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Development and Assessment of a Polymer Processing Learning Module

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Abstract

A polymer processes module has been introduced into a manufacturing course for mechanical engineers. The module takes place over two 2-hour class periods and includes an injection molding lab, question formulation technique activity, jigsaw activity, and business proposal mini-project. In addition to polymer process knowledge, the module targets learning objectives such as curiosity, customer focus, economic decision making, and motivation for continued learning. In Fall 2020, the learning objectives were assessed using a variety of methods including an ABET outcome assessment instrument, assignment grading rubrics, quizzes, and surveys. The assessment results show a promising level of learning on the new objectives and a disappointing level of learning of polymer processes. Student evaluations of the four components of the module will be used to target improvement efforts.

Introduction

The mechanical engineering students at Campbell University are required to take a manufacturing engineering course in the senior year. The course introduces students to a wide variety of manufacturing processes. It stresses the mechanics of how the processes work, their applications, their capabilities and limitations, and product design considerations. Because manufacturing decisions are an integral part of the project development process, this course is an ideal place to integrate an authentic learning experience that involves additional learning objectives such as customer focus and economic decision making [1,2]. Adding learning objectives to an already full course creates challenges, however. Recognizing that students cannot learn every manufacturing process in the same detail, it becomes necessary to stimulate their lifelong learning skills, and that becomes another possible learning objective. A new polymer processes module was developed that attempts to combine the following student learning objectives:

1. Show curiosity about polymer processes
2. Consider customers in design of a polymer product
3. Make decisions based on economic analysis
4. Gain knowledge about polymer processes
5. Increase motivation for continued learning about polymer processes

The new polymer processing module was first introduced in the Fall 2019 offering of the manufacturing course [3]. In Fall 2020, improvements were made to further develop the module. For example, the amount of class-time devoted to the activities was adjusted, and more guidance was given for the economic analysis portion of the mini-project. The effectiveness of the module in achieving the five learning objectives was assessed for the first time in Fall 2020. This paper will describe the revised module and present the assessment results.

Description of Polymer Processing Module

The module activities include an Injection Molding Lab, Question Formulation Technique (QFT), Jigsaw, and Business Proposal Mini-Project. These activities took place over two 2-hour lab sessions.

The first session was devoted to the injection molding lab. In the previous week, students designed and milled a mold suitable for our Morgan Press injection molding machine. During the injection molding lab, students produced multiple polyethylene and ABS parts with their mold while attempting to identify the best operating conditions.

The following week's lab session was devoted to the other three activities in the module. In the QFT activity [4,5], students responded individually to a compelling prompt about polymers. A worksheet asked them to generate as many questions as possible arising from the prompt. Subsequently, students worked in teams to review the questions and come up with a team list of the most interesting questions.

In the jigsaw activity [6], students were assigned to 5-person home teams. Each student on the team became an "expert" in one of five polymer manufacturing processes: injection molding, rotational molding, blow molding, vacuum thermoforming, or 3D printing. Eight question prompts from the instructor guided their research of their assigned process. Then, the "expert" teams for each process met to review and strengthen their process documentation. Finally, students rejoined their home teams and took turns teaching each other about the five processes.

In the mini-project, the same home teams were charged with creating a plastic swag item that could be given away at university recruiting events. The purpose of the project was for students to make use of the knowledge they gained in the jigsaw activity. Students would design a swag item and choose a suitable polymer manufacturing process. An important aspect of choosing the polymer process is to consider the effect of production quantity on the manufacturing cost per part. The project assignment was improved this year by providing additional guidance on doing the economic analysis (see Appendix).

The timing for the polymer module in-class activities was as follows:

- 110 minutes - injection molding lab
- 20 minutes - question formulation technique (10 minutes individual, 10 minutes group)
- 60 minutes - jigsaw (5 minutes home team, 25 minutes individual, 10 minutes expert team, 20 minutes home team)
- 30 minutes - mini-project with the home team

Assessment of Polymer Processing Module

The learning objectives were assessed by using student work on the jigsaw exercise, mini-project, quiz, and a survey. In Fall 2020, twenty mechanical engineering seniors took the manufacturing course. Table 1 describes the assessment method for each objective.

Table 1. Summary of the learning objectives and assessment methods in the new polymer processes module

Learning Objective	Assessment Method
1. Show curiosity about polymer processes	Jigsaw responses assessed for level of detail and extra information
2. Consider customers in design of polymer product	Mini-project rubric item on rationale for product selection
3. Make decisions based on economic analysis	Mini-project rubric items on economic analysis and rationale for production method selection
4. Gain knowledge about polymer processes	Quiz on polymer processes and comparison to machining process quiz performance
5. Increase motivation for continued learning about polymer processes	Survey on student engagement and comparison to machining survey results

Curiosity Students submitted their jigsaw exercise work. In addition to receiving a grade, these submissions were also assessed as part of our ABET continuous improvement process for outcome 7 (lifelong learning). The instructor plus one other faculty member assessed the submissions using a three-item rubric that included curiosity. The assessors considered whether "The student provided specific detail (rather than vague generality) in their responses and/or reported an interesting piece of information in response to Question 8." Their ratings could range from 1=strongly disagree to 5=strongly agree. The instructor assessed all 20 students in the course, and the average rating was 3.75. The external faculty member assessed a sample of 10 students, and the average rating was 4.40.

Customer focus The team mini-projects were graded by the instructor using a four item rubric that included: product drawing, product selection rationale, production method selection rationale, and economic analysis. The customer focus learning objective was assessed using the product selection rationale item. The ratings ranged from Novice to Competent to Proficient. Three of the four teams received Proficient ratings, and one team received a Competent rating.

Economic decision making This learning objective was assessed using the production method rationale and economic analysis items in the mini-project grading rubric. For production method rationale, two teams were rated as Proficient, and two teams were rated as Competent. For the economic analysis item, two teams were rated as Proficient, one as Competent, and one as Novice.

Polymer process knowledge Because polymer process knowledge was a learning objective before the new polymer module was introduced, an ideal assessment would be to compare knowledge gains between the old and new approaches. Does the learning of new skills (such as customer focus and decision making) come at the expense of polymer process knowledge? A control group taught in the old traditional way would have been ideal. However, it was undesirable to teach some students with the new approach and some with the old. As an alternative, the learning in the polymer module was compared with the learning in a machining process module which was taught in a more traditional way. Machining was selected because it is a similar topic to polymer molding in that there are many processes to choose from, each with unique capabilities, limitations, and economic considerations. At the conclusion of both modules, quizzes were given to assess learning gains. Table 2 compares the quiz results for the two modules. The machining and polymer quizzes had 13 and 9 questions, respectively.

Table 2. Comparison of quiz scores for two learning modules in the manufacturing course

	Machining	Polymer
Average quiz score	86.6%	67.3%

Students scored substantially lower on the polymer quiz than the machining quiz. The types of questions on the two quizzes were similar. They involved identifying pictures of the processes, characterizing process capabilities/limitations, and design considerations. The Discussion section below describes potential reasons for the large disparity in performance.

Motivation for continued learning A student engagement survey was given at the end of both the polymer and machining modules. Motivation was assessed along multiple dimensions as guided by the expectancy-value motivation theory [7]. According to this theory, aspects of motivation include:

- Expectancies - expectation of success
- Attainment value - personal importance of doing well
- Intrinsic value - interest, enjoyment
- Utility value - relationship to current and future goals
- Cost - amount of effort required, fear of failure

The survey questions, shown in Table 3, address expectancies (questions 3, 4), intrinsic value (questions 1, 2), and utility value (5, 6). The table presents the results of the surveys from 19 students given after the polymer and machining modules.

Table 3. Comparison of student engagement survey results. Students indicated their agreement using a scale of 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree

	Machining	Polymer	*p*
1. Before this learning module, I was interested in learning about these processes	4.2	3.7	0.035
2. My level of interest in this topic is higher now than before the learning module	3.8	3.9	0.331
3. Before this learning module, I already knew a lot about these processes	3.1	2.5	0.002
4. My level of knowledge about this topic is higher now than before the learning module.	4.5	4.4	0.667
5. Knowledge about this topic will help me in my future career.	4.3	4.1	0.135
6. Knowledge about this topic will help me to create new products.	4.3	4.1	0.095
7. I want to learn more about this topic.	4.3	4.1	0.380

The results for the modules are compared using a paired two tailed t-test. A p value of less than 0.05 would indicate statistical significance. By this criterion, only two items showed a difference: before the module, student interest in and knowledge about machining was higher than for polymer processes. Because the sample size is small at 19 students, it is difficult to draw any further conclusions from the data.

An additional assessment was done to gain information about the components of the polymer module so that improvement efforts could be targeted. Table 4 shows student ratings of the effectiveness of the four components of the polymer module along two dimensions: enhancing learning and increasing interest.

Table 4. Average student ratings (N=19) of the effectiveness of the components of the polymer processing module on a scale of 1=not effective to 5=very effective

	Enhancing your learning about polymers	Increasing your interest about polymers
Injection molding lab	4.2	4.2
Question formulation exercise	3.2	2.1
Jigsaw exercise	2.9	2.3
Mini-design project	2.6	2.5

The hands-on injection molding lab was rated most highly with the other activities having ratings in the range of 2 to 3. Although these ratings were not compared to the traditional lecture treatment of machining (and it is possible that lecture would have low ratings), they are lower than desired for a new teaching approach!

Discussion

The new module targeted learning objectives beyond technical content knowledge about polymer processes. The module had some success in achieving the additional learning objectives. For the curiosity objective, a target would be that students would average at least 4 on the 5-point rubric scale. That target is met based on an external faculty member's assessments but not based on the instructor's assessment. In the area of customer focus, three of the four teams were Proficient. In the area of economic decision making, two of the four teams were Proficient in both aspects of the assessment. While a majority of students achieved the new learning objectives, a sizable minority did not, which means there is room for improvement.

Ideally, the introduction of the additional learning objectives would not cause technical content learning to suffer. The polymer quiz results suggest that polymer processes learning did suffer. In hindsight, low polymer quiz scores could have been expected. The amount of time spent on polymers was significantly less than the time spent on machining. The Fall 2020 version of the course devoted seven 50-minute class periods, one 2-hour lab, and two out-of-class homework assignments to machining. Machining topics included the mechanics of machining, tool wear, turning, milling, grinding, and non-traditional machining process. In the lab session, students milled injection molding molds. In contrast, the polymer module spanned just two 2-hour lab sessions (as described earlier) and an out-of-class project report. Admittedly, much of the machining content involved quantitative problem solving which was not part of the qualitative quizzes. That brings the time comparison between the machining and polymer modules closer, but it remains lopsided.

Another factor in the higher machining quiz scores is the likelihood that instructor lectures aligned more closely with the quiz questions. During the jigsaw, the expert in each group researched answers to questions prompts that included: how the process works, what the equipment looks like, sizes and shapes of parts that can be produced, common applications, cost, production rate, and polymer materials that can be used. The expert teams reviewed their findings with the purpose of improving and unifying them. This did not necessarily happen, and some experts would have been better teachers than others. All students taught about their process by talking, and very little questioning or interaction took place. Each student probably learned only one process well. The mini project was a time to put the group knowledge to work. Such application of recently gained knowledge could further increase learning. However, groups tended to settle quickly on a manufacturing process--either 3D printing or injection molding. Thus, they applied only a small subset of what they learned in the jigsaw activity.

With respect to student motivation, the results are better than the learning results in some respects. Post-module, student interest in polymers and motivation to learn more about polymers were similar to machining. That is an encouraging result considering that pre-module student interest in polymers was noticeably lower than for machining. On the other hand, the module activities were designed to increase student motivation, and thus achieving results on par with machining is somewhat disappointing.

The effectiveness ratings in Table 4 identify areas for improvement in the polymer module. The question formulation technique might benefit from more follow-up where students research the answers to their top questions. The jigsaw would benefit from coaching students on how to teach their teammates in more active ways. The mini-project would benefit from a round of peer and instructor feedback and a second iteration. Finally, the polymer module took place in the last two weeks of the semester when student enthusiasm tends to be low. Moving it earlier in the semester may help.

Conclusions

The implementation of this module has highlighted the difficulties of achieving multiple objectives from the same learning activities. Transferring some of that responsibility from teacher to student can improve student interest, but that increase in student interest may occur at the expense of content knowledge that the faculty member finds important. The manufacturing course has much more content to cover than time allows. Fostering independent learning ability would prepare students to learn additional manufacturing process knowledge if and when it becomes necessary during their careers. Therefore, the sacrifice of some content knowledge may make sense if other types of learning gains can be realized.

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Appendix - Mini-Project Economic Analysis Guidance

Include a table along the lines of the following that shows how the cost per part changes depending on the production quantity. I have made up numbers for the costs below; include more cost items and the best cost estimates you can find. State your planned quantity, the production cost/part, and the price/part that you would charge the university recruiting office.

Quantity	**1**	**10**	**100**	**1000**	**10,000**	**100,000**
Fixed Costs						
Machine purchase	5000	5000	5000	5000	5000	10000
Molds	500	500	500	500	1000	5000
…						
Variable Costs						
Labor	.5	5	50	500	5000	50,000
Material	.5	5	50	500	5000	50,000
…						
Total Cost	5501	5510	5600	6500	16,000	115,000
Marginal Cost	5501	551	56.00	6.50	1.60	1.15