Work-in-Progress: Design of Polymer Processing Learning Module in a Manufacturing Course for Mechanical Engineers

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Abstract

In addition to teaching about polymer molding processes, the polymer processing module was designed to increase student curiosity, promote independent learning, and add a customer focus. The module activities included a Question Formulation Technique, Jigsaw, and Mini-design project/business proposal. The module could be delivered in 2-3 class sessions. This paper describes a schedule for the in-class and out-of-class components of the activities. It concludes with instructor observations about implementation issues, and how the module could be improved in a second offering.

Introduction

Project-based learning is becoming more common in engineering education. Litzinger et al. argue that expertise is developed through significant learning experiences such as applying knowledge to real-world problems [1]. Solving real-world problem increases student motivation as well as promotes deep learning and development of expertise. Improvement in engineering education can be realized by the introduction of more "authentic" learning experiences. Authentic learning is social as well as cognitive and includes interpersonal communication, self-directed research, and a focus on the customer just like in a real workplace [2]. Business context is another element of authenticity. Projects that enhance the ability to create value are worthwhile for both budding entrepreneurs and engineers in traditional companies [3]. The new polymer processes module was developed with the goals of improving student motivation for the topic and better connecting the technical and economic considerations involved with producing plastic parts.

Senior mechanical engineering students at Campbell University take a Manufacturing Engineering course that focuses on processes, including bulk metal forming, sheet metal forming, casting, machining, and polymer processing. This course is an ideal place to integrate an authentic learning experience that involves value creation and decision making. A new module on polymer processing was introduced in the fall 2019 offering of the course. In addition to conveying relevant details about the most common polymer manufacturing processes, the new module has these student learning objectives:

- Demonstrate curiosity about the manufacturing of plastics products that are all around us
- Integrate information from multiple sources to gain insight about the pluses and minuses of plastics manufacturing processes
- Predict the plastics manufacturing cost for a small part based on quantity
- Choose an optimal manufacturing process to meet customer requirements
- Mitigate the occurrence of flaws in the manufacture of a plastic part

The module pursued these objectives with three main activities:

- Question Formulation Technique (QFT)

- Jigsaw
- Mini-design project and business proposal for producing a plastic swag item

In previous offerings of this course by the instructor at another university, two lecture hours were devoted to polymer processing. Portions of 2-3 lecture days could be devoted to this new module. The purpose of this paper is to describe the activities in enough detail that others may adopt or adapt them for their own courses. The paper will also discuss the lessons learned from the first implementation and make recommendations for improvement.

Question Formulation Technique Activity

One way to improve motivation for learning a new topic is to spark student curiosity. The Question Formulation (QFT) [4,5] is designed to do just that and thus was a good way to start off the polymer processes module. Starting with a question prompt (or focus), students are asked to write as many questions as they can that are related to that focus. Plastics manufacturing is a good topic for this technique: advances in the technology have led to ever increasing volumes of plastics in our society; converting to plastic often produces cost advantages; plastic parts are usually lighter weight than their metal counterparts; polymer molding processes afford designers a lot of geometric flexibility. There is a serious downside to plastics usage, however, in the form of environmental cost. Many compelling statements could be used as the start of a QFT. The one used in the fall 2019 offering was:

> In 1900, plastics did not exist. In 2012. US plastics manufacturers produced $373B in plastics goods. In 2013, 107.5 billion pounds of plastics were manufactured in the US. What questions does this statement raise for you?

After students list as many questions as possible, they could be instructed to improve them and prioritize them. In my case, the next step was for groups of four students to compare their questions and prepare a team list. The list of student questions does not necessarily need to be turned in. But if they are, they can be used to drive lecture material or as an assessment of student curiosity. The questions in fall 2019 reflected a wide variety of interests on the students' part. Some focused attention on the environmental issues, some on the material property issues, some on the industries that use plastics the most. By better understanding student motivation, subsequent lectures could be targeted to better meet student interests.

Jigsaw Activity

An increasingly popular cooperative learning technique is the jigsaw [6,7]. In this activity, teams of students work together to learn a new topic. Each team member is tasked to become the team "expert" on a portion of the topic. In the manufacturing class, the topic was polymer processes, and each team member was responsible for learning about one process and subsequently teaching their team about it.

This type of activity is good practice for lifelong learning skills. In the fall 2019 course, students were given a list of eight questions to guide their inquiry (see the Jigsaw assignment in the Appendix). With more practice with this type of learning, students could be expected to come up with their own questions and categories of information. In the manufacturing class, students worked in teams of five. Each member investigated one of the following processes:

- Rotational molding
- Blow molding
- Vacuum thermoforming
- 3D printing
- Injection molding

Students entered their answers to the questions in a google form. Then all of the responses for each topic were organized together into a google sheet that was shared with the class. With additional time, a good class activity would be for all of the experts of each topic to meet to curate and edit the combined submission so that the key information is presented in a concise way without repetition.

In the next class period, I shared the link to the assembled responses. Sitting with their home team, each student took turns reviewing the key points about their process. To make the jigsaw learning relevant, team members need to use the information they have just been taught. A quiz could be used for this purpose. In our case, the task was for the team to work together on a mini-design project.

Mini-Design Project and Business Proposal

Polymers have a compelling business case at their heart. Their entry into the market is often in the form of replacing an existing metal product. This mini-project provided an opportunity for students to apply their recently acquired knowledge about polymer manufacturing to considerations of design and economic decision making. The assignment charged student teams to create a proposal for a plastic swag item that could be given away at student recruiting events. They would identify a desired quantity, estimate the cost per part, and select a production method. In their proposal, they would include a drawing of their design and a rationale for the production method they selected. They would provide an economic analysis that included a discussion of whether to outsource or make the parts in-house. It would also include a breakdown of the material, labor, and machine maintenance costs. Designs included a wrench, a gear, a camel (Campbell's mascot), and several types of key chains. Student teams started this project in-class and had the opportunity to ask questions. They finished it outside of class.

Schedule of Activities

The three module activities combine in-class and out-of-class work. Table 1 summarizes the sequence of events for carrying out the three activities and indicates which portions are done during and outside of class time.

Table 1. Scheduling logistics for three module activities

Task Time/Place (duration)	**Task Description**
Outside of class	Instructor selects QFT focus prompt. Instructor prepares jigsaw assignment (selects topics, questions to answer, and teams).
Class period #1 (20 minutes)	**QFT** activity – 15 minutes **Jigsaw** part 1, students meet with home teams and decide who will be responsible for which topic – 5 minutes
Outside of class	Instructor may use QFT results for assessment or to design lecture materials. Students investigate processes and submit information using google form. Instructor creates google sheet based on all the google form submissions.
Class period #2 (50 minutes)	**Jigsaw** part 2, students assemble with their fellow experts to edit the information about their topic on the google sheet – 20 minutes (we did not do this in fall 2019) **Jigsaw** part 3, students assemble with their home teams and take turns instructing about their process – 20 minutes **Mini-Design Project,** students work with the home teams to begin their project – 10 minutes
Outside of class	Student teams complete their mini-project and submit a short report.
Class period #3 (25-50 minutes)	**Mini-Design Project**, student teams give short presentations (we did not do this in fall 2019)

Note that the QFT is an in-class activity for the students. The Jigsaw has significant in-class and out-of-class components. The Mini-Design Project is primarily done outside-of-class. The time for Jigsaw part 3 time seems too short. However, students tended to do their instruction in even less time than this. This part needs to be improved so that students spend more time teaching and learning.

Conclusions and Recommendations

The first implementation of this module was moderately successful. It replaced rather dry lectures about polymer processes with activities that attempted to spark student curiosity, off-load the teaching of processes to the students themselves, and require students to use process knowledge to design a polymer product that could be cost-effectively produced. The implementation experience revealed several areas that could be improved.

1. Develop assessments to measure the five objectives listed at the beginning of the paper. Individual contributions to the jigsaw were assessed with a three-item rubric (addressing explanation clarity, completeness, curiosity). The mini-design project report was also assessed with a three-item rubric (addressing drawing quality, product rationale, production method rationale). Both rubrics could be improved by adding detail and aligning them more closely to the stated objectives.

2. Make better use of the results of the QFT. In the first implementation, there was no follow-up after the in-class QFT activity. The questions could be a source of a follow-on lecture or assignment.
3. Add guidance or structure to the Jigsaw part 3 to ensure that all students learn all five processes. A follow-up quiz could accomplish this. Another approach might be to ask student teams to discuss all five processes (and why they rejected or adopted them) in their mini-design project.
4. Provide students with resources to do the mini-project's economic analysis. The students had all taken an Engineering Economics course, but the teams' treatments of this analysis varied widely.
5. In the project assignment, be more explicit about asking students to connect the product design with the molding process. Teams provided a rationale for their process selection, primarily based on production volume and cost per part. They did not discuss how the process was well-suited to the product geometry; they did not discuss how they considered the manufacturing process when designing particular features or choosing dimensions. For example, they might have discussed the need to add ribs to achieve a desired stiffness while keeping the overall section thickness small to realize fast molding cycle times.

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Appendix

QFT In-Class Activity Handout

Prompt: In 1900, plastics did not exist. In 2012, US plastics manufacturers produced $373B in plastics goods. In 2013, 107.5 billion pounds of plastics were manufactured in the US.

What questions does this statement raise for you? Write as many as you can.

Jigsaw Assignment

In a team of five, you will teach each other about five polymer molding processes:

- Rotational molding
- Blow molding
- Vacuum thermoforming
- 3D printing
- Injection molding

Each of you will become an "expert" in one of these processes. For your assigned process, use the textbook, internet, and other reference books to find out the following:

1. How does the process work? What does the equipment look like?
2. What is the web address for a video that does a good job explaining the process in 3 minutes or less?
3. Which shapes can this process make? How large or small? Which shapes can it not do?
4. What are common applications for this process?
5. How does the cost of this process compare to other polymer processes? (consider equipment costs, mold costs, cycle time)
6. What is a typical production rate for this process (parts/min or parts/hour)?
7. What types of polymers can be molded with this process? Are they recyclable?
8. Are there other interesting aspects of the process you want to share with your team?

Keep your responses brief—use a few sentences or use bullet point lists. Type them up on your laptop and then copy/paste into this form: _____

In the next class, you will teach your teammates about your process.

Jigsaw Grading Rubric

Rate the student's submission on a scale of 1 (strongly disagree) to 5 (strongly agree).

1. Clear Explanations – The explanation of how the process works (from Question 1) would be easy for a teammate to understand.
2. Completeness - The student provided complete and informative answers to all questions.
3. Curiosity - 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.

Mini-Design Project: Swag Production Proposal Assignment

The process information submitted by class members is here: ______

Starting in class and finishing out of class, create a proposal for a plastic swag item that could be given away at student recruiting events. Make assumptions about the desired quantity and production cost per part. Then choose a design and production method.

a. For the design, include a sketch or perspective view from solid model. Choose a polymer material. Also, give the rationale for your choice of product, its design, and material.
b. The production method should be one of the five that you investigated. Give a rationale for your choice of production method.
c. Provide an economic analysis. For your target production quantity, what would be the production cost per part? Provide a breakdown of costs. If you would outsource, find a job shop web site that would give you a rough cost estimate. If doing it on campus, break out the material cost, labor cost, machine maintenance cost.

Submit one proposal for your team by Tuesday next week. I anticipate that this proposal will be 2-3 pages long.