DEVELOPING STUDENT LEARNING OUTCOME METRICS FOR MAKERSPACES: A STEM PILOT COURSE

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Abstract
Preparing undergraduate engineering students with the competencies needed for future work environments is a central objective of college engineering programs. Recently, access to 3D printers and other digital fabrication technologies in academic makerspaces has increased opportunities for students to engage with people and tools essential for improving their engineering and design competencies, and has led researchers to explore how to increase and measure student learning in these spaces. The literature reveals interests in and the need for exploring how makerspaces affect undergraduate student learning outcomes, but few universities are actively engaged in this type of research. The University of Texas at Arlington (UTA) Libraries’ FabLab has endeavored to integrate their makerspace into the undergraduate curriculum and measure the learning that takes place when students engage in making. Toward this goal, a list of eleven transdisciplinary makerspace competencies, each with multiple dimensions, was proposed and tested across a diverse range of undergraduate courses between 2016-2018. This paper summarizes results of a senior-level Engineering Project Management course that participated in the program in Spring 2018. Competencies examined in this course were assembling effective teams and demonstrating understanding of digital fabrication processes. Homework-based interventions for both competencies were designed and integrated into a semester-long makerspace project. Mixed-methods including pre- and post-self-assessments, project rubrics, team member evaluations and oral presentations were used to assess and measure student learning. Preliminary results indicate that students gain competency in assembling effective teams and demonstrating their understanding of digital fabrication processes by completing projects in makerspaces.

Keywords

Introduction
Preparing undergraduate engineering students with the competencies needed for future work environments is a central objective of college engineering programs. Recently, access to 3D printers and other digital fabrication technologies in academic makerspaces has increased opportunities for students to engage with the types of people and tools that are increasingly essential for gaining engineering and design competencies, as well as soft-skill competencies like teamwork, communication, ethics, and others.

Ease of access to makerspaces has led researchers to explore how to increase and measure student learning in these spaces. Hira, Joslyn & Hynes (2014) provide a concise and current review of the history of makerspaces in education, theoretical foundations, implications for pedagogy, and relevance of makerspaces to national science standards. For a deeper dive, Andrews (2017) provides an exhaustive literature review on the state of the art in “Making Literacies,” and Rosenbaum & Hartmann (2017) provide a meta-analysis that distills recent literature on educational makerspaces into discrete areas of research. The literature reveals an interest in, and the need for, exploring how makerspaces affect student learning outcomes, but, as Rosenbaum & Hartmann are quick to point out, few universities are actively engaged in this type of research. As Koh & Abbas (2014) proclaim, the current literature focuses mainly on 1) history and models of makerspaces; 2) case studies or informal reports of how specific makerspaces were founded; 3) advice and resources for how to start a makerspace; 4) suggested technology and sample
students. engineering design related tasks. This early phase of the study consisted of 498 first-year undergraduate engineering course, the other, perhaps more obvious choices, such as “Applies design praxis” (Competency 2) and “Demonstrates understanding of digital fabrication processes (Competency 8). At the time of our initial consultation for planning this using a validated instrument for engineering design self-efficacy (Carberry, Lee, & Ohland, 2010), the researchers females and minorities to broaden their participation in engineering. At the conclusion of the first year of the study, risk student retention, impact students’ idea generation abilities and design self-efficacy, and positively influence Fabrication Technologies” (EFTs) into school curriculum and developing a statistically validated instrument for makerspace-course integration and assessment, developing a regime for integrating what they call “Exploration and Blikstein, Kabayadondo, Martin, & Fields (2017) are similarly engaged in research surrounding K-12 designed, executed and assessed an assignment or project to be completed at their institution’s makerspace. The Maker Literacies Pilot Program at The University of Texas at Arlington The University of Texas at Arlington (UTA) Libraries’ FabLab has endeavored to create a competencies-based framework for integrating their makerspace into the undergraduate curriculum and to measure the learning that takes place when students engage in making (Wallace, 2017a). Toward this goal, a list of eleven transdisciplinary makerspace competencies, each with multiple dimensions, was proposed and drafted in fall 2016 (Wallace, 2017b). Between spring 2016 to spring 2018, these competencies have been adopted as course learning outcomes and beta-tested across a diverse range of 29 undergraduate courses in twelve disciplines at five universities. Disciplines have included Architecture, Art, Biology, Computer Science, Education, Engineering (Civil and Industrial), English, Geology, History, Mathematics, Public Administration, and Philosophy. Other Universities that have participated thus far have been Boise State University, UMass Amherst, UNC Chapel Hill, and University of Nevada, Reno. In addition to adoption of one or more of the maker competencies as student learning outcomes, instructors in these courses designed, executed and assessed an assignment or project to complete at their institution’s makerspace.

Blikstein, Kabayadondo, Martin, & Fields (2017) are similarly engaged in research surrounding K-12 makerspace-course integration and assessment, developing a regime for integrating what they call “Exploration and Fabrication Technologies” (EFTs) into school curriculum and developing a statistically validated instrument for measuring skills attainment of these technologies. EFTs are a distinct class of technologies, separate from general computing and information and communication technologies (ICT). While Blikstein et al. focus on technology literacy among K-12 students, our program focuses on interdisciplinary, transferable competencies among college undergraduates. While these domains clearly intersect and overlap in various ways, our work centers around high-level competencies such as team building, communication, design thinking, and project management, and the makerspace serves as laboratory for acquiring these competencies.

This paper summarizes results of a senior-level Engineering Project Management elective course in UTA’s Industrial, Manufacturing, and Systems Engineering program, which participated in the program in Spring 2018. While nearly all of the eleven makerspace competencies were highly relevant to this course, we chose to examine only two for the sake of managing our scope: Assembling effective teams (Competency 4) and Demonstrating understanding of digital fabrication processes (Competency 8). At the time of our initial consultation for planning this course, the other, perhaps more obvious choices, such as “Applies design praxis” (Competency 2) and “Demonstrates

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time management best practices” (Competency 3) were already being implemented in numerous other courses. Neither competency 4 nor 8 had yet been adopted, so the Engineering Project Management course presented an opportunity to implement and begin collecting data about them. A project management course in engineering overlaps extremely well with most of ABET’s a-k criteria, but UTA IMSE selected d,f, and h for this course while spreading out the others over the rest of the curriculum. Criteria (d) is an ability to function on multi-disciplinary teams, and the homework assignment described below is used for ABET purposes. Criteria (f) is an understanding of professional, and ethical responsibility, and a week on engineering ethics is spent in this course. Criteria (h) is the broad education necessary to understand the impact of engineering solutions in global/societal context, and several assignments over the course of the semester are used to meet this requirement.

Homework-based interventions for both competencies were designed and integrated into a semester-long makerspace project. Both homework assignments and the over-arching makerspace project are described in the Methodology section, below. Because of the experimental direction we were taking this course, we agreed upon a mixed-method approach for assessment, employing formative and summative and direct and indirect methods. These techniques included pre- and post-self-assessments (indirect summative), a project rubric (direct summative), team member evaluations (indirect formative) and two oral presentations with open Q&A (direct, formative and summative). This paper will focus primarily on data gathered from the pre- and post-self-assessment surveys. Preliminary analysis of the pre- and post-self-assessment survey results indicate that students gained competencies in both assembling effective teams and demonstrating their understanding of digital fabrication processes while completing the two homework assignments and the semester-long makerspace project.

Methodology

Engineering Project Management introduces project management (PM) concepts and tools needed to form, develop and manage cross-disciplinary engineering design teams. Overarching topics include: understanding R&D organizations, teams and work groups, job design specifications, organizational effectiveness, and leading technical professionals. Students complete a team-based, semester-long project to gain hands-on experience with PM tools, techniques and principles, including project planning (Specs, SOW, and WBS), network scheduling techniques (PERT and CPM), project graphics (Gantt charts, etc.), pricing and estimating (effort-hours/task/job code, overhead and fringe rate), risk management, and performance appraisals (tracking team member performance, providing feedback, resolving issues).

Although the course covers all aforementioned topics in project management, the information gathered for this paper focuses only on the two makerspace competencies: assembling effective teams and demonstrating understanding of digital fabrication processes, including additive and subtractive processes.

In spring 2018, there were a total of 43 students enrolled in the course. 34 of the students assented to participate in this study. The assessment tool discussed throughout this paper is comprised of pre- and post-self-assessment survey combination. One problem with this type of tool is that it is unknown when a student took the time to read and understand survey questions and answer them fully and honestly. Some students probably clicked through quickly just to finish the survey. We used statistical analysis described by Horowitz & Golob (1979) to assign each survey response an intraclass correlation coefficient based on comparison of their pre- and post- responses. This helped us to identify and remove responses with a high probability of being unreliable, leaving a total of 22 students in the study. All data and analysis provided herein is aggregated from those 22 students’ participation in the study.

Semester-Long Project

The purpose of the Engineering Project Management course is to expose undergraduates to creating teams, using project management tools, and then work on a project using the FabLab in the library. Before the assignment of the project a tour of the FabLab is given, and students then work on creating teams with the data provided from the survey. The project phases consist of idea/design, prototype, and production of a men’s dress shirt. The requirements consist of primary and secondary; the former encompass: sewing, additive & subtractive manufacturing, 2-color screen print, sewing pattern, wooden hanger, and quality check. The latter requirement is an embellishment each team could elect to do for extra credit.

After students created teams for the class project they met with their teams, and presented ideas/designs for the first phase. A Subject Matter Expert (SME) from the FabLab attended the presentation and judged the feasibility of the ideas with the equipment currently available. Several weeks later the teams presented their prototypes and discussed what issues arose, and what actions were to be taken before final production. At final production phase the teams had to display the shirt, and show it is a wearable product.

Exhibit 1, starting on the left, shows an idea for team 6’s logo, initially proposed as a hand drawing. During prototyping (middle) students realized the parts of the drawing which give depth don’t translate well on the
embroidery machine, so changes were made to the Illustrator design to remove some of the finer detail. The image on the right is the final, completed embroidered logo. Exhibit 2, starting on the left, shows Team 2’s initial idea taken from a university landmark. The middle image shows the vinyl-cut stencils which were used on the screen press. It took several iterations of prototyping this screen print before students figured out the optimal order of layers needed, allowing enough drying time between layers, and how to avoid ink bleeding under the stencils. The picture on the right shows the final product.

**Exhibit 1.** Idea, prototype, & production phases of Team 6’s logo.

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**Exhibit 2.** Design inspiration, vinyl-cut templates, and final result of Team 2’s screen print.

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**Assessment of Semester-long Project.** The overarching methods for assessing the semester-long project included a project rubric, an oral progress presentation at midterm with open Q&A, and a final oral presentation with open Q&A. Teams demonstrated their completed dress shirts during their final oral presentation. This being a project management course and not a design course, the teams’ dress shirts were not assessed for quality, function or aesthetics. Rather, teams were assessed for their ability to work as a team to complete the project on time while addressing all project requirements. Assembling effective teams and demonstrating understanding of digital fabrication processes, including both additive and subtractive fabrication, were but two criteria that were assessed, in addition to the myriad other PM fundamentals taught in the course such as scheduling, time management, communication, cost estimation, and risk management.

**Assembling Effective Teams Homework Assignment**

Nagel, Ludwig, & Lewis (2017) used the Clifton StrengthsFinder 2.0 self-assessment with their biology, pre-nursing and engineering students in an interdisciplinary Community Health Innovation course at James Madison University. Students worked together in teams to design and prototype solutions to problems associated with metabolic syndrome.
using their university’s makerspace. Students used the StrengthsFinder data to identify and submit their preferences for team members from among classmates. Instructors used a combination of student preferences, disciplines and needs of the entire group to place students into teams. This model for assembling teams gave students agency in the selection of their team members using real-world data gathered by StrengthsFinder.

We adopted a similar technique using a survey developed in-house that was custom-tailored for the Assembling Effective Teams homework assignment. Our survey utilizes Likert scale, multiple choice and open-ended questions to collect data about students’ experience with project management, team building, working in teams, digital fabrication and other relevant PM topics.

**Assessment of Assembling Effective Teams Homework Assignment.** Competency 4: Assembles effective teams, is comprised of four dimensions: Recognizes opportunities to collaborate with others; Evaluates the costs & benefits of Doing-it-Together (DIT) vs. Doing-it-Yourself (DIY); Seeks team members with skills appropriate for specific project requirements; and Joins a team where his/her skills are sought and valued. In order to measure the impact that the homework assignment had on competency acquisition, we included questions about these dimensions directly into the survey tool utilized in the Assembling Effective Teams homework assignment. The questions asked students “How good are you with the following team building practices?” and listed the four dimensions. Answer options took the form of Likert scales ranging from 1 to 5, where 1=Extremely bad, 2=Somewhat bad, 3=Neither good nor bad, 4=Somewhat good, and 5=Extremely good. In combination with the other project management data collected in the pre-self-evaluation survey, students were able to use these four data points as criteria for creating their Dream Team and “Spread the Awesomeness” scenarios in the homework assignment.

Students who assented to participate in this study answered these questions again at the end of the semester in a post-self-assessment survey. In the post-self-assessment survey, students were asked how good they were with the four team building practices after having completed a project in the makerspace, and they were also asked to reflect back to the beginning of the semester and re-evaluate how good they were with the team building practices before completing the makerspace project. Combined, we collected three data points from each student on all four dimensions of the competency. We can compare these three values in aggregate to get an idea of how much students over- or under-rated their competency when they answered the pre-self-assessment survey, and to compare their competency ratings before and after completing the makerspace project. Exhibit 3 shows the aggregate averages for the three values.

**Exhibit 3. Competency 4: Assembles Effective Teams.**

<table>
<thead>
<tr>
<th>Dimension of Competency</th>
<th>Average from pre-assessment</th>
<th>Average from post-assessment (reflection)</th>
<th>Average from post-assessment (now)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognizes opportunities to collaborate with others</td>
<td>3.18</td>
<td>3.18</td>
<td>3.64</td>
</tr>
<tr>
<td>Evaluates the costs &amp; benefits of Doing-it-Together (DIT) vs.</td>
<td>3.14</td>
<td>3.00</td>
<td>3.55</td>
</tr>
<tr>
<td>Doing-it-Yourself (DIY)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeks team members with skills appropriate for specific project</td>
<td>3.41</td>
<td>3.27</td>
<td>3.73</td>
</tr>
<tr>
<td>requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joins a team where his/her skills are sought and valued</td>
<td>3.18</td>
<td>3.14</td>
<td>3.73</td>
</tr>
</tbody>
</table>

**Digital Fabrication Homework Assignment**
The rapid growth and disruptive potential of digital fabrication technologies found in makerspaces demand education programs that address the fundamental principles of digital fabrication, both additive and subtractive, and enable designers to realize their capabilities (Go & Hart, 2016). The practices in digital fabrication involve a dynamic understanding of how computer programming, design, materials, tools, and processes of fabrication merge in ways that generate rich opportunities for decision making, critical evaluation, and problem solving (Bilkstein et al., 2017).

**Assessment of Digital Fabrication Homework Assignment.** We used a similar pre- and post-self-assessment survey method for assessing Competency 8: Demonstrates understanding of digital fabrication processes. Competency 8 includes three dimensions, namely: Recognizes additive and subtractive fabrication techniques; Applies 3D modeling principles; and, Creates 3D models using appropriate software. Rather than using Likert scales to measure these three dimensions, we employed open-ended essay questions to better capture technology, software and process literacy for
each. Questions included: “Explain the difference between additive and subtractive fabrication techniques”; “List the graphic design and 3D modeling software that you have used”; and “Describe the 3D modeling principles that you might consider during the digital design and fabrication process.”

Additionally, we used Likert scales to capture knowledge of each of the types of fabrication technology that students were expected to learn and use while completing their dress shirts. The question was posed thusly: “Please rate your knowledge of how to use the types of equipment found at the UTA FabLab and other makerspaces,” followed by the list of equipment. Equipment included 3D Printers, Laser Cutter/Engraver, CNC Vinyl Cutter, Screen Printing Press, Sewing Machines/Serger, CNC Embroidering Machine, CNC Mill/ShopBot, and File Preparation for Digital Fabrication (Software). We used a seven-point Likert scale where 1=None, 2=Beginner, 3=Novice, 4=Intermediate, 5=Competent, 6=Advance, and 7=Expert.

All of the questions about digital fabrication processes and technology were included in the same survey used for the Assembling Effective Teams homework, and the responses were included in the data used by students to complete the Assembling Effective Teams homework assignment, adding to the “real world” data that students were able to use to complete that assignment.

Just as with the post-self-assessment for Competency 4, students who assented to participate in this study answered both the open-ended essay questions and the Likert scale technology questions again in a post-self-assessment survey at the end of the semester; and again, students were asked to reflect back to the beginning of the semester and re-evaluate their knowledge of makerspace equipment before completing the makerspace project. Exhibit 4 shows some examples of answers to the open-ended questions; the answers in each row are from the same student, but not all rows are from the same student. Exhibit 5 shows the aggregate averages for the three equipment knowledge values for each type of equipment.

**Exhibit 4.** Sample answers from the Digital Fabrication Processes open-ended essay questions.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer from Pre-Self-Assessment Survey</th>
<th>Answer from Post-Self-Assessment Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explain the difference between additive and subtractive fabrication techniques.</td>
<td>Subtractive is where the 3d printer cut from a material to make the shape and additive is where 3d printer building the design where the materials are on a layer.</td>
<td>Additive is start building up the object from the zero. example, 3d printing. Subtractive works the opposite way by cutting the object we want to form from a whole materiel. example, shop bot.</td>
</tr>
<tr>
<td>List the graphic design and 3D modeling software that you have used.</td>
<td>catia, creo, solidworks, autocad LT</td>
<td>solidworks, creo, catia, autocad, for 3d design experience and inkscape for digital design</td>
</tr>
<tr>
<td>Describe the 3D modeling principles that you might consider during the digital design and fabrication process.</td>
<td>I would make sure not to make materials too thin, make each connection thorough with no accidental spaces, and make holes large enough for easy removal of the mesh filler.</td>
<td>Designing for structure over looks</td>
</tr>
</tbody>
</table>

**Exhibit 5.** Knowledge of FabLab equipment.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Average from pre-assessment</th>
<th>Average from post-assessment (reflection)</th>
<th>Average from post-assessment (now)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printers</td>
<td>2.45</td>
<td>2.73</td>
<td>3.73</td>
</tr>
<tr>
<td>Laser Cutter/Engraver</td>
<td>1.55</td>
<td>1.81</td>
<td>2.45</td>
</tr>
<tr>
<td>CNC Vinyl Cutter</td>
<td>1.41</td>
<td>1.50</td>
<td>2.00</td>
</tr>
<tr>
<td>Screen Printing Press</td>
<td>1.23</td>
<td>1.36</td>
<td>2.23</td>
</tr>
<tr>
<td>Sewing Machines/Serger</td>
<td>2.27</td>
<td>2.09</td>
<td>2.64</td>
</tr>
<tr>
<td>CNC Embroidering Machine</td>
<td>1.50</td>
<td>1.45</td>
<td>2.27</td>
</tr>
</tbody>
</table>
Analysis

Assembling Effective Teams
Having the students design their own teams with skill assessment data survey worked well. The assignment allowed them to create their own teams based on real-life data. For purposes of data analysis, we wanted students to reflect on how good they believed they were in the four dimensions of Competency 4: Assembling effective teams during the post-self-assessment, so that the data would truly represent their self-evaluation at the time of the post-self-assessment, rather than rely on the self-evaluation that they provided at the beginning of the semester. We predicted that students’ self-evaluations at the beginning of the semester would be distorted either high or low, as many of them had likely never encountered a situation requiring them to intentionally, methodically and thoughtfully assemble a team based on real-world data and criteria such as found in the Assembling Effective Teams homework assignment. Therefore, it seemed likely that students would simply take their best-guess about these dimensions of assembling teams. We used the two values for each dimension gathered in the post-self-assessment survey (“reflection” and “now”, as shown in Exhibit 3) to show their actual improvement after having completed the makerspace project.

From the data, we can see that students tended to over-estimate their competencies at the beginning of the semester by an average of 2.46%. This number is derived by averaging the percent difference for all four dimensions in Exhibit 3, “Average from pre-assessment” and “Average from post-assessment (reflection).” In the same fashion, we can see that across all four dimensions, students increased their competencies since the beginning of the semester by an average of 14.07%, derived by averaging the percent difference for all four dimensions in Exhibit 3, “Average from post-assessment (reflection)” and “Average from post-assessment (now)”. Exhibit 6 shows the distilled data.

Exhibit 6: Competency over-estimations at pre-assessment, and increase in competency, as percentage and average change.

<table>
<thead>
<tr>
<th>Dimension of Competency</th>
<th>% Over-estimate at pre-assessment</th>
<th>Average difference</th>
<th>% Increase in Competency (reflection v. now)</th>
<th>Average improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognizes opportunities to collaborate with others</td>
<td>0.00</td>
<td>0.00</td>
<td>12.64</td>
<td>0.46</td>
</tr>
<tr>
<td>Evaluates the costs &amp; benefits of Doing-it-Together (DIT) vs. Doing-it-Yourself (DIY)</td>
<td>4.46</td>
<td>0.14</td>
<td>15.49</td>
<td>0.55</td>
</tr>
<tr>
<td>Seeks team members with skills appropriate for specific project requirements</td>
<td>4.11</td>
<td>0.14</td>
<td>12.33</td>
<td>0.46</td>
</tr>
<tr>
<td>Joins a team where his/her skills are sought and valued</td>
<td>1.26</td>
<td>0.04</td>
<td>15.82</td>
<td>0.59</td>
</tr>
<tr>
<td>Average</td>
<td>2.46</td>
<td>0.00</td>
<td>14.07</td>
<td></td>
</tr>
</tbody>
</table>

Demonstrating Understanding of Digital Fabrication Processes
We anticipated that after having completed the digital fabrication homework assignment, and having completed their makerspace projects, that students’ essay answers would reflect a richer use of makerspace and digital fabrication jargon, a broader collection of software use, and more detailed descriptions of digital fabrication processes. The sample responses in Exhibit 4 weigh up against our expectation in the following ways.

The sample answers in the first row of Exhibit 4 shows a slight improvement in the student’s knowledge of subtractive fabrication. By the end of the semester, the student appears to have learned that a 3D printer does not cut into material, and rather has listed the ShopBot as a subtractive fabrication technology. However, the student’s general understanding of additive vs. subtractive manufacturing didn’t appear to change much. This is an example of where the student seemed to maintain about the same degree of knowledge. This is a predictable scenario for engineering
seniors who have most likely had exposure to both additive and subtractive fabrication technologies at some point in their cohort.

The sample answers in the second row of Exhibit 4 show a much more obvious increase in experience with digital fabrication software. Most of the software products listed in the post-self-assessment were present in the pre-self-assessment, but the student has added the software Inkscape for digital design which presumably the student had not used prior to taking this course. This was a trend among students who answered the surveys, most had picked up experience with one or two new software products. Anecdotally, during their final presentations, nearly every team acknowledged that their members had to use software that they had never used before, most notably vCarve, Illustrator, Photoshop, Gimp and Inkscape. In this case, the oral presentations confirmed survey results which lend to the validity of this survey question.

The sample answers in the third row of Exhibit 4 is an example of the inverse of what we expected to see. The student clearly got lazy or impatient and didn’t take the time to fully answer the question in the post-self-assessment survey. If taken seriously, we would have to draw the conclusion that the student left the course knowing less about 3D modeling principles than they started with. Sadly, this sample is exemplary of the majority of the open-ended essay answers we received. We can imagine that at the end of the semester students simply won’t take the time to answer these types of questions, especially when the surveys are not graded and are completely voluntary. For the most part, students answered these questions fully and honestly in the pre-self-assessment survey, but that survey was part of the Assembling Effective Teams homework assignment, was required of all students, and was factored into the homework grade.

From the equipment knowledge Likert scale data, we can see that for each of the technologies listed in Exhibit 5, students tended to under-estimate their competencies at the beginning of the semester by an average of 5.22 percent. This number is derived by averaging the percent difference for all nine types of technology in Exhibit 5, “Average from pre-assessment” and “Average from post-assessment (reflection).” In the same fashion, we can see that across all nine types of technology, students increased their knowledge since the beginning of the semester by an average of 31.97 percent, derived by averaging the percent difference for all technology types in Exhibit 5, “Average from post-assessment (reflection)” and “Average from post-assessment (now)”. Exhibit 7 shows the distilled data.

**Exhibit 7:** Equipment knowledge under-estimations at pre-assessment, and increase in knowledge, as percentage and average change. Negative values represent over-estimations.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>% Under-estimate at Pre-assessment</th>
<th>Average difference</th>
<th>% Increase in Equipment Knowledge (reflection v. now)</th>
<th>Average improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printers</td>
<td>11.43</td>
<td>0.28</td>
<td>26.81</td>
<td>1.00</td>
</tr>
<tr>
<td>Laser Cutter/Engraver</td>
<td>16.77</td>
<td>0.26</td>
<td>26.12</td>
<td>0.64</td>
</tr>
<tr>
<td>CNC Vinyl Cutter</td>
<td>6.38</td>
<td>0.09</td>
<td>25.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Screen Printing Press</td>
<td>10.57</td>
<td>0.13</td>
<td>39.01</td>
<td>0.87</td>
</tr>
<tr>
<td>Sewing Machines/Serger</td>
<td>-7.93</td>
<td>0.18</td>
<td>20.83</td>
<td>0.55</td>
</tr>
<tr>
<td>CNC Embroidering Machine</td>
<td>-3.33</td>
<td>0.05</td>
<td>36.12</td>
<td>0.82</td>
</tr>
<tr>
<td>CNC Mill/ShopBot</td>
<td>-5.66</td>
<td>0.09</td>
<td>45.05</td>
<td>1.23</td>
</tr>
<tr>
<td>File Preparation for Digital Fabrication (Software)</td>
<td>13.50</td>
<td>0.27</td>
<td>36.77</td>
<td>1.32</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>5.22</strong></td>
<td></td>
<td><strong>31.97</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions and Future Work**

In Spring 2018, we successfully integrated a makerspace project into the Engineering Project Management course. We were able to identify two of our draft Maker Competencies that could be mapped directly to the course learning outcomes, and created homework assignments intended to address each: Assembling Effect Teams, and Demonstrating Understanding of Digital Fabrication Processes. Finally, we developed an assessment method utilizing pre- and post-self-assessment surveys to evaluate and measure student learning and acquisition of the competencies.

Our program team will continue working with this course and other courses for makerspace-course integration and we aim to continue collecting data about the competencies gained when completing projects in makerspaces. Still in the early stages of our research, there is much room for improving our data collection and validation methods. We intend to improve upon the pre- and post-self-assessment surveys by experimenting with
better wording and various response option configurations (Barnette, 2000; Maeda, 2015). We will also validate the survey tools by conducting the Cronbach alpha tests on them, as described by Saorín, et al. (2017).

As we improve our data collection and validation methods, we will also begin looking for patterns to emerge from the data and identify possible correlations between the different data points; for example, we may be able to answer questions about student perceptions of their competencies and how self-perception changes after exposure to working in makerspaces. Not discussed in this paper, we note that 10 participating students indicated that they had previously used the UTA FabLab before taking this course, and 12 indicated that they had not. We could further break down the data analysis above into these two groups and compare their differences. Similarly, we have plans to compare data derived from this data set with future section of the course where students are not required to complete a project in the makerspace, thus providing a natural control group.

Future work will also go more into depth on the other assessment methods used in the course, i.e. project rubric, peer-evaluations and oral presentations. We believe analysis drawn from those sources may help support data gathered by the surveys and will show where these methods corroborate one-another, and where they show disparity.

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Martin Wallace is the Maker Literacies and Engineering Liaison Librarian at the University of Texas at Arlington Libraries. He holds an MLIS from The University of North Texas and an MS in Information Systems from The University of Maine. He has been a liaison to various academic departments in engineering and the sciences for over ten years. He specializes in patent information and information literacy. In his role as Maker Literacies Librarian at UTA, he is investigating ways to incorporate makerspaces into the undergraduate curriculum.