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# Impact of Inclusion of Makerspace and Project Types on Student Comfort with Additive Manufacturing and Three-Dimensional Modeling in First-Year Engineering Program

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# Full Paper: Impact of Inclusion of Makerspace and Project Types on Student Comfort with Additive Manufacturing and Three-Dimensional Modeling in First-Year Engineering Program


## Abstract

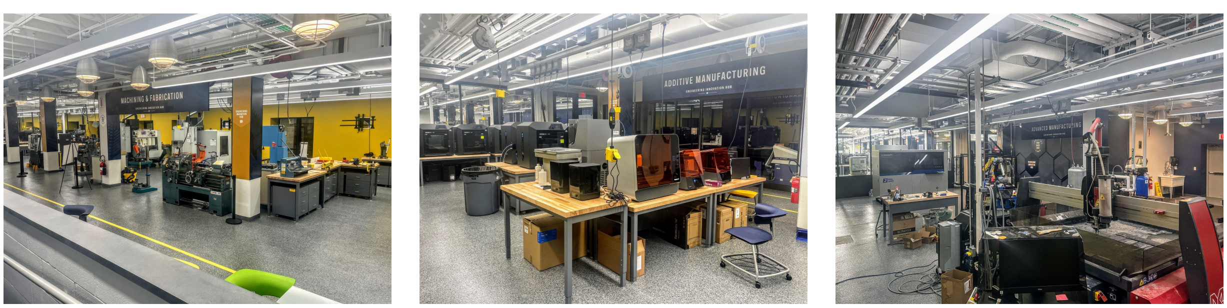
The following evidence-based practice study investigates the impact of utilizing a makerspace on the exposure to additive manufacturing and three-dimensional modeling practices for first-year students. This document builds upon recent literature which illustrated statistically significant gains in a plethora of self-efficacy and sense of belonging metrics over an academic year in which a makerspace was introduced into the course. The metrics analyze results based on gender, race, and high school exposure to college credit academics [1]. This paper presents how a first-year course at the University of Notre Dame incorporated a brand new makerspace (Engineering Innovation Hub) into the first-year engineering sequence of classes. The study explored how student's comfort with both additive manufacturing and three-dimensional modeling changed at three critical points during the fall semester. The student's comfort was gathered through the use of survey questions. The analysis demonstrated that the overall population had statistically significant gains in comfort over the duration of the first-year course as expected. The analysis also determined there were statistically significant gaps in comfort in these topics between female and male students, students whose high schools had three-dimensional modeling courses and those that did not, and students whose high schools had makerspaces and those that did not. For all three of these population pairings, the statistically significant gap in comfort at the start of the semester was reduced by the end of the semester, in a couple of cases to the point that the gap in student comfort in the aforementioned topics was no longer statistically significant. Interestingly, this study did not find statistically significant differences in student comfort based on whether a student was a member of an underrepresented minority population or whether or not the student's high school had programming experiences. Finally, this study presents the impact of project type and the use of an iterative design project on the changes in student comfort with additive manufacturing and three-dimensional modeling.


## Introduction

The Maker Movement arose from individuals who expressed interest in the creation, design, and manufacturing of new objects, and the further sharing these experiences with their peers [2]. These individuals go by makers. As a result, physical locations that serve as meeting spaces for these maker communities have been commonly referred to as makerspaces. Makerspaces provide access to technology, different trainings, inspiration for ideas, and collaboration among members when developing projects [2]. In 2016, the increased popularity of the Maker Movement led to a total of 1,400 makerspaces made available worldwide, 14 times more than those that were available in 2006 [3].

Recent literature has investigated the impact of including a visit to a makerspace during an engineering course. One such study demonstrated statistically significant gains across factors such as design self-efficacy, technology self-efficacy, innovation orientation, innovation self-efficacy, sense of belonging within the makerspace, and sense of belonging within the engineering community. Furthermore, the study looked at the data through the lens of year, gender, and race of the students demonstrating gaps in each [1]. The study outlined in this paper builds upon this previous work to explore how the University of Notre Dame's inclusion of a brand-new makerspace influenced first-year students' comfort with additive manufacturing and three-dimensional modeling through both individual and group projects. The analysis includes a breakdown by gender and race, as well as a comparison based on the resources at the student's high schools. Based on the timing of the surveys, the paper investigates the role that different project components had on student comfort towards additive manufacturing and three-dimensional modeling.

The study was conducted at the University of Notre Dame, a medium-sized, private, Midwestern, residential university, and analyzed the response of students in the First-Year Engineering Program in the Fall 2022 semester. With the creation of a new 10,000 square-foot makerspace, called the Engineering Innovation Hub, the university sought to immerse the first-year students into the new space through three experiences. The first was a tour and safety training of the space during a class period early in the academic year. The next experience was a group project, which was an iterative design project that required the students to create and 3D print a Computer-Aided Design model of a valve that controls the flow of water with a servo motor. The students tested the valves and then based on their results, redesigned the valve in a second iteration. The third experience was an individual project that required students to create an object that met a user-defined set of requirements. The object had to be created with the manufacturing/fabrication capabilities of the makerspace, additive manufacturing, laser cutting, and/or waterjet cutting. Pictures of the Engineering Innovation Hub are shown below in Figure 1.




a) b) c)

**Figure 1.** Engineering Innovation Hub Photos; a) Manufacturing and Fabrication Space, b) Additive Manufacturing Space, c) Advanced Manufacturing Space

The study's analysis is based on three surveys. The first survey occurred at the start of the academic year, the second at the middle of the fall semester (after the first iteration of the group project and before the individual project began), and the third survey was administered at the end of the fall semester. The initial survey asked for students' comfort with the topics of additive manufacturing and three-dimensional modeling along with the resources available at the student's high school. The second survey asked the same questions related to comfort with additive manufacturing and three-dimensional modeling. The end-of-the-semester survey asked the same questions as the second survey, but also included questions about the accessibility to the resources in the makerspace, the amount of interaction between the course and the makerspace, and an open-ended question related to the positive elements/areas of improvement for the space. The timing of the second and third surveys was strategically aligned to gain insight into how the comfort levels towards additive manufacturing and three-dimensional modeling changed initially through only a group project and then secondly through both a group and individual project.

**Previous Work**

In the context of academic settings, makerspaces serve as shared learning hubs that provide students with open access to technology and tools for hands-on making, prompting creative collaboration, and innovative exploration [4, 5]. Making these opportunities in a single location widely accessible to an academically diverse campus is crucial to the development of engineers. Thus, the arrival of academic makerspaces on college campuses indicates an important advancement in the field of engineering design education [2]. Through their use, makerspaces also provide opportunities for students in technical programs to develop professional skills as they practice communicating their designs and ideas to peers [4]. These combined experiences allow students to experiment with the design process, developing a better understanding of it, and have already shown to provide critical benefits in students' engineering design education [3, 4].

Both educators and students agree that the overall effect of having access to makerspaces is positive on both teaching activities and active learning [6, 7]. Makerspaces have proven to boost students' building and prototyping skills. As students share these skills with their fellow makers, students could learn systematic prototyping techniques, which often lead to the creation of more effective prototypes [3].

Survey-based studies conducted at universities representing different demographics and following different teaching curriculums show a positive correlation between engineering design self-efficacy (EDSE) and involvement in academic makerspaces. These studies further revealed that students with higher levels of EDSE tended to remain more engaged in their learning communities and were more likely to excel within their engineering major [3]. Further research regarding the relationship between the use of makerspaces and student self-efficacy suggests that students of all kinds, but particularly students of color, benefit from supportive, affirming peer groups [5]. In fact, students classified as underrepresented minorities (URMs) have been found to have statistically significantly higher levels of anxiety when developing engineering designs as part of their class requirements [3]. Thus, makerspaces benefit URMs because they provide students with supporting peer groups, while giving them the opportunity to visualize themselves as successful within the previously established predominantly white and male STEM population [5].

This study will look to build upon the previous work done in this field with a focus on the modality of the types of projects conducted in the makerspace. Furthermore, the study will use the lens of gender, ethnicity, and resources of students' high schools as part of the analysis.

## Context and Framework

### *Research Questions*

The authors focused on the following two research questions:

1. RQ1: What was the impact on student comfort in additive manufacturing and three-dimensional modeling of the second iteration of the group project and the individual project? ("Question #1)
2. RQ2: Were there gaps in comfort levels with additive manufacturing and three-dimensional modeling between different populations entering the course? Furthermore, if there were, did the projects, with extensive use of the makerspace, close those gaps? ("Question #2)

### *Framework*

Surveys were used as the primary modality to gain insights into student comfort levels with additive manufacturing and three-dimensional modeling through the fall semester. Table 1 outlines the relevant questions asked on the surveys and on which survey they appeared. In addition to the survey questions, ethnicity data was also used in the analysis. A total of 422 students completed at least one survey and agreed to participate in the analysis. The survey was originally sent to a population of 523 students (i.e., 81% of students invited to participate completed at least one survey and agreed to participate).

Two tailed t-tests were used to determine statistical significance and the calculated p-values were compared to the threshold value of 0.05 in order to establish statistical significance at a 95% confidence level.

**Table 1.** Summary of Survey Questions

<table>
<tr><th>Survey Question</th><th>Response Type</th><th>First Survey</th><th>Second Survey</th><th>Third Survey</th></tr>
<tr><td>To what degree do you agree with the following statement:<br><br>“I am comfortable with the topic of Additive Manufacturing (i.e., 3D Printing)”</td><td><u>Likert Scale:</u><br>Strongly Agree<br>Somewhat Agree<br>Neither Agree Nor Disagree<br>Somewhat Disagree<br>Strongly Disagree</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>To what degree do you agree with the following statement:<br><br>“I am comfortable with the topic of SOLIDWORKS (i.e., 3D Modeling)”</td><td><u>Likert Scale:</u><br>Strongly Agree<br>Somewhat Agree<br>Neither Agree Nor Disagree<br>Somewhat Disagree<br>Strongly Disagree</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>What types of programs were offered at your high school or place of secondary education?</td><td><u>Select all that apply:</u><br>STEM AP Courses<br>Courses on Computer Programming<br>Courses Involving 3D Modeling<br>3D Printers/Makerspaces</td><td>X</td><td></td><td></td></tr>
<tr><td>Gender</td><td>Male<br>Female<br><br>Note: Non-binary, prefer not to answer, and a write in option were included, but due to less than 5 responses to each option, they are not included in the analysis</td><td>X</td><td></td><td></td></tr>
</table>

## Results

*Results to Research Question 1*

The first analysis conducted was related to the change in student comfort with the topics of additive manufacturing and three-dimensional modeling over the course of the semester. Since the course included instruction and experiential learning related to both of these topic areas, it was expected that student comfort would increase throughout the semester. The focus of this analysis, however, was to investigate if the increase in the comfort level of the students would occur towards the second half of the semester. This would indicate that the second iteration of the project and/or the individual project were beneficial in increasing student comfort with these topic areas. Figures 2 and 3 contain the student responses at the start, middle, and end of the semester for the students’ agreement with the following statements, respectively:

I. I am comfortable with the topic of Additive Manufacturing (i.e., 3D Printing)
II. I am comfortable with the topic of SolidWorks (i.e., 3D Modeling)

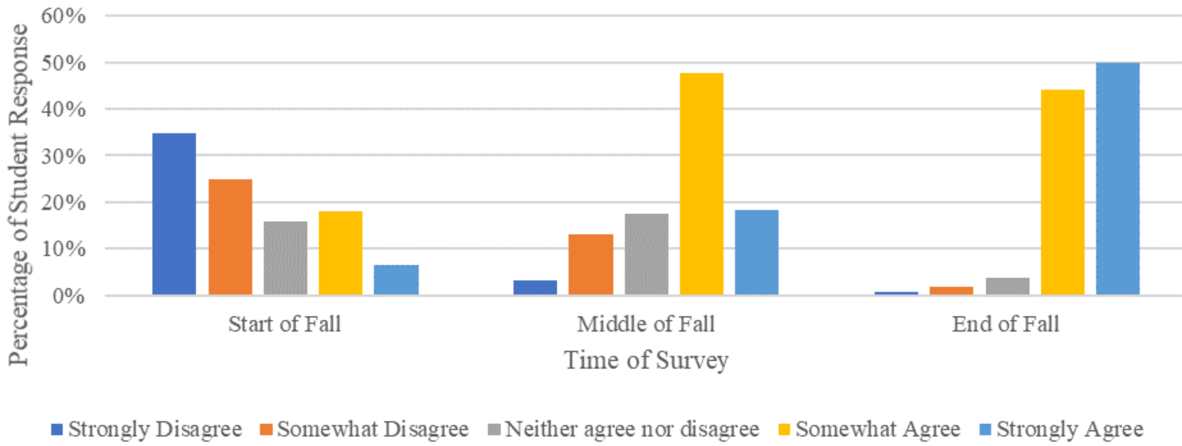



**Figure 2.** Student Comfort with Additive Manufacturing at Different Points in Fall Semester

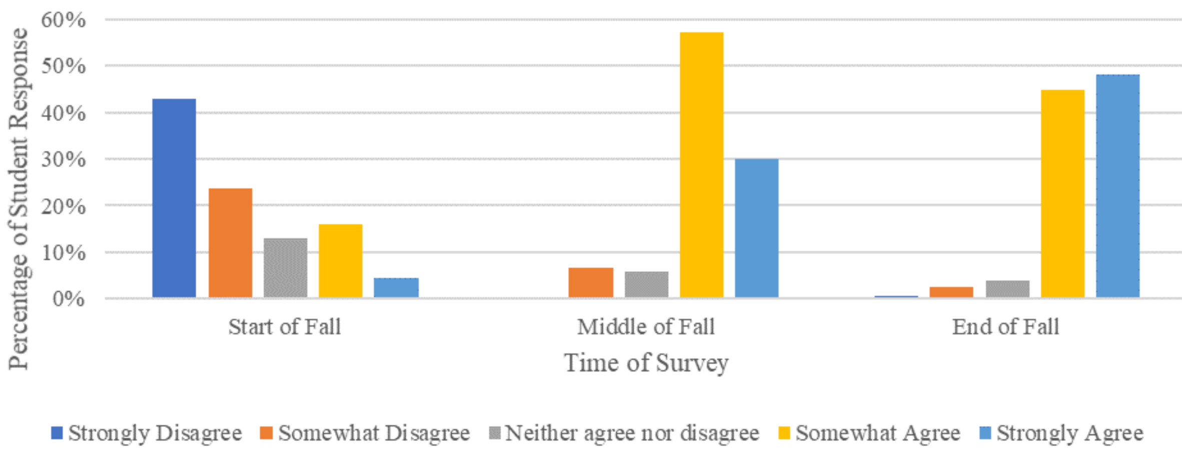



**Figure 3.** Student Comfort with 3D Modeling at Different Points in Fall Semester

Table 2 has the numerical averages for this data on a 1-5 scale, with a 5 representing Strongly Agree and 1 representing Strongly Disagree. Table 2 also contains the Gap Reduction between the Middle and Start of the Semester and the End and Middle of the Semester. This metric is the difference between the respective survey values divided by the difference between 5 (i.e, maximum value) and the earlier of the two survey points. This represents the percentage of the "gap" closed between the two survey points.

**Table 2.** Numerical Data on Student Comfort with Additive Manufacturing and 3D Modeling[1]

| | **Start of Fall** | **Middle of Fall** | **Gap Reduction (Middle:Start)** [2] | **End of Fall** | **Gap Reduction (End:Middle)**[3] |
|---|---|---|---|---|---|
| **Additive Manufacturing** | 2.36 (N = 422) | 3.65* (N = 392) | 49% | 4.41* (N = 416) | 56% |
| **Three-Dimensional Modeling** | 2.15 (N = 422) | 4.10* (N = 392) | 68% | 4.37* (N = 416) | 30% |
| * denotes a p-value < 0.05 | | | | | |

As expected, using a paired T-test for students responding to all surveys, the gains for both questions from the start to middle and the middle to the end of the semester were significant.

**Additive Manufacturing:** Note that the significant gains from the student comfort levels occurred primarily from the middle of the fall semester to the end of the fall semester, during which the students completed the second iteration of the project and an individual project. In fact, using the gap reduction metric (which is a means to measure what percentage of the gap between the starting average and maximum average was reduced at the second time point), the gap reduction was larger from the middle of the fall semester to the end of the fall semester than from the start of the fall semester to the middle of the fall semester for students' comfort with additive manufacturing. Given the layout of the course, this is likely because during the second half of the semester, the students received their 3D printed parts from the first and second iterations as well as completed their individual projects.

**Three-Dimensional Modeling:** For student comfort with three-dimensional modeling, the larger gap reduction was during the first half of the semester. This is likely because all of the classroom instruction and individual homework assignments in SolidWorks occurred in the first half of the semester (whereas in the second half of the semester, the student had to apply their three-dimensional knowledge to projects).

*Results to Research Question 2*

Next, the analysis focused on whether there were initial gaps in student comfort for additive manufacturing and three-dimensional modeling by gender, minority status, and the student's high school resources.

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[1] These averages are between 1 and 5.
[2] Gap Reduction (Middle:Start) equals the Middle of Fall average minus the Start of Fall average divided by the difference between 5 (maximum score) and the Start of Fall average.
[3] Gap Reduction (End:Middle) equals the End of Fall average minus the Middle of Fall average divided by the difference between 5 (maximum score) and the Middle of Fall average.

**Analysis by Gender:** The authors first parsed the data by gender. Figure 4 and Figure 5 show the average response (1 represents Strongly Disagree, 5 represents Strongly Agree) at the start, middle and end of the fall semester by gender for student comfort with additive manufacturing and three-dimensional modeling, respectively. Table 3 contains these average values in tabular form.

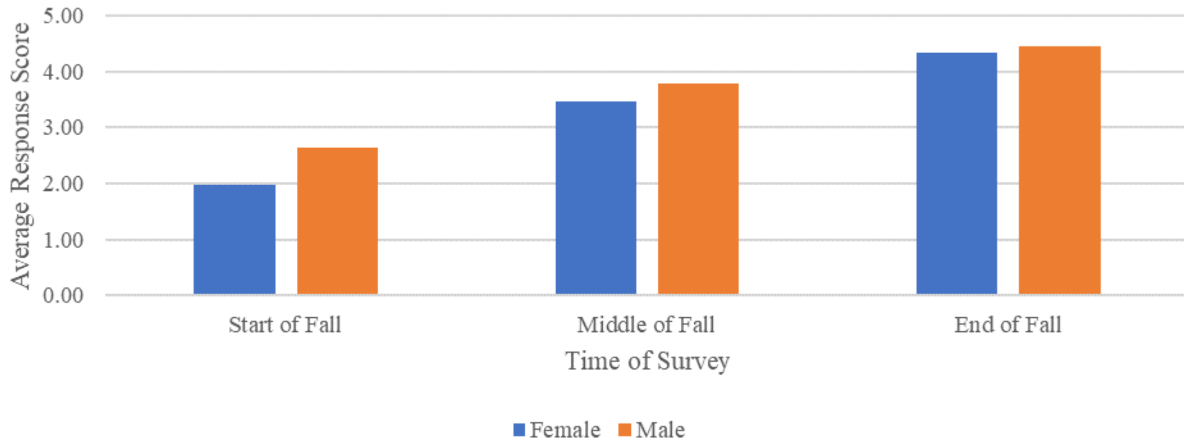


**Figure 4.** Student Comfort with Additive Manufacturing at Different Points in Fall Semester By Gender

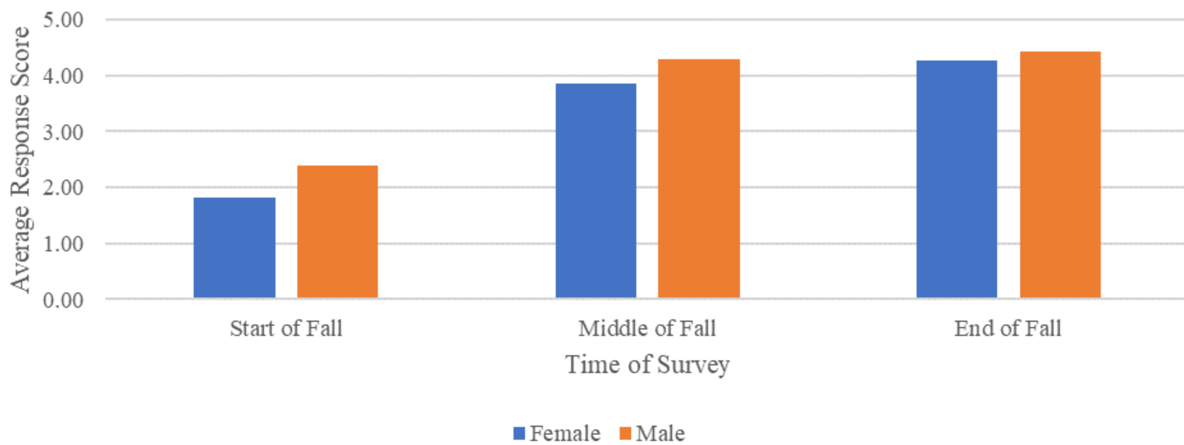


**Figure 5.** Student Comfort with 3D Modeling at Different Points in Fall Semester By Gender

**Table 3.** Student Comfort with Additive Manufacturing and 3D Modeling By Gender

| | | Start of Fall | Middle of Fall | End of Fall |
|---|---|---|---|---|
| **Additive Manufacturing** | **Female** | 1.98 (N = 178) | 3.47 (N = 169) | 4.34 (N = 174) |
| | **Male** | 2.63 (N = 241) | 3.78 (N = 220) | 4.46 (N = 239) |
| | **P-Value** | p < 0.001 | p = 0.004 | p = 0.12* |
| **Three-Dimensional Modeling** | **Female** | 1.81 (N = 178) | 3.85 (N = 169) | 4.26 (N = 174) |
| | **Male** | 2.39 (N = 241) | 4.29 (N = 220) | 4.44 (N = 239) |
| | **P-Value** | p < 0.001 | p < 0.001 | p = 0.02 |

Figures 3 and 4 show a narrowing gap between the responses from female and male students over the course of the semester in terms of their comfort with both additive manufacturing and three-dimensional modeling. Furthermore, the gap between these two populations is statistically significant for both additive manufacturing and three-dimensional modeling at the start of the semester. At the middle of the semester, the gap is smaller, yet still statistically significant. However, by the end of the semester, the gap is no longer statistically significant for the additive manufacturing comfort (denoted by the * in Table 3) and the gap for three-dimensional modeling comfort is significantly smaller (although the gap is still statistically significant). This demonstrates that the exposure through both a group project and an individual project over the course of the fall semester closed the gap between female and male students in regards to their comfort with additive manufacturing and three-dimensional modeling.

**Analysis by Ethnicity:** Next, the authors parsed the data by under-represented minority status. Since different organizations may have different guidelines regarding which populations are included in the under-represented minority status, the analysis included two variations:

- Variation 1 - Underrepresented minority status includes: American Indian, Alaskan Native, Black, Asian or Pacific Islander, Native Hawaiian Pacific Island, or Hispanic (sample size was between 106 and 116 depending on the survey)
- Variation 2 - Underrepresented minority status includes: American Indian, Alaskan Native, Black, Native Hawaiian Pacific Island, or Hispanic (sample size was between 78 and 86 depending on the survey)

For both sets of variations, there was no statistically significant difference between the underrepresented minority population and the students that were not in the underrepresented minority population (p-values all greater than 0.10).

**Analysis by Resources offered at the Student's High School:** Lastly, the authors analyzed the student responses based on the opportunities available at the students' high schools or locations of secondary education. It should be noted that the question asked was "what was offered at the students' high schools" and not "which resources were utilized". Future iterations of this research will inquire about which resources were used.

**Availability of Makerspaces or 3D Printing:** The first type of resource that was investigated was availability of makerspaces or 3D printing. Figure 6 and Figure 7 show the average response (1 represents Strongly Disagree, 5 represents Strongly Agree) at the start, middle, and end of the fall semester for student comfort with additive manufacturing and three-dimensional modeling, respectively, based on whether or not makerspaces or 3D printing was available at the student's high school. Table 4 contains these average values in tabular form.

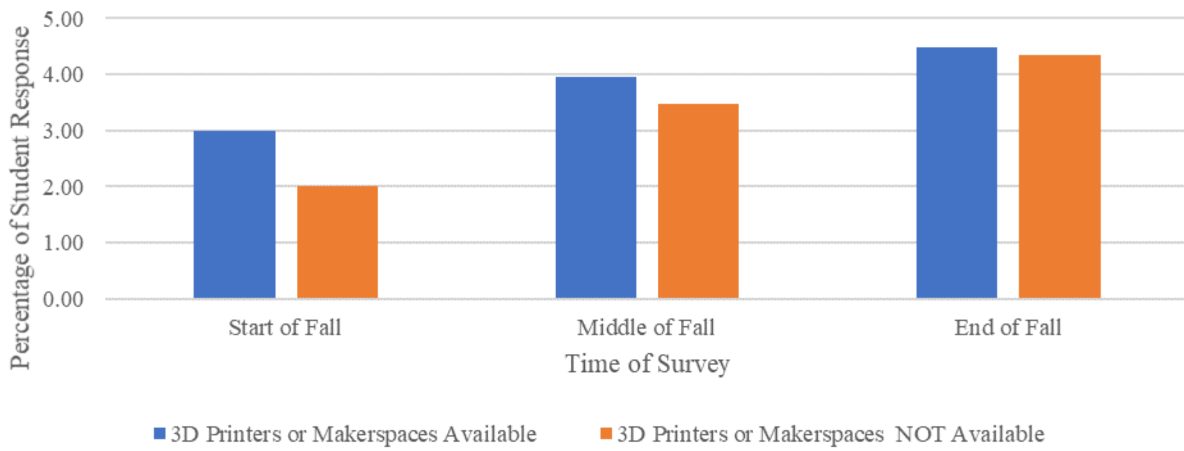


**Figure 6.** Student Comfort with Additive Manufacturing at Different Points in Fall Semester By Availability of 3D Printers or Makerspaces in High School

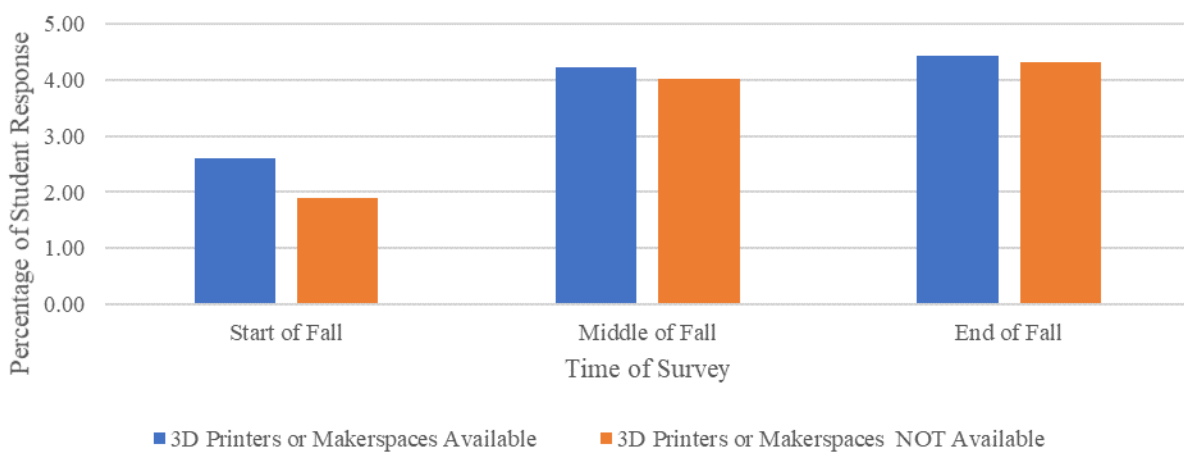


**Figure 7.** Student Comfort with 3D Modeling at Different Points in Fall Semester By Availability of 3D Printers or Makerspaces in High School

**Table 4.** Student Comfort with Additive Manufacturing and 3D Modeling By Availability of 3D Printers or Makerspaces in High School

| | | Start of Fall | Middle of Fall | End of Fall |
|---|---|---|---|---|
| **Additive Manufacturing** | **Makerspaces or 3D Printing Available** | 2.99 (N = 155) | 3.97 (N = 143) | 4.49 (N = 154) |
| | **Makerspaces or 3D Printing *NOT* Available** | 2.00 (N = 267) | 3.47 (N = 249) | 4.35 (N = 262) |
| | **P-Value** | $p < 0.001$ | $p < 0.001$ | $p = 0.04$ |
| **Three-Dimensional Modeling** | **Makerspaces or 3D Printing Available** | 2.60 (N = 155) | 4.23 (N = 143) | 4.44 (N = 154) |
| | **Makerspaces or 3D Printing *NOT* Available** | 1.90 (N = 267) | 4.03 (N = 249) | 4.33 (N = 262) |
| | **P-Value** | $p < 0.001$ | $p = 0.02$ | $p = 0.15$* |

For both student comfort with additive manufacturing and three-dimensional modeling, there are initially statistically significant differences between those students that had makerspaces or 3D printing at their high schools versus those who did not. This is consistent with what one would expect. However, by the end of the fall semester, the gap between the two populations of students had closed and there was no statistically significant difference for three-dimensional modeling (denoted by the * in Table 4). Furthermore, the gap for comfort with additive manufacturing closed substantially, although the p-value was slightly lower than the threshold for statistical significance (i.e., the difference in the populations were still statistically significant).

**Availability of 3D Modeling Courses:** The next variable that was investigated was related to students who came from a high school with courses involving three-dimensional modeling. Figures 8 and 9 illustrate the data following the same format as Figures 5 and 6. Table 5 contains these average values in tabular form.

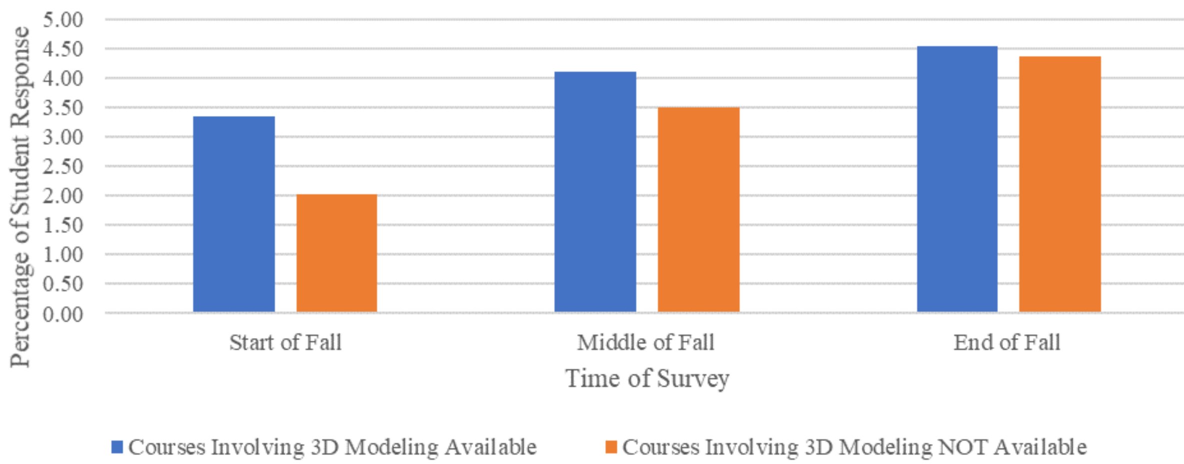

**Figure 8.** Student Comfort with Additive Manufacturing at Different Points in Fall Semester By Availability of Courses on 3D Modeling

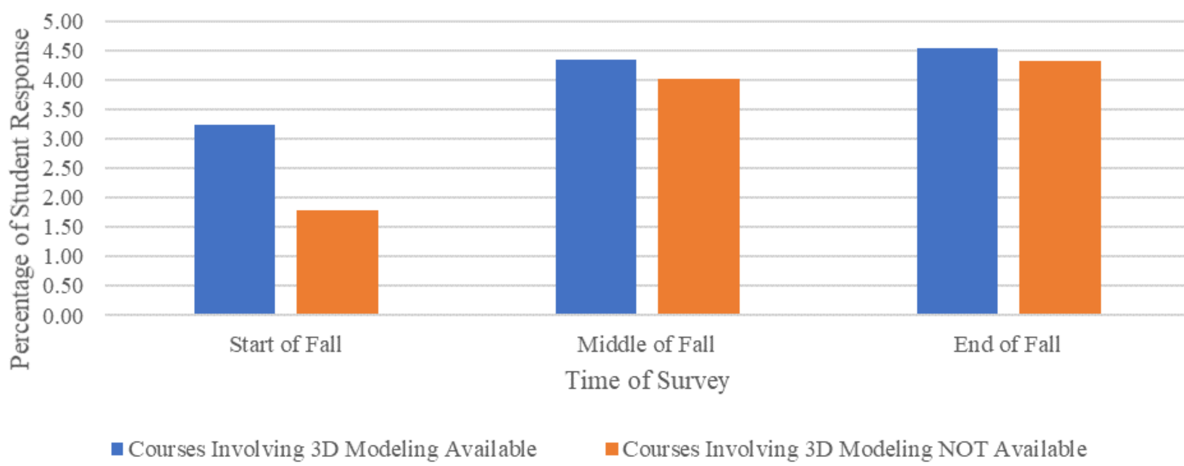


**Figure 9.** Student Comfort with 3D Modeling at Different Points in Fall Semester By Availability of Courses on 3D Modeling

**Table 5.** Student Comfort with Additive Manufacturing and 3D Modeling By Availability of Courses on 3D Modeling

| | | **Start of Fall** | **Middle of Fall** | **End of Fall** |
|---|---|---|---|---|
| **Additive Manufacturing** | **Courses on 3D Modeling Available** | 3.35 (N = 106) | 4.11 (N = 99) | 4.53 (N = 105) |
| | **Courses on 3D Modeling *NOT* Available** | 2.03 (N = 316) | 3.49 (N = 293) | 4.36 (N = 311) |
| | **P-Value** | $p < 0.001$ | $p < 0.001$ | $p = 0.02$ |
| **Three-Dimensional Modeling** | **Courses on 3D Modeling Available** | 3.25 (N = 106) | 4.33 (N = 99) | 4.52 (N = 105) |
| | **Courses on 3D Modeling *NOT* Available** | 1.79 (N = 316) | 4.02 (N = 293) | 4.32 (N = 311) |
| | **P-Value** | $p < 0.001$ | $p = 0.001$ | $p = 0.007$ |

For both student comfort with additive manufacturing and three-dimensional modeling, there are initially statistically significant differences between those students that had courses related to 3D modeling at their high schools versus those that did not. This is again consistent with what one would expect. However, over the course of the semester, the gap between these two populations decreased substantially as illustrated in Figures 8 and 9.

**Availability of Programming Courses and STEM AP Courses:** Lastly, the authors also looked at the differences in student comfort with additive manufacturing and three-dimensional modeling based on whether courses in programming were offered at the students' high school and whether or not the high school offered STEM AP courses. These breakdowns are presented below in Tables 6 and 7, respectively.

**Table 6.** Student Comfort with Additive Manufacturing and 3D Modeling By Availability of Courses on Programming

| | | **Start of Fall** | **Middle of Fall** | **End of Fall** |
|---|---|---|---|---|
| **Additive Manufacturing** | **Courses on Programing Available** | 2.44 (N = 288) | 3.72 (N = 265) | 4.42 (N = 283) |
| | **Courses on Programing _NOT_ Available** | 2.20 (N = 134) | 3.50 (N = 127) | 4.38 (N = 133) |
| | **P-Value** | p = 0.08* | p = 0.05* | p = 0.54* |
| **Three-Dimensional Modeling** | **Courses on Programing Available** | 2.22 (N = 288) | 4.12 (N = 265) | 4.39 (N = 283) |
| | **Courses on Programing _NOT_ Available** | 2.02 (N = 134) | 4.07 (N = 127) | 4.33 (N = 133) |
| | **P-Value** | p = 0.14* | p = 0.58* | p = 0.49* |

**Table 7.** Student Comfort with Additive Manufacturing and 3D Modeling By STEM AP Course Availability

| | | **Start of Fall** | **Middle of Fall** | **End of Fall** |
|---|---|---|---|---|
| **Additive Manufacturing** | **STEM AP Courses Available** | 2.34 (N = 388) | 3.68 (N = 359) | 4.41 (N = 383) |
| | **STEM AP Courses _NOT_ Available** | 2.65 (N = 34) | 3.27 (N = 33) | 4.36 (N = 33) |
| | **P-Value** | p = 0.23* | p = 0.09* | p = 0.76* |
| **Three-Dimensional Modeling** | **STEM AP Courses Available** | 2.13 (N = 388) | 4.09 (N = 359) | 4.37 (N = 383) |
| | **STEM AP Courses _NOT_ Available** | 2.38 (N = 34) | 4.18 (N = 33) | 4.33 (N = 33) |
| | **P-Value** | p = 0.31* | p = 0.57* | p = 0.82* |

Table 6 demonstrates that there were not significant gaps in student comfort with additive manufacturing and/or three-dimensional modeling between students who had programming courses at their high school and those that did not (as denoted by the * in Table 6). The small gap that did exist at the start of the semester became even smaller by the end of the semester.

Interestingly, those students that did not have STEM AP courses available at their high school initially expressed more comfort on average in additive manufacturing and three-dimensional modeling at the start of the semester than those with STEM AP courses. Nevertheless, this gap remained statistically insignificant throughout the semester (as denoted by * in Table 7). One hypothesis for this observation is that curriculums without STEM AP courses available had more hands-on experiential learning opportunities available, thus increasing the student's overall comfort via a hands-on learning approach. Another hypothesis could be that schools without AP courses may communicate career options differently than those schools with AP courses and thus students at these schools feel more compelled to explore hands-on opportunities. A more detailed understanding of the student's secondary education would be needed to understand this difference more definitively.

**Future Works**

The study outlined in this paper focused on student perceptions of their abilities rather than their performance using these technologies in the classroom. One reason for this was that most grades in the course related to these technologies were either (i) group work or (ii) included rubric items not related to students actually using the technologies (i.e., on-time submission, presentations, following project scope, etc.). Future studies could investigate student perceptions of their abilities and their performance using the technologies as well.

Furthermore, additional questions/context could be added to the survey to provide additional insights:

- A question asking what the students mean by comfort or providing context about how we define comfort would help narrow the range of what comfort might mean to the students.
- A question asking about engineering self-efficacy could be added to see if there are correlations between comfort with the technologies mentioned in this study and students' engineering self-efficacy.
- A question about the likelihood that the students will use the space again to determine how many and which students are most likely to continue using these technologies.

Finally, similar future assessments could consider differentiating between the overall concept of 3D modeling and the individual skills needed in SolidWorks to understand potential differences in student's comfort with the overall concept of modeling in three dimensions and their ability to use specific SolidWorks tools and/or features.

**Conclusions**

This paper outlined a study focused on student comfort related to additive manufacturing and three-dimensional modeling through the fall semester of a first-year engineering course at a medium-sized midwestern university. The first-year engineering course, which focused on the engineering design process, integrated a brand-new makerspace into the curriculum through both a multiple iteration group project and an individual project. Students stated their comfort level with the aforementioned topics through three surveys. The first survey was at the start of the academic year, the second survey was after the first iteration of the group project, and the last survey was after the second iteration of the group project and the individual project.

The results showed statistically significant increases in comfort for the entire student population. The comfort increase in additive manufacturing was most significant in the second half of the semester, during the second iteration of the group project and the individual project. The comfort increase in three-dimensional modeling was more significant in the first half the semester, which was when SolidWorks was initially taught and students completed homework assignments related to SolidWorks along with the first iteration of the group project. At the start and middle of the fall semester, there were statistically significant gaps between the following pairs of populations: (i) male and female students, (ii) students whose high school had courses on three-dimensional modeling and those that did not, and (iii) students whose high school had makerspaces and those that did not. However, these gaps substantially narrowed by the third survey, demonstrating the effectiveness in the course assignments in narrowing gaps in student comfort towards additive manufacturing and three-dimensional modeling. There were no statistically significant gaps between students who are underrepresented minorities and those that were not. Additionally, there were no statistically significant differences between students whose high school had programming courses and those that did not or between students whose high school had STEM AP courses and those that did not.

Finally, based on the final survey, approximately 50% of students felt that they interacted with the makerspace the right amount of time while approximately 50% of the students felt that they want more interaction with the makerspace in the future. This demonstrates the potential for even more collaboration between the first-year engineering program and the makerspace.

In summary, the main takeaway of the study was that the use of a multiple iteration group project paired with an individual project (both of which relied on the use of a makerspace) was able to significantly improve student comfort with additive manufacturing and 3D modeling consistently throughout the sequence of the projects. Furthermore, the study demonstrated the narrowing of the initial gaps in student comfort of these topics for various subgroups of students (female vs. male; students with prior experience with the technology vs. those that had no prior experience, etc.).

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