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University Maker Spaces: Discovery, Optimization and Measurement of Impacts

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Abstract

It is essential that modern engineers not only master engineering science and analysis, but they must also learn to drive the next generation of design, creation, and innovation. In parallel to the success of community maker spaces outside of academic settings, many universities are moving beyond traditional machine shops and building multi-disciplinary maker space design centers. This project seeks to understand and use these new environments to achieve elusive aims in engineering education such as improving at-risk student retention, fostering diverse learning environments, and promoting multi-disciplinary teams. We will also investigate the potential of maker spaces to positively influence females and minorities and thereby broaden participation in engineering.

Impact will be measured through engineering design self-efficacy; retention in the engineering major; and idea generation ability. Impacts will be measured at two levels. The first level of the project will use a randomly assigned experimental design to assess the impact of early maker space engagement on females and minorities through longitudinal measurements. In the second level, we compare segment snapshots and longitudinal measurements between extensive maker space users and those with minimal exposure. We will also identify best-practice approaches and guidelines for designing maker spaces, through discussions and interviews with leaders of maker spaces from educational institution around the country.

Introduction

It is essential that the 21st century engineer is creative and innovative in order to solve the problems of the future [1], and these skills can be taught and nurtured[2-4]. This can be a challenge due to lack of resources and limited time available in engineering curriculums.

Fostering the maker spaces environment may be one solution to cultivating creativity and innovation in universities. Maker spaces can become a supplemental part of traditional engineering education by offering a different way of learning. The benefits of maker spaces on education have been recognized by many universities, leading to the development and improvement of their student design spaces to become something different from the customary machine shop. Maker spaces provide an interdisciplinary center that promotes collaboration and hands-on engineering by empowering the users with the tools to design, prototype, and test their creations.

There have been some studies about the maker space phenomenon outside educational institutions but few that have focused on universities' maker spaces and their impact on the students [5, 6]. We believe that the impact of university maker spaces goes well beyond improving creativity and innovation. These spaces could increase retention of students in STEM related fields and improve their confidence when solving technical problems because they highlight the creative aspects of engineering and build a community of practice that increases students' sense of belonging.

The two main objectives of this project are to assess the impact of university maker spaces on the student population and to determine the best practices and novel approaches associated with development of highly effective university maker spaces. Both of these objectives will be implemented in the construction of general and transferable guidelines for universities desiring to develop, or improve their maker space.

To determine the impact of university maker spaces on the student population, the project will focus in two different areas. The first area encompasses the effect of maker spaces on students with a particular focus on women and underrepresented minorities. This will be studied through a longitudinal randomly assigned experiment. The second area will focus on comparing the students that are highly involved in maker spaces against minimal engagement students.

Determining the best practices and novel approaches associated with the development of university maker spaces will be achieved by collecting data through interviews with leaders of maker spaces from educational institution around the country.

The project will be mainly focused on the following three universities: Georgia Institute of Technology, James Madison University, and Texas State University. The focus on these universities is important because they possess maker spaces in three different phases of development. Georgia Institute of Technology has a well-established maker space called the Invention Studio, the maker space at James Madison University is maturing and Texas State is in the first steps of development of a maker space. Simultaneously studying university maker spaces in three different levels of development can be extremely valuable in the creation of related best practices. Also, this multi-university project will allow capturing more representative sample population.

Georgia Institute of Technology's maker space, the Invention Studio, is an example of a fully developed, student-run university maker space. Figure 1 shows images of the Invention Studio. It is characterized for its free and open access policy, and it is utilized by student and faculty for class, personal, and research oriented projects. The Invention Studio is staffed with more than 70 students. These students are responsible for the maintenance, safe use, and management of the studio. The Invention Studio has been the focus of a study that identifies the culture and characteristics associated with this university maker space [7].

Figure 1: The Invention Studio has significant potential to transform engineering education.

James Madison University Department of Engineering has been developing its maker space since the program's founding in 2008. In order to nurture and promote its design-build-test mentality [8], the program has developed four general purpose spaces and two studios (freshmen and sophomore studio) with restricted use. All these spaces are staffed with full time lab managers or undergraduate Teaching Assistant (TA), and with the exception of the freshmen studio, they have open hours in the afternoon and evenings.

Specific tool purchases for the Texas States University's Bobcat Maker Space will be tailored to take advantage of the best practices determined from the first two years of this proposal.

Background

One of the engineering education's most elusive goals has been to increase the recruitment and retention of women and underrepresented minorities. Based on our experience with the Invention Studio, we believe that university maker spaces offer an environment that could increases recruitment and retention of these groups. In the 1990s, two influential studies discovered that the lack of self-confidence, boredom, and disappointment with the required courses were significant factors in the disproportionate amount of people from these groups dropping out of STEM related fields [9, 10]. Besides the academic factors (e.g. difficulty of curriculum) influencing the decision of leaving engineering, Marra et al. discovered that non-academic factors such as the lack of belonging in engineering also affected the decision [11]. We believe that self-efficacy or "the beliefs in one's capacity to organize and execute the courses of action required to produce given attainments" [12], can help to strengthen the feeling of belonging in engineering. Having high self-efficacy is particularly important for engineering students because it can be related to their perseverance despite difficulties and obstacles [13]. Students with high self-efficacy will maintain the same amount of effort even after facing failure because of their belief in themselves [14]. There is a strong relationship between the amount of engineering experiences and engineering design self-efficacy [15]. Additionally, self-efficacy has been found to positively affect the retention of student in difficult courses (e.g. engineering courses) [16, 17]. We believe that the culture and activities associated with maker spaces can greatly affect self-efficacy, and ultimately improve retention of the women and minorities population.

Increasing the confidence (self-efficacy) of women has been related to their retention in engineering [18]. Other factors that positively affect retention are the availability of role models, and mentors that can demonstrate balance between successful work and personal life [17, 19]. University maker spaces are an example of a community were students take role model and leadership position.

There are other ways in addition to improving retention that university maker spaces can improve engineering education. Promoting informal learning, prototyping and building are important aspects of the maker space culture which can benefit practices for the student population. The maker space culture promotes informal learning, which can account for the majority of learning in organizations[20-22]. Additionally, informal learning allows students to retain content better than traditional education[23, 24]. Creating and building physical representation is extremely important practice in engineering design. Physical models are used by student design teams to identify issues with their ideas[25-27]. Physical representation can enhance the transmission of information as well as the understanding of a design [28]. Maker spaces empower the users with the tools to create physical models of their ideas. Since there is value in creating physical representations, the use of this model and representations has been encouraged by researchers [29, 30].

Research Plan

The two main objectives of this paper are to measure the impact of maker spaces developed within academic institutions on students and to determine the innovative approaches and best practices associated with the development of university maker spaces. The study of the impact will be approached in two different ways: through a randomly assigned longitudinal experiment which will focus on the impact on women and minority populations, and through the comparison of students that are highly involved in the university maker space to students that have minimum involvement.

By answering the following three research questions we will be able to measure the impact of maker spaces on students:

1. By engaging women and under-represented minorities in maker spaces at the beginning of their careers, can we increase retention rates?
2. To what extent are there differences between students who participate frequently in maker spaces (high involvement) and our typical engineering student (low involvement)?
3. To what extent do maker spaces impact students' idea generation abilities and design self-efficacy?

The effects of the early engagement in maker spaces on the women and underrepresented minorities population will be measured through a randomly assigned four year longitudinal experiment. In this experiment, participants will be exposed to the type of activities that can be performed at the Invention Studio, the Georgia Institute of Technology's maker space. The participants will be randomly divided into a control and experimental group. Both groups will participate on a guided tour through the Invention Studio and then work on a small project that will show them a possible use of the prototyping machines. The experimental group will be further engaged by working on hands-on prototyping activities using multiple resources that are readily available in the Invention Studio. The following metrics will be used to compare the difference between the two groups throughout the 4 years of the project: retention in engineering and major, graduation rates, GPA, design self-efficacy, demographics (gender, race, and ethnicity), and idea generation ability.

A quasi-experimental approach will be used to compare students that are highly engaged in university maker spaces to those that are not. This study will be performed at the Georgia Institute of Technology, James Madison University, and Texas States University. Participants will be recruited from multiple engineering design classes (e.g. capstone courses) and they will self-report their engagement in the university maker space throughout their career. This data will be used to separate the participants into high and low involvement groups. The following metrics will be used to determine the difference between the two groups: graduation rates, GPA, design self-efficacy, demographics (gender, race, and ethnicity), and idea generation ability.

Metrics

To quantify the impact of university maker spaces on students the following data will be gathered: cumulative and major GPA and retention in major.

Data corresponding to design self-efficacy will be collected by administering an instrument developed by Carberry, et al [14]. The self-efficacy instrument is divided into four areas: anxiety, expectancy of success, motivation, and self-efficacy when working on engineering design related tasks. The participant will be asked to rate themselves in nine different situations related to the four areas previously discussed.

To measure idea generation ability, the four metrics developed by Shah et al. will be implemented [82]. The participants will be asked to come up with ideas to solve a specific design problem and the solutions will be graded by quantity, quality, novelty, and variety of ideas submitted. Since this test will be given every year for four years, the specific design problem will have to vary, and at the same time, be equivalent. Five previously tested equivalent design problems will be used[31-33]. Some examples of comparisons between high, and low quality, and novelty solutions for a design problem can be seen in Figure 2.

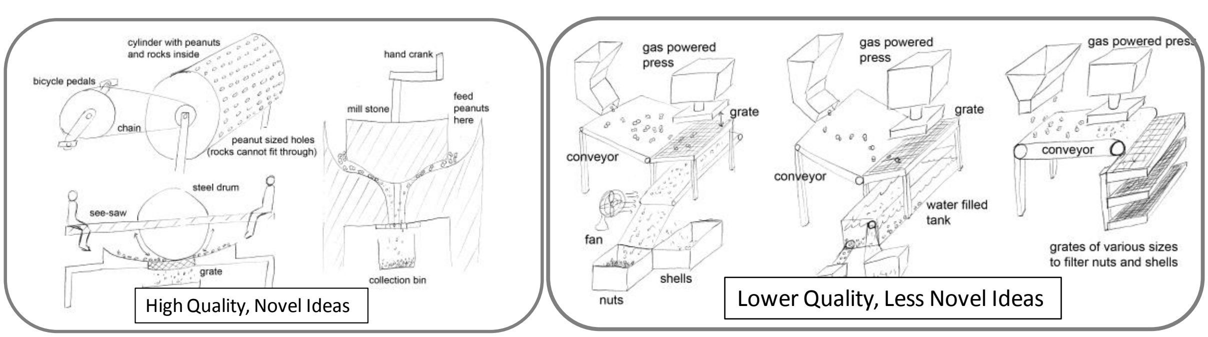

Figure 2: Examples of high and low quality along with a range of novel ideas.

Data Analysis Plan

Data from the randomly assigned experiment on the impact of the Invention Studio on women and minorities will include retention rates for both in major and in engineering, graduation rates, design self-efficacy and idea generation ability. We expect the metrics to be independent and to only see effects for some of the outcome variables, so we do not plan to use multivariate approaches such as MANOVA. Retention in engineering and major will be analyzed using logistic regression with GPA and SAT scores as covariates. ANOVA will be used for the Idea Generation Ability metrics (quantity, novelty, and variety) and for the Design Self-Efficacy.

Current Results

Given the large amount of participant this project requires, there will be multiple first engagement sessions in the longitudinal study in order to accommodate this number. A group of 22 students has been recruited. Also, a group of 26 participants was surveyed in the Georgia Institute of Technology's capstone course; data collected from this group will be used in the comparison of high against low maker space involvement students. The survey mainly asked for contact and demographic information, but also basic knowledge about the Invention Studio and whether they use the invention studio for school or personal purpose. The next step for the capstone group will be to measure idea generation ability, self-efficacy, and self-reported weekly involvement in the Invention Studio. The participants of the longitudinal study will be surveyed and randomly separated into two groups. The experimental group will then be contacted to participate in another prototyping activity.

Identifying Novel Practices for Maker Spaces- Moving Beyond Traditional Machine Shops

To further extend the impact of this work and to provide avenues for improving university maker spaces, we will identify and document other approaches, including both common and novel practices. In this documentation project, it is possible that the effectiveness of many of the novel practices will not be determinable from the data collected. This data will show correlations between outcomes but will not determine causality. The documentation follows an empirical product study method which has been used to develop design for X principles (e.g. design for flexibility), characteristics of innovative products, environmental guidelines, and design taxonomies[34-38]. It is an efficient, low-resource approach for studying a wide range of features. Inherently a qualitative approach, it will identify patterns, provide guidelines, and highlight areas for further study.

We will form a user group of faculty and staff who are engaged in developing or improving their universities' maker spaces. Virtual meetings will be held where intermediate data and findings can be presented. Comments, feedback, and further insights on initial best practices will be sought prior to the publication of the work or the initial formal webinars.

The process of identifying and documenting the design features along with novel approaches and practices has begun with identifying maker spaces and reviewing available literature (websites, conference papers, university reports, etc.). Further work in this area is being done concurrently by the authors [39]. Through participation at the NCIIA Open 2013 session on "Spaces of Innovation" we have identified over twenty university maker spaces and established contacts at each. We will lead cross-university discussions of how to identify best practices and novel approaches. We will also survey existing maker and hacker spaces outside the university (e.g., TechShop, Freeside Atlanta) to leverage some of their practices and innovative approaches. Many are likely to have developed other low-cost solutions. For example, many maker spaces outside the university setting occur in old or disused buildings, people's garages and other low-cost or under-utilized spaces. We will also implement more formal, structured interviews to gather data. The initial list of best practices and novel approaches will be present to the user group prior to publication or presentation in more formal webinars.

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Reference

1. National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. 2002.
2. Torrance, E.P. "Can we teach children to think creatively?" *Journal of Creative Behavior* 6 114-143 1972.
3. Mansfield, R.S. "The effectiveness of creativity training." *Review of Educational Research* 48(4): 517-536 1978.
4. Ma, H.H. "A synthetic analysis of the effectiveness of single components and packages in creativity training programs." *Creativity Research Journal* 18(4): 435-446 2006.
5. Lande, M., Jordan, S.S., and Nelson, J. "Defining makers making: Emergent practice and emergent meanings". *ASEE Annual Conference & Exposition*. Atlanta, GA, 2013.
6. Sheridan, K., Halverson, E.R., Litts, B., Brahms, L., Jacobs-Priebe, L., and Owens, T. "Learning in the Making: A Comparative Case Study of Three Makerspaces." *Harvard Educational Review* 84(4): 505-531 2014 http://hepg.metapress.com/content/BRR34733723J648U.
7. Forest, C.R., Moore, R.A., Jariwala, A.S., Fasse, B.B., Linsey, J., Newstetter, W., Ngo, P., and Quintero, C. "The Invention Studio: A University Maker Space and Culture." *Advances in Engineering Education* 4(2): 2014.
8. Prins, R., and Pappas, E. "Exploring the Value of Design and Build Experiences for Undergraduate Engineering Students". *ASEE Annual Conference and Exposition*. Louisville, KY, 2010.
9. U. S. Department of Education. *Women and men of the engineering path: A model for analysis of undergraduate careers*. 1998.
10. Seymour, E., and Hewitt, N.M. *Talking about leaving: Why undergraduates leave the sciences.*, CO: Westview Press, 1997.
11. Marra, R.M., Rodgers, K.A., Shen, D., and Bogue, B. "Leaving Engineering: A Multi-Year Single Institution Study." *Journal of Engineering Education* 101(1): 6-27 2012.
12. Bandura, A. "Self-efficacy: Toward a unifying theory of behavior change " *Psychological Review* 84(2): 191–215 1977.
13. Pajares, F. "Self-efficacy beliefs in academic settings." *Review of Educational Research* 66(543-578): 1996.

14. Brown, I., and Inouye, D.K. "Learned helplessness through modeling: The role of perceived similarity in competence." *Journal of Personality and Social Psychology* 36(8): 900 1978.
15. Carberry, A.R., Lee, H.-S., and Ohland, M.W. "Measuring engineering design self-efficacy." *Journal of Engineering Education* 99(1): 71-79 2010.
16. Downing, R.A., Crosby, F.J., and Blake-Beard, S. "The perceived important of developmental relationships on women undergraduates' pursuit of science." *Psychology of Women Quarterly* 29(4): 419-426 2005.
17. Bettinger, E., and Long, T.L. *Help or hinder? Adjunct professors and student outcomes*, Ithaca, NY: Cornell University, 2005.
18. Fisher, A., and Margolis, J. "Unlocking the clubhouse: the Carnegie Mellon experience." *SIGCSE Bull.* 34(2): 79-83 2002.
19. Milgram, D. "How to Recruit Women and Girls to the Science, Technology, Engineering, and Math (STEM) Classroom." *Technology and Engineering Teacher* 71(3): 4-11 2011 http://www.library.gatech.edu:2048/login?url=http://search.proquest.com/docview/902759036?accountid=11107.
20. Online Submission. *Reviewing Theory and Research on Informal and Incidental Learning*. 2006.
21. Cross, J. *Informal learning: rediscovering the natural pathways that inspire innovation and performance*: San Francisco, Calif., 2007.
22. Mattox Ii, J.R. "Measuring the effectiveness of informal learning methodologies." *T and D* 66(2): 48-53 2012 http://prx.library.gatech.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=edselc&AN=edselc.2-52.0-84861359999&site=eds-live&scope=site.
23. Barker, B.S., and Ansorge, J. "Robotics as Means to Increase Achievement Scores in an Informal Learning Environment." *Journal of Research on Technology in Education* 39(3): 229-243 2007 http://prx.library.gatech.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ768878&site=eds-live&scope=site http://www.iste.org/Content/NavigationMenu/Publications/JRTE/Issues/Volume_39/Number_3_Spring_2007/Robotics_as_Means_to_Increase_Achievement_Scores_in_an_Informal_Learning_Environment.htm.
24. Prince, M. "Does active learning work? A review of the research." *Journal of Engineering Education* 93(3): 223-231 2004 http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=800.pdf.
25. Horton, G.I., and Radcliffe, D.F. "Nature of rapid proof-of-concept prototyping." *Journal of Engineering Design* 6(1): 3-16 1995.
26. Raucent, B., and Johnson, D. "Linking design and simulation: a student project." *Journal of Engineering Design* 8(1): 19-31 1997.
27. Horton, G.I. "Prototyping and Mechanical Engineering". *Mechanical Engineering*. Brisbane, Australia: University of Queensland 1997.
28. Henderson, K. *On line and on paper: Visual representations, visual culture, and computer graphics in design engineering*, London: The MIT Press, 1999.
29. Kelley, T., and Littman, J. *The Art of Innovation: Lessons in Creativity from IDEO, America's Leading Design Firm*, New York: Harper Collins Business, 2001.
30. McKim, R.H. *Experiences in Visual Thinking*, Boston: PWS Publishing Company, 1972.
31. Glier, M., Tsenn, J., and Linsey, J.S. "Methods for supporting bioinspired design". *ASME IMECE*. Denver, CO, 2011.
32. Glier, M., Tsenn, J., McAdams, D., and Linsey, J.S. "Evaluating the Directed Intuitive Approach for Bioinspired Design." *ASME Journal of Mechanical Design* accepted.
33. Glier, M., Tsenn, J., McAdams, D., and Linsey, J.S. "Evaluating the Directed Method for Bioinspired Design". *2012 ASME IDETC*. Chicago, IL, 2012.
34. Rajan, P.K., Van Wie, M., Campbell, M.I., Wood, K.L., and Otto, K.N. "An empirical foundation for product flexibility." *Design Studies* 26(4): 405-438 2005 http://www.sciencedirect.com/science/article/B6V2K-4F8TVYR-1/2/f3e5c460e880f17f23b575fb40942d49
35. Saunders, M.N., Seepersad, C.C., and Holtta-Otto, K. "The characteristics of innovative, mechanical products." *Journal of Mechanical Design* 133(2): 021009-021009 2011 http://dx.doi.org/10.1115/1.4003409.
36. Kurtoglu, T., Campbell, M.I., Arnold, C.B., Stone, R.B., and McAdams, D.A. "A component taxonomy as a framework for computational design synthesis." *Journal of Computing and Information Science in Engineering* 9(1): 011007-011017 2009 http://dx.doi.org/10.1115/1.3086032.

37. Stone, R., and Wood, K. "Development of a functional basis for design." *Journal of Mechanical Design* 122(4): 359-370 2000.
38. Telenko, C., and Seepersad, C.C. " A methodology for identifying environmentally conscious guidelines for product design." *Journal of Mechanical Design* 132 091009 2010.
39. Nagel, R.L., Levy, B., Barrett, T., Pizzico, M. Forest, C., Newstetter, W.C., Talley, K.G., Linsey, J.S. "Maker Spaces and Pedagogy: A Review of University Maker Spaces". *American Society for Engineering Education Annual Conference*. Seattle, WA. in review, 2015.