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# Work in Progress--Analysis of Flipped Classrooms in Thermodynamics Courses

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As a result of Covid, faculty made a great many changes to how they teach as additional resources were developed for remote instruction. Even as students return to in-person instruction, these resources may offer unique opportunities to enhance student learning. This paper will explore how we have used videotaped lectures created for remote delivery of two thermodynamics courses: an introductory course and an applications course, to implement a flipped classroom structure. In this model, rather than information being shared in a group setting, the instructor provides individual feedback as students work on problems in small, self-selected groups. We will describe how these classes were delivered and present preliminary analyses of data used to study student attitudes, expectations and learning from the student and faculty perspectives.

This paper reports on feedback collected from student surveys, student interviews and instructor reflections. The study is based on data collected during Fall 2021 at a predominately undergraduate institution. Each class has 30 students enrolled. The introductory course is typically taken by upper sophomores, lower juniors and the second course taken by seniors. Student surveys were collected from all students periodically during the semester about how they were studying and learning. Student interviews further explored these experiences. Finally, instructor reflections examined how this approach to flipped classrooms is implemented and how it enhances the student experience. These data provide insights about how faculty and students can use this new approach to instruction and learning. The data suggest student responsibility for learning become more student focused and student controlled as work shifts from the tradition model of attending in-class lectures and taking notes, to watching videos before class, taking notes and working problems to prepare for an in-class, interactive experience. Based on these data, the authors propose a five-element model for implementation of STEM flipped classrooms. This model includes three student- focused and two instructor-focused elements.

**Literature Review**

The research shows that many students are more interested in multimedia learning than using a textbook (1). This provides a unique opportunity to use a flipped classroom model with multimedia supports that can be accessed outside of class. Multimedia resources can take varied forms including voice over Power Point, sourced videos, multimedia created by the instructor. Bishop and Verleger (2) provide a survey of flipped classroom research in engineering and testing model-eliciting activities (3) and the many types of multimedia resources that can be used in flipped classrooms. However, the authors did not find ones where detailed lectures were created as was done in our current investigation. Holdhusen (4) gives a detailed discussion of a statics course he taught using a flipped classroom model where videos were of a brief lecture video followed by a problem-solving video. He contrasts results from the flipped class and a traditional lecture class and did not find significant differences in student performance. Class time was devoted to students working on problems individually with hints given to the whole class. Kerr (5) provides a survey of research on empirical studies related to flipped engineering classrooms and provides synthesis of strategies to more effectively change learning environments, such as a mini-lecture to begin the class, provide credit for work done outside of class. Garrick (6) discusses the value of having students view multimedia videos viewing in an engineering technology course before their class. These were short videos of about 5-10 minutes, typical of what one might find on Khan Academy and similar to our approach. Garrick's analyses showed that students did view the video before class.

**Methodology and student reactions**

Our exploratory research examined if use of the proposed flipped classroom model would result in student watching the videos and engaging with the instructor during course time. Further, we were interested in beginning to identify the key elements of this model. The data were collected from two classes with a relatively small number of students.

The first course in Thermodynamics that was part of this study includes material from eight chapters, beginning with the philosophical underpinnings, systems, and properties, and concluding with second law analysis. For this class the instructor created 37 lecture videos, each about 15-20 minutes long covering content in the eight chapters. Research has shown that 15-20 minutes is the optimal length for a lecture video (7,8). This is also consistent with student comments during both courses regarding their own attention span when video watching. The second course had thermodynamics applications from HVAC to internal combustion engines to vapor power systems. There were 60 videos associated with this course. These videos included detailed solutions to problems and include more complex and sophisticated problems, hence the larger number of videos although the length of individual vides remained between 15 and 20 minutes. The videos and text for both courses are available on the web (9) and were included in the course Blackboard. The inclusion on Blackboard allowed the instructor to check on the number of times students watched each video, as well as the total amount of time spent viewing all the videos. Students were anonymously surveyed four times during the course with Likert scale responses, which helped assure completion of the survey since it did not require much time and could be done at the end of class.

The classes for both courses meet twice a week for 80 minutes each session. Prior to meeting in person, students were expected to watch the relevant video. All videos were available on Blackboard at the start of the semester. At the beginning of each class, the instructor asked if there were questions associated with content or problems discussed or assigned in the videos linked to that day's class. Invariably there were none. The instructor then provided a 10-minute high-level overview of the video lecture content. At this point, a problem would be assigned, and students would begin working on the solution. They were encouraged to use their notes (presumably written while watching the videos) and the text to help solve the problem. The instructor would then circulate around the class and observe what aspects of the work students were succeeding or struggling with. Students had the option to work by themselves or with others and seated themselves to allow this to happen. About a third of each class opted to work individually while the remaining worked in groups of two or three. Whenever the instructor found a challenge that many students were encountering, he would pause the class, and discuss what the issue was and how it might be resolved. Examples of these include understanding what quality is for a pure substance, when to use it, when not to do so; and how the fuel/air ratio relates to heat in for internal combustion engines.

**History of Video Lecture Development**

The strategy for creating videos evolved over time. In the spring of 2017 one of the authors had to miss a week of classes and created video lectures for the topics on the second law of thermodynamics and entropy. A staff member with experience in audiovisual production videotaped the lectures and edited them. Based on this experience, and reinforced by data from this study, students prefer video lectures where the instructor uses a blackboard (or whiteboard) and talks to them, rather than voice over slides in PowerPoint. Patrick Winston also discusses this approach in his MIT open classroom lecture (10). The equipment needed for our approach is modest: a good video camera with a microphone that captures sound with high clarity, chalk/marker, and a board. In terms of personnel, someone is needed to operate the camera and a person needs to edit the raw video. It was found that recordings that lasted about 15 minutes was an adequate and preferred amount of time for students to watch a segment on a particular topic, it also provided the instructor with time to discuss a particular topic or topics, depending on complexity. Editing of the videos was found to be important. While software like iMovie or Movie Maker simplifies editing of videos, it is still something many instructors, including the instructor of this study, do not have the time or expertise to do. This was an intense experience for all, as chapter lecture notes were created and videos taken, given to the editor and the process repeated for the next chapter.

**Data Collection and Analysis**

Students were asked for their thoughts about the course at multiple points throughout the semester. Except for the final survey, Likert scale questions were provided on a slip of paper near the end of class, so students could anonymously and quickly respond. The final survey also included an open-ended question. The surveys were completed approximately every three weeks, with questions revised as the semester progressed and more was learned about the process. The results for both courses were very similar, essentially the same.

The first set of questions was asked after three weeks in the course. Responses could range from 1 – Agreement with the statement to 5 – Disagreement with the statement.

**Table 1 Responses to First Set of Statements**

| Statement | Initial Course N= 26 | Senior Course N = 28 |
|---|---|---|
| I find using the lecture videos helps me learn thermodynamics better than traditional lecture | average = 2.8, median 3 | average = 2.7. median 3 |
| I find doing problems in class with the professor providing support helps me understand how to solve problems. | average = 1.4. median 1 | average = 1.4 median 1 |
| I being able to work with classmates was helpful and made the classroom more enjoyable. | average = 1.6. median 1 | average = 1.6 median 1 |

From this we can see that students are slightly more positively disposed to watching lecture videos and taking notes from these than from in-class lectures, but very much appreciated the individual attention by the professor during class as they worked on problem sets. There is also strong support for working with classmates. Some students preferred to work alone, which may explain the 1.6 average, and median of 1.

The second set of questions, given about the half way point in the semester, explored students use of video lectures in more detail. They were asked how often they did several things to help them learn in this new classroom structure. Responses could range from 1 – Always to 5 – Never.

**Table 2 Responses to Second Set of Questions**

| Statement | Initial Course N = 27 | Senior Course N = 27 |
|---|---|---|
| I watch the lecture videos prior to class. | average = 2.3 median 2 | average = 2.0 median 2 |
| I take notes on the lecture videos | average = 1.7 median 1 | average = 1.2 median 1 |
| I attempt homework problems before class | average = 3.2 median 3 | average = 3.2 median 3 |
| I find the synopsis of video content at the start of class helpful | average = 1.6 median 1 | average = 1.6 median 1 |
| I find the individual support by the professor during class to be helpful | average = 1.5 median 1 | average = 1.2 median 1 |

Students were not as diligent watching videos before class, but overwhelmingly when they watched videos, they took notes. The synopsis of the day's lesson was important and the individual support was very important. This was anecdotally verified by the instructor when he worked with them individually and they referred to the notes they had taken. As the semester went on the instructor noted there was a slacking off on doing homework problems before class, and this was confirmed by responses to the survey. It was speculated that this might occur because students worked on problems in class and did not value solving problems beforehand. However, this was somewhat troubling since one or two problems were completed during class, more remained to be completed outside of class.

The third set of questions were given the week before Thanksgiving break, so the courses were at three-quarters point. These questions asked the students to reflect on how easy or difficult they found various tasks during the class. Responses could range from 1--Easy to 5--Difficult.

**Table 3 Responses to Third Set of Statements**

| **Statement** | **Initial Course N = 25** | **Senior Course N = 24** |
|---|---|---|
| I found it easy to use the videos to gain an understanding of thermodynamic concepts | average = 2.4 median 2 | average = 2.4 median 2 |
| I am finding the right balance between doing homework problems and in-class problems. | average = 2.1 median 2 | average = 2.7 median 3 |
| The class structure makes it easier to text in class while working on problems | average = 2.8 median 3 | average = 3.0 median 3 |

The responses were somewhat challenging to interpret. The first two questions are connected in that if students don't attempt homework problems on their own in conjunction with the video lectures, then the concepts are more challenging to grasp. In terms of strategy, the instructor encouraged students to attempt the problems done in the video, not copying what was done, but having that as step-by-step support. Based on discussions with the students, it was clear some attempted this, but it is unknown how many. For the initial course, the content during this part of the course was entropy and the second law of thermodynamics and for the senior course it was gas turbine power plants. Part of distracted life for students is their compulsion to be connected to their phone which contributes to poor attention, making understanding of more complex concepts more challenging. The casual nature of the classroom seems to have not diminished this compulsion and may have inadvertently enhanced it.

The final set of questions included two questions were more summative in nature, as students reflected on their experience in the course. Responses options differed to algin with the content of the question.

> Q1. Should I continue the class next year in the same format as this year? Yes, No, No Opinion
>
> Q2. There is an interest by some professors to create voice over Power Point video lectures for students to view before class and the work with students, as I do with you, in class. How effective do you think this strategy will be? (Responses ranged from 1-Very Effective to 5- Not Effective)

Q3. Lastly, I would like your opinion about the course format (you don't need to like thermodynamics). What worked for you, what didn't, what might I change to improve it?

**Table 4 Responses to Final Set of Questions**

| Question | Initial Course<br>N = 24 | Senior Course<br>N = 23 |
|---|---|---|
| Should I continue the class next year in the same format as this year? | 17 Yes (71%)<br>4 No (17%)<br>3 No Opinion (12%) | 14 Yes (61%)<br>6 No (26%)<br>3 No Opinion (13%) |
| There is an interest by some professors to create voice over Power Point video lectures for students to view before class and the work with students, as I do with you, in class. How effective do you think this strategy will be? | average =2.8<br>median 3<br>Four very effective | average =2.8<br>median 3<br>Two very effective |

There was not strong support for voice over Power Point lectures in either class, as indicated by the average and medians for the question in both courses. However, the responses suggest there is somewhat stronger support to continue this model of flipped classrooms among students in the initial course than from students in the senior course. It is possible students in the senior course experienced greater stress since they were learning about vapor power systems which involve solving time-consuming problems and working on individual thermal design projects when the survey was administered.

The final question "Lastly, I would like your opinion about the course format (you don't need to like thermodynamics). What worked for you, what didn't, what might I change to improve it?" was analyzed by reading each response and sorting responses into broad categories. A preliminary qualitative analysis indicates the following:

- The overall format of the course was viewed very positively
- Students liked the personal attention and support while solving problems, it helped them with conceptual and calculational difficulties
- Providing a beginning overview (about 10 minutes) was important in setting the context for problems they would be doing in class
- The instructor needed to fully complete the in-class assigned problems, not just give the results.

**Analysis of student video views**

It is possible to analyze each student's viewing of each video, how often they viewed the video, date and time of day, as well as the whole classes' viewing of a given video. For purposes of illustration, a video dealing with polytropic processes for an ideal gas was analyzed. The polytropic process is an important concept that is used throughout the remainder of the course and homework and in-class problems used knowledge of the process.

The classes met on Tuesdays and Thursdays at 1 pm (1300). The 'hits' refer to the number of times a video is watched but does not indicate how long the video had been watched. As seen in Figures 1 and 2, the peaks occur on Tuesday (Day 3) and Thursday (Day 5), the days that the class met.

**Table 5 Number and percentage of views by day of week**

| Day of week | Number of views | Percentage of all views |
|---|---|---|
| Sunday | 96 | 13.73% |
| Monday | 114 | 16.31% |
| Tuesday | 194 | 27.75% |
| Wednesday | 46 | 6.58% |
| Thursday | 128 | 18.31% |
| Friday | 52 | 7.44% |
| Saturday | 69 | 9.87% |
| Total | 669 | 100% |

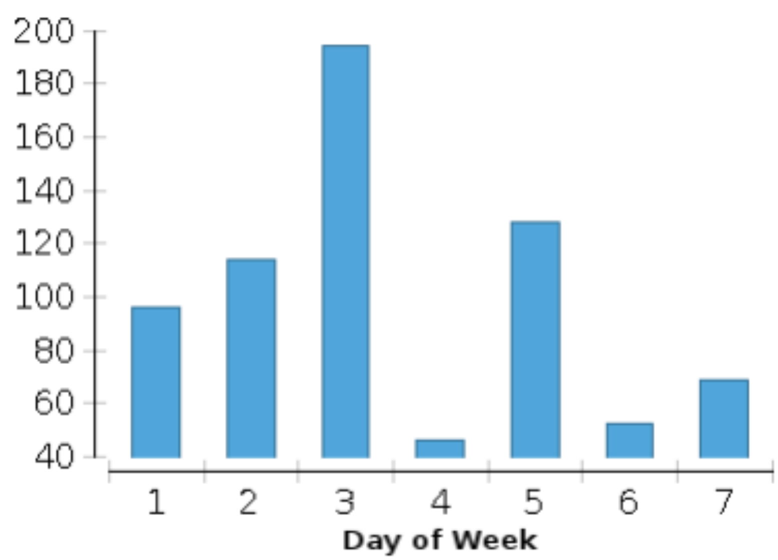


**Figure 1 Graphical Representation of Data in Table 5**

When the information was further analyzed by time of day, video viewing peaking before and during class time.  Some students accessed the videos as they were problem solving during class.  This meant they were likely using their notes, the video, and the instructor as resources.

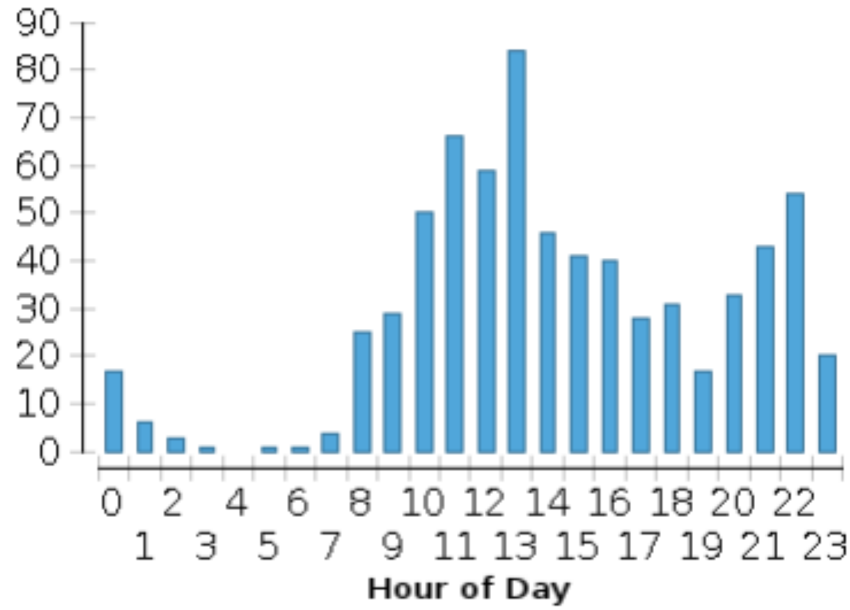


**Figure 2 Student Viewing of Video as a Function of Time of Day**

To further explore how these data can be used to understand the proposed flipped classroom model, the number of views for the selected video were examined for each student and for the entire class.  The number of times the video was viewed ranged from a high of 67 to a low of 2.  While there was not a correlation between the number of views of this specific video and the grade received on the exam connected to this content, there was some evidence that view watching may contribute to test success.  The total number of views of the specific video was highest among students who were in the top quartile on the related test.  The total number of views, aggregated among students, decreased by quartile, with the lowest quarter having only seven views in total.

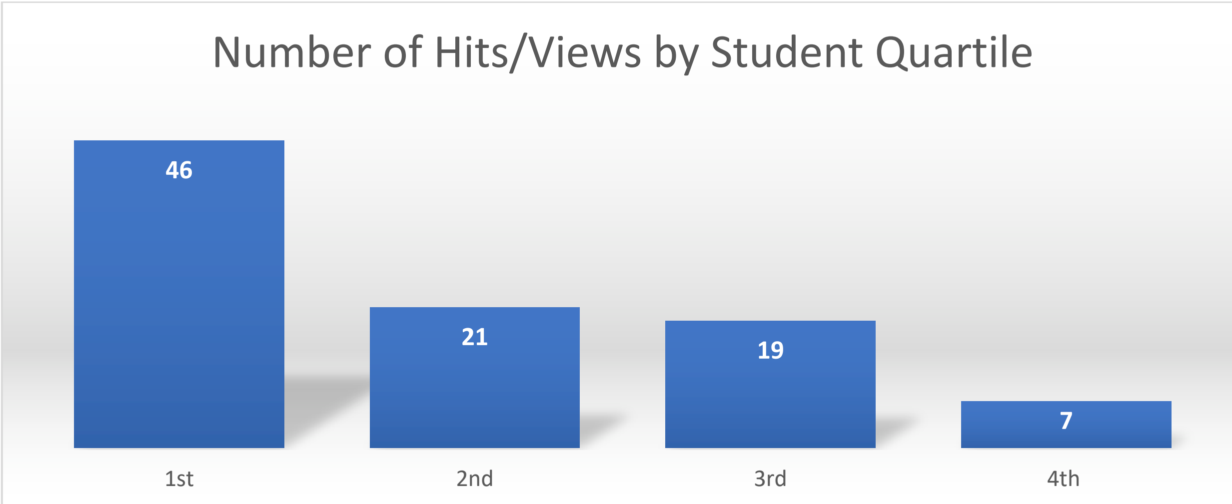


**Figure 3 Variation of views by quartile based on exam on video content**

**Preliminary Model**
A flipped classroom delivery model evolved through this work. The model includes three student elements and two instructor elements about the roles and expectations for each person. The student tasks are: watch the videos, take notes about the video, and attempt the homework problems before class. The instructor tasks are: provide a brief synopsis at the start of class; and two, provide individual problem-solving support during class.
The data were used to support each element of the model.

**Student elements**

- Student task one: watching the videos before class. This was moderately successful with greater success at the beginning of the semester. It is likely as the demands in other courses increased students spend less time outside of class preparing for class. This is not uncommon in all classes as the semester progress.
- Student task two: take notes on lecture videos. While there is not direct data regarding this, the instructor's observations indicated that when students reported they watched the videos the were likely to come to class with some notes
- Student task three: attempt homework problems before class. As the data indicates, this was modestly successfully accomplished.

**Faculty elements**

- Faculty task one: provide a brief synopsis at the start of class. This was accomplished although the instructor had to focus on not redoing the lectures, but rather providing a brief overview to focus the students before they began problem solving.
- Faculty task two: provide individual problem-solving support during class. This was accomplished with few difficulties and is perhaps the most important aspect of the flipped classroom experience for students and the faculty member.

**Conclusions**

This work was exploratory to help learn about both the feasibility of delivering a flipped classroom and the methodologies that might be used to study the model. It should be remembered the number of students in both courses was small and the findings need to be further studied. However, the data supports that the flipped classroom methodology can be used in engineering courses at different levels of content sophistication. Despite including both an initial course taken by many different engineering majors and a senior course by mechanical engineering students, there was consistency in the responses to the brief surveys between the courses.

Almost universally, students liked having individual instructor support which can only occur if video lectures are watched outside of class. While a few students told the instructor they preferred a traditional lecture format, they also did not really want to let go of the individual support.

It was initially challenging to fully capture data about student watching of the videos since Black Board initially timed students out if they were not interacting with the video; therefore, pausing it while taking notes or working on a problem would often result in the video closing. This situation was remedied after the first month. The data do suggest that as the semester progressed and the workload in other courses increased, students increasingly resisted watching videos before class, resulting in students cramming to watch multiple videos before tests. This made the in-class problem solving more important, although the instructor found without watching the videos many students were not as prepared as they should have been. Further, while texting during classes is a challenge in all courses and the flipped classroom format does not discourage this, the instructor found moving around the class, peering at what they were doing, reduced texting momentarily.

This study did not explore the quality of the videos, although anecdotally it appears they matter. Students commented to the instructor that they liked the music introduction, the transition between different segments of a lecture were engaging. These effects were achieved by the engagement of someone with video editing expertise, not something the faculty member was able to do alone. We suspect that unedited, raw footage, would not have been as effective.

An improvement that will be included for the next iteration of the flipped classroom, is that videos will be identified on the syllabus that are associated with each day's content so they can be viewed ahead of class. As currently presented students may find it confusing to link specific videos to a week's lecture. Some other considerations before implementing a flipped classroom with the model we employed relate to classroom size and ease of moving around the room. We are fortunate that the rooms reserved for these classes allowed this amount of movement. A crowded environment would diminish this important feature of the model. The interactions between the faculty member and student are somewhat more personal and informal than those in a traditional classroom environment. It needs to be non-critical and supportive. And as in most situations, a good sense of humor helps.

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