3-D Printing in a First-Year Engineering Design Project

Dr. Kerry Meyers, Youngstown State University

Dr. Kerry Meyers holds a Ph.D. in Engineering Education (B.S. & M.S. Mechanical Engineering) and is specifically focused on programs that influence student's experience, affect retention rates, and the factors that determine the overall long term success of students entering an engineering program. She is the Director of the STEM College's First-Year Engineering Program and formerly the director of First-Year Engineering at the University of Notre Dame). She is committed to the betterment of the undergraduate curriculum and is still actively involved in the classroom, teaching over half of the First-Year Engineering Students each semester.

Dr. Brett P. Conner, Youngstown State University

Dr. Brett Conner is the Director of Advanced Manufacturing Workforce Initiatives and Associate Professor of Mechanical and Industrial Engineering at Youngstown State University. Dr. Conner has research interests in additive manufacturing of the following: multi-material systems, functional graded materials, shock and energy absorption applications, and economics of additive manufacturing. Dr. Conner had fifteen years of experience in government and industry prior to joining the faculty at YSU.

Mr. Andrew Scott Morgan

3D Printing in a First-Year Engineering Design Project

Abstract

The current study is a work in progress. First-Year Engineering Students from a medium-sized, urban, public university took part in a semester long design project. The Honors Students (1 section or approximately 20% of the class) had an additional design project that utilized 3D print technologies. During the 2015-2016 school year the honors students worked in small groups to develop a concept that was then 3D printed for a design competition and then students had the opportunity to revise their design for a final design competition. Course instructors assessed the experience to better understand how the use of 3D printing technologies could be used as an educational method to teach the design process. Students participated in three anonymous surveys. The surveys were administered at: (1) the start of the fall semester to all students (honors and non-honors) for baseline data, (2) after the first 3D Print experience (a car), and (3) after the second 3D print experience (flying disc). Findings indicate that 3D Printing based projects are perceived to be both interesting and relevant by students; further there were no statistically significant differences between male and female or honors and non-honors students in terms of their prior experiences with the technology or in their interest in learning about the technology.

Introduction

National attention has been given to the need to train and educate a larger STEM workforce, including engineers, in order to be globally competitive [1-2]. To that end, there is a high demand for qualified engineers and educators are carefully considering the factors that promote recruitment and persistence while maintaining high academic standards for the discipline [3]. Engineering education has long been noted for challenging academic pathways rooted in traditional practice; however, more recently educators recognized that persistence can be promoted by removing educational road blocks and utilizing educational best practices [2]. To that end, there is a wide range of research citing the need to transform traditional lecture courses into more interactive and responsive environments [4-6].

In general terms, the distinguishing attribute of engineering is design; design has been incorporated throughout engineering curricula beginning in the first-year with cornerstone design and concluding in the final year of engineering study with capstone design which are often referred to as Project-Based Learning (PBL). In particular, cornerstone design projects are thought to increase student interest in engineering, increase retention, motivate future engineering courses, and enhance performance in future PBL experiences [7]. Project-Based Learning experiences have been recognized as educational best practices [8-9] for heightened student engagement [10-11]. Cooperative, project-based learning experiences grounded in a broader societal context have been recognized as positive influences for all students, including underrepresented groups such as women and minorities [12-14]. Engineering differs from other academic majors by: (1) the low numbers of women enrolled and (2) the matriculation of students out of the program (very few students migrate into engineering from other majors) [15]. In particular, women enter with similar levels of academic preparation to their male peers but leave engineering earlier in their academic pathway despite being in good academic standing [6,16]. Given that Cornerstone projects are an opportunity to increase student interest and retention, it is critical that projects used as educational experiences are of interest to both male and female students.

In order for a Cornerstone project to conform to educational best practices the focused learning objective is on "design thinking," which relates to: handling uncertainty, making decisions as part of a team, technical communication, and viewing design as an iterative process [7]. Offering engineering students access to rapid prototyping is a novel approach to understanding the iterative nature of the design process [17]. Design experiences can be facilitated by the use of 3D printing technologies [17-19], in fact the use of 3D printers within the educational setting has increased significantly over the past several years. With Fused Deposition Modeling (FDM) printers becoming more affordable [19-20], the expansive growth and accessibility of such 3D printers is an opportunity to revolutionize STEM education by allowing for technology driven iterative design experiences [19]. A study by Johnsons and associates, found that students designing and "printing" their own objects provides significant interaction [18]. Another study by Johnson and associates found that the use of 3D printers was an effective tool for a graphics design course in which students were asked to recreate an object from a 3D printer using the given 3D CAD software. Throughout the duration of the course, the students were given multiple, iterative design opportunities to further advance their original designs and by the conclusion of the course all students successfully recreated the original design [18]. In the current study, the students had an opportunity to design a flying disc in SolidWorks® which was then 3D printed and physically tested (a competition between teams to see how far the disc could fly consistently).

One of the wide-spread impacts of low-cost, entry level 3D printers is on STEM (Science, Technology, Engineering and Mathematics) education. Several studies have highlighted the positive role of 3D printing along with traditional tools (subtractive and design optimization), particularly in the case of undergraduate STEM education for design-prototype and manufacture projects [21-24]. One study by Bailey suggests that presenting students a final implementation objective and general design guidelines, helps facilitate learning and promotes creativity within the design process [25]. Overall, the development and implementation of courses that utilize low-cost, entry level 3D printers for K-12, undergraduate, graduate, and distance education students has the potential for significant impact [26]. With only a few prior educational studies on the use of low-cost, entry level 3D printers in design project experiences, the current study sought to assess student perceptions in a First-Year Engineering Cornerstone design course which address the following research questions.

Research Questions

1. Is the use of 3D printing technologies in a First-Year Engineering design project interesting to students? (male / female and honors / non-honors)

2. Is the use of 3D printing in a First-Year Engineering design project deemed relevant from a student's perspective? (male / female)

Background of the Institution Studied

The institution studied was an urban, public, university located in the Midwest serving ~13,000 undergraduate students, 86% of which come from within the state. It is a very accessible school for students of diverse academic preparations and socioeconomic backgrounds. Specifically, it guarantees admission to any student earning a high-school degree or GED equivalent (although engineering does have restricted admissions). Due to its organizational structure, this university combined demographics of students with a science and engineering background. The demographic makeup of students with a science or engineering background is 72% male and 28% female and ~12-15% minority student population. Most of these students are of traditional college age (80% less than 25 years old), are full time students (85%), and live off campus and commute (90%).

Background of the Course Studied

The First-Year Engineering Program is a 2 semester course sequence, with a 2 credit course in the fall (Engineering Concepts) and a 2 credit course in the spring semester (Engineering Computing). There are two design projects in the Engineering Concepts (fall) course and one design project in the Engineering Computing Course (spring). All students complete these courses / design projects but there is a separate honors section of the course that includes experiences with 3D printing / Additive Manufacturing. The Honors students also: go on a tour of AmericaMakes (the National Additive Manufacturing Innovation Institute), listened to a class presentation on 3D printing, had their design from the fall semester course 3D printed, and participated in an iterative design project.

Methods

A formal study of the First-Year Engineering Cornerstone Courses was conducted during the 2015-2016 school year. In particular, the honors students were surveyed at 3 points throughout the school year and were compared to the other sections of the course which did complete a design project but did not have any of the enrichment experiences related to 3D printing. Five sections of this course were taught, of which one was the honors section. Only the honors section (all students registered for the course) participated in 3D printer utilization. Baseline data was collected from all students (honors and non-honors) at the start and end of the school year, and additionally the honors students were surveyed at the following times: (1) at the start of the fall semester (baseline data), (2) after the first 3D Print experience (car – Survey 1), and (3) after the first-design iteration in the second course (flying disc, iteration 1, Survey 2). The data provided by these additional surveys is used in assessing 3D Printing relevancy in the course.

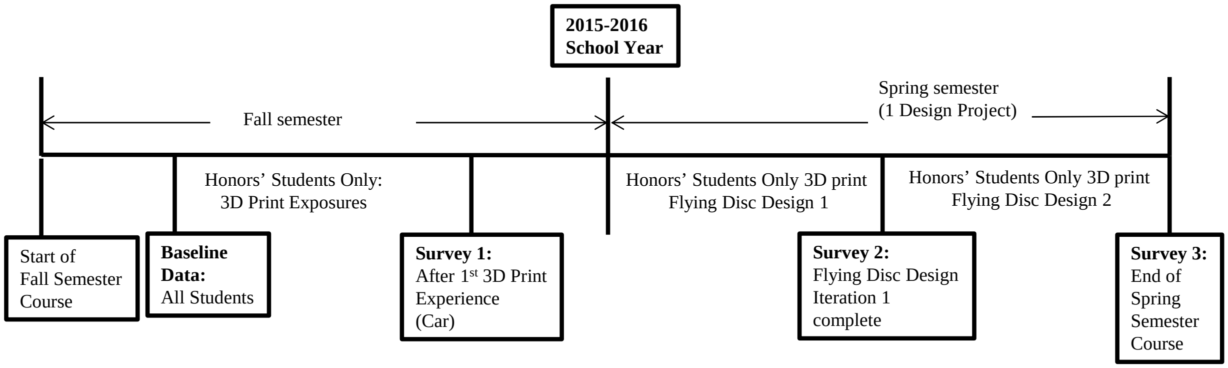

Figure 1. Timeline of Survey Administration

Each of the surveys were administered online using BlackBoard since it is the tool used for all course assignments. Responses were anonymous; however, students were given course credit for each survey completed. For the baseline data collected of all students, there were 181 students and for Survey 1 which was only for honors students there were 40 respondents as indicate in Table 1.

Table 1. Summary of Student Respondents

	2015-2016 Respondents					
Surveys	Honors Students			Non-Honors Students		
	Actual	Potential	Rate	Actual	Potential	Rate
Baseline Data	45	48	94%	136	154	88%
Survey 1	40	48	83%	N/A		
Survey 2	38	40	95%			

Summary statistics are reported, as well as Wilcoxon Rank-Sum Tests of statistical significance were evaluated. Rank-Sum tests are a non-parametric test that does not assume a normal population distribution [25]. All of the questions were on a Likert scale, and the quantitative responses were coded such that a more positive response was a higher value and a less positive response was a lower value. Statistical analysis was conducted using the statistical software package STATA®.

A Makerbot 2X was used to print all designs in 1.75mm ABS material on high quality. Although other material extrusion printers were not used, students had the opportunity to witness other machines, materials, and types of 3D printing in the laboratory. While witnessing their 3D part printing, a quick presentation on the different types of materials used in 3D printing was conducted. With a build constraint of nearly 6 inches in width on the Makerbot 2X, the size of this build area will provide an ample surface to prepare a large enough disc for flight.

The students went through three total experiences with a 3D printer: (1) a car, (2) team design project (flying disc – first iteration), and (3) team design project (flying disc - second iteration). The purpose of the car project was to offer students an opportunity to collaborate with peers in a first design exposure. All students had the same challenge, but there were many designs that could achieve the design objectives. The first 3D printing experience to create the car model was limited. Students submitted a Solidworks Part (.sldprt) file and the Teaching Assistant determined orientation and printing speeds. The students did not a have firsthand involvement with a 3D printer during this experience.

The second experience included more student involvement. The honor students had the opportunity to witness their design being printed on the Makerbot. This included the conversion of their SolidWorks® model to a .stl file for printing, the setup and slicing of their model using the printer's software, and physical encounters with the printer. On the scheduled day of printing, each group was individually brought into the 3D printing laboratory to learn and evaluate their model before actually printing. The students were briefly introduced to the way .stl files work, the different types of 3D printing and polymers, and the types of printers the university has available. Upon ending, each group witnessed its own model being processed through the slicing software corresponding to the printer in use. The group ultimately determined which orientation was most practical to use the least amount of material, reduce post processing time, and exhibit the best overall product for their team's flying disc. The entire class evaluated each of the designs and voted for: best/ favorite flying disc design (they couldn't vote for their own). A later competition of which flying disc flew the furthest was conducted to evaluate the best overall design.

Results

The honors students that participated in this project were asked about their prior experience with both solid modeling as well as 3D printing. Table 2, shows that prior to taking the First-Year Engineering courses the majority of students were aware of solid modeling as a tool but did not have any experience with using it (values were between 2-3 on a 5 point scale). In terms of 3D printing, most students had no prior experience (but were aware of it) or limited observational experience (values were between 2-3 on a 5 point scale). There were a few students in the course that had experience with solid modeling or 3D printing. The z values indicate the difference between the expected outcome and the actual result, a statistically significant difference would indicate that male students perceive the project differently than female students (or honors vs. non-honors students). There were no statistically significant differences for male and female students or honors and non-honor students. But despite having limited prior experience, all student indicated a relatively high interest in learning more about 3D printing technologies (male, female, honors, and non-honors were all >4 on a 5 point scale).

Table 2. Summary of Prior Student Experience

Mean Responses (5 point Likert Scale)						
Survey Questions on Experience Prior to taking the course	**Male Students**	**Female Students**	**Z Value Male vs. Female**	**Honors**	**Non- Honors**	**Z Value Honors vs. Non-Honors**
Had you ever been exposed to any form of solid modeling software (Solidworks, AutoCAD, ProE, etc.)?	2.660	2.540	0.657	2.710	2.630	-0.641
Had you ever been exposed to 3D printing?	2.630	2.460	0.645	2.620	2.600	-0.438
To what extent do you agree with the following statement: I would like to learn more about 3D printing	4.400	4.030	1.378	4.270	4.370	0.202

As part of the first 3D printing design experience, student project teams created a SolidWorks model of their design and it was printed by the TA (students did not have any observational or hands-on involvement with the printing process). An example of a 3D printed part from a student car project is shown in Figure 2. And an example of a 3D printed flying disc is shown in Figure 3.

Figure 2. Example of a 3D Printed Model Car

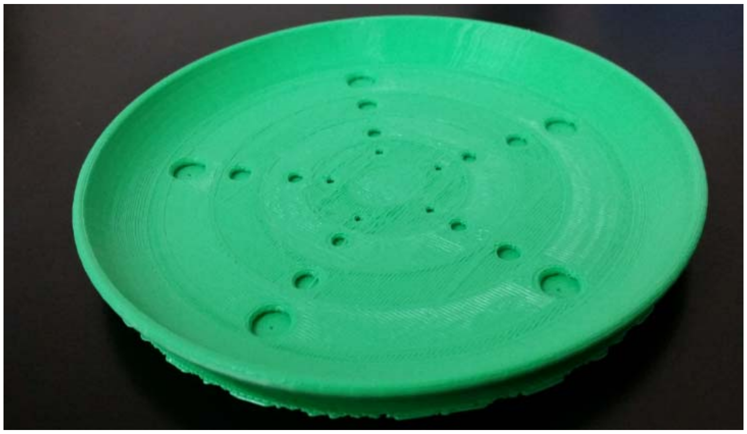

Figure 3. Example of 3D Printed Flying Disc

The honors students responded to surveys after each of the 3D printing experiences and the results are shown in Table 3. By comparing the means using a Wilcoxon Rank Sum test for statistical significance, the difference in responses between male and female students was not statistically significant for any of the questions including how interesting, relevant, and valuable the students perceived the experience. The relatively high mean values for interest and relevance and the lack of difference between male and female students would indicate that this is an appropriate project that is interesting to most students and not just a particular group.

Table 3. Comparison of Student Responses across 2 Surveys

Survey Questions on a Likert Scale out of 5 (higher value is a more positive response) related to 3D Print Design Project	Survey 1			Survey 2		
	Mean Value for all surveys combined		Female vs. Male	Mean Value for all surveys combined		Female vs. Male
	Male Students	Female Students	Rank Sum p value	Male Students	Female Students	Rank Sum p value
Interesting Leanring Experience	4.31	4.42	0.00	4.32	4.47	0.27
Relevant Learning Experience	4.13	4.00	0.61	4.16	4.13	0.48
Valuable Engineering Design Experience	3.85	3.71	0.67	3.95	4.00	0.09

Returning to the Research Questions

Each of the research questions is revisited and related student quotes from the free response items of the survey are introduced.

1. Is the use of 3D printing technologies in a First-Year Engineering design project interesting to students? (male / female and honors / non-honors)

   Both male and female students indicated interest in participating in a 3D printing project with no statistically significant differences. Although the non-honor students do not yet have the opportunity to participate in a 3D printing project (long term it is hoped that the resources and logistics will allow all students to participate), they do indicate the same level of interest as non-honors students.

   The 3D printing was very interesting, and it has made me want to learn more about it. – female honor student

2. Is the use of 3D printing in a First-Year Engineering design project relevant from a student's perspective? (male / female)

   Both male and female students indicated that the 3D printing project was a relevant and valuable design experience with no statistically significant differences.

   I thought the 3D printing was neat and it peaked my interest. I'd like to know more about its technologies and future applications. –male honor student

Conclusions / Limitations

Design is a key element of engineering; and engineering education research has recognized the value of using design project based learning experiences to teach students starting in the first year of engineering about this process through Cornerstone Design. The nature of design is a continuous process wherein engineers continue to reevaluate the needs and make improvements, and the rapid growth and accessibility of 3D printing technologies makes it an effective and affordable tool to allow students to physically see the changes they make to a design. Teaching design in an academic setting, which must adhere to the time constraints of the institution such as semesters or quarters is somewhat artificial, using 3D printing as a rapid prototype method allows students to design and redesign multiple times because of the short lead time. Furthermore, any opportunity to take a design from a computer design concept to a physical item is meaningful for visualization. The reaction from both male and female students was equally positive, and they recognize using 3D printing technologies as an interesting and relevant approach to learning the design process.

The current study was based on self-reported data from the students enrolled in the First-Year Engineering Program at a medium sized, Midwestern, Urban institution. The study would benefit from additional administrations at dissimilar institutions. In terms of the project itself, it could be improved by allowing the students to more opportunities to interact with the equipment to better understand its uses and limitations – as opposed to such extensive support from the teaching team. Using 3D printing technologies for functional parts would expose students to other facets of design such as design clearances, geometric dimensioning and tolerancing and how changes to their design influences design performance.

References

1. Duderstadt, J. Engineering for a Changing World: A Roadmap to the Future of Engineering Practice. Research, and Education, 2008.
2. National Academy of Engineering (NAE). Educating the Engineer of 2020: Adapting Engineering Education to the New Century. (2005). Nataional Academy Press.
3. French, B., Immekus, J., Oakes, W. An Examination of Indicators of Engineering Students' Success and Persistence. Journal of Engineering Education. October 2005, pp. 419-425.
4. Bonwell, C., and Eison, J. Active Learning: Creating Excitement in the Classroom. ASHEERIC Higher Education Report No.1, George Washington University, Washington, DC , 1991.
5. Felder, R. and Brent, R. Active Learning: An Introduction. ASQ Higher Education Brief, 2(4), 2009.
6. Goodman, I., Cunningham, C., Lachapelle, C., Thompson, M., Bittinger, K., Brennan, R., and Delci, M. Final Report of the Women's Experiences in College (WECE) Project. April 2002. http://www.grginc.com/WECE_FINAL_REPORT.pdf
7. Dym, C., Agogino, A., Eris, O., Frey, D., and Leifer, L. Engineering Design Thinking, Teaching, and Learning. Journal of Engineering Education, January 2005, pp. 103-120.
8. Frank, M., Lavy, I., and Elata, D., Implementing the Project-Based Learning Approach in an Academic Engineering Course. Journal of International Journal of Technology and Design Education (2003), Volume 13, No. 3, pp. 273-288.
9. Millis, J. and Treagust, D. ENGINEERING EDUCATION – IS PROBLEMBASED OR PROJECT-BASED LEARNING THE ANSWER? Australian Journal of Engineering Education (2003), pp. 2-16.
10. Haidet, P., Morgan, R., O'Malley, K., Moran, B., Richards, B. A Controlled Trial of Active Versus Passive Learning Strategies in a Large Group Setting. Journal of Advances in Health Sciences Education (2004), Vol. 9, No. 1. pp 15-27.
11. Biggs, J. What the Student Does: Teaching for Enhanced Learning. Higher Education Research & Development. Volume 18, Issue 1, 1999, pages 57-75
12. Burke, R. and Mattis, M. Women and Minorities in Science, Technology, Engineering, and Mathematics: Upping the Numbers. Edward Elgar Publishing, 2007.

13. Farrell, E. Engineering a Warmer Welcome for Female Students: The Discipline Tries to Stress its Social Relevance, an Important Factor for Many Women. C*hronicle Higher Education.* 2002, *February 22*.
14. Widnall, S. Digits of Pi: Barriers and Enablers for Women in Engineering. Presented at the SE Regional NAE Meeting, Georgia Institute of Technology, April 26, 2000.
15. Ohland, M., Sheppard, S., Lichtenstein, G., Eris, O., Chachra, D., and Layton, R. Persistence, engagement, and migration in engineering programs, Journal of Engineering Education, volume 97(3), 2008.
16. Seymour, E., Hewitt, N. (1997) Talking about leaving: Why undergraduates leave the sciences. Westview Press.
17. Jaksic, N. New Inexpensive 3D Printers Open Doors to Novel Experiential Learning Practices in Engineering Education. 121st American Society of Engineering Education (ASEE) Annual Conference & Exposition. Indianapolis, IN. June 15-18, 2014. Paper ID #10642.
18. Johnson, W.,Coates, C., Hager, P., Stevens, N. Employing Rapid Prototyping in a First-Year Engineering Graphics Course. ASEE Southeast Section Conference (2009).
19. Sirinterlikci, A., Sirinterlikci, S. Utilizing Rep-Rap Machines in Engineering Curriculum. 121st American Society of Engineering Education (ASEE) Annual Conference & Exposition. Indianapolis, IN. June 15-18, 2014. Paper ID #8580.
20. Taylor, S. (2014) "The TriBot Combines 3D Printing, CNC & Molding in One Machine", 3D Printing Industry, available at http://3dprintingindustry.com/crowd-funding-2/ (accessed September 24, 2014).
21. Fidan, I., Patton, K. (2004), "Enhancement of Design and Manufacturing Curriculum through Rapid Prototyping Practices", *Proceedings of IMECE04 2004 ASME International Mechanical Engineering Congress and Exposition*, November 13-20, 2004, Anaheim, California USA.
22. Flynn, E.P. (2011) "From Design to Prototype –Manufacturing STEM Integration in the Classroom and Laboratory", *1st IEEE Integrated STEM Education Conference (ISEC)*, April 2, 2011, Ewing, NJ, pp. 3B1- 3B4
23. Flynn, E.P. (2012) "Design to Manufacture –Integrating STEM Principles for Advanced Manufacturing Education", *2nd IEEE Integrated STEM Education Conference (ISEC)*, March 9, 2012, Ewing, NJ, pp. 1-1-1-4
24. Perez, O., Pitcher, M., Espinoza, P., Gomex, H., Hemmitt, H., Anaya, R., Golding, P. and Nevarez, H. (2015) "Analysis of the Impact of 3D Technology in STEM-Based Courses; Specifically Introduction to Engineering Courses". 122nd American Society of Engineering Education (ASEE) Annual Conference & Exposition. Seattle, WA. June 14-17 2015. Paper ID #11600.
25. Bailey, R (2015) "Using 3D Printing and Physical Tsesting to Make Finite-Element Analysis More Real in Computer-Aided Simulation and Design Course". 122nd American Society of Engineering Education (ASEE) Annual Conference & Exposition. Seattle, WA. June 14-17 2015. Paper ID #11664.
26. Liou, F.W., Ming, L.C., Landers, R.G. (2012) "Interactions of an Additive Manufacturing Program with Society", *Proceedings of 23rd Solid Freeform Fabrication Symposium*, Austin, TX, August 12-13, 2013, pp. 45-61.
27. Conover, W. and Iman, R. Rank Transformations as a Bridge Between Parametric and Nonparametric Statistics. The American Statistician, August 1991, vol. 25, Issue 3, pp 124-129.