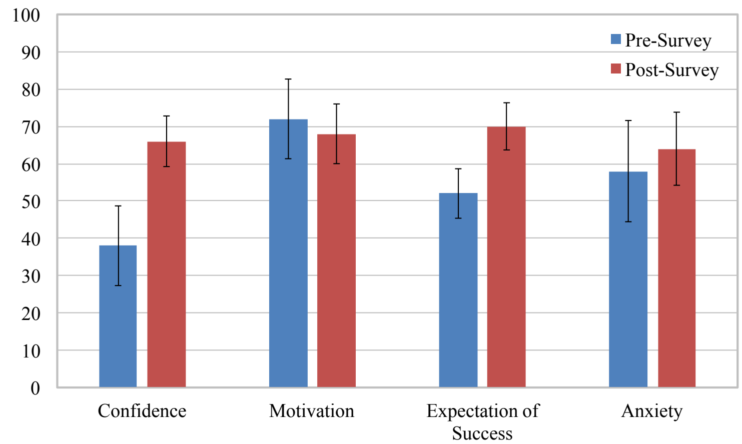

Figure 1: Pre- and Post-semester survey results from Introduction to Engineering section with a making project (n=5)

During the Fall 2016 semester, the instructor of TECH 1311 was asked to add a making project to their Engineering Design Graphics course as well as to administer the pre- and post-surveys to the class. The very small response of only three students who took both the pre- and post-survey out of 21 students in the class, indicated that the method of simply asking the students to please participate was not as effective as desired. The response rates varied considerable between instructors, indicating that this method did not produce consistent results. In TECH 1311, the pre- and post-semester EDSE results did not show any significant changes (Figure 2), however the small data size (n=3) means that there really is not enough information to draw conclusions from this one class.

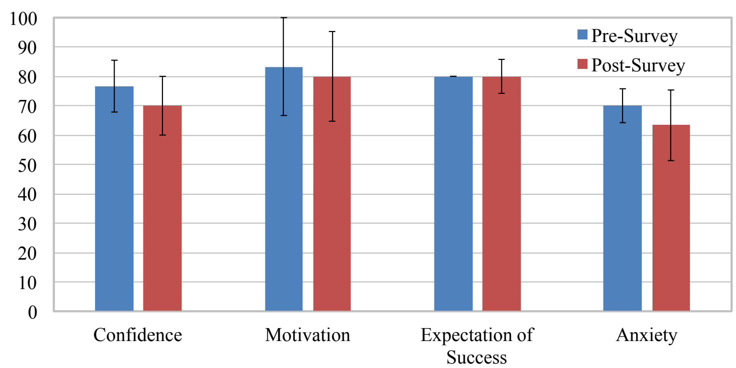

Figure 2: Pre- and Post-semester survey in TECH 1311, Fall 2016 (n=3)

During the preceding semester, Spring 2016, in the same class, only students' expectation of success appeared to increase appreciably between the pre- and post-semester surveys as shown in Figure 3. Spring 2016 was the first semester in which this instructor assigned a making-based project for their course, and the project was loosely defined. The small sample size with considerable scatter in the data is why the standard error is so large and why it is hard to draw any meaningful conclusions from this class's data set.

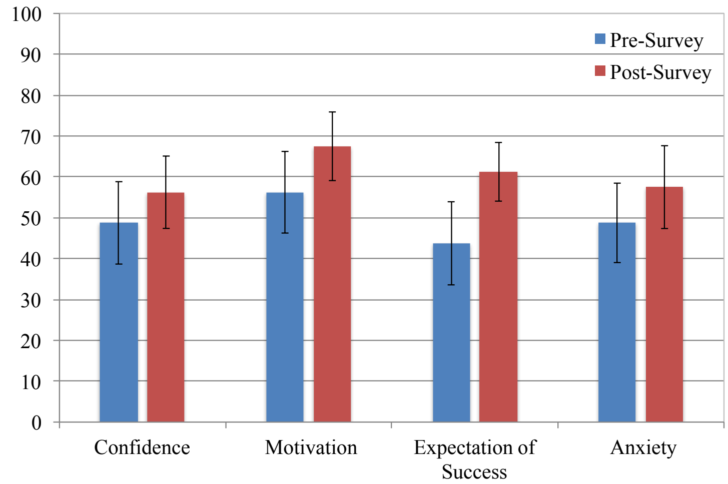

Figure 3: Pre- and Post-semester survey in TECH 1311, Spring 2016 (n=8)

A making project was also added to TECH 2310 in Spring 2016, and there were eleven students who completed both the pre- and post-semester survey. There was some difference observed between pre- and post-surveys during this semester, with student confidence rising appreciably from the beginning to the end of the semester as shown in Figure 4. Unexpectedly, student anxiety also rose, although there was a sizable standard error amongst student anxiety scores, which may limit the significance of this change. As was the case for TECH 1311, Spring 2016 was the first semester that the instructor for TECH 2310 introduced a making project into their class, and an increase in student anxiety could have been from an ill-defined project. Additional analysis will be conducted to screen out students who answered every question with the same response. As these data sets are so small, a few students speeding through a survey by marking the same answer throughout without reading the question could skew the results.

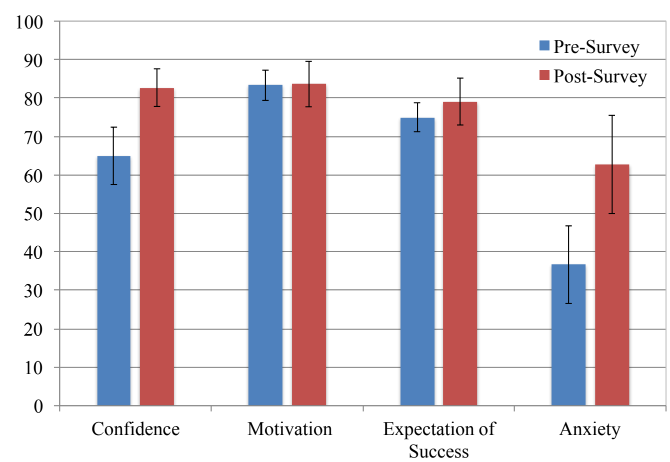

Figure 4: Pre- and Post-semester survey in TECH 2310, Spring 2016 (n=11)

Discussion & Conclusion

Throughout this first year, the instructors of TECH 1311 and 2310 were asked to add a making-based project, but those projects were left up to the instructor to define. Further, there was no requirement that the students have to implement the engineering design process to create these projects. The students in the Introduction to Engineering course (a US 1100 section), however, were given explicit instruction to use the engineering design process to develop their projects that they then created in the university maker space.

In addition to offering special making projects in classes as described, there were three special making events held during the Fall 2016 semester in order to draw in and introduce additional students to Bobcat Made and making in general. These events were typically held in the evenings and were set up to target certain populations such as residence halls, student support services, and pre-service STEM teachers. As such, the flyers advertising these special events were posted in these targeted areas, typically by the event co-sponsor.

Future work in the coming grant years will investigate if the students who attended these special events return on their own during open use hours. Additionally, more special evening events will be held to continue to attract more and more diverse users to the makerspace. Owing to a low response rate, especially during the second semester of implantation, the research team is planning some changes in the participant recruitment. The survey is again being offered in an online format, but there will now be a stipend offered to students who complete both the pre- and post-surveys while taking one of the targeted classes.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. EEC-1531375. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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