Assessing the Effectiveness of a Large, Open-Ended Design Project in a Junior-Level Engineering Technology Course

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At our university, junior-level Engineering Technology majors in Applied Systems Technology take a course entitled, "Rapid Tooling and Prototyping." Historically, the focus of this course has been on machine shop practice and the use of numerically-controlled machine tools in manufacturing. During Fall semester of 2017, we implemented modifications to the Rapid Tooling and Prototyping course that were intended to emphasize the effective use of computer aided engineering tools in the product development and prototyping process. These modifications included the addition of a five-week-long, open-ended design and fabrication project. The project objective was to give students experience with the entire computer-aided design and fabrication process and to apply it to their own, original design. Interestingly, surveys indicated that students did not respond well to the open-ended nature of the design project. In response to this feedback, the course was re-structured for the Fall of 2018 and the large, open-ended project was replaced by a series of smaller, more well-defined design and fabrication projects. In this paper, we compare student achievement and student self-assessment of learning and engagement between the Fall 2017 and Fall 2018 versions of the course. In particular, we examine student response to the large, open-ended design project and the effects that the project had on student engagement. We then draw conclusions as to how original design and fabrication project work could be more effectively integrated into this course.

Introduction

The College of Engineering and Technology at Western Carolina University offers degree programs in engineering and engineering technology with concentrations in mechanical, electrical, and power systems engineering. The curricula of these programs include a strong focus on the skills and knowledge needed in engineering practice. All programs include a five-course, interdisciplinary, project-based learning (PBL) sequence that focuses on student-driven projects with application-oriented outcomes.[1,2] In addition to the PBL sequence, courses throughout the Engineering and Technology curricula incorporate projects that are intended to give students the opportunity to apply skills and theory to practical problems. It has been demonstrated that this project-based approach can foster student engagement and build self-confidence. [3 - 5]

One of the undergraduate degrees offered in the College of Engineering and Technology is a Bachelor of Science in Engineering Technology (BSET) with a focus on Applied Systems Technology. The curriculum for this degree is a blend of courses that are often found in Manufacturing Engineering Technology and Mechanical Engineering Technology programs. Students take courses in solid mechanics, thermodynamics, materials, manufacturing, and statistical process control.

ET 349, Rapid Tooling and Prototyping, is a required, junior-level course that is taken exclusively by BSET majors. The university catalog describes the course content as follows: "Prototyping methods and rapid tooling practices for product fabrication. Emphasis on computer methods, 3D prototyping, CNC machining and tooling systems." [6] The course is a combined lecture/lab course, with two hours of lecture and two hours of lab per week. Most students taking the course have completed their math and physics requirements and have taken courses in Statics, Materials and Manufacturing, and a two-course sequence in Computer-Aided Design (CAD).

In the past, ET 349 focused almost exclusively on machine shop practice and the use of NC machine tools. Assignments focused on selection of cutting tools and process conditions, use of CAM tools, NC programming, and operation of Haas NC mills and lathes. Lab assignments consisted of a series of small machining projects in which students followed step-by-step instructions to make a pre-designed product. Table 1 lists the topics covered in the course during the past few years.

In Fall 2017, a change in instructors presented the opportunity to update the content and structure of the course. It was decided that the focus of the course should be expanded to cover the entirety of the rapid design and prototyping process. The emphasis on fabrication using NC machine tools was maintained, however the course content was expanded to cover shop-level metrology and the integrated use of CAD and CAM tools for rapid design and prototyping.

A major feature of the revised course was the inclusion of a large, open-ended design and fabrication project. This project, which spanned the last five weeks of the course, was intended to give students an opportunity to apply the entire rapid design and prototyping process to an original product design. Students were presented with a scenario in which an entrepreneur hires them to design and prototype a single, hand-held device that could serve as both a flashlight and a bottle opener. In order to successfully complete the project, students had to construct a virtual prototype in CAD, present their design ideas to a "customer," construct a process plan using both an NC mill and an NC lathe, select tooling and process parameters, fabricate components, and finally, assemble and debug their prototypes.

Table 1: Course content for the pre-2017, 2017, and 2018 versions of ET 349.

<table>
<tr><th>Week</th><th>Pre-2017</th><th>Fall 2017</th><th>Fall 2018</th></tr>
<tr><td>1</td><td>Mill Tooling and Process Conditions</td><td>Survey of mechanical fabrication processes</td><td>Survey of mechanical fabrication processes</td></tr>
<tr><td>2</td><td rowspan="2">Fixturing, setup, and controller operation on the Haas mill</td><td>Mill Tooling and Process Conditions</td><td>Mill Tooling and Process Conditions</td></tr>
<tr><td>3</td><td>Fabrication of a simple part on the Haas mill</td><td>Use of CAM software to generate NC code for the Haas mill</td></tr>
<tr><td>4</td><td>Manual NC programming on the Haas mill</td><td>Effective use of CAD tools in rapid product design and prototyping</td><td>Fabrication of a simple part on the Haas mill</td></tr>
<tr><td>5</td><td>Use of CAM software to generate NC code for the Haas mill</td><td>Use of shop-level metrology tools to verify component geometry</td><td rowspan="2">Use of shop-level metrology tools to verify component geometry</td></tr>
<tr><td>6</td><td rowspan="2">Fabrication of a complex part on the Haas mill</td><td>Manual NC programming on the Haas mill</td></tr>
<tr><td>7</td><td>Use of CAM software to generate NC code for the Haas mill</td><td>Effective use of CAD tools in rapid product design and prototyping</td></tr>
<tr><td>8</td><td>Lathe Tooling and Process Conditions</td><td>Design and fabrication of an assembly using the Haas mill and Haas laser cutter</td><td rowspan="2">Design and fabrication of an assembly using the Haas mill and Haas laser cutter</td></tr>
<tr><td>9</td><td>Use of CAM software to generate NC code for the Haas lathe</td><td>Lathe Tooling and Process Conditions</td></tr>
<tr><td>10</td><td rowspan="2">Fabrication of a simple part on the Haas lathe</td><td rowspan="5">Large, open-ended design and fabrication project. Included the fabrication of parts on the Haas mill and Haas lathe</td><td>Manual NC programming on the Haas mill</td></tr>
<tr><td>11</td><td>Lathe Tooling and Process Conditions</td></tr>
<tr><td>12</td><td>Using CAM software to generate NC code for the Haas laser cutter</td><td>Use of CAM software to generate NC code for the Haas lathe</td></tr>
<tr><td>13</td><td>Basic operation of the Haas laser cutter</td><td rowspan="2">Design and fabrication of a component using the Haas lathe</td></tr>
<tr><td>14</td><td>Introduction to Additive Manufacturing</td></tr>
</table>

One of the primary reasons for the inclusion of this large, open-ended project was to increase student engagement and generate enthusiasm for the field of product design and development. As discussed below, results of this engagement aspect of the project were mixed. Student Assessment of Instruction (SAI) surveys showed that while some students did find the project engaging, many were frustrated with the open-ended, less-structured nature of the project. These students interpreted the lack of project structure as a lack of organization and did not respond favorably to the challenge of creating a unique product.

In order to address this frustration, the course was modified for the Fall of 2018. In this iteration, the large project was removed and the course was structured as a series of smaller, more well-defined projects. The focus on the entire design and rapid prototyping process was retained and most of the projects retained some original design content, however, choices of tooling and process parameters were narrowed and the projects were designed to utilize specific process steps. The goal of these changes was to reduce student confusion and frustration associated with the open-ended project while still fostering engagement by allowing students to perform original design. Table 1 includes the sequence of topics covered in this version of the course.

In this paper, measures of student achievement and engagement for the Fall 2017 and Fall 2018 versions of the course are presented. Instructor assessment of student learning and student self-assessment surveys are compared and used as the basis of a discussion of the effects of a large, open-ended project in a skills-based, Engineering Technology course such as ET 349.

Methods

Data collected for this study comes from multiple sections of ET 349, all of which were taught by the same instructor. In Fall 2017 there were three sections with 17, 15, and 10 students. In Fall 2018 there were two sections with 15 and 8 students. While the total number of students in the study varies between the two years, the average class size is similar.

The data comes from three sources:

1) Instructor assessment of student achievement of course outcomes

2) Student responses to SAI statements related to engagement and learning

3) An end-of-semester survey designed to assess students' self-confidence and engagement with the course material

The four learning outcomes that were assessed were selected for their high degree of relevance to the course material. These outcomes are listed in Table 2. Achievement of each outcome was assessed by the course instructor using exam problems and excerpts from lab projects. In most cases, the assignments that were assessed were the same for both years, however there were some differences caused by changes in the laboratory assignments between years.

Four statements from SAI surveys were considered; these are included in Table 3. These statements were selected because they pertain to student engagement and their self-impressions of learning.

In order to obtain more detailed information regarding student engagement, interest, and self-assessment of learning, a second end-of-semester survey was created and administered at the end of Fall 2017 and Fall 2018. Questions in this survey were focused on students' confidence in their ability to perform tasks related to primary course outcomes. The survey begins by describing the following hypothetical scenario:

> *A friend introduces you to their aunt, who has an idea for a new kind of hand-held, adjustable wrench. By the nature of the idea it is clear that the wrench will consist of multiple components held together by some sort of fastening methods.*
>
> *The idea seems workable, however the aunt is not an engineer and does not have the skills needed to develop her idea into a working prototype. She offers you a considerable sum of money if you can develop her idea into a design plus a working prototype in one month.*
>
> *You have access to all of the computer-aided design, analysis, and manufacturing tools and all of the fabrication and measurement tools that you might need. You also have access to skilled technicians that will perform any fabrication operations that you specify.*

Following this description, students were asked the first four questions shown in Table 4. Each of these questions is intended to measure a student's self-confidence in their ability to perform tasks related to the primary course outcomes. Questions were phrased in terms of self-confidence in order to explicitly target the student's own impression of their abilities after taking the course. Rather than asking the question, "Do you think that you learned this?," the survey was intended to ask, "Do you think that you can do this?" In a skills-based course such as ET 349, development of a student's confidence reflects their development of skills.

The last question in the secondary survey was, "How happy would you be to spend part of your career working in the field of mechanical design?" The changes to the course beginning in the Fall of 2017 expanded the focus of the course to include the design aspect of rapid prototyping in addition to the fabrication skills. This question was intended to measure student interest and engagement with this more holistic curriculum.

Results

The results tabulated in this section are from the Fall 2017 and Fall 2018 sections of ET 349. All sections were taught by the same instructor. There were three sections in Fall 2017 and two sections in Fall 2018. As previously discussed, the primary difference between the two semesters was the inclusion of a large, open-ended project in 2017. This large project was replaced by multiple smaller, more defined projects in the Fall 2018 version of the course. Although the sample sizes seem to be significantly different, the number of students per sections was similar in Fall 2017 and Fall 2018.

Table 2 gives the results of instructor assessment of achievement of four of the primary course outcomes. Achievement level is normalized to a ten-point scale for each outcome. A score of 10 indicates the highest level of achievement while a score of 0 indicates no achievement.

Table 2: Achievement of Student Learning Outcomes for Fall 2017 and Fall 2018.

Outcome	Achievement of Outcome (Normalized to a Ten Point Scale, 10 = High Achievement)						
	Fall 2017			Fall 2018			
	Mean	Std. Dev.	N	Mean	Std. Dev.	N	P
Select tooling and cutting conditions for a fabrication process	9.1	0.6	41	8.6	1	21	0.07
Select measurement tools to make shop-level measurements	8.1	1.8	41	9.8	0.6	17	0
Utilize CAD tools in a top-down fashion to construct a virtual prototype	9.2	0.7	41	9.4	1.3	19	0.52
Utilize CAM tools to define toolpaths and generate NC code	9.4	0.6	35	8.6	0.7	20	0

Table 3 provides student responses to four statements from the SAI survey that are intended to measure student self-assessment of learning and engagement. Responses use a 0 – 4 scale where 4 is the most positive response and 0 is the most negative response.

Table 4 summarizes student responses to the secondary end-of-semester survey. Responses use a 0 – 4 scale where 4 is the most positive response and 0 is the most negative response.

Discussion

Examination of Table 2 shows that the instructor's assessment of student achievement was not appreciably different between Fall 2017 and Fall 2018. In both years, the scores for all outcomes were above 8 (out of 10) which is considered acceptable as per the department's assessment metrics. The largest difference between years is in the "shop-level measurements" outcome, for which the 2018 course had a higher score. However, this outcome was almost certainly affected by the acquisition of new metrology equipment and a re-work of the measurements lab.

While instructor assessment of student achievement was relatively constant between years, student assessment of the instructor and the course changed dramatically between Fall 2017 and Fall 2018. Table 3 shows that there was a large, positive change in students' assessment of their interest, engagement, and learning. This large change certainly cannot be entirely attributed to removal of the large, open-ended project. Fall 2017 was the first semester that the course was taught with the curriculum expanded to include design and measurement topics. Problems with equipment availability and laboratory hours had to be worked out, leading to student frustration. By Fall 2018 these problems

Table 3: Student Responses to Student Assessment of Instruction Statements Regarding Engagement and Learning.

SAI Statement	Student Response to SAI Statement						
	Fall 2017			Fall 2018			
	Mean	St. Dev.	N	Mean	St. Dev.	N	P
The lab assignments and lecture topics are interesting.	2.3	1.0	29	3.8	0.4	12	0.00
My instructor stimulates my thinking.	2.3	1.0	29	3.5	0.5	12	0.00
My instructor advances my knowledge of course content.	2.4	1.0	29	3.7	0.5	12	0.00
My instructor expands my knowledge and promotes my curiosity about the subject matter.	2.4	1.0	28	3.6	0.5	12	0.00
4 = Strongly Agree, 3 = Agree, 2 = Disagree, 1 = Strongly Disagree							

Table 4: Student Responses to the Supplementary Course Survey.

Survey Question	Student Response to Survey Question (0 = Not at all, 4 = Very much)						
	Fall 2017			Fall 2018			
	Mean	Std. Dev.	N	Mean	Std. Dev.	N	P
How confident are you that you could use computer-aided design tools to develop a design in which the components fit together correctly?	3.5	0.6	35	3.5	0.6	20	0.94
How confident are you that you could specify a series of fabrication processes that could be used to create a functioning prototype of your design?	3.2	0.8	35	3.4	0.8	20	0.44
How confident are you that you could make measurements of the fabricated components in order to verify that they will function correctly?	3.5	0.8	35	3.8	0.4	20	0.18
How happy would you be to spend part of your career working in the field of mechanical design?	3.3	1.0	35	3.9	0.4	20	0.01
4 = Very confident/happy, 3 = Somewhat confident/happy, 2 = Neutral, 1 = Not very confident/happy, 0 = Not at all confident/happy							

had been solved and the course ran more smoothly. However, it is likely that the move away from a large project with little structure to multiple smaller, more structured projects is partially responsible for the increase in student interest and engagement.

Student responses to the first three questions of the supplemental course survey show that students from both years are confident in the skills that they take away from the course. This is in agreement with the instructor assessment in Table 1 which showed that students are meeting the course outcomes. Interestingly, the survey question with the largest difference between years is the fifth question, which was intended to measure student engagement with the expanded course content. Students in the Fall 2018 course showed a higher level of enthusiasm for a career in mechanical design compared with students from Fall 2017. Again, this change cannot be directly attributed to the removal of the large project. However, the result does indicate that students in the 2018 course achieved a high level of engagement with the course material even without the large, unstructured project. Although the results cannot be statistically evaluated due to small sample sizes, the observations can be clearly discerned from the trends detected in the data.

Conclusions

In this paper we have described the effects of modifications to the content of a Junior-level, Engineering Technology course in rapid tooling and prototyping. The focus of the course was changed from a narrow focus on the operation of NC machine tools to a broader focus on the entire rapid design and prototyping process. The redesigned course, which was taught for the first time in Fall 2017, included new laboratory exercises in the effective use of CAD tools, shop-level metrology, and effective integration of CAD, CAM and NC tools. The 2017 version of the course also included a large, unstructured project that was intended to increase student engagement by giving them an opportunity to apply the entire design and prototyping process to a product that they designed. Results of student surveys indicate that many students did not find the 2017 version of the course to be engaging and felt that the course was not well-structured. While some of these negative responses can be attributed to trying out a new curriculum, student dissatisfaction with the lack of structure in the course was almost certainly exacerbated by the inclusion of a large, open-ended project.

In response to this student feedback, the course was modified for the Fall of 2018. The most significant change was the replacement of the large project with a series of smaller, more focused projects. These projects retained some original design content, however the path to completion of each project was more well-defined and bounded. Surveys indicate that students were generally satisfied with the 2018 version of the course and data indicated that they were confident in their ability to meet the outcomes of the course and showed a higher level of interest and engagement with the subject.

While student satisfaction with the course increased when the projects were smaller and more well-defined, these smaller projects may not be representative of most real-world design and prototyping projects. In practice, most products are assemblies of multiple, interconnected components that must function together as a whole. This is because decisions regarding the design and fabrication of one component can affect other components in the assembly. In the future, we would like to adopt a course structure in which a relatively complex, multi-component product is designed and fabricated in a series of small, well-structured laboratory exercises. Such a structure would allow the course to contain multiple laboratory exercises that are well-bounded and defined, but the final result is a relatively complex product with multiple, shared constraints between the designs of individual components. This would provide scaffolding to student learning and mitigate student anxiety about a large and open-ended project. Such a structure could allow us to introduce complexity into the course without reducing student engagement while providing experience with realistic design constraints and the intertwined nature of design and manufacturing.

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