FLIPPING THE ENGINEERING CLASSROOM
LESSONS LEARNED IN THE CREATION, PRODUCTION AND IMPLEMENTATION

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Abstract: The objective of the present educational research is to develop an innovative teaching method that will enhance student learning and conceptual understanding. This paper will present the development, structure and lessons learned during the establishment of a blended flipped classroom for engineering students at the undergraduate level. A range of topics including software used for video development to evaluation and assessment techniques is discussed. Problem solving is a critical component of engineering education; an engineering student must be able to apply the knowledge gained from a lecture. However, duration of student contact in the classroom is constrained by credit hours. For many students, graded homework assignments and exams are the only experiences they have in solving complex engineering problems. Virtual lectures provide students the opportunity to apply their knowledge of mathematics, science, and engineering during class time, thereby increasing their ability to identify, formulate, and solve engineering problems. The proposed instructional process leverages advancements in technology combined with programmed problem solving exercises to increase a graduate's proficiency as an engineer.
Key words: flipped classroom, video lectures, self-paced learning

Introduction:

In recent years, the concept of "flipping the classroom" has become popular within the educational community. In this pedagogical methodology, class work is done at home and homework is done in the class. This resurgence is due in large part to the popularity and success of online instructional videos by Salman Khan, the founder of the Khan Academy. In the Khan Academy model, students are required to watch video lectures independently and complete exercises to evaluate the students' understanding of the topic. Once the student achieves mastery of a topic, he or she moves on to the next topic in a self-paced learning model, advancing independently of one another. The effectiveness of this method remains the subject of much debate; however, many organizations and individuals, including the Bill & Melinda Gates foundation, Google, Netflix CEO Reed Hastings, and Irish Entrepreneur Sean O'Sullivan, believe that the Khan method is the future of education, and have provided financial backing of over $15.5 million collectively to see it succeed. [1]

The concept of flipping the classroom is not new; and in many ways it is reminiscent of the original "Thayer Method" at the United States Military Academy. Named after Colonel Sylvanus Thayer, the father of the Military Academy, the Thayer Method required students to prepare for class and then to recite topics to their instructors who would evaluate student performance every day. Students were grouped by ability in order to provide "each student a task of study proportional to his capacity." [2] This method, however, left little time for in-class instruction and placed the onus for learning predominantly on the student. [Figure 1]

In the Department of Civil and Mechanical Engineering (C&ME) at the United States Military Academy, the Thayer Method was modified over time to place less burden on the students who were learning more complicated technical material. In the "CME method" the students are expected to prepare for class by simply reading or skimming assigned portions of the text book. The instructor provides an engaging lecture using physical models, laboratory exercises and demonstrations, and multi-media assets whenever possible. Instructors or student groups work example problems in class as time permits. Course faculty assign a variety of homework assignments, including problem sets, engineering design problems (EDP), and laboratory reports, all of which are to be completed outside of the class. In the classroom, instructors evaluate student performance using conventional instruments, most notably timed examinations.

Historical time-on-task data collected from students as part of the Department's course and program assessment system often reveals that the majority of students conduct little or no daily preparation when there are no graded requirements due. By contrast, the student time data shows large spikes in effort when out of class assignments are due or prior to in-class examinations, [Figure 2].

The data in Figure 2 imply at least two possible behavioral trends. First, some students may not be taking responsibility for their learning, subsequently waiting for information to be presented to them for the first time during lectures. Second, the time data suggests that some students may struggle with out-of-class requirements, often the night before an assignment is due. With no access to an instructor for assistance, these students may be spending more time than necessary to complete an assignment. Courses with a broad range of topics in a single semester, such as course in thermal sciences, often require a large portion of class time for theory development through lecture, leaving little time for in-class student work and problem solving.

Problem solving is a critical component of engineering education. Most engineering students cannot achieve subject mastery by reading problem statements or attending lectures; however, there is usually not enough time to do both in class period. Typically, in class lectures require an instructor to teach a certain amount of material in a limited timeframe irrespective of the rate at which each student can retain or comprehend that information. To enable efficient problem-solving and application of theory, many courses at USMA provide a study guide to students with an array of optional sample problems. However, in a recent survey, most students indicated that they would not take the time to complete the problems that are not required or graded on their own after class due to competing interests both academic and personal [Figure 3]. For many students, graded homework assignments are the first and only experience they have solving complex engineering problems prior to exams. By only receiving lectures and struggling to work homework problems individually, it is arguable that few students are able to progress beyond the lower tiers of Bloom's taxonomy. [3]

Over the past year, we have developed and implemented an instructional method that employs blended classroom methods to improve student learning. Dubbed "Thayer 2.0," [Figure 2], the method leverages technology and blends some of the best characteristics of the C&ME Method, the original Thayer Method, and the Khan Academy. In conjunction with a literature review, a beta test of Thayer 2.0 was conducted during the spring semester of academic year 2013 to gauge student feedback and to establish operating procedures and instructional best-practices for a broader implementation. The lessons learned from development and student input are discussed in this paper. A broader test, which includes a robust assessment package, is ongoing and results will be reported in a future publication.

Experimental Setup:

Instructional Method:

Students are provided a syllabus, a text book, and a study guide complete with detailed lesson objectives, assigned readings, and practice problems. Lecture videos are posted on Blackboard by lesson objective which most lessons consisting of three to five lesson objectives per lesson. As opposed to complete lectures. This method is similar to the concept of "teaching nuggets" proposed by Wallace and Weiner [4]. By making videos by lesson objectives, a course can restructured without having to recreate entire lesson videos. Additionally, students can select objectives to watch or review without having to watch or skip through the entire lecture. Students are required to watch no more than 40 minutes of video footage prior to each class. Students are given a conceptual quiz at the start of each class period to ensure that they are watching the videos and to identify common areas of confusion, challenging concepts and any deficiencies in the manner in which the videos present the material.

In the classroom, students have the opportunity to witness live demonstrations and have access to training aids of concepts discussed in videos. During the class period, the students will work study guide problems to allow them the chance to apply the concepts learned prior to class. The instructor will be moving throughout the classroom helping students as needed to clarify issues. This method is similar to methods applied by Wallace and Weiner [4] as in-class exercises and by Foertsch, et al [5] as group projects. However, like the Thayer Method, our students are required to work individually. If the instructor finds that multiple students are struggling with the same part of a problem, he/she may choose to demonstrate the problem on the board.

Students will be afforded time to work on homework in class when the instructor is available. (Based upon time estimated to complete homework, divided over the number of lessons from the date issued to due date). The intent is for students to work on homework problems in class, so that the videos are not viewed as additional homework. [Figure 1]

Rather than provide a broad lecture, instructors will be able to tailor their instruction to the individual student via multiple means for multiple learning styles, and explain specific topics based on a student's comprehension of a lesson objective indentifying inaccuracy on the spot with increased efficiency. In this manner, instructors will still be able to form a genuine relationship with the students not as a "sage on a stage, but a guide on the side," to use the words of Salman Khan.[1]

Desired Outcomes:

Increase the time spent in the classroom solving problems. The goal is to increase a student's ability to indentify, formulate, and solve engineering problems. We hope to increase one-on-one time in the classroom where the instructor can better approach each individual's issue instead of providing a broad-spectrum lecture. West Point classes are limited to 20 students; which is about the maximum number of student one instructor effectively split his/her focus. Larger course would require a teaching assistant or graduate assistant.

Provide students with videos covering lesson objectives granting the student with the ability to pause, rewind, or re-watch as needed allowing them to learn at their own pace. Additionally the student is able to review the lecture after solving problems to improve his or her understanding of the material, ultimately, creating a valuable study tool for exam preparations. Ideally, the student will follow along with the textbook and take notes as well.

Encourage and enable students to take more responsibility for their learning and become lifelong learners. Students need to understand the impact of engineering solutions in a global, economic, environmental, and societal context. As future professionals in a changing world they will be responsible to maintain a high level of knowledge and information with regards to their trade. The proposed approach will reinforce the concept that learning is not limited to the one hour spent in the classroom, but rather is refined while in the classroom. [6]

Improve the quality and efficiency of student learning by conducting lectures outside of class and homework during class. We seek to level the time survey data [Figure 2] so that students perform as well or better as previous semesters with less time spent outside of the classroom and have better predictability. Decrease the intense amount of additional instruction (office hours) students seek for engineering courses which in turn reduces the required instructor preparation. This additional time will provide more time for instructors to focus on research and improving the next generation of engineers.

Production of Lesson Objective Videos:

As mentioned in Orange, et al.[7] as well as in Wallace and Weiner [4] and in Foerthsch, et al. [5], the upfront time expenditure of the instructor is considerable and in the first few semesters will consume considerably more time than traditional teaching and teaching preparation even for low cost videos if a reasonable level of professionalism is desired. With the multitude of software for this purpose, much of our initial time was invested in experimenting with a variety of software, determining what we felt were their pros and cons and attempting to gain a level of moderate proficiency. Intermediate student feedback helped us determine which aspects mattered the most to the students (speed, clarity, etc.) and adapted accordingly. In addition to the time spent learning software, a considerable amount of time was invested in the actual creation of the videos which ranged from anywhere from two hour to six hours depending on the method of production for each three to seven minute video. In our course alone, we have over 130 lesson objectives. Additional “low tech” methods exist that can save the instructor time, such as recording an actual lecture or recording the lecturer teaching to an empty classroom for a more individual production. However, our goal was to create clear presentations that made the student feel as if the instructor was speaking directly to him/her as a tutor would enhancing the quality of the videos and therefore the learning experience of the cadets.[8] The aforementioned techniques, though considerably time saving, did not accomplish that intent.

As with any lecture, building the videos began with a review of the instructor’s notes. Accuracy in this case was extremely critical as what was said would be recorded for posterity. In that regard, several re-recordings of audio and writing were often required. We also attempted to keep the videos succinct in order to maintain the students’ attention. For a normal lecture to a class we normally have built in questions used to illicit student responses, but with video lectures we had to plan how to incorporate that drawn information in a manner that would encourage the student to ponder the information without having to actually respond.

Our initial conceived notion was to simply lecture and write our board notes on white pieces of paper with a camera over our shoulder; in the style of the math tutorial videos offered by PatrickJMT of justmathtutoring.com, who has created over 1500 math videos in this manner (many of which were utilized by the authors in graduate school and served as the original motivation for this project). This method is reminiscent of the overheads projectors and acetate of yesteryear’s classroom, but provides the student with an intimate instruction for relative low instructor time investment. However, this technique was dismissed in favor of more advance method that would allow animations and the incorporation of schematics and pictures.

Our first video productions were created in a similar manner as the Khan Academy and many other online tutorial sites.[9] We used an off the shelf drawing application called *SmoothDraw 3* in conjunction with *Wacom Bamboo* writing tablet. Audio recording and video capture were accomplished using *Camtasia*. Writing on the table took considerable practice and was extremely difficult to master because it requires you to use a stylus to write on the tablet but view what you are writing on the screen of your computer. The results were very slow and very sloppily, nearly illegible, videos lectures. To rectify this eye-to-hand disconnect, we began using a Dell Latitude XT2 touch-screen laptop. However, even with the hand-to-eye disconnect removed, we could see what we were writing but the Dell platform's screen sensitivity left much to be desired. The key drawback of this platform's lack of sensitivity was requirement to write very slowly in order to ensure the entire letter or word would be drawn and drawn clearly. As a result of the rate of material decrease, the corresponding length of the videos increase—and became slow and boring—even to the instructor. As a work around, we would record the handwritten portions of the video, play the video back at twice the speed, and then voice-over the instructor afterwards. This method shortened the videos and provided comfortable atmosphere for students, but requires considerable production time on the part of the creator.

Since screen sensitivity seemed to be a considerable issue, we chose to experiment with the Apple iPad. The iPad itself is a great tool, but with Apple products there are drawbacks such as software compatibility, lack of a USB or external microphone port and the fact that an iPad is a tablet not a computer in terms of processing capability. Fortunately, there exist several iPad apps for the distinct purpose of creating instructional videos and we explored several of them. The first app we experiment with was called *ShowMe Interactive Whiteboard*, which proved simple to use and allowed the import of pictures into screen. Best of all, the basic app is free and is a great basic tool. However, it was not without its limitations. The capabilities are pretty limited and do not allow the user to save a board and advance to the next, require the user to erase the current page and write over it as they progress. This prohibit the instructor from being able to flip back to a previous board or seamlessly move content around to save relevant material on the screen as you proceed through the topic. Additionally, with all of the iPad apps, the sensitivity of the screen, which gives its use a considerable advantage over the Dell touch-screen laptop, can also be a disadvantage at times. The hand of the instructor is constantly making accidental contact with touch the screen which causes interference with what you are writing or forces you to write in an unnatural position. It is highly recommended that if using an iPad to invest in a *Hand Glider Tablet Glove* ($24.99). We found several other iPad apps that had far more capability than *ShowMe*; however most require the user to upload your videos to that app's website for viewing and the author does not retain rights to that material. Our university already has a course information sharing site (Blackboard) and we did not want to require students to accesss course information from two locations. There are two more advance apps that provide the user control over their content: *Doceri* and *Explain Everything*. Both applications allowed us to draw the content and create the videos. Both allowed us to download the video file to our own computer, though *Explain Everything* had a better system for this task as it integrated with Google Drive. Both apps allowed us to insert pictures. Yet neither app allowed us to write fast enough to so that the drawings were not holding up the videos. It is not clear if this is a function of hardware or software. Editing recorded videos was possible but not user friendly in comparison to *Camtasia* on a desktop with which we had become accustom.

We eventually reverted to creating a majority of our videos using PowerPoint; which, if done properly, takes considerably longer to make than any of the previously discussed methods. However, the result is a professional, perfectly legible product that can be custom animated to allow the presenter full control of the rate of the presentation and the rate of exposure of material. PowerPoint also, unlike all aforementioned apps, allows the user to quickly flip back to a slide with related information if tying in a concept. Video can be imbedded as can pictures. PowerPoint integrates with *Camtasia* which makes producing the videos easier to record and easier to edit. However all of this capability comes at the price of a huge time investment to create each slide, create equations in the symbol/equation editor, and animate each component in a customized manner to your teaching style. With animation, the presentation can be built as the lecturer speaks without slowing the speaker down. A secondary benefit is that when speaking errors were made while recording the videos, we only had to restart the presentation and record again rather than redraw the slides again. The most common downside to the PowerPoint videos is that some students felt that they were less intimate and at times more cold. Additionally, PowerPoint videos must be edited to the speaker; and not just have all of the information presented at once. If the teacher is using the slides to build as he/she lectures that is one matter; if he/she is just reading a slide with all the information displayed, it saves production time, but creates a boring video. Lastly, some students felt that the PowerPoints, even animated were too fast for them to take notes, though they can simply pause the video. (Conversely, a similar number of students felt the handwritten presentation using *SmoothDraw, Doceri* and *ExplainEverything* were too slow and hence boring despite doubling the playback speed on *SmoothDraw* videos.) This mixed feedback from some students was a concern, but we felt that the clarity of material provided by the PowerPoint more than justified its continued use and it is easier to pause rather than try to fast forward indiscriminately and risk missing key information.

We originally built all videos with a white background, but halfway through began experimenting with dark backgrounds such as black or green. In addition to mimicking the chalkboards used in our classrooms, the dark background with light text made the text standout more. There is conflicting research as to which method provides less strain to the eyes as much of it depends on other factors (ambient light, glare off the screen, etc.)

All of our videos were published on Blackboard for access by the students. Lesson Objective Videos were organized by lesson so the students could easily tell which videos they needed to watch before class. We looked at numerous other sites, but decided that Blackboard contained the functionality we needed and was already in use at USMA and provide statistical tracking.

Results and Discussion:

Outcomes of the Beta Test:

Students were given surveys at the beginning of the semester that were repeated at the end of the course to determine the level at which students preferred video instruction and to ascertain how, if at all their preferences for video instruction changed after the experiment. For the initial beta test, the Thayer 2.0 method was applied to the first third of the course only. The remainder of the course was taught in its traditional manner in accordance with the C&ME model to provide the students a basis of comparison when determining which method they preferred for the material. Additionally, as a standard, C&ME requires students to anonymously complete time surveys daily to indicate time spent preparation for each class. These mandatory time surveys provided us with a unique opportunity for comparative analysis with years past, as the department maintains historic data on both time surveys and grades going back nearly two decades.

Admittedly, from the beta test, the surveys yielded mixed results that for many areas proved to be inconclusive. Students seemed to favor video lectures for their ability to be viewed multiple times at the convenience of the students (supported by large viewing spikes prior the TEE) but also wanted in-class lectures and in-class problem solving, for which there is simply not enough time.

Despite some mixed feedback, we did learn some important lessons; some we predicted and some we did not consider:

The students will push back but will come around. Like most people, students are resistant to change and many students resisted the beta test before it even started. They had become comfortable to not preparing for class; they had become comfortable only being lectured; they had become comfortable waiting until the last minute to do homework. Our first mistake was telling them that the video method of teaching was only for the first portion of the class. Armed with this knowledge some of the students refused to watch videos and decided to wait out the experiment until lectures resumed. This error contributed to some of the conflicting Likert data. However, student's free text responses still proved to be very valuable. Interestingly enough, Blackboard tracking data shows that while only some students actually watched the videos before every class, nearly every student re-watched or watched the videos prior to the TEE (with some videos being viewed 230 times by the 30 students in the week prior to the TEE—double the views for the actual lesson) [Figure].

Teachers have to fight the urge to lecture. Students have to have an incentive to change their habits and learn how to learn again. If the only way they get the lecture is through the video they will watch the videos; if they know they are going to get lectured on the material or get you to lecture the material most will lose the incentive to watch the videos. This observation was noted by Wallace [4], Swedberg[10], Foertsch [5] and was reinforce by our survey. During the conduct of the beta testing, one instructor strictly adhered to the pedagogy's methodology, while the other could not resist his urge to lecture, which several of the student coaxed him into doing since they had not viewed the videos. The difference in the free form response feedback portion of the surveys for each instructor clearly identified and validated this difference. The instructor who did not lecture but facilitated problem solving had more positive reviews of the video lectures and in-class problem solving method while the lecture professor had lower reviews of the effectiveness of the videos and several free form responses stating that the students felt it their time was wasted since they had watched the videos prior to class only to receive the same lecture in class. As unnatural as it is initially for students to not get lectured and to work problems individually, so too will be it unnatural to the instructor to not teach but the urge must be fought. As students work individual problem and homework, the instructor still has the ability to brief a concept of a problem on the board if he/she identifies that several of the students in the class are struggling on a similar concept of the problem or homework solving.

Group work is not as effective as individual work. Students almost universally like to see problems worked before they work them themselves. The time to do this is as a video prior to the class period, despite student's desire to see it done in class. Nearly every student feedback survey indicated that **students want to see videos of not only lecture but of problems being solved.** Working a problem on the board leaves the same problem that Khan Academy Model seeks to avoid/address. Some students will be confused or lost and some will grasp the material yet the problem is worked at a **single** rate: too fast for some, just right for some, and too slow for others, preventing students from self paced learning. Usually this method consumes the entire hour, robbing students of the opportunity to work multiple problems or their homework (which increases their out of class requirements) Additionally, working problems as class does not provide the students with the muscle memory and the struggle of solving and making mistakes which will inevitably help students retain the methodology and any errors he/she makes. Additionally, if working in groups, the students often take longer to solve the problems, not all students contribute, and the instructor doesn't have a clear picture of what each individual person's disconnects are with the material. Individual problem and homework solving places the onus on each student and allows the instructor to foster each one separately and connect different dots for different students. From our beta testing, **about 20 students per instructor/TA/GA is the maximum ratio for appropriate circulation.**

Forcing functions (incentives) are valuable and must be weighted appropriately. We utilized daily 10 point conceptual quizzes at the start of each lesson each day to try and ensure student viewed the videos. Because the beta test was only the first third of the course, the quizzes only totaled 100 points combined in a 2000 point course. For the actual experiment in AY14-1 the quizzes total 300 points or 15% of the student's overall grade. Initial indications lead us to believe that the combination of strict adherence this semester to not re-lecturing the material from the videos and the overall weight of the quizzes has already resulting in a significant increase in the percentage of students not only watching the videos but taking notes while watching and coming prepared to class.

Upfront cost in terms of time is huge if done correctly and careful planning and problem selection is critical. As discussed previously, the creation of the videos is a significant upfront time cost for the instructor. Additionally, conceptual quizzes need to be created for each class. More importantly, careful selection of the daily problems is critical. One of our initial failures was to simply have students work study guide problems regardless of their complexity. Many of those same problems would normally take the instructor 20-30 minutes to work on the board with/for the class. To expect that to be the first problems of that type that those students complete is unreasonable and time consuming and robs the student of critical time to work the homework in class while the instructor is present. Ideally, daily problems should be simpler, foundation principle problems that students can use for reinforcement of concepts and tie together in the homework which is primary desired outcome of this pedagogy.

Future Research:

The intent is to utilize this model in "Thermal Fluid Systems" for engineering majors and "Introduction to Thermal Fluid Systems with Army Applications" for non-engineering majors over several semesters starting with the fall semester of academic year 2014 which is currently underway. During which approximately 260 engineering students from multiple engineering programs and 37 students in the Mechanical Engineering minor from a variety of liberal arts majors will be enrolled in these thermal-fluids courses. Follow on papers will discuss analytical results of those tests will be discussed in later papers after the semester is complete. We will reference time survey data to analyze the average time spent in preparation for class and how the fluctuations are affected.[Figure 1] Additionally, we will use the Term End Exam (which does not change from year to year) to assess students' understanding of the material as compared to previous semesters. Finally, we will compare student survey data from surveys given at the beginning of the course to surveys that will be given at course completion.

Thayer 2.0 will continually evolve and become more refined and interactive. As we improve our video production, the original videos (34) will be recreated to a higher standard. We plan to add interactive flash-media applets that allow students to manipulate parameters to see effects. As our textbook, written by our Department Head, is available to students in portable document format (PDF), we would like to imbed the lesson objective videos in each chapter along with example problem solutions.

Future development would also require each student to have an *iClicker* to answer quiz questions in class electronically so that the instructor can receive immediate feedback for the class and each individual student as well as instantaneous grading and grade input.

After Thayer 2.0 is polished in 2014 it will be implemented in larger courses under IRB regulations to increase the sample size and establish a control group (non-Thayer 2.0 sections) over several years in order to provide more supporting or non-supporting grade, survey and time data.

Conclusion:

An ever-growing body of research is being conducted on video-based focusing on different aspects thereof. Not every technique or solution will be suitable for every course or every university, but with multiple methods for students to receive information on YouTube, Khan Academy, and other venues, the modern student has shown a strong preference for quick, convenient access to knowledge. To accommodate digital learners, educators must adapt the modern classroom. The authors do not believe there will be any suitable replacement for old fashioned problem solving nor do we believe that videos will make the teacher any less relevant or important in the development of the student. Our hope is that the information and lessons learned from our attempt at creating a flipped classroom prove useful to other instructors who implement similar techniques in their classrooms.

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Figures:

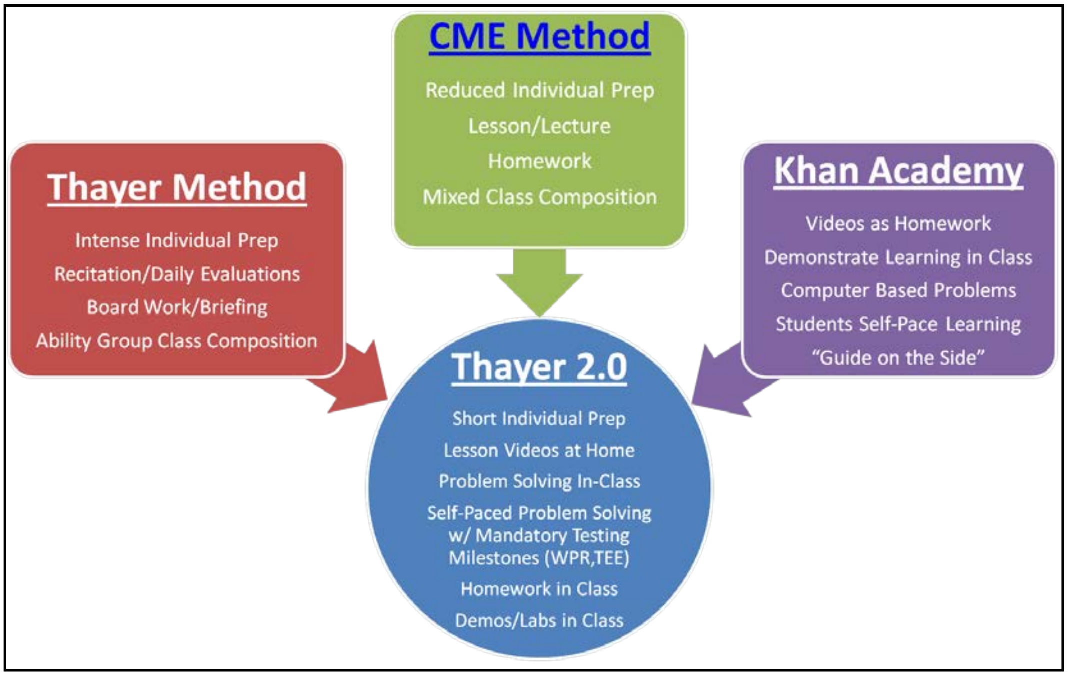

Figure 1: Thayer 2.0 pedagogy relationships compared with the Thayer Method and the Khan Academy Method.

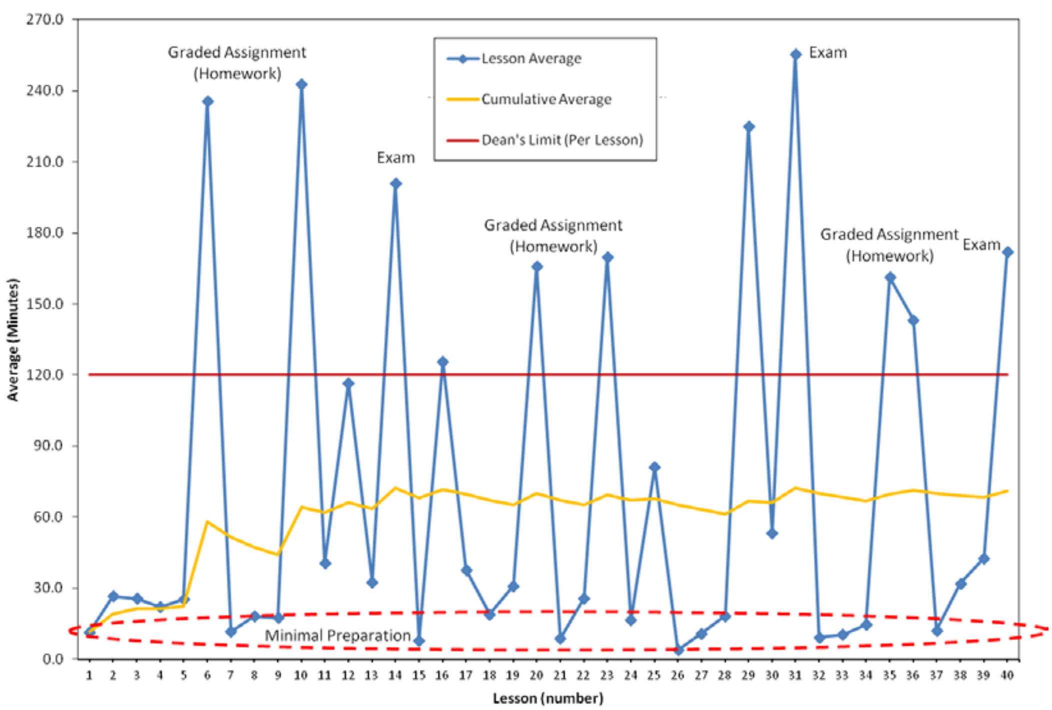

Figure 2: Time-on-task data, representing student preparation outside of class, in minutes. Student report data anonymously. The solid line with diamonds demonstrates large spikes, prior to graded events, exceeding the Dean's guidance of 120 minutes of preparation per class per lesson.

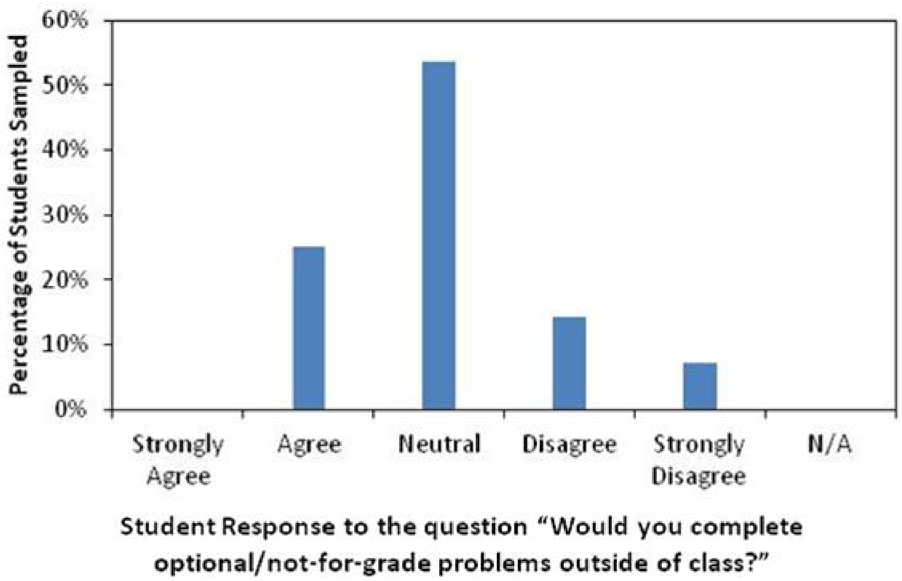

Figure 3: Student responses to the survey

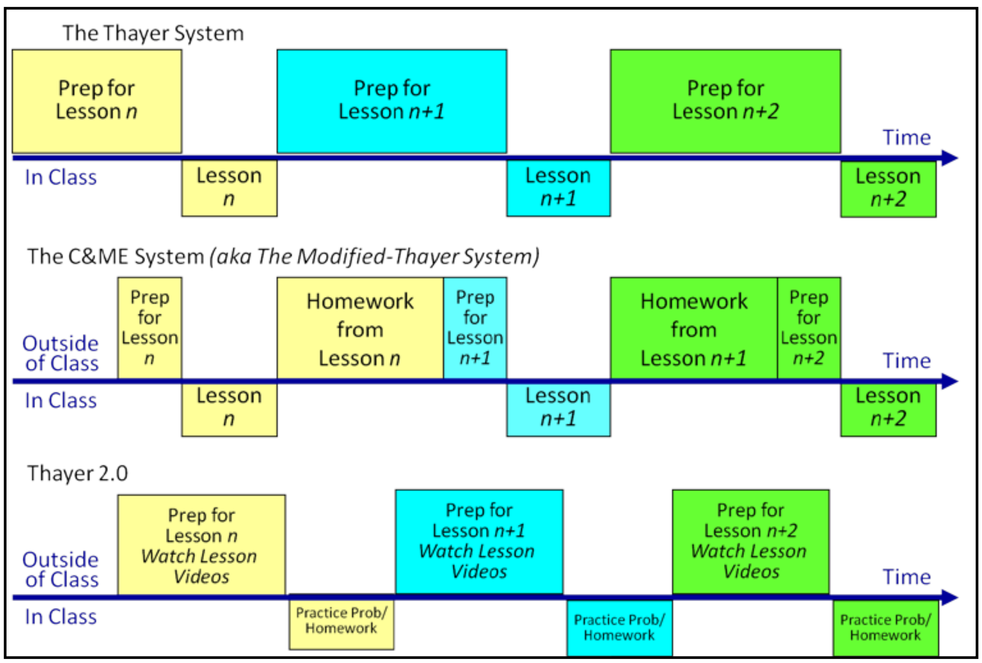

Figure 4: Student time distribution for the Thayer Method, the CME Modified-Thayer Method, and the proposed Thayer 2.0.

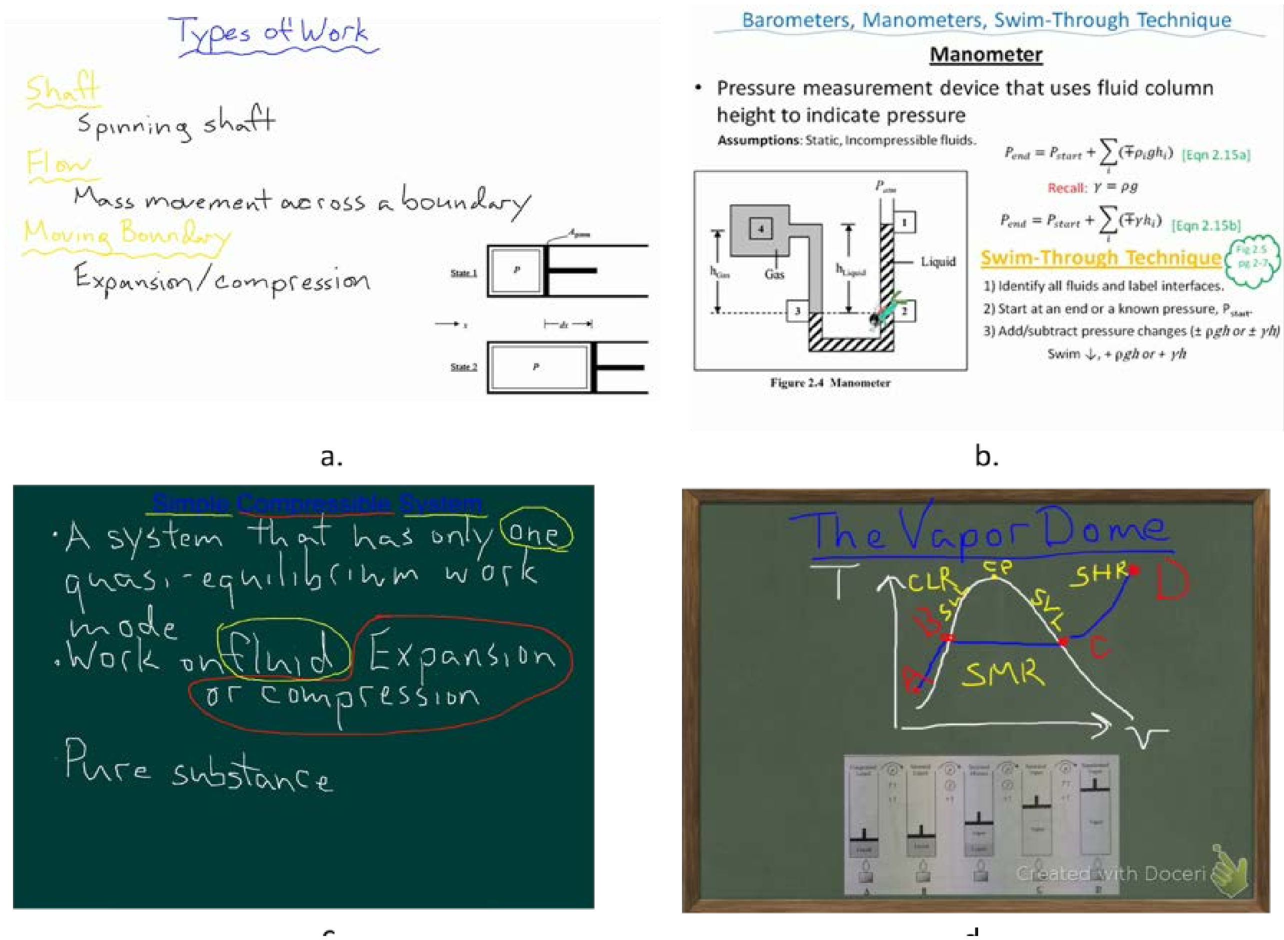

Figure 5: Screenshots of 4 different methods used to illustrate concepts in videos. a. SmoothDraw 3; b. Microsoft PowerPoint; c. Explain everything on an Apple iPad; d. Doceri on an Apple iPad.

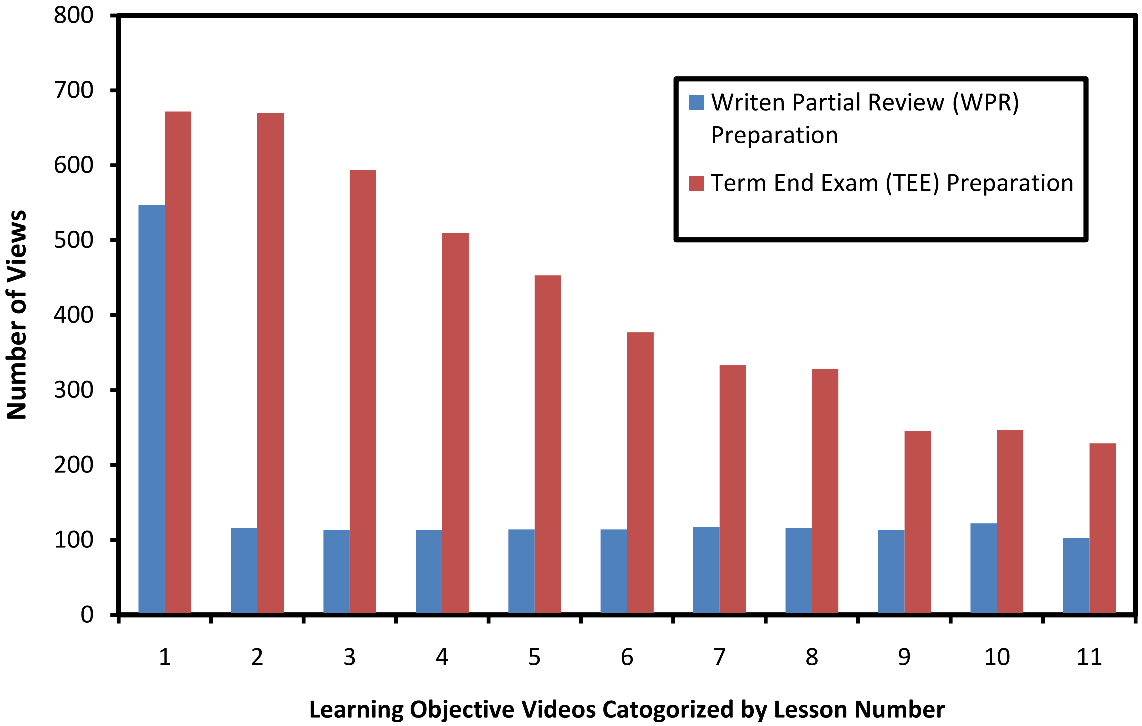

Figure 6: Student views of Lesson Objectives prior to the Written Partial Review (WPR) and the Term End Examination (TEE)