Investigation of a Flipped Engineering Classroom Designed for Non-Engineers

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***Abstract* - Flipping a classroom is an innovative teaching method in itself and extremely complex when the students are not engineering majors. The purpose of this paper is to discuss the development, implementation, and assessment of a flipped classroom for a thermal-fluids course for non-engineering majors.**

Problem solving is a critical, if not the main, objective of engineering education. However, extent of student contact in the classroom is constrained by credit hours. In a local survey, most students indicated that they would not complete not-for-grade problems on their own after class. For many of these students, graded homework assignments are the first and only experience they have in solving complex engineering problems prior to exams. By only receiving lectures and struggling to work homework problems individually, it is arguable that few of these students are able to progress beyond the lower tiers of Bloom's taxonomy. Historical time survey data suggests that the students conduct little to no daily preparation when there are no graded requirements, and conversely show extremely large time spikes when out of class assignments are due or prior to in-class evaluations. Finally, in class lectures force 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 regardless of the experience level of the student.

Inspired by the pedagogical concept of 'flipping the classroom' which has gained recent popularity due in part to the work of the Khan Academy and its online instructional videos, and a classical college teaching method whereby students would prepare prior to class and recite the topic to their instructors and receive daily evaluations, the authors created a blended course that leverages the digital age through video lectures before class and combined it with traditional engineering problem solving in class. The goals of this blended course are as follows: improve the quality and efficiency of student learning by conducting lectures outside of class and homework during class; allow non-engineering students to learn each lesson's material at their own pace and provide a valuable study tool for exam preparation; increase the time spent in classroom solving problems with instructors; leverage one-on-one time in the classroom where the instructor can better approach each individual's issues; encourage and enable non-engineering students to take more responsibility for their learning and become lifelong learners; and inspire intellectual curiosity in the field of engineering.

I. INTRODUCTION

At the United States Military Academy (USMA), all students are required to either successfully complete an ABET-accredited major in one of the offered engineering disciplines or complete a three-course core engineering sequence. The rational for this requirement is simple: a leader's ability to understand and shape the physical world "can both enhance and constrain a leader's ability to influence the action of people" and "engineering is the process of shaping the physical world to further human goals."[1] The belief is that graduates who have studied engineering are well prepared to solve problems when confronted with complex, ambiguous situations that require the need to articulate requirements and constraints and formulate solutions.[1]

II. PROBLEM STATEMENT

Students taking a three-course core engineering sequence have various academic majors ranging from foreign language to law, history, and even physics. Due to schedule conflicts, the second course in their mechanical engineering core sequence, ME350 *Introduction to Thermal-Fluid Systems with Army Applications* is limited to a 3.0 credit hour course in order to facilitate the students' extremely diverse and already full academic schedules. By comparison, the similar course taken by engineering majors, MC311 *Thermal-Fluid Systems I* which actually covers fewer topics but in greater depth is a 3.5 hour double-blocked course. (Engineering majors continue on to MC312 Thermal Fluid Systems II for an additional 3.0 credit hours and cover far more additional topics including those covered in ME350.)

Historical time-on-task data collected from students as part of the course often reveal that the majority of these students conduct little or no daily preparation when there are no graded requirements due. By contrast, the student time data shows large spikes in before out of class assignments are due or prior to in-class examinations (Figure 1).[2]

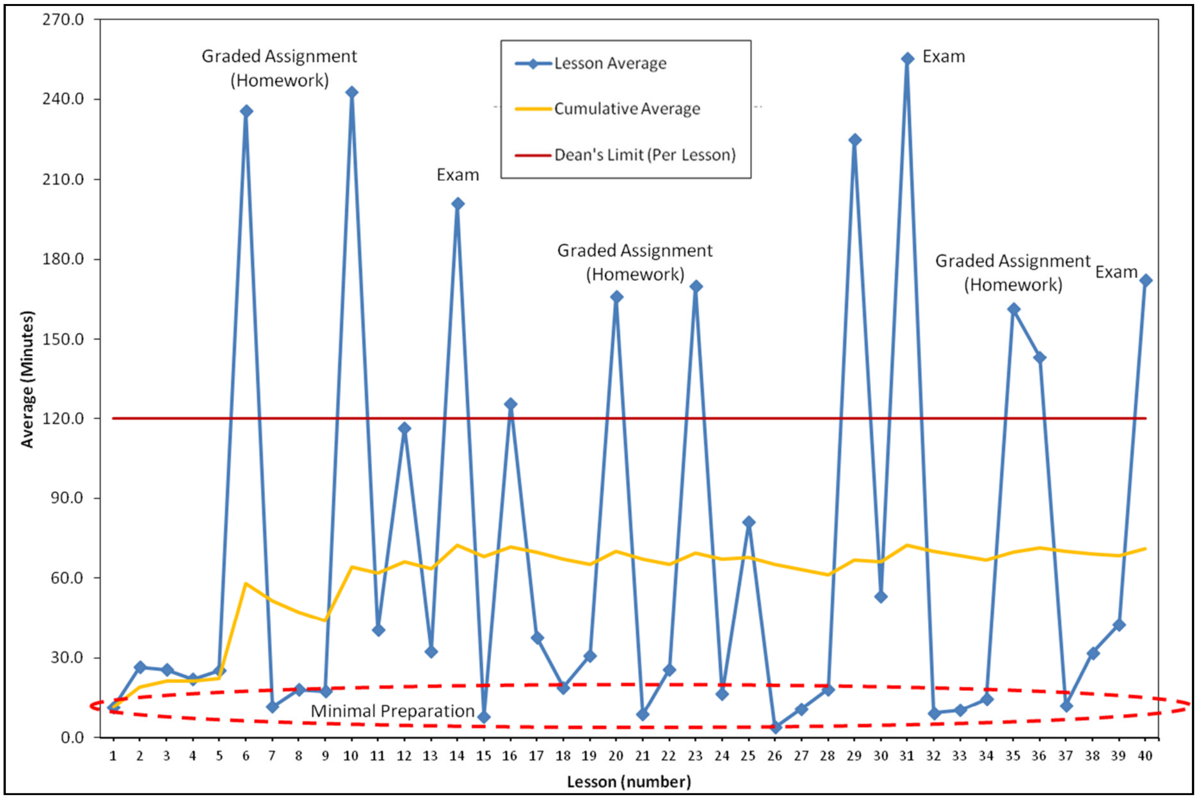

Figure 1: Time-on-task data, representing student preparation outside of class, in minutes. Student report data anonymously. The solid line with diamonds demonstrates large spikes, prior to graded events.

The data in Figure 1 implies 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.[2]

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 a class period. It is, therefore, safe to say that the same holds true for non-engineering students. Typically, the 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 academic and personal interests [Figure 2]. For many of these students, graded homework assignments are the first and only experience that they have solving complex engineering problems prior to exams.[2] By only receiving lectures and struggling to work homework problems individually, it is arguable that few students are able to gain an appreciable knowledge of the physical world and apply to an organized engineering problem solving process that they will need as future leaders.

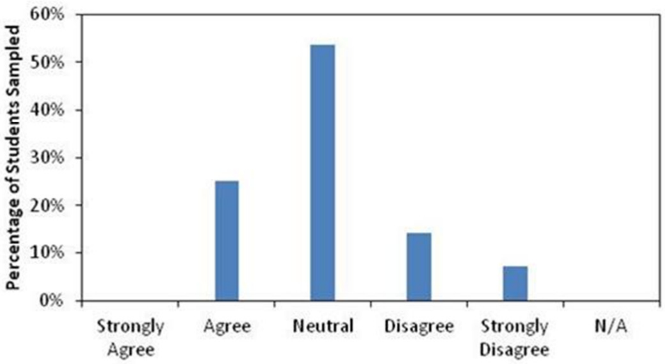

Figure 2: Student Response to the question "Would you complete optional / not-for-grade problems outside of class?"

In an effort to address this problem, the authors studied and attempted to blend and leverage what they considered the benefits of three major pedagogies within the constraints of the program. The first pedagogy, was that of "flipping the classroom" which 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, with students advancing independently of one another.[2] Due to graduation timeline requirements, however, a complete self-paced model was not feasible.

The second pedagogy examined was that of the traditional "Thayer Method from 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."[3] This method, however, left little time for in-class instruction and placed the onus for learning predominantly on the student [Figure 3].[2] Re-sectioning students by ability is no longer a viable option.

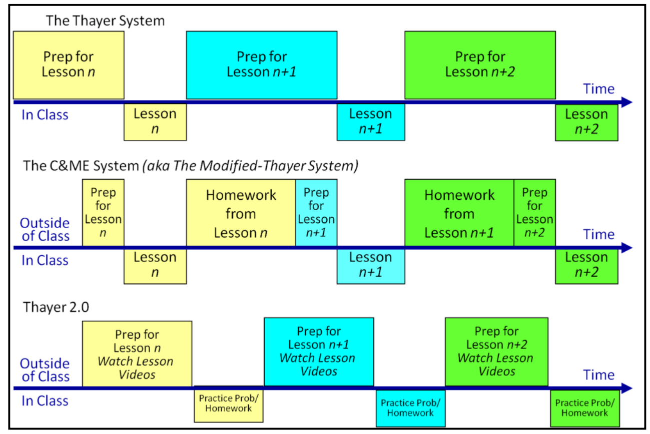

Figure 3: Student time distribution for the Thayer Method, the traditional method, and the proposed Thayer 2.0.

Finally, the authors included the department's traditional pedagogy. In this model, the Thayer Method was modified over time to place fewer burdens on the students who were learning more complicated technical material. In the traditional 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. Instructors evaluate student performance using conventional instruments, most notably timed examinations.[2]

Over the past year, the authors developed and implemented an instructional method that employs blended classroom methods to improve student learning. Dubbed "Thayer 2.0," the method leverages technology and blends what the authors considered to be some of the best characteristics of the traditional method, the original Thayer Method, and the Khan Academy [Figure 4]. In conjunction with a literature review, a beta test of Thayer 2.0 was conducted for ten lessons during the spring semester of academic year 2013 (AY 13-2) to gauge student feedback and to establish operating procedures and instructional best-practices for a broader implementation. The lessons learned from that development and student input were discussed in a previous paper [2]. The question remained, however, if non-engineering students, some with no real interest in the subject matter, could be successful with a flipped classroom, self-teaching model. In the fall semester of academic year 2014 (AY 14-1), the fully implemented Thayer 2.0 pedagogy was employed for both sections of ME350 *Introduction to Thermal-Fluid Systems with Army Applications*, consisting of 36 non-engineering students. The results and observations of which, will be discussed in this paper.

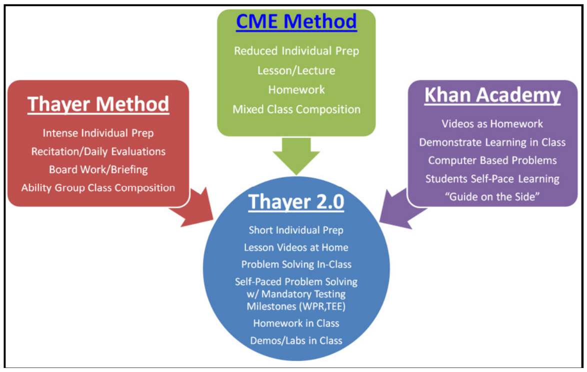

Figure 4: Thayer 2.0 pedagogy relationships compared with the Thayer Method, the traditional method, and the Khan Academy Method.

III. INSTRUCTIONAL METHOD

Students were provided a syllabus, a text book, and a study guide complete with detailed lesson objectives, assigned readings, and practice problems. Lecture videos were posted on Blackboard by lesson objective with 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 were required to watch no more than 40 minutes of video footage prior to each class. Students were given a conceptual quiz at the start of each class period valued at 10 points each for a total of 300 points or 15% of their overall class grade in order to ensure that they would watch the videos prior to class. Additionally, it allowed the instructors to identify common areas of confusion, challenging concepts, and any deficiencies in the manner in which the videos presented the material.

In the classroom, students had the opportunity to witness live demonstrations and have access to training aids of concepts discussed in the videos. The students would also work study guide problems individually on the blackboards or at their desks reminiscent of the Thayer Method. The instructors would move throughout the classroom and help students as needed to clarify issues similar to methods applied by Wallace and Weiner [4] as in-class exercises. At times, the students would work in pairs or teams as was done by Foertsch, et al [5]. Additionally, if the instructor found that multiple students are struggling with the same part or whole of a problem, he would sometimes choose to demonstrate the problem on the board with the entire class as is done in the CME Method. These in-class exercises, allowed students the chance to apply the concepts they learned in their preparations prior to class either from the videos or their own reading rather than be lectured to.

Rather than provide a broad lecture, instructors were 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 identifying inaccuracy on the spot with increased efficiency. In this manner, instructors were 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.[6] Students were also afforded time to work on homework in class while the instructor was available. The intent was for students to work on homework problems in class, so that the videos were not viewed as additional homework. [Figure 3]

IV. DESIRED OUTCOMES

- Increase the time spent in the classroom solving problems. The goal was to increase a student's ability to identify, formulate, and solve engineering problems. Expand one-on-one time in the classroom where the instructor could better approach each individual's issue instead of providing a broad-spectrum lecture. USMA classes are limited to 20 students; which is about the maximum number of student one instructor could 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 would 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.[1]

- Improve the quality and efficiency of student learning by conducting lectures outside of class and homework during class. We seek to level the time homework survey data [Figure 1] so that students perform as well or better as previous semesters with decreased time spikes and more consistent and predicable preparation. 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.

V. PERFORMANCE OUTCOMES

The most objective metric to evaluate the feasibility of the flipped classroom for non- engineering students is through traditional graded evaluations. However, evaluating student performance utilizing solely final course grades as a metric is difficult and uncertain given the multiple variables; different students from year to year, different homework and exams, and different graders for the assignments. What doesn't change semester to semester is the final exam for the course, which is altered by no more than 10% each semester, solutions are never released to students, and the historic cut sheet is provided instead of being created by the grader. By using the final exam scores as the basis of comparison, variability is reduced though not eliminated. It still, however provides us with a better assessment of whether or not the non-engineering students were able to solve thermal-fluids problems to the same level as previous students who learned the material using the traditional method of instruction. If students

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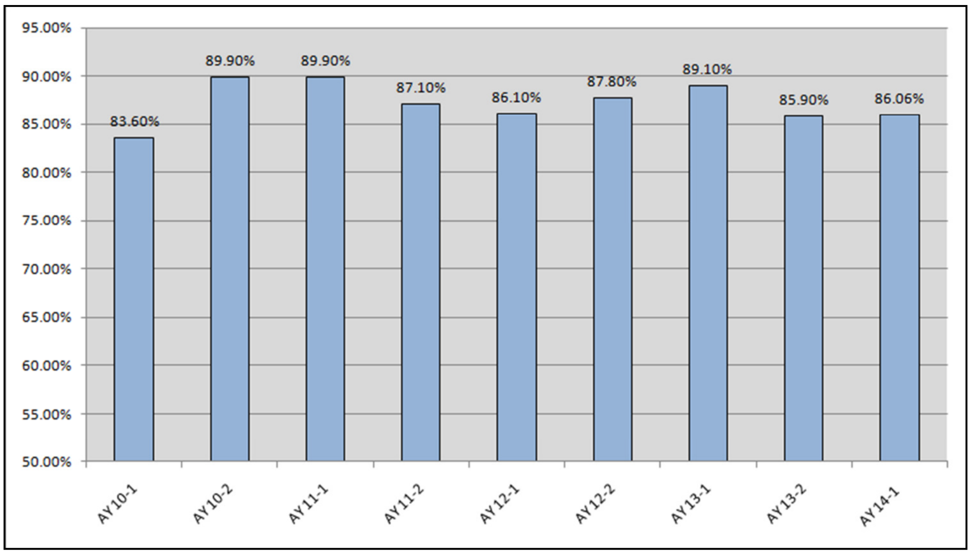


Figure 4: ME350 Final Exam Scores per Academic Semester.

could perform similarly or better on the final exam, which encompasses the entirety of the course, one could draw the conclusion that non-engineering students can learn the material and develop an engineering problem solving methodology using the Thayer 2.0 method.

By inspection, one can see that the students who complete the course using the Thayer 2.0 (AY 14-1) method performed on par with previous semesters taking the same exam. The mean final exam year from AY 10-1 to AY 13-2 was 87.43% with a standard deviation of 2.2%. Therefore, the AY 14-1 average of 86.06 was well within that range and is marginally higher than the year prior. The slight deviation below the average could be due to the individuals, the method, or most likely, slight variations in the graders' interpretation of and adherence to the exam cut sheets.

AY 13-2 is the best comparison to AY 14-1 because the course was taught by and the exams graded by the same instructors. Though the Thayer 2.0 method did not clearly result in a marked increase in student performance from the traditional method, it also did not result in a marked decrease which shows that the method in itself is successful with non-engineering students.

VI. OUTGOING STUDENT SURVEYS

In order to further evaluate the viability of the Thayer 2.0, the authors also chose to study student end-of-course survey data. While more subjective, it could be compared to data for the university, the department, the mechanical engineering program, and previous semesters of ME350. One of the primary goals of the Thayer 2.0 method was to encourage students to take responsibility for their own learning. It does not matter if students prepare for class by watching the videos, by reading the text, or a combination of both. What matters is that students actually come to class prepared so that they can work problems and learn by doing not by lecture. It can be seen from Figure 6 below, that on a standard Likert scale with one being “strongly disagree” and five being “strongly agree,” students taking the ME350 using Thayer 2.0 had a mean response of 4.75 with a standard deviation of 0.43 when asked if their “instructor encouraged students to be responsible for their own learning.”

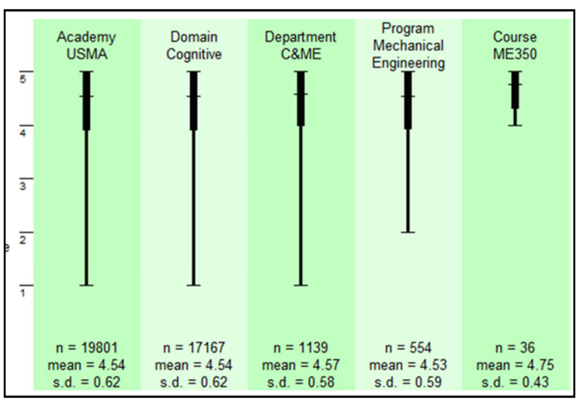
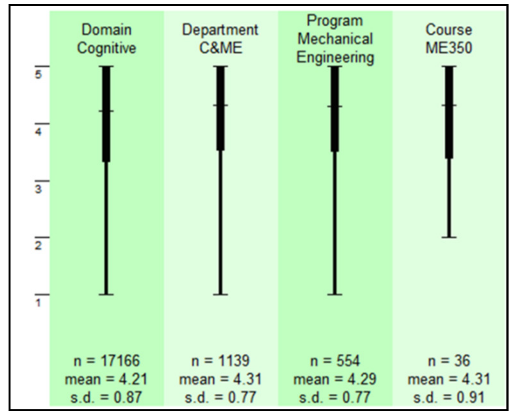


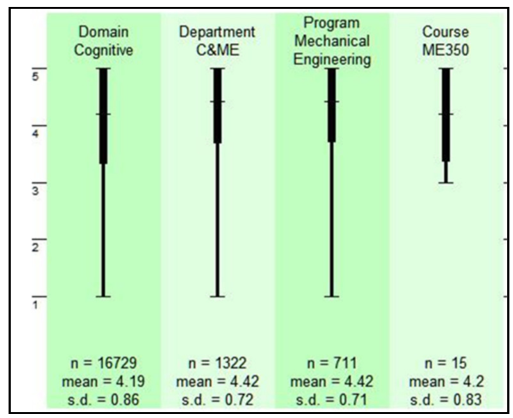
Figure 5: AY14-1 Student Response to "My instructor encouraged students to be responsible for their own learning." (5 equals Strongly Agree decreasing to 1 equal to Strongly Disagree)

This value is 0.22 points higher than the remainder of the Mechanical Engineering Program (which includes the results of ME350), which had a mean of 4.53.

Furthermore, when asked if their critical thinking increased as a result of the course, students in the Thayer 2.0 method of ME350, AY14-1, responded with a mean of 4.31 and with a standard deviation of 0.91 [Figure 7(a)]. This response value is on par with both the Mechanical Engineering Program and the C&ME department, all of which are 0.1 higher than the mean response for the combined scores for all other courses in the cognitive domain at USMA.



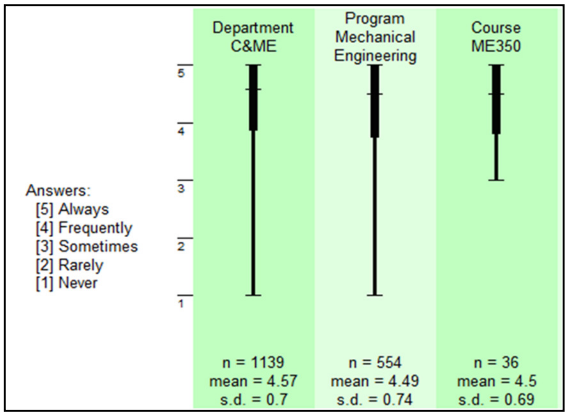
(a) AY 14-1



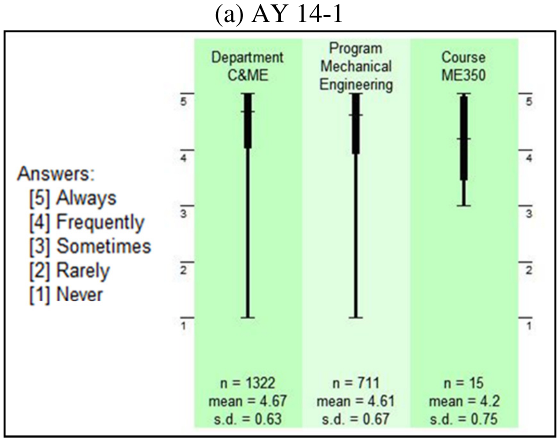
(b) AY 13-2

Figure 6: AY 14-1 Student Response to "In this course, my critical thinking increased."

One could arguably state that the positive response for ME350 is due solely to the content of the course and not the pedagogy used. However, it is important to note that the remainders of the courses in the department do not use the Thayer 2.0 methodology, yet the scores are the same. Additionally, when compared to data from AY 13-2 [Figure 7(b)], the response increased by 0.1 for ME350 while the mean scores for the Mechanical Engineering Program and the department decreased by that same amount from AY13-2 to AY 14-1.



(a) AY 14-1



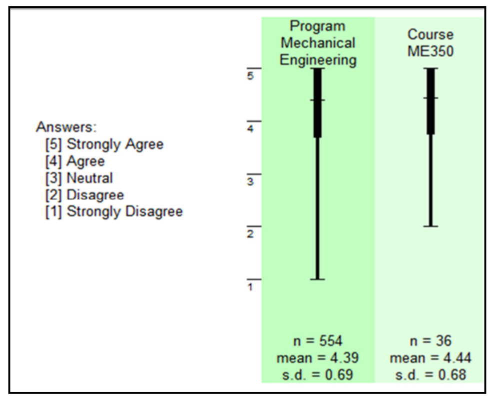
(b) AY 13-2

Figure 8: Student Response to "My instructor helped me to understand the importance and practical significance of this course."

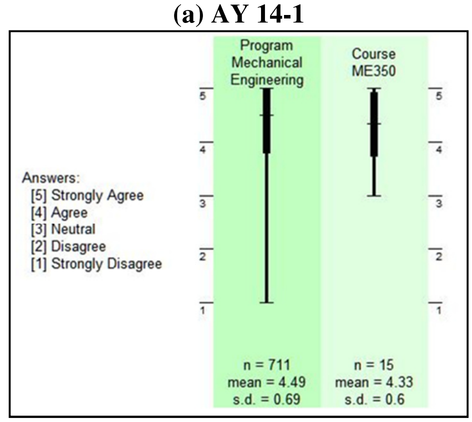
One of the greatest challenges of teaching non-engineering students in general is trying to get students enrolled in a course outside of their chosen major to understand and appreciate the significance of the course. This became a significant concern for Thayer 2.0 since students would not be receiving a lecture and therefore would possibly have less opportunity for instructors to inspire the students and convey the importance. For students who major in engineering, one would assume that this understanding should be self-evident. Therefore, it was surprising to find that when surveyed, the non-engineering students in ME350 undergoing the Thayer 2.0 method responded with a score of 4.5 of 5. This value was on par with the Mechanical Engineering Program with a similar standard deviation of 0.69, and only marginally lower than the department score of 4.57 [Figure 8(a)].

Most encouraging was the fact that this response score increased 0.3 from the ME350 students in AY13-2 while those for ME and the department decreased by 0.1 [Figure 8(b)], showing that with self-teaching, online videos, and in class problem solving, non-engineering students could be inspired to see the practical significance of the material.

Students also reported positively when asked about their confidence in their ability to apply their knowledge of mathematics, science, and engineering as a result of the course. [Figure 9(a)] Their mean score of 4.44 was not only marginally higher than the Mechanical Engineering Program for AY14-1 but also showed a significant increase over ME350 from the previous year [Figure 9(b)].



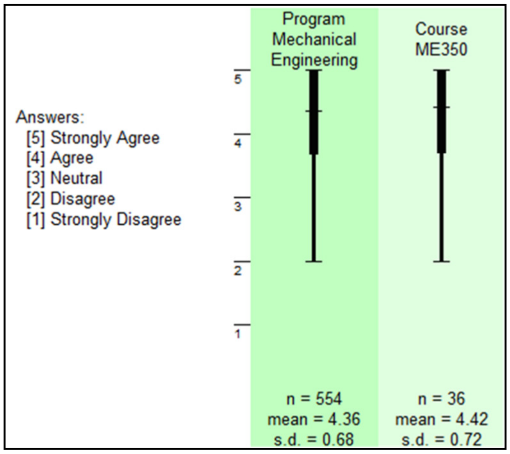
(a) AY 14-1



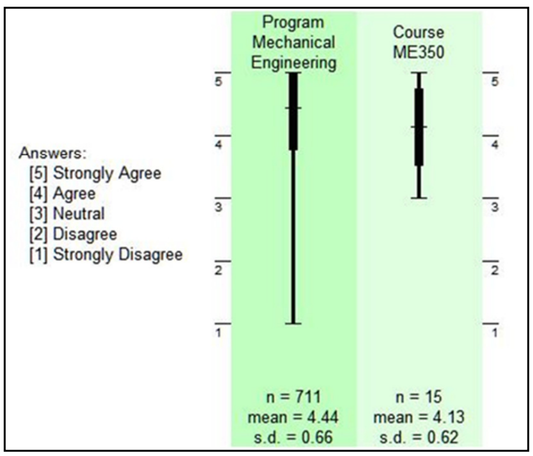
(b) AY 13-2

Figure 9: Student Response to "This course improved my ability to apply my knowledge of mathematics, science, and engineering"

Recall the purpose behind the core-engineering sequence: the need for future leaders to be able to shape the physical world through their ability to identify, formulate, and solve engineering problems. Students completing ME350 using Thayer 2.0 during AY14-1 showed a mean response of 4.42 [Figure 10(a)], slightly higher than the Mechanical Engineering Program, but remarkably 0.39 points higher than ME350 students in AY13-2. [Figure 10(b)]



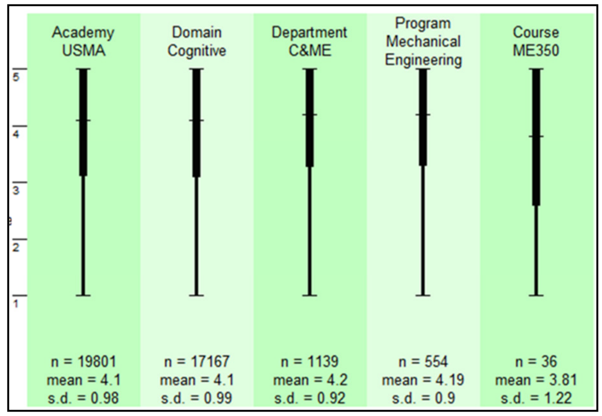
(a) AY 14-1



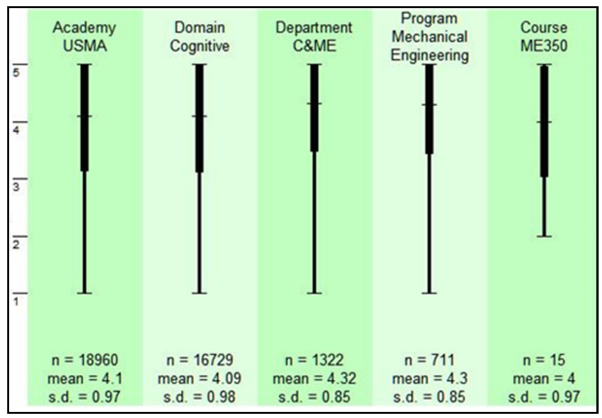
(b) AY 13-2

Figure 10: Student Response to "This course improved my ability to apply to identify, formulate, and solve engineering problems"

Not all student feedback regarding the flipped classroom showed positive results. One of the primary intended outcomes of the course was to increase students' motivation to learn and to become lifelong learners. The survey results [Figure 11(a)] indicated a mediocre response (3.81 with a large standard deviation of 1.22). This response was well below averages for the university, the department, the program, and the previous year [Figure 11(b)].



(a) AY 14-1



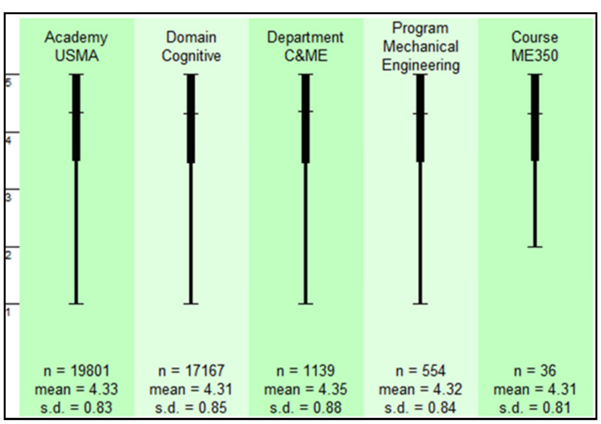
(b) AY 13-2

Figure 11: Student Response to "My motivation to learn and to continue learning has increased because of this course."

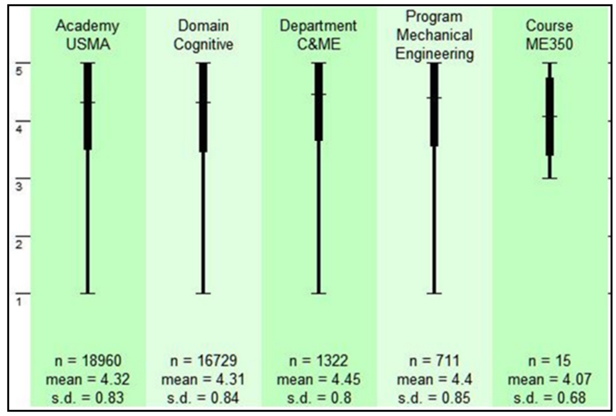
Thayer 2.0 resulted in non-engineering students who are more confident in their abilities to solve engineering problems, but less motivated to further their engineering education. One of the key assumptions of self-based learning models is that students' will be interested in the material. However, for some the course became too much work and too little fun; it could also simply be a reflection of the students' bias or disinterest in engineering to begin with. Without a requirement to complete the course, it is unlikely that students would choose to learn it on their own. Like any class, there is a broad range of students. When teaching non-engineering students, students' attitudes ranged from thinly veiled disdain for engineering by those who saw the course as an unnecessary and overly difficult burden, to students within the course who would send the instructors articles, web links, and videos of related topics beyond those that were taught in the course. It is unlikely that this interest gap will ever be eliminated, but it is clear that a lecture based model seems to be more effective. A video lecture must state the facts as concisely as possible in the interest of time. A good video lecture includes the instructor's introspection and should be enthusiastic. However, there is only so much genuine enthusiasm that can be relayed in recorded format. Without interaction, student questions, and classroom dialogue, it is difficult to inspire the uninterested to want to learn more; particularly when it is not in their chosen field of study. Many times, those inspirational moments come from a student inquiry or comment that the instructor did not plan or think of. That is not to say that video lectures and class room problem solving create an unnatural separation between the teacher and the student. Nor do the video lectures create a teacher who simply stands at the side, seemingly unnecessary, as critics of flipped-classrooms may claim.

VII. STUDENT-TEACHER RELATIONS

Creating lesson objective videos is a difficult and time consuming venture as was discussed in our previous paper [2]. However, if done correctly, combined with various methods for in-class problem solving, the technique can be as effective as traditional methods for teaching. Figure 12(a) illustrates student responses when asked if the instructor used effective techniques for learning, both in class and for out-of-class assignments. For the Thayer 2.0 ME350 course, the students responded with a nearly identical mean score and standard deviation as the remainder of the Academy, courses within the cognitive domain, the department, and the Mechanical Engineering division with a higher minimum value with a smaller sample population.



(a) AY 14-1



(b) AY 13-2

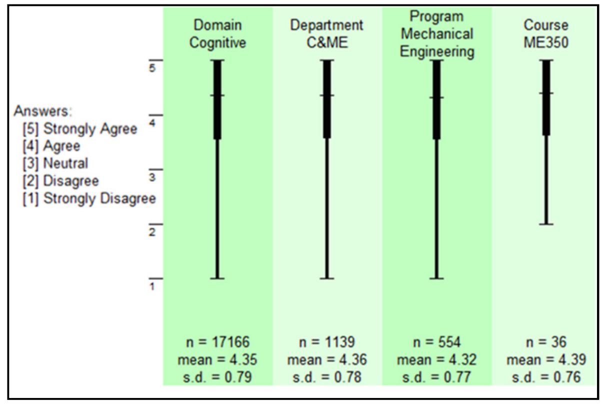
Figure 12: AY13-2 Student Response to "This instructor used effective techniques for learning, both in class and for out-of-class assignments"

More notably, the mean score for Thayer 2.0 method of ME350 increased by 0.24 from the previous semester that utilized the standard traditional method [Figure 18]. Though, one might note that the standard deviation is greater for the Thayer 2.0 method [Figure 12(a) & 12(b)] and has a lower minimum than for the previous year. This larger disparity will be discussed further later in the paper.

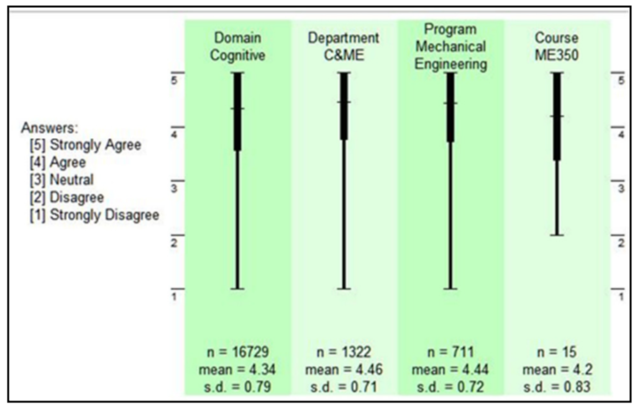
One of the keys to the effective techniques lies not only in the production of the videos but in the problem solving in class. When originally conceived, Thayer 2.0 was going to require students to work all problems on their own either at the boards or at their desks. While this methodology is likely to be successful with engineering majors, the authors found that it was not always effective with non-engineering majors. For many of the non-engineering majors, it had been more than a year since their last physics, engineering, or mathematics courses. As one might expect, these students struggled with in-class problem solving to a point that some did not even know how or where to start a problem. On the other hand, the students who were physics or chemistry majors were solving problems quickly. Every class has a dynamic and a collective personality, this aspect is no different with a flipped classroom.

The instructors decided to adapt the in-class problem solving relative to the material, the students' perceived understanding of that material based upon the daily quiz scores, and the frequency of the exposure to the material. If the topics were new or more difficult, the instructor would demonstrate the problem on the board with interaction and input from the class. If the problems were fundamental or the students had completed similar problems previously, the students completed the problems at the boards. However, student dialogue and interaction was authorized; this technique allowed the instructors to leverage the students who understood the material. By doing this, it reinforced the material to the student providing help, increased the efficiency of the instructor by allowing more students to receive help, and provided struggling students with a different presentation or approach of the material by a peer. Following board work, students would be selected by the instructor to brief the class on how they solved the problem. This traditional Thayer Method technique helps to ensure that struggling students would not just copy someone else's board because they would have to explain it. As an instructor it was important to continually monitor the students' work on the boards to identify where each student was struggling and where multiple students were struggling. This way, the instructor could help an individual or help guide the entire class back on azimuth. Additionally, during the briefings by the students, it was beneficial to direct students' attention to multiple boards as a means to show and explain different techniques and paths to solve the same problems. This allowed students to see more correct methods than a singular method demonstrated by the instructors. Finally, if students were working homework, it was done individually at their desks, usually with classical music playing at a low volume to provide a more relaxing, less exam-like atmosphere.

By adapting in-class methods, the instructors were able to stimulate the students' thinking equally as well as did students in traditionally instructed courses within the Academy, domain, department, and mechanical engineering program, [Figure 13(a)] with a moderate improvement from the purely lecture-based ME350 of the year prior [Figure 13(b)].



(a) AY 14-1



(b) AY 13-2

Figure 13: Student Response to "This course improved my ability to apply to identify, formulate, and solve engineering problems"

Additionally, these personal interactions with the students whilst solving problems were as effective as traditional methods at demonstrating the instructor's concern for student learning [Figure 14].

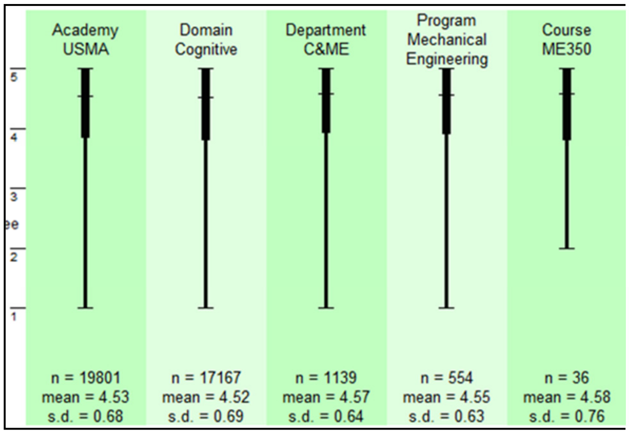


Figure 14: AY 14-1 Student Response to "My instructor cared about my learning in this course."

Lastly, students' were able to identify the time and effort the instructors put into the creation of the lecture videos. When lecturing, everyone makes mistakes, some of which the students identify, some of which the instructor self-identifies either during or following a lecture. Such mistakes are natural and actually help to increase student interaction and help to humanize the instructor. However, such is not the case with a lecture video. Attention to detail and accuracy are important. There are no students to stop you at the boards and ask a question; there are no alibis. What you put on video is eternal. The students will learn the material using solely these videos and their textbook. The entire purpose of making your own lesson objective videos is to provide students with course specific and correct/accurate information regarding the topic. This fact is a cause for a lot of research prior to the creation of videos, fact checking, and often times, editing and reshooting. All of which are time consuming. However as a result, students responded extremely positively when asked if their instructor (the creators of the videos) demonstrated depth of knowledge in the subject matter. ME350 Thayer 2.0 scored a 4.94 of 5.0 with a standard deviation of only 0.23—a full 0.3 points greater than the Mechanical Engineering program and 0.21 points higher than the department with a minimum score of 4.0. It can therefore be concluded that it is important for developers of flipped classrooms to create their own videos [Figure 15]

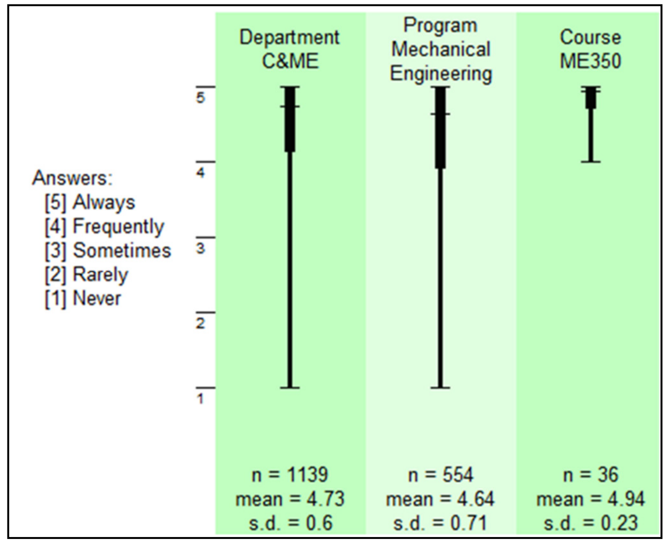


Figure 15: AY 14-1 Student Response to "My instructor demonstrated depth of knowledge in the subject matter."

VIII. TIME SURVEY DATA

One of the additional goals of the Thayer 2.0 method, was to level the time survey data [Figure 1] so that students perform as well or better as previous semesters with decreased time spikes and more consistent and predicable preparation. It is understood that regardless of the methodology used, spikes would always occur before exams when students increase study and prior to the submission of lab reports and projects for which students were not afforded class time. However, the authors envisioned with Thayer 2.0 that homework spikes would be eliminated. Unfortunately, this method was unable to eliminate spikes in time outside the classroom for homework despite allotting classroom time for its completion. [Figure 16] In some cases, students did not make the use of the time afforded, in others, the instructors failed to estimate the time it would take the students to complete the homework. There were several lessons where time for homework was reduced because it took too long for the class to solve a problem or because so many people performed poorly on the daily quiz that the first twenty minutes of class were spent clarifying topics that some students struggled with from the videos.

However, by comparing time survey data from AY14-1 to AY13-2 [Figure 17], some positive comparisons can be made in support of the Thayer 2.0 method. While the flipped classroom did not eliminate spikes, it did successfully reduce the magnitude of a majority of the peaks, while simultaneously reducing the cumulative average outside the classroom and increasing the daily preparation time for each class. AY 13-2 demonstrates multiple lessons with a preparation average of less than five minutes.

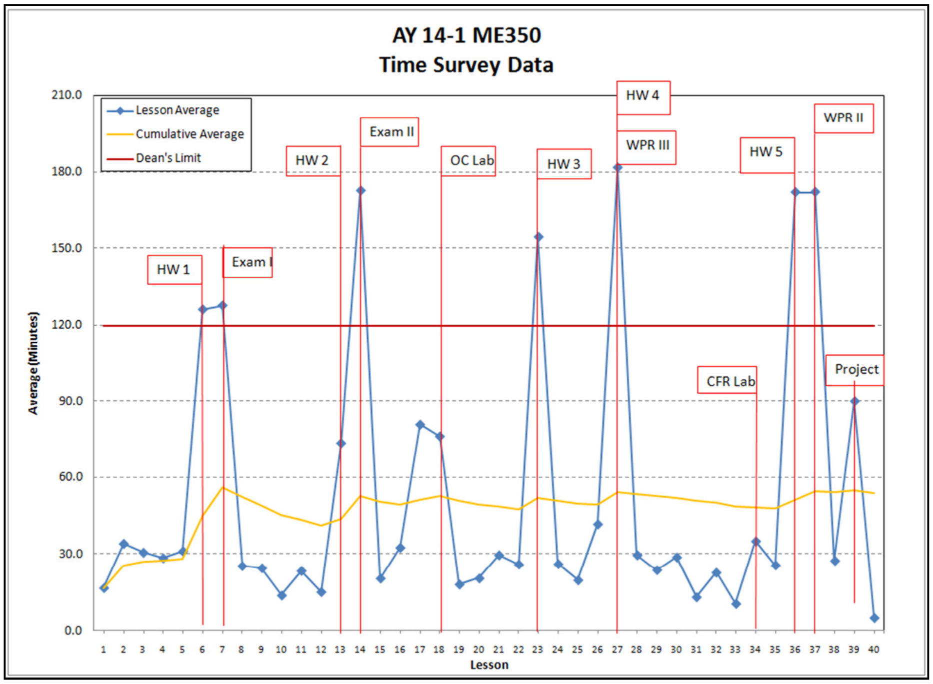


Figure 16: AY 14-1 Time-on-task data, representing student preparation outside of class, in minutes using Thayer 2.0

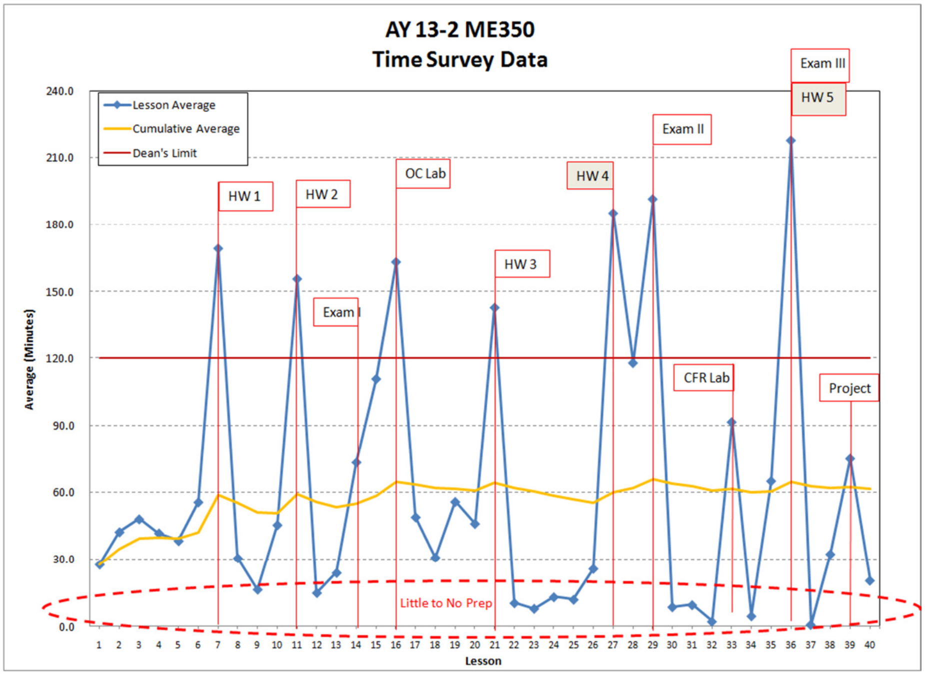


Figure 7 AY 13-2 Time-on-task data, representing student preparation outside of class, in minutes Traditional Method

Obviously the increased daily preparation is a direct reflection of the requirement to watch video lectures prior to the class, but it shows that students are actually doing it. It is imperative that the students watch the videos prior to class, lest they will not understand nor be able to solve problems, effectively making class period worthless. The authors chose to ensure compliance through daily quizzes at the beginning of class. These quizzes were administered on a traditional paper format, consisted of purely conceptual questions based directly from the lesson objectives, and were limited to five to ten minutes. The instructor would then review the quiz with the class, allowing students to self-grade. The quizzes were then passed in and problem solving initiated. When asked for free text comments about the course and the Thayer 2.0 method, students opinions on the course were nearly equally split, though supporters of the method were passionately so. What was consistent amongst students nearly across the board was dislike of the daily quizzes. Many simply stated they did not like the daily quizzes but did not elaborate. Other students offered that the quizzes should be offered with less frequency because they cut into class time that could otherwise be used to solve problems and work on homework. While these students are correct about cutting into class time, the authors do not believe that eliminating the quizzes is an option. Even with daily quizzes some students came to class unprepared at times and could not follow along with the problems, or when they were working individually would monopolize the instructor's attention.

There must be some form of enforcement for daily preparation. The authors propose three options to address this problem. The course could be completely self-paced with computer based problems completed individually in class as done by Capaldi in his STEMSI Online Learning Environment.[9] Such a method, while ideal, requires the creation of an online learning environment and authorization of the institution to allow a truly self-paced course, neither of which the authors have.

A second alternative would be to post daily quizzes to some online medium such as Blackboard for students to complete prior to class. This method has two benefits. First, class time would not be spent on quizzes, freeing up between 10-20 minutes per lesson; a significant increase over forty lessons (between a 122% and 157% more usable class time). It would also allow the instructor to view student scores prior to class for a better idea of where students are struggling. This method is not without its drawbacks. Most obviously, there is no way to ensure that students do not simply obtain the answers from a friend. While this is ethically objectionable, it also does nothing to ensure that the students come prepared to effectively utilize class time.

A third alternative, likely to be adopted by the authors, is to use a feedback response program such as iClicker to allow students to take the quiz quickly, have responses automatically graded so that the instructor can immediately identify trends, and allow students to immediately begin working problems upon completion so as that they are not held back by those struggling on the quiz.

IX. CONCLUSION

While teaching non-engineers may seem like an educational scenario that is specific to this institution, it is likely to become more common place due to the STEM initiative philosophy outlined by President Barack Obama when he stated that "Leadership tomorrow depends on how we educate our students today—especially in science, technology, engineering and math."[8] It behooves students of all levels of higher education to have some type of STEM background in their curriculum, since many of the major issues the nation will face in the future (energy, environmental, infrastructure, etc) will "require the technical expertise and savvy problem solving of the engineering mind."[9] While this experiment was used in a mechanical engineering course, it can just as easily be applied to any STEM discipline course.

For these non-engineering students, we conclude that flipped classrooms are a viable option when compared to traditional lecture based methods of instruction. All-in-all, non-engineers increased their knowledge of engineering and their confidence in their ability to formulate and solve engineering problems. However, this method required significant increase in the individual effort of the students, making them more responsible for their own learning but less motivated to continue to do so in the future. What must be considered is desired outcome. Is it more important for the non-engineers to learn the required concepts and be able to apply them while learning how teach themselves the material while in a course, or to motivate them to learn more engineering on their own. We would argue the former is more important. Not every non-engineering student will be interested in engineering, just like many engineers find other academic topics uninteresting. What is important is that these non-engineers have developed the tools to learn what they must when the time arrives that they may need it. It is our belief that a flipped classroom with problem solving helps reinforce their ability to do just that.

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