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Teaching Undergraduate Manufacturing in a Flipped Classroom

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Teaching Undergraduate Manufacturing in a Flipped Classroom

We present a case study of a flipped classroom for an intermediate undergraduate manufacturing class at the Massachusetts Institute of Technology. Students prepare for lecture by watching pre-recorded videos and then participate in Challenges in pairs during class time. This paper includes the technology used for the flipped classroom and the design of the Challenges is detailed for use by other interested Universities. As a result of the flipped classroom, the instructors noted increased numbers of questions during class time as well as more detailed questions. According to end-of-semester surveys, students preferred the flipped-classroom format (average response: 6.4 out of 7 on a Likert Scale). The students noted their preference for more advanced content in class while the instructors were available for assistance.

Introduction

Teaching students in an effective and efficient way is a major goal of university education. Many studies have found that increased interaction during class, more open-ended problems, and more feedback about the problem-solving process can lead to increased student learning. In response to student survey data that found this intermediate-level manufacturing class, titled Design and Manufacturing II, at a top-tier research university to be unrelated to "real world", uninteresting, and also time-intensive, the course instructors decided to implement a flipped-classroom style of teaching.

The manufacturing class was flipped through a variety of high-tech and low-tech methods. For each week (which roughly corresponds to one topic), the students would watch a pre-recorded video lecture online. The students would then have to answer some questions online based on the video. These viewing-comprehension questions were straightforward and meant to assess only if the student had watched the video, not if the student had created deep thoughtful knowledge on this topic. Then the students would come to class where they would do a more difficult set of questions on the topic in the form of a Challenge. In random pairs, students would tackle a longer assignment with much more detailed critical thinking and synthesis, but they would be able to ask unlimited questions of the course staff in class (2 instructors and 4 teaching assistants for 75 students). At the end of class, the students would turn in their Challenge document (usually on paper). Synthesis between topics was achieved through a laboratory project outside of class and an exam near the end of the semester.

The flipped-classroom experience was evaluated via student surveys at the end of the semester where students ranked their agreement with various statements on a 7-point Likert scale.

Background

Much research has been done about how to best teach students and often active learning methods such as group discussion, working problems together, hands-on activities, and student experimentation lead to improved student outcomes when utilized in class. For example, Smith et. al. [1] investigated the effect of students having discussions together on their understanding of concept questions. Carl Wieman has done a variety of experiments about various active learning techniques at the university level in the United States and Canada, summarized in his recent book *Improving How Universities Teach Science* [2] and it is likely that similar teaching methods could be applied to engineering and manufacturing. An excellent survey of flipped-classroom examples was presented by Bishop and Verleger [3] at the ASEE conference in 2013 which notes the way that various active learning techniques [4] can be integrated into flipped classrooms.

Faculty might not be interested in a flipped classroom because of the amount of preparatory work to create videos to be watched by students in advance, or they may not be comfortable with the more open-ended style of discussion that might ensue during class time. However, in the case of the authors, the decision to try a flipped-classroom style of teaching was driven by course reviews that noted that lectures were disconnected from “real world” examples and the amount of homework outside of class was above the standards set by the department for a typical undergraduate class. In this case, most of the preparatory videos had been completed in an earlier year when the manufacturing class material was presented on the EdX platform [5].

Methods

The manufacturing class was flipped through a variety of high-tech and low-tech methods. Support for these changes was given through the Mechanical Engineering Department in the form of additional teaching staff and also the Department of Physics allowed the researchers access to their video creation resources. This class also includes a laboratory component where students manufacture parts in a machine shop, but the lab assignments were independent from lecture and therefore not described in this paper.

The activities for each week of the class are as follows. The students would watch a pre-recorded video lecture online related to the topic or topics of the week. These videos were produced using a Lightboard [6] provided by the Physics Department. A Lightboard is a sheet of glass illuminated by LEDS along the edges. By writing on the Lightboard with fluorescent dry erase markers, the lecturer can face the camera while talking and writing, and then the video is flipped in post-processing so that the writing appears in the correct orientation to the viewers. Videos were a combination of Lightboard writing and overlaid PowerPoint slides of the manufacturing material. After watching the video for a given week (totaling approximately one hour of viewing time), the students would then have to answer some questions online based on the video called viewing comprehension questions. These viewing comprehension questions were straightforward and meant to assess only if the student had watched the video, not if the student had a deep understanding of the topic. Then the students would come to one 3-hour class per week where they would do a more difficult set of questions on the topic in the form of a Challenge (a series of guided questions, usually provided on paper with space for answers, with much more detailed critical thinking and synthesis). During class, students would be assigned a random partner and together these pairs of students would tackle the Challenge assignment. However, because this more detailed assignment was in class, the students would be able to ask unlimited questions of the course staff (2 instructors and 4 teaching assistants for 75 students). At the end of 3-hour class, the students would turn in their Challenge document. There was no outside "homework" beyond preparing for the following week via videos and viewing comprehension questions. Synthesis between topics was achieved an exam near the end of the semester.

The Challenges were the main innovation of the class. Each Challenge was centered around a topic or topics. Most Challenges involved a physical object or objects that the students had to observe, take apart, or analyze. A list of topic areas and objects is listed in Table 1. We will go into detail about the injection molding Challenge for illustrative purposes.

Table 1: Weekly topic areas and Challenges in manufacturing class

Topic	Challenge/Object
Process Planning	Hairdryer
Machining	iPhone housing
Injection Molding	See 'N Say
Forming	Plastic thermoformed to-go containers, stamped metal flatware
Casting	Pipe fittings (brass, iron, copper)
Additive Manufacturing	3D printed joints, castable-resin jewelry
Quality & Variation	Multiple yo-yo exteriors
Cost	1/8 of an Amazon Fire tablet
Systems	Hairdryer (repeated)
Automation & Robotics	Blue jeans (video)

The injection molding Challenge was centered around the children's toy See n' Say by Fisher-Price (shown in Figure 1). Each pair of students was given a See n' Say toy, a screwdriver (for disassembly), and micrometers (to measure dimensions of various parts after disassembly). The learning objectives of injection molding Challenge activity were:

- Identification of mold design necessary to manufacture a part, based on inspection of the part
- Identification of key features of injection molded parts, and how to manipulate process parameters to eliminate common defects (the "process window")
- Estimation of injection molding cycle time (including filling, cooling, and ejection), and understanding of how cycle time scales with part geometry and material
- Estimation of injection pressure and clamping force , and use of this information to select a molding machine
- Understanding of how polymer properties (e.g., melt temperature, viscosity, shrinkage) relate to the selection of injection molding process parameters and part quality

Figure 1: Fisher-Price See n' Say, taken apart as the injection molding weekly Challenge. [7]

Each student filled out a Challenge packet (a series of questions printed out with room to answer questions, do calculations, and sketch ideas). For the injection molding Challenge, the framing of the Challenge and the questions asked were:

> *You have been hired to consult for a local manufacturing company, Precision Molding, Inc. (PMI). The contract of the current supplier of plastic parts for the Fisher-Price See-N-Say is up for renewal, and PMI wants to know if they can bid for this contract and win by undercutting the current supplier.*
>
> *Your role is to figure out what it would take to manufacture the injection molded parts of the See-N-Say and compare to the capabilities of PMI currently. If you have time, you will also make suggestions of what capabilities PMI should add based on the volume (in number of parts produced) of the contracts that PMI would like to receive in the future.*
>
> *(1) First, remove the screws on the back of your See-N-Say and separate the two halves of the toy. Sketch the inside of each half, annotate the critical modules, and briefly describe how the mechanism functions.*
> *(2) How many parts are made by injection molding? List them, assigning descriptive names to each part.*
> *Of the parts made by injection molding:*
> *(3) Which is the smallest? The largest?*
> *(4) The simplest to mold? The most difficult? Describe why.*
> *(5) Note at least 2 defects on each of two different parts. Describe in words and sketch your findings. For one of the parts, describe how the process might be tuned to eliminate the defects and why your solution might work.*
> *(6) Consider the back case part of the See-N-Say. Sketch a cross section of the mold used to manufacture this part. Include key features needed for injection and ejection. Calculate and annotate the width of the mold cavity based on the final part dimensions (hint: consider shrinkage). For this problem, assume the material is ABS.*
> *(7) Estimate the shot size needed to mold the smallest and largest parts, based on your approximate dimensions.*
> *For all following questions, assume the material is HDPE.*
> *Consider the smallest part. Estimate:*
> *(8) the injection pressure for a fill time of 0.1 second*
> *(9) the cooling time*
> *(10) the cycle time*
> *Now consider the largest part. Estimate:*
> *(11) the injection pressure for a fill time of 1 second*
> *(12) the cooling time*
> *(13) the cycle time*
> *(14) Assuming a safety factor of 1.3, calculate the clamping force for the large part.*

(15) See the attached list of machines and their specifications. Which machine is best suited to making the largest part?

Students were also given a list of machine specifications and material properties for reference during the Challenge. Students were not expected to answer all of the questions by the end of the 3-hour class time. They were expected to work diligently during class and then turn in however far they got at the end of the class period for grading. Any questions that they did not complete could be used for self-study before the exam. Grading was based on the accuracy of their answers, not on how many correct answers they gave so that students did not feel a significant time pressure to get to the "end" of the Challenge (and in fact the Challenges were designed so that they could not be completed in the time given). The intention was to leave students with additional ideas of questions to consider on each topic if they wanted to delve deeper.

The grading criteria of the class ensured that the students were appropriately incentivized to fully participate in the flipped classroom. The pre-class video viewing comprehension questions were worth relatively few points in the final grade (1% per week), however, the students were not eligible for the points from the weekly Challenge (4% per week) unless they scored at least 70% on the viewing comprehension questions. This was to incentivize the students to watch the videos and come prepared to class, without having to check that the students had done the preparatory work by giving in-class pop quizzes or other evaluations.

Results and Discussion

The flipped-classroom experience for this intermediate manufacturing class was evaluated via student surveys at the end of the semester where students ranked their agreement with various statements on a 7-point Likert scale. Results of the end-of-term survey questions can be found in Table 2. Seventy-one students completed the class and thirty-nine completed the voluntary survey, giving a response rate of 54.9%.

The students were asked to compare their experiences in the flipped-classroom format to a "traditional class format (lecture followed by at-home problem sets)". The manufacturing class described in this paper is for a second-level class in, so all students experienced an introductory manufacturing class with the "traditional" format of lecture and take-home problem sets prior to their experience in the flipped-classroom format. However, since the students only experienced the flipped-classroom format in this upper-level class, their comparisons may be also affected by other factors such as instructor variability. In order to attempt to alleviate some of this variability, two weeks of content (electronics and micro/nano processes) were presented in a "traditional" format of lecture during class time and students were instructed to use that as a reference point for answering the end-of-year surveys.

Table 2: Student responses to end-of-term survey questions, where 7 is "strongly agree" and 1 is "strongly disagree".

Question	Average	Median	St. Dev.
Compared to a traditional class format (lecture followed by at-home problem sets), I preferred this semester's format.	6.4	7	1.21
Compared to a traditional class format, I spent less time doing the pre-lecture material (videos and questions) than I would have expected to spend on problem sets and class preparation (combined).	6.3	7	0.99
Compared to a traditional class format, I felt there was more time to ask questions in this semester's format.	6.3	7	1.15
I felt comfortable asking questions during the challenges.	6.7	7	0.58
I learned important real-world manufacturing details from the challenges.	6.4	7	0.93
The videos and pre-class questions prepared me well to complete the in-class challenges.	5.8	6	1.55
The time spent on challenges in class could have been better spent on more lecture content.	2.8	3	1.7

From these student responses, it appears that the students preferred the flipped-classroom format (average 6.4 out of 7, median score of 7). They indicated that they spent less time preparing for class, however their exam scores were higher than previous semester scores on a similar exam. The authors postulate that this is because of the increased learning efficiency caused by challenging the students with the most difficult questions at the same time that they are surrounded by course staff who are ready and waiting to help them. Students felt like there was more time for questions and they also felt comfortable asking those questions, according to the data from Table 2. Together, we believe this was part of the cause of the increased learning efficiency. By removing barriers to asking questions on hard problems, the students were able to get their questions answered quickly and effectively, giving them more time to understand the material more in-depth. Traditional-format classes introduce students to the material in class, and leave them to fight through the more complicated understanding on their own or in study groups, without the expertise of more experienced staff to help guide the students' learning. Flipped-classroom instruction places the instructors and students together at the time that the students are most challenged by the questions, leading to an efficient exchange of information and knowledge.

The manufacturing class had no final examination, so no additional comparison between students in the flipped-classroom class and previous traditional-format classes were possible. Future work could more closely align questions in Challenges with questions from previous years' homework questions to investigate more fully the difference in learning achieved via the flipped-classroom format.

Some unexpected outcomes were also observed during the in-class Challenges. For example, no instructions were given about technology usage during the first challenge. However, both instructors noted that students put away computers and cell phones when they were handed hairdryers for disassembly and the paper packets of Challenge questions. Student engagement and focus was much higher than generally observed in other classes. This could be an interesting area for future investigation, especially as more programs are relying on technology. Future experiments could compare a paper-based Challenge to an internet-based or smartphone-based interface for collecting responses.

An additional surprise outcome was the students bringing home their Challenge materials (take-apart pieces or example parts). Multiple faculty from the department approached the authors to explain how the students had brought the materials into another class and excitedly shared what they learned with other students and faculty. Both of the authors have taught this class before and neither has ever received feedback from a colleague about a student discussing what they learned in class. We interpret this as an increased excitement and engagement with the materials, and the physical objects are a great vehicle to translate that interest into excitement and sharing amongst the students.

Conclusions

This paper gives a case study of a flipped classroom for an intermediate undergraduate manufacturing class at the Massachusetts Institute of Technology. Students prepared for lecture by watching pre-recorded videos and then participated in Challenges in pairs during class time. The methods of flipping the classroom as well as the activities and examples used were detailed for other universities interested in creating a similar flipped-classroom environment. Student survey results showed that students preferred the flipped-classroom style and that they were comfortable asking questions in this environment.

The instructors noted that the students performed better on the course exam and also had a more nuanced understanding of complex topics. Also, students seemed more engaged in class, having put away their computers and cell phones voluntarily while working on the Challenges. Future work will investigate possible additions of technology to the Challenge learning environment and also investigate larger student group sizes beyond pairs.

References

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