Work in Progress: Development, Implementation, and Student Perceptions of Pre-Class Thermodynamics Videos

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Flipping course lectures using online videos has demonstrated mixed results in various contexts (e.g., in different courses, with or without post-assessments, in tandem with reading guides). This work will describe the initial results of flipping the content lectures (ca. 15 in total) in an Introduction to Thermodynamics course, with mostly first and second year Chemical Engineering undergraduates.

The videos were produced by re-apportioning and recording the PowerPoint lectures (developed in the previous year) which covered theoretical concepts and principles only—PowerPoints which covered example problems were reserved for class time. The video lectures were scripted and then recorded at the maximum (talking) speed at which the instructor was comfortable, thereby ensuring that a majority of the videos are less than 10 minutes in duration, and none are longer than 15 minutes. Videos took approximately 2-3 hours to produce, including scripting, recording, and editing (plus roughly one hour to compile and upload to the LMS). Student learning is encouraged using short, ungraded online quizzes (available for most of the videos) for which they receive participation points. In addition to the videos, students are provided regular reading guides and reading quizzes (developed by the instructor of a separate section of this course).

Students are anonymously surveyed via the LMS at the end of the course as to their use of the videos (self-reporting is compared to LMS access data), their opinion of the format of the videos (length, speed, quality), and their opinion of the content and usefulness of the videos, in addition to open comments. Student performance (as measured by exam and final grades) is compared against students' self-reported use of the videos by means of swarm plots, revealing correlations between performance and video use. In addition, quantitative results and frequent comments from the video survey (and those made about the videos during mid-term and final course evaluation surveys) will be included in the analysis.

Initial results (from early submissions to the mid-term evaluation survey) suggest the videos are highly appreciated by and useful to the students, but too fast and perhaps too long for some students. Although it is too early to tell with certainty, the introduction of these videos does not appear to have had a strongly negative effect on student performance. Nevertheless, the material presented in the videos (roughly two hours in total) is done in a far more time-efficient manner (sparing roughly seven hours of in-class time over the entire semester). While the initial time investment is significant (ca. 2-3 hours for every hour lecture, presented in 10-15 min), the same videos may be re-used as-is, or with minor modifications, in future years. This affords the instructor more flexibility to introduce (potentially time-consuming) active learning techniques during class time, and to experiment with other didactic interventions.

Introduction

The concept of the Flipped Classroom has become increasingly popular within the context of approaches to Active Learning, and its use in early or introductory Thermodynamics courses in undergraduate education is documented in the literature [1]–[3]. While this term is broad enough to encompass a vast array of different pedagogical strategies, this paper will primarily focus on the use of produced videos on theoretical lecture topics, and related quizzes, as pre-class assignments. The course studied herein is the first (of two) thermodynamics courses which are a required part of the curriculum of Chemical Engineering at the Colorado School of Mines.

A great deal of research has been done into students' attitudes toward the flipped classroom as well as some research into its effects on student performance [4]–[9], yet it is still largely unclear as to whether this technique is *always* effective in enhancing learning or otherwise improving student performance. It is nevertheless proven that a significant portion of students exhibit a slight to strong preference for this mode of learning [10]–[12], and further that the technique can be used to free up valuable class time (contact hours) for more tailored and interactive techniques, especially active learning [13].

There have been a number of articles which present suggestions or even guidelines on producing instructional videos of varying types (e.g., lecture material, example problems/solutions, software tutorials) [14-15], and some of their best practices have been incorporated by the authors, as shown below in the Methods section, including: keeping individual videos *as short as possible*, focusing a video on *no more than 3-4* learning outcomes, recording *high-quality audio* at sufficient volume, and more.

Methods

This section will first describe the process of video production for this course section and summarize the videos ultimately produced. Next, it will describe the specific interventions applied to this section of the course to better motivate and sustain student interaction with the videos. After this, the course structure will be briefly described, including a comparison to the other two sections of the course offered simultaneously by different instructors. And finally, the methods of assessment used for this paper will be listed.

The lecture material for the videos was produced in PowerPoint for previous iterations of this course, and thus was based on existing work. Videos were recorded using the built-in functions of Microsoft PowerPoint[1] and a quality microphone[2]. Videos were produced during the course of the semester, with the associated Video Quizzes released about one week prior to the deadline (the date and time of the class session for which the video viewing was necessary).

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[1] While this method is by far the easiest for one without video production experience, it is not without limitations (e.g., the recorded audio is automatically faded in and out during slide transition animations) and it is recommended that video production or video screen capture software be used to record audio and video *separately*. Producing separate tracks also enables more precisely targeted and/or advanced video editing techniques, helping the instructor to condense the video to a shorter run-time.

[2] The authors have more recently added an attached pop filter, and this is recommended to improve audio quality.

The lecture material for the videos consists of anywhere from seven to fifteen slides, three of which were always of the same template: first a title slide, second a list of learning outcomes for the video, and last a closing slide. The remaining content slides usually contained animations (of both text and images) to introduce and reinforce information at the same time as it is conveyed verbally. One example from the second video is the description of the Gibbs' phase rule: a two-phase, single-component mixture is described while at the same time it is also animated as a point on the phase boundary of a PT-phase diagram in order to demonstrate how it is bound to the line between the two phases (and hence, has only one degree of freedom). A summary of the flip lecture videos produced for this course is provided in **Table 1**.

Table 1. Summary of flip lecture (theory) videos produced, where EQ stands for "equilibrium" and T.E.R. stands for "Thermal Energy Reservoir".

Lecture	Length (m:s)	Brief Description of Content
1	09:05	Basic concepts (state, property, system)
2	07:39	EQ, Phases, Process, Property
3	06:12	Pressure in Fluids, Manometers
4	10:48	Equations of State
5	08:03	Phase Diagrams
6	11:30	Steam Tables & Interpolation
7	08:29	First Law Derivation (et al.)
8	07:56	First Law Application (single step)
9	06:34	First Law (multi-step)
10	11:22	Open (flow) systems
11	15:29	Reversibility, Heat Engines & T.E.R.'s
12	08:37	Entropy & 2nd Law of Thermo
13	08:16	Entropy Balance & Rankine Cycle
14	11:11	Reactions & Reaction Extents
Total	2:11:11	

Content and animations had mostly been created for previous versions of this course, but the text for the audio narration was scripted (and edited) immediately prior to video production. This step occupied the most of the instructor's time, averaging at least 1-2 hours per ~10 min video. Recorded video was limited to screencasts and slides only, but audio always included the instructor's voice as the authors believe familiarity of voice is important to the students' connecting to the material[3]. The theory videos required roughly 2-3 hours of work, most of which (1-2 hours) was occupied by scripting and editing the text. Fixing up the PowerPoints and writing the quiz took roughly 30 minutes, while recording (and re-recording) audio for a 10-minute clip also took about 30 minutes[4]. While this ratio (12:1 up to 18:1) may seem like an unreasonably large time investment, it is important to recognize that the 10-minute clip covers roughly 50-75 minutes of class time as most, if not all, of these videos were taken from a whole class period lecture. Justifying the time investment further is the fact that pre-existing material may be easily used (see Recommendations at the end).

The additional contact time freed up through the use of these videos was largely filled by working example problems (from homework or prior quizzes and exams) and by the insertion of

[3] Anecdotal results from student interviews and course evaluations suggest this is recognized as important to the students as well—even as many students used other online resources such as LearnChemE.com, Khan Academy, and YouTube.com, the students generally relied *more* on the course-specific videos, ranking them of higher importance on the end-of-course survey

[4] After this, however, it took an average laptop roughly 20-30 minutes to save the file in a video format (i.e., for PowerPoint to compile it into an mpeg- or wmv-file) and another 10-20 minutes to upload the file to the LMS. While this time requires no active work by the instructor after the initiating action, it nevertheless bears mentioning.

several “Stop ’n Think” periods where the instructor asked the students a broad conceptual question in a think-pair-share format (individual contemplation, discussion with another student, and subsequent sharing out with the rest of the class). One example of an early question is “What is Temperature?” These moments were viewed by the instructor as an opportunity to stimulate student-driven exploration and learning, as well as to delve deeper into theoretical concepts, thereby motivating student interest in the material.

It has been demonstrated that one of the most likely pitfalls of the Flipped Classroom is that students will not be motivated to perform the required pre-class or out-of-class activities (e.g., reading a chapter, watching a video) before the assigned deadline. Instead, students arrive unprepared to apply concepts they should have learned from the out-of-class work, and the instructor may end up recovering this material for the benefit of those students but at the detriment of those students who are prepared. In order to better motivate the students to complete this out-of-class work on time, quizzes were built for most of the videos and students were required to complete these on the Learning Management System (LMS) before a particular class session. While these were scored for performance, students received participation points simply for completing the quiz on time.

As mentioned above, two other sections of this course were delivered simultaneously by two different instructors. Section A (with 60 students who received a final grade at the end of the semester) was delivered in the traditional manner, while Section B (47 students) provided optional Reading Guides for students as well as mandatory Reading Quizzes prior to certain class sessions. Much like the Video Quizzes, these Reading Quizzes were scored for performance but graded only for (on-time) participation, which made up 3 of the 10% homework category for this section. Section C (39 students), which required both Reading Quizzes as well as Video Quizzes, weighted these as 2% and 1%, respectively, of the 10% homework category. The remainder of the grading and assessments between the sections was identical, including very similar weekly quizzes and identical midterm and final exams, and the use of a third party online homework system and Just In Time lecture notes [16]. A summary of the homework grading category for each section is provided in **Figure 1**. All three sections shared a common LMS page for the course, but while all information was technically accessible to students enrolled in any one section, each section hosted its own set of pages (containing information such as lecture notes and class schedules) on the LMS. Consequently, students visited the pages related to their own section far more often (if not exclusively), as is described below in the results section. A future publication will focus more on the comparison of these three sections, but this paper is primarily focused on the effect of the videos used in Section C. It should be noted that section C held the

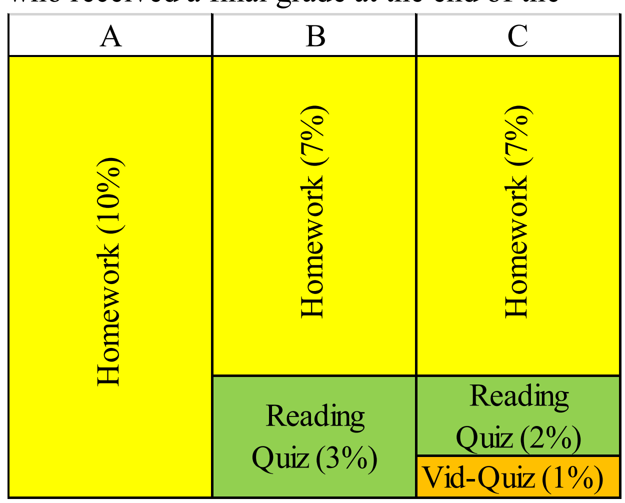

Figure 1. Different breakdowns in homework category weighting for each class section.

lowest average incoming GPA (2.91, compared to 3.23 & 2.98 for sections A & B, respectively) as well as the highest number of new freshmen and transfer students (30 percent, compared to zero & 18 percent for sections A & B) for whom no GPA data was yet calculated at this University.

Students in Section C were asked to provide mid-semester feedback on the course by means of an online anonymous survey (hosted separately from the LMS, to assure students' anonymity), as well as a focus group with the students performed by the Trefny Center, a part of the University which supports improving instruction and engineering learning. Finally, students in all three sections were asked to provide feedback on the course in the form of an anonymous survey at the end of the semester on the course LMS—while individual identification is not possible for this data, the section of each student was nevertheless identified. Additionally, the results of traditional course evaluations (issued via the LMS by the University) were collected for all sections, as well as course website access history recorded by the LMS. All these sources, plus the individual performance of students in Section C were used to generate the results presented in the following section. The produced swarm plots represent each individual data point while the superimposed box-whisker diagram represents the median and quartiles.

Results

The anonymous mid-semester survey of Section C saw only eight unique responses (and at this point in the semester there were still 48 students enrolled, hence a 19% response rate and therefore not necessarily representative), but these nevertheless provided useful preliminary insights into student attitudes. While four students voted that the videos were neither helping nor hindering their learning, three voted that the videos are helping (while one abstained). Furthermore, in the open-ended question "What features of this course, and its instruction, are *helping* you learn?" two students mentioned the video lectures, two mentioned the Reading Guides, and two mentioned the lecture notes, while five students mentioned worked examples in class. There were no common responses to (and four abstentions from answering) the question "What features of this course, and its instruction, are *hindering* your learning?"

This demonstrates that, while the students may not all appreciate the flipped lectures directly, many, if not most, students appreciate the additional time they have in class to work example problems as this is highly valued. Four students responded to the question about what they can do to improve their performance with some mention of working additional problems on their own. Yet in response to the question about what the professor can do, four students mentioned doing more examples in class, two students requested example problem videos, and four students also mentioned going slower and/or probing deeper into the material during class time (e.g., pausing to explain problem-solving strategies and reasoning). This limited early anecdotal evidence was an excellent early indicator of the more comprehensive data gleaned from the Trefny Center intervention, described in the following two paragraphs.

The mid-semester focus group surveying the 42 students at this time still enrolled in Section C confirmed these results (in a more representative manner) and added new information. In a memo from the Trefny Center describing the feedback agreed upon by a majority of the students, the things students found most helpful were “example problems” (all), “clicker questions” (all), lecture notes and Reading Guides (most). In addition, “seeing real world applications” (most), “office hours”, and “being able to rewatch [the video lectures]” (half – most) were mentioned as helpful, with only one student commenting that they avoided the video lectures entirely and used the book instead.

Suggestions for improvement from the students were fourfold and unanimously agreed upon: (1) slow down the videos (and possibly divide them into smaller ones), and work examples in them; (2) show all of the math steps in worked examples, e.g., integration steps; (3) clearer feedback for wrong answers in online quizzes; and (4) explain concepts in class briefly before first applying them to a problem [17]. While it was not possible to accommodate *all* of these suggestions mid-semester, there were several interventions made by the instructor in response to these comments. Firstly, videos recorded after this point were done so at a slower pace, which necessitated dividing the topics further in order to keep the total run-time low. Next, additional worked example problem videos (eleven, by the end of the semester), in which all mathematical steps were detailed and explained, were recorded and posted to a separate page on the LMS. These were viewed far less often than the lecture videos, as nearly all students who visited the example videos page also visited the lecture video page but with a *much* higher frequency. In addition, some of the Video Quiz questions (especially the multiple-choice ones) created after this point were furnished with automatic responses for wrong answers—prior to this point this had only been done for the Reading Quiz questions. And finally, the instructor was careful to explain the concepts and ask and answer any questions during class *before* each concept was applied to an example problem for the first time.

The anonymous survey collected at the end of the semester from all three sections showed a response rate of 127 of 146 students (87%), with a slightly higher response rate from section C (92%). Among other things, the survey asked: whether they viewed the videos; how the videos ranked compared to five other resources; and, the importance of these videos to their overall learning of the course material. In the ranking question students were asked to “Rank the following parts of the class in terms of how useful they were for learning the course material? Rank each item from 1 (highest) to 6 (lowest).” In the question addressing the importance of the videos, students answered on a scale from 1(Very Unimportant) -5 (Very Important). Students could answer “Not applicable” to any resource they did not use, and this data is not graphed. Because these two ranking scales are inverses of one another, the ranking data responses were inverted such that 6 would be the best ranking and 1 would be the lowest, in an effort to make the graphed data more uniform.

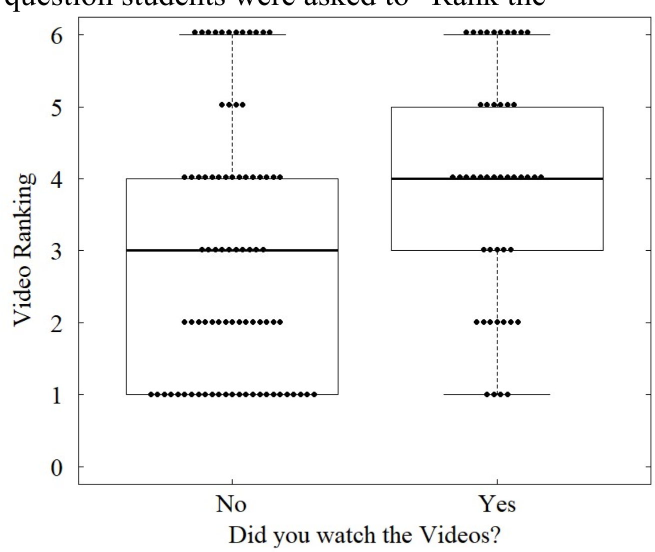

Figure 2. Ranked position of the videos among class resources vs self-reported viewing. No N=81, Yes N=46

Figure 2 shows how students' rankings of the videos (including both theory and example videos) correlates with their reported viewing of the videos, with the self-reported video watchers showing only a slightly higher average ranking of 2.93 vs. 3.89. **Figure 3** reveals more discrimination between these two groups as students were allowed to freely rate the importance of the videos on a scale from 1-5. While the group who reported not having watched the videos showed a fairly even distribution around 3, video-watchers were far more likely to rank the importance at the highest listed value.

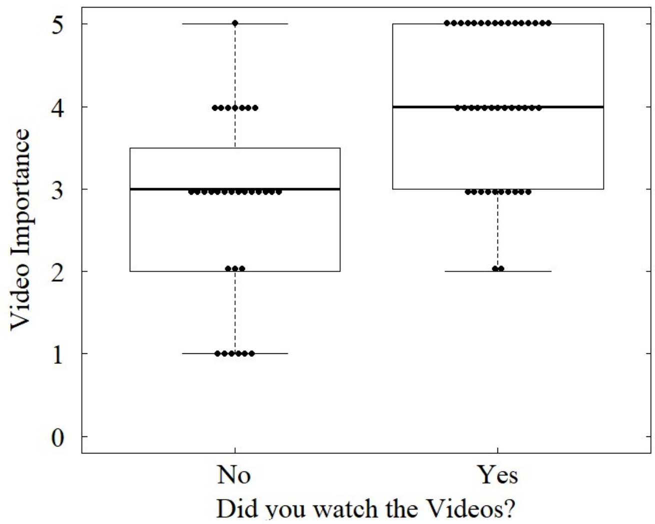

Figure 3. Rated importance of videos vs reported viewing. No N=31, Yes N=41

The LMS stores data on how many times a student had opened the course page on which all of the theory videos were hosted—and this page was the only way to access the videos, as they were not downloadable. However, detailed information such as viewing statistics on individual videos was not available. The number of page views was recorded for all students and categorized into groups of None (zero video page views), Low (1-12 unique page views), Medium (13-25), and High (26 or greater). Medium was defined from 13 to 25 views as it implies the student came back to watch a few videos for study material and at minimum viewed the page each time a new video was rolled out. "High views" is defined as any number above 25.

This data may be used to try to verify that the students saying they were watching videos did, in fact, visit the video page. Due to the anonymous nature of the survey the direct numbers could not be compared to their report of yes or no, however the students' sections *were* recorded. By comparing the number of students who said they watched the videos to the amount of actual video watchers (as defined by having *more than one* unique video page view) in each section, as shown in **Table 2** it seems likely that students' self-reporting was accurate, if conservative, in this regard.

Table 2. *Final course survey results and LMS data on video viewing for each section.*

Section	# of students who reported watching videos (survey)	# of students with *theory* video page views > 1 (LMS)	# of students with *example* video views > 1 (LMS)
A	5 / 50 (10%)	9 / 60 (15%)	5 / 60 (8%)
B	7 / 41 (17%)	10 / 47 (21%)	7 / 47 (15%)
C	34 / 36 (94%)	39 / 39 (100%)	34 / 39 (87%)

Most students enrolled in Sections A and B did not view the video pages, as they were neither required nor actively encouraged to do so by their instructors. Thus, the sample size for no video views is noticeably larger than any grouping, and no student from Sections A or B viewed the videos a Medium or High number of times. **Figure 4** shows that the final course grades for students who viewed the video page more than 25 times fell closest together, with a *slightly* higher median score than any other group as well. While the results for the final exam (not shown) were far less conclusive, these data suggest that the repeated viewing of videos is correlated with *slightly* increased performance in the class, over the course of a semester, and that this correlation may be fairly *repeatable* (given the narrower distribution). This correlation could be interpreted as more causal when recognizing that data in **Figure 5** show that while students with a Low number of views (some of whom, presumably "get it" upon the first viewing, or require no viewing at all after reading the textbook) score about average or slightly above average, those students in the Medium group show the lowest median and average grade. This suggests that the students watching the videos only about once (or occasionally twice) *might* have seen performance improvements had they *returned* for additional viewings.

Finally, focusing only on Section C provides a slightly more controlled experiment as all students viewed the theory video page more than once since it was often required in order to complete the video quiz. **Figure 5** and **Figure 6** demonstrate the much stronger trend of final exam score and final grade, respectively, with the category of video viewership. While this trend is evident in the final exam scores, shown in **Figure 5**, it is even more pronounced with the course grades in **Figure 6**, reinforcing the conclusion that increased viewing can help lead to performance improvements.

Finally, a note about anomalous data. In the survey section, three students reported that the videos were very important to their learning (5) but that they were the least important resource of the six listed in the first survey question (1). The authors believe this to be a simple misunderstanding and that the students rated their resources believing that 6 was

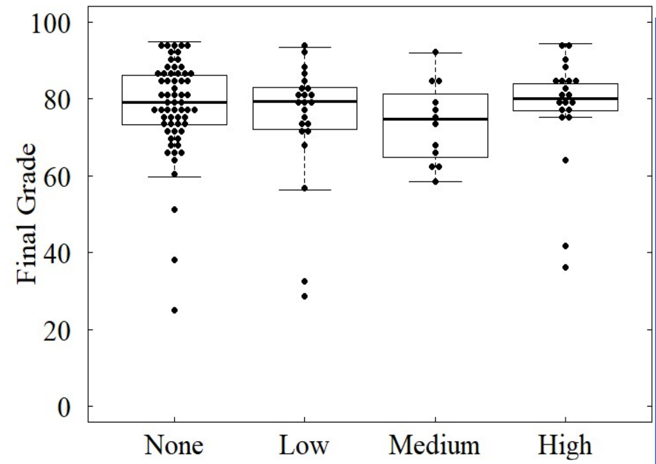

Figure 4. Final Course Grade given to students vs their viewing of the LMS video page. None N=62, Low N= 23, Medium N=12, High N=21

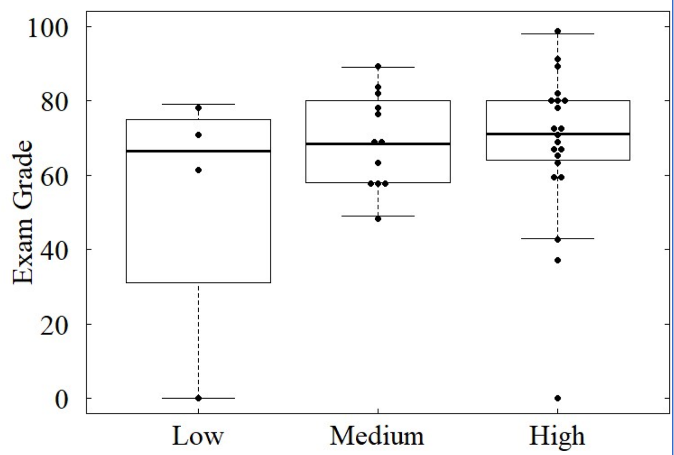

Figure 5. Final Exam score of Section C students vs their viewing of the LMS video page. None N=0, Low N= 4, Medium N=12, High N=21

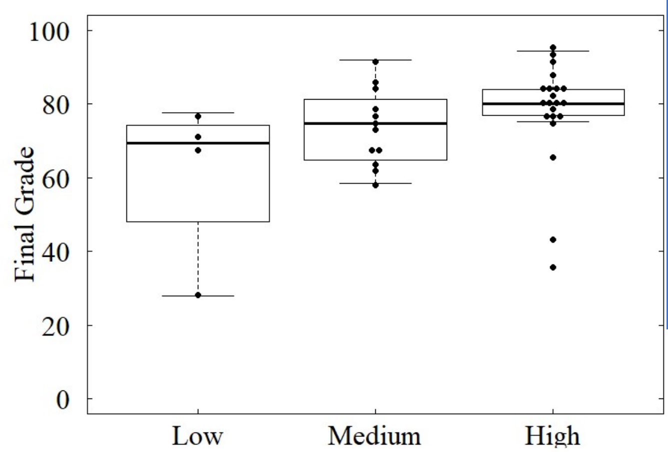

Figure 6. Final course grade for Section C students vs their viewing of the LMS video page. None N=0, Low N= 4, Medium N=12, High N=21

the *highest* they could possibly rank the videos when it was actually the *lowest* (recognizing that the ranking system was flipped for the purpose of graphing so that it would be visually intuitive). Furthermore, two students in section C reported that they did not use the videos, but also rated the videos highly in importance and rank. Viewing statistics also show that *not one student* in Section C *did not watch any* videos at all, and the corresponding high rank and degree of importance points to this as being a simple misreport. These types of anomalies in the data may have obfuscated the observed trends in the data.

Conclusions/Recommendations

The distribution of grades between sections is complicated by the difference in styles, structure, and instructors, but nonetheless the effect of High rates of video watching (as compared with Medium and Low) on course performance appears to be significantly positive. It should be noted that the average final grades of those fifteen students from section A who visited video pages more than once was over 80% and that for the twelve from section B was over 72%, while that for section C was 70.5%.

The survey indicates a *mostly* positive response to the videos, and only isolated problems[5]. When pairing this information with the results of student performance it becomes apparent that the videos are a good resource for most of the students for learning and studying. The diminished spread of grades for students in the high viewership group indicates that if more is done to incentivize the repeated and sustained use of the videos (without heavy grade penalties) then grades should increase for a flipped classroom section. The small N and self-selection of this study preclude any broad conclusions about flipping theory videos in general, but the authors nevertheless strongly recommend this practice to interested faculty in courses where it is possible (or more easily applied), especially in lower-level core/required courses.

It has been demonstrated that the amount of time invested in flipping the theory lectures (roughly 3:1 during the first year) may be steep, but it is an investment for future years in which only minor tweaks or improvements to perhaps only a few videos per year is necessary. Next year, for example, the instructor intends to leverage the existing material by simply breaking up the videos into smaller chunks lasting no more than 5-7 minutes (and likely removing all of the tag information, i.e., the first and last slides). Not only was this specifically requested by the students (during the mid-semester focus group as well as in final course evaluations), this is generally recognized as good practice as it allows students to "chunk" their learning into more digestible pieces [18]. Furthermore, it allows them to be more focused on their second looks at particular videos and topics, repeating only those which require more time and effort to sink in.

The class time which is freed up by flipping the theory lectures (and properly motivating students to perform this pre-lecture work) is valuable and may be invested in several ways including: spending more contact time solving problems (not necessarily *new* problems, but having the instructor solve quiz or exam problems during class is also *very welcome* to many students); allowing more time for probing concepts more deeply (e.g., think-pair-share exercises,

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[5] One student reported avoiding the videos entirely (though still had >1 hit on the page), using the book instead, but performed above average nonetheless, despite being "unhappy" about the course delivery method.

open Q&A sessions about concepts); and responding to student requests for (re-)coverage of specific material. In short, there is ample room for experimentation with active learning strategies as well as more traditional worked-problem lectures.

Although they *were* in this execution of this course, it is not necessarily recommended to *completely* silo the theory videos from the example videos. While students watched the theory videos far more, the example videos may have proven more useful if they had mentioned or reinforced concepts introduced in the theory videos and/or connected more to the (specific) theory videos, perhaps *literally* in the form of active links. The same is true for class time: theory videos should be briefly reinforced with at least a mention of the outcomes or main points of the video that will be used to solve the example problem.

Finally, and on a more practical note: the speed of the first several videos, recorded at a pace that was as quick as the instructor could muster and still remain coherent, was far too high. Most students complained about this, and none saw the advantage[6]. Videos made after the mid-semester feedback sessions included audio recorded at a more normal pace. Nevertheless, it should be noted that the video *may* (and in many cases *should*) be sped up in order to better match normal speaking pace and to eliminate most (if not all) long silences. Student complaints were restricted to rushed audio recordings, perhaps because of the urgency heard in the narrator's voice.

In conclusion, the authors strongly recommend the use of individual instructor-produced videos for flipping lectures, especially lower-level core classes which are required for advancement within a major or department. It is an excellent way to free up class time for active learning and supports learning at least as well as (if not better than) traditional methods.

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