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Comparison of Four Flipped Classroom Implementations in a Civil Engineering Curriculum during the COVID-19 Pandemic

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Abstract

Due to the public health policies put into place by institutions in response to the international COVID-19 pandemic, many engineering educators were required to implement alternative pedagogies into their courses. The flipped classroom was viewed by many educators as a method to continue to teach within the constraints created by the pandemic. At its most fundamental form, a flipped class moves activities, which commonly take place in-person, outside of the classroom by providing students with alternative educational resources. Students are expected to engage in these activities prior to attending class which allows students to use the valuable in-person class periods to complete example problems and study advanced topics in a collaborative and creative learning environment. In the 2021 academic year, the Department of Civil and Mechanical Engineering at the U.S. Military Academy implemented the flipped classroom into four undergraduate civil engineering courses: Mechanics of Materials, Hydrology and Hydraulic Design, Soil Mechanics and Foundation Engineering, and Design of Reinforced Concrete Structures. The objective of this study is to evaluate the approach taken by each individual course to implement the flipped classroom pedagogy. The design of the four courses varied based on the execution of asynchronous content out-of-class, schedule for in-person learning, and delivery of graded assessments. The impact of each flipped course design was determined by comparing the results to historical student performance, the time spent by the students on out-of-class activities, and anecdotical feedback from both the instructors and students. The results of the study confirmed a more deliberate design approach is required than simply rearranging the order of learning activities to effectively execute a flipped course.

Introduction

The Flipped Classroom

Over the past decade, the flipped classroom model of learning has increased significantly in popularity within the higher education community, specifically within STEM fields of study [1]. The flipped classroom approach transfers the learning responsibility from the instructor onto the student [2]. In its most basic form, flipped learning is defined simply as "schoolwork at home and homework at school" [3]. In other words, the approach reallocates activities that are traditionally conducted within the classroom, such as lectures, to educational resources that the students engage with *prior to* attending class. This frees up valuable in-person contact time to be used for creative and interactive learning strategies [4]. A broader definition of the flipped classroom states it is an active learning, student-centered approach created to increase the quality of in-class instruction [5]. Research has shown that students prefer in-person activities including in-class lessons compared to video lectures, but greatly prefer an interactive classroom environment over a traditional in-class lecture [6].

The development and popularization of the flipped classroom pedagogy was a result of rapid development of accessible classroom technology for both students and teachers, widespread access to the internet, and a continual trend to incorporate active learning approaches [5].

Researchers have referred to flipped classrooms as both a "fad" and a "movement" [4], [7]. However, a flipped classroom cannot be developed over night. The success of a flipped classroom hinges on the design and execution of the course. To ensure that courses are properly designed, the Flipped Learning Network [8] has outlined the four pillars of a successful flipped classroom:

1) Provide a ***flexible learning environment*** where students can interact with their instructor and peers, reflect on the course material, and explore different methods of learning and practicing.
2) Build a ***culture of independent learning*** where students can engage with the course material without the direct supervision of the instructor.
3) Create ***intentional course content*** which directly shifts students focus to the course material the instructor wants them to engage with outside of class. This ensures they are spending their time learning the desired fundamental concepts.
4) Serve as a ***professional educator*** who is available for students, provides frequent and formative assessments, controls a chaotic active classroom environment, and is constantly improving their course delivery and content.

These four pillars of the flipped classroom directly support the teaching and learning model of the American Society of Civil Engineers (ASCE) Excellence in Civil Engineering Education (ExCEEd) teaching workshop. The ExCEEd Teaching and Learning model states that civil engineering instructors must provide a structured organization to the class, engaging presentations for students, enthusiasm for the course material, positive rapport with students, frequent assessment of student learning, and appropriate use of technology [9]. Significant planning and time are required to ensure that each of these objectives are achieved in the flipped classroom environment.

Flipped Civil Engineering Classes

A significant number of civil engineering instructors have successfully implemented the flipped classroom in courses such as Statics, Mechanics of Materials, Computer Aided Design, and Soil Mechanics [10]–[13]. Many instructors who have built flipped classrooms have done so slowly and are continuously refining their courses. This has resulted in the "blended" or "mixed-mode" flipped class where part of the content is covered in class and part is covered virtually [14], [15]. This allows for a more seamless transition for students and instructors from traditional lecture style in-class format to a more active classroom environment. The primary advantage noted by students was the ability to work problems in class with instructor supervision, both individually and in small groups [1]. This class format benefited a diverse set of students who preferred to either investigate course content on their own, watch videos, practice problems, or receive content directly from the instructor. It is critical to provide a variety of learning activities including daily or weekly assignments to encourage engagement with the material outside of class and provide frequent assessment of student learning. Other civil engineering instructors have found the flipped classroom format frees up in-class contact time with students to explore advanced topics that would be difficult to implement in the traditional classroom setting [10], [12], [16].

Pandemic Forced Transitions

The onset of the COVID-19 pandemic forced many educators to quickly develop alternative delivery methods for their courses to effectively execute them in a constrained environment with social distancing and quarantine requirements. Many viewed the transition as "Panic-gogy" as instructors rushed to create new content for virtual learning [17]. However, the pandemic provided a significant boost to innovative teaching approaches and a proliferation of new technology to support remote and hybrid teaching. Many instructors who had already developed and used the flipped classroom for in-person learning decided to use the content they had created for remote teaching.

Instructors integrated different technology into their courses to improve the level of engagement and clarity of the material for their students [18], [19]. One of the key items noted by instructors was the need to clearly define requirements for students both in-class and out-of-class in the remote environment [20]. To incentivize students to engage with the material outside of class, instructors embedded questions in their asynchronous videos, or asked concept/reading questions at the start of class [21]. To ensure that students actively participated in-class, instructors used virtual break-out rooms to allow students to work with their peers. However, there was still a disconnect in the remote environment with students who struggled to actively participate or ask for help which can typically be overcome by face-to-face interactions with instructors [22]. The flipped classroom takes more organization, effort, and resources for both the instructor and the student [20]. Students must be self-motivated to complete all out-of-class assignments and take the initiative to reach out to their instructor if they have any issues [23]. This can be challenging for many students in the virtual environment.

Deciding to "Flip"

At the start of the 2021 Academic Year, the U.S. Military Academy decided it was critical for students to return to campus to successfully complete the institution's mission. To ensure the health, safety, and wellness of all students, faculty, and staff, special operating procedures were put into place including maintaining six feet of social distancing, wearing face coverings, and cleaning desks and surfaces after each use. Classroom capacity was reduced anywhere from 40%-60% by removal of desks and chairs. To provide students with the best learning experience possible for a wide variety of courses from different disciplines, courses were offered in a mix of in-person, hybrid, and fully remote instruction.

The Civil Engineering program, housed in the Department of Civil and Mechanical Engineering, wanted to maximize in-person classes where hands-on activities and physical models could be used to engage with the learner, which may be difficult from behind a screen. To accomplish this objective, instructors had to either reduce section sizes or meet with only a portion of the students during each class meeting. Four different civil engineering instructors chose to transition their courses from the traditional instructor led format to a flipped classroom to 1) provide students with high quality asynchronous content to view when preparing for class or absent due to quarantine or travel, 2) use in-person contact time to achieve higher levels of learning, and 3) encourage in-person interactions between students and instructors.

The purpose of this paper is to evaluate the implementation of the flipped classroom for four civil engineering courses: Mechanics of Materials (MC364), Soil Mechanics and Foundation Design (CE371), Hydrology and Hydraulic Design (CE380), and Design of Reinforced Concrete Structures (CE483). The specific research question which this paper aims to answer is: what are the requirements and impacts on both instructors and students from rapidly implementing a flipped classroom? The unique designs of the four courses will be discussed in the next section including delivery of asynchronous content, schedule for in-person classes, and graded assessments. The flipped classrooms were evaluated by comparing i) the overall performance in the course, ii) the performance on historical final examinations, iii) self-reported time spent preparing for class, iv) student feedback, and v) instructor feedback to a traditional non-flipped class. The results of the study may provide future instructors with insight into the requirements for implementing the flipped classroom to create an active learning environment.

Flipped Classroom Design

Each instructor took their own approach to design their flipped classroom. The course objectives and capabilities for each course varied drastically, however the primary objectives outlined above were at the forefront of each instructors' design while trying to minimize the overhead burden of creating new asynchronous content and/or graded assessments. Table 1 shows an overview of the graded requirements for each class in the flipped classroom format and in the traditional non-flipped format. It is worth noting that the grade distribution did not change solely as a result of the transition from not flipped to flipped. The following sections will describe the design of each course.

Table 1: Grade distribution for assessments in each course

	Mechanics of Materials MC364		Soil Mechanics & Foundation Design CE371		Hydrology and Hydraulic Design CE380		Design of Reinforced Concrete Structures CE483	
	Not Flipped	Flipped	Not Flipped	Flipped	Not Flipped	Flipped	Not Flipped	Flipped
Reading Quiz	20%	25%	-	-	5%	5%	-	-
Homeworks	-	-	32%	50%	17.5%	15%	35%	35%
Lab Reports/Projects	25%	20%	18%	-	25%	35%	15%	15%
Midterm	30%	30%	30%	30%	30%	37.5%	25%	25%
Final	25%	25%	20%	20%	15%	15%	25%	25%

Mechanics of Materials

Mechanics of Materials (MC364) is a 3.5 credit hour course required for all 2nd year civil and mechanical engineering majors and 3rd year nuclear engineering majors. The course covers the basics of internal forces, stress, and deformations due to axial, bending, and torsional loading, analysis of indeterminate structures using force-methods, calculation of principal stresses due to combined loading, and theories of failure for ductile and brittle materials. The course includes a laboratory component. MC364 was taught in the flipped classroom format during the Spring of 2021. The results were compared to the non-flipped course in the Spring of 2019. Minimal changes were made to the course aside from allocating more points to the Reading Quizzes to incentivize student engagement with the material, including watching the videos, outside of class. Prior to the shift to virtual learning, MC364 was an active learning environment where students spend a large portion of the class, approximately 50%, solving problems in-class with instructor supervision.

The primary requirement for transition to a flipped classroom was creation of the asynchronous content. Students were provided 2-4 videos for each lesson topic. A total of 75 videos were created for the entire course with an average length of 11.5 minutes. Previous research has showed students prefer shorter video content (15 minutes or less) [13]. The videos were created using a tablet either in Microsoft PowerPoint, Microsoft OneNote or the app Notability. Each lesson included an introductory video which introduced the topic for the lesson and 2-3 problem solving videos. Examples of excerpts from the videos are shown in Figure 1. Practical real-life examples were included in the videos to provide the students context for the material. The videos were posted on Microsoft Stream and accessed by students through Microsoft Teams.

In the Spring of 2021, MC364 was taught to 118 students. Additional sections were added so no section had more than 12 students to meet social distancing requirements in the classroom. This allowed every student to attend each lesson in-person. Students spent the class period working individually or in small groups on practice problems. Reading quiz assessments were assigned at the start of 23 of the 35 lessons to verify the students were preparing for class and provide students with frequent feedback on their performance. The students also had four laboratory assignments, three mid-term examinations, and a final examination.

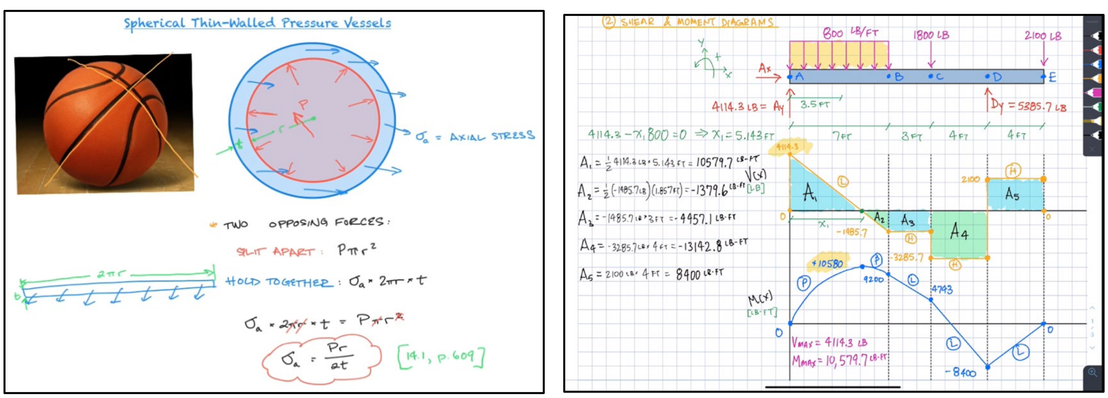


Figure 1: Screenshots of Asynchronous Video Examples for Mechanics of Materials

Soil Mechanics and Foundation Design

Soil Mechanics and Foundation Design (CE371) is a 3.5 credit hour course required for all 3rd year civil engineering majors. The course covers the physical properties and strength of soil, effective stress, soil compaction, consolidation, flow rate through soil, and design of earth retaining structures. The course has eight laboratories integrated throughout the course. In the Spring of 2021, the instructor of CE371 decided to transition the course to a flipped classroom to guarantee sufficient class time to complete the laboratories in-person. The results were compared to the non-flipped course in the Spring of 2019.

The instructor created high-quality videos using a light-board purchased by the institution at the start of the pandemic. The course included 17 topics. Each topic was covered in one or as many as eleven videos. A total of 70 videos were created for the course with an average length of 15 minutes per video. Examples of the videos are shown in Figure 2. Using a light-board allowed the students to see the instructor during asynchronous learning to facilitate the development of positive rapport. The videos were posted on a private, unlisted YouTube channel.

The CE371 flipped course was taught to 34 students over 3 sections, so there were less than 12 students per section. The in-person class period was primarily spent by students watching the asynchronous videos, collaborating on one of the 12 combined homeworks and individual laboratory reports, or completing one of the laboratories. The instructor was available during the entire class period to answer questions on course concepts or assignments. The students took three mid-term examinations and a final examination.

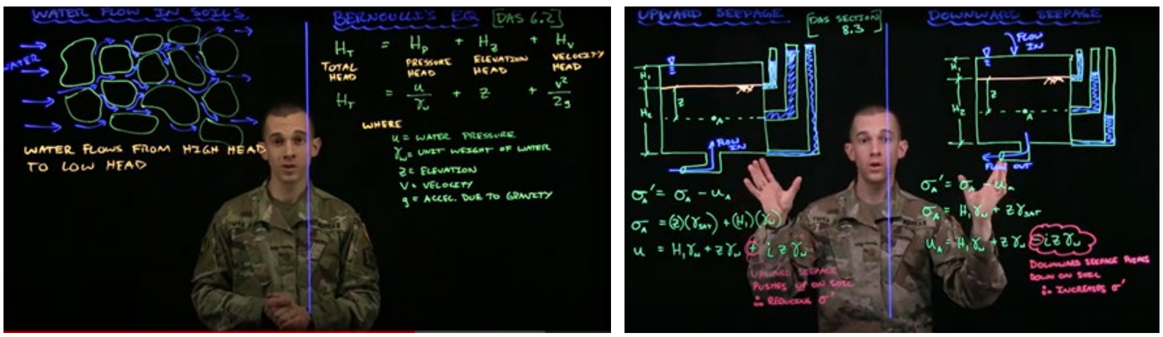


Figure 2: Screenshots of Light-Board examples for Soil Mechanics and Foundation Design

Hydrology and Hydraulic Design

Hydrology and Hydraulic Design (CE380) is a 3.5 credit hour course required for all 3rd year civil engineering majors and is also an elective for environmental engineering majors. The course covers open channel flow, the hydrologic cycle, and analysis and design of hydraulic structures. The course includes eight laboratories throughout the semester. For the Fall of 2020, the instructor for CE380 decided to transition the course to a flipped classroom to ensure that all basic course content was effectively delivered to each student regardless of class attendance. The results were compared to the non-flipped course in the Fall of 2021.

The instructor created a single lecture video for 24 lessons in the course. The videos ranged in length from 10 minutes to 50 minutes with the average video being approximately 30 minutes. The videos were recorded in Microsoft PowerPoint with instructor annotating notes on a blank slide with a stylist as they would on a chalk board in a traditional classroom. To develop rapport with the students through asynchronous videos, the instructor would play a short 30 second clip of a song at the beginning of the lesson that related directly to the lesson topic. For example, on the lesson for “Gradually Varied Flow: Direct Step Method”, the song “Gimme Three Steps” by Lynyrd Skynyrd kicked off the lesson. Links for the videos were sent to students via Dropbox. Figure 3 shows examples of marked up PowerPoint slides from the videos for CE380. PowerPoint allowed the instructor to include several practical examples and applications related to the content of the lesson. The in-person class was used for recitation of the course material and to answer students' questions. The instructor encouraged students to attend recitation periods in the videos for additional help on complex concepts. To guarantee the students interacted with the instructor in-person, attendance was required for at least 25% of the recitation lessons.

CE380 was offered to 41 students across two sections, therefore the entire class could not attend an in-person recitation period at the same time due to social distancing requirements. The laboratories were conducted in a larger dedicated space to support in-person attendance of the full section. Students who were quarantined or could not attend the laboratories in-person had to retrieve the information from their group members. Since most of the students' out-of-class time was spent watching the videos and learning the concepts, the points associated with problem sets were reduced. The instructor wanted to incentivize preparation for the major graded examinations and group assignments, so larger point values were assigned to midterm examination, laboratory reports, and projects.

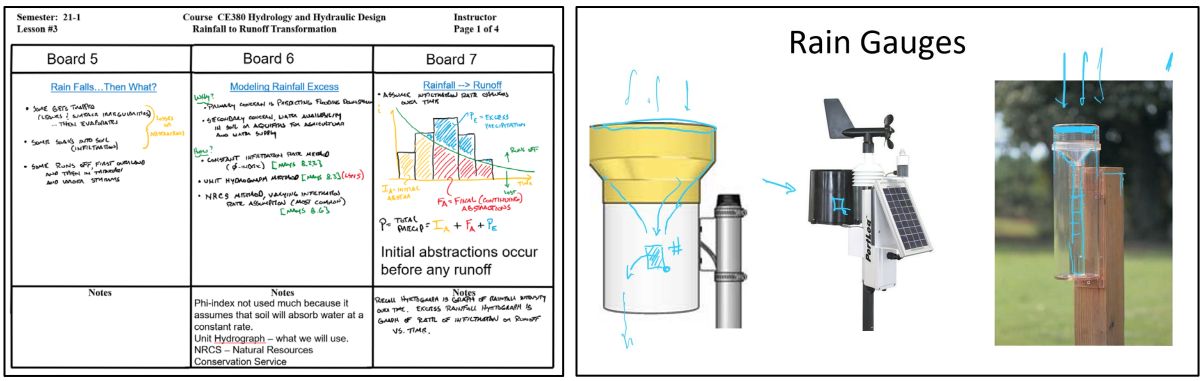


Figure 3: Screenshots of PowerPoint Video examples for Hydrology and Hydraulic Design

Design of Reinforced Concrete Structures

Design of Reinforced Concrete Structures (CE483) is a 3.5 credit hour course required for all 4th year civil engineering majors. The course covers the advantages and disadvantages of reinforced concrete, concrete mixture designs, and analysis and design of concrete structures. The course includes eight integrated laboratories throughout the semester. The two primary reason the instructor for CE483 developed the flipped classroom for the Fall of 2021 was to free up in-class time to work complex design problems for a common real-world building plan. The intent was to help students connect concepts to a single building design as they progressed through the course. The results were compared to the non-flipped course in the Fall of 2021.

The instructor created 1-2 videos for each lesson. The average length of each video was approximately 20 minutes. The videos were posted on Microsoft Stream and accessed by students on Microsoft Teams. Figure 4 shows examples of videos created by the instructor. This instructor took the approach to vary delivery of the course material. They used PowerPoint to show excerpts from the American Concrete Institute Concrete Building Code, PowerPoint and a stylist to annotate notes and solve problems, and even a video camera and a chalk board to provide students with course delivery similar to a traditional classroom. When voicing over PowerPoint slides, the instructor always included a thumbnail video of themselves in a corner of the screen to facilitate a personal connection with their students to help with rapport. Because of limited laboratory space and the hands-on nature of reinforced concrete construction, the lab program was not conducted in its typical format in order to meet social distancing requirements. Instead, the instructor created in-depth, close-up videos of each of the laboratory exercises for students to watch and then during the lab period, elements of the lab activities were completed by groups of students who attended for only a portion of the designated lab period.

CE483 was taught to 41 students across 3 sections, which allowed all students to attend each in-person lesson. Initially, the in-person lessons were spent with students working individually or in groups on advanced problems focused on the design of a concrete building. Part way through the semester, the instructor realized the students were spending far too much time outside of class watching the videos and working on homework and laboratory assignments. The instructor transitioned into allowing the students to work on their homework in the classroom with instructor supervision. The students completed 9 out-of-class homeworks, 8 laboratory exercises, 2 midterm examinations, and a final examination.

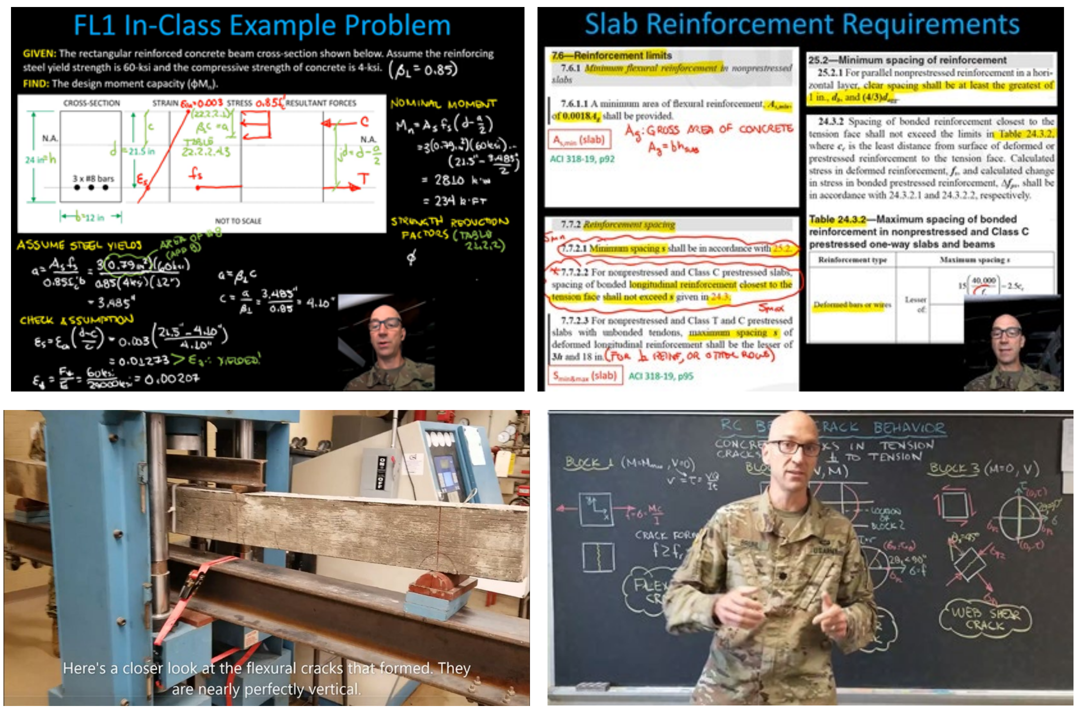


Figure 4: Screenshots from Videos for Design of Reinforced Concrete Structures

Results

Overview of Student Performance

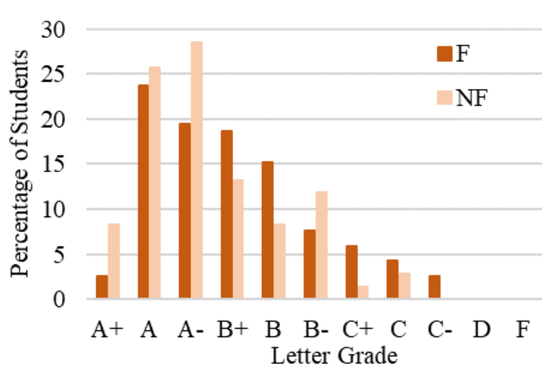
Each of the flipped courses were directly compared to a traditional, non-flipped version of the course. To assess the impact on students' overall performance, this study analyzed the course average and grade distributions. The authors recognize that variations in student performance may also be influenced by the instructor who taught the course during each semester or external factors such as student mentality before and after the COVID-19 pandemic. Demographic information was not collected for the students in the courses. The students' overall course average decreased in two of the four courses: MC364 by 2.3% and CE380 by 5.4%, with increases in CE371 by 1.7% and CE483 by 6%. The change in the incoming grade point average (GPA) compared to the outgoing GPA showed a similar trend as shown in Table 2. Figure 5 shows the grade distribution for each of the courses.

For MC364, the students appeared to be more successful in the non-flipped classroom with 16.7% more students earning better than an A- compared to the flipped classroom. There were also more lower performing students in the flipped class with 8.5% more students earning a C compared to the non-flipped course. For CE380, the flipped classroom had a relatively normal distribution of grades with an average of a B, however 30.9% more students earned a C or D in the course compared to the non-flipped class. In CE371, 14.7% more students earned an A in the flipped class compared to the non-flipped class, however a similar percentage of students (approximately 10%) earned a C in both the flipped and non-flipped course. In CE483, students appeared to perform significantly better in the flipped course with 36.5% more students earning an A in the course and 27.5% less students earning a C or D in the course. At the end of each semester, the instructors for each of the courses assessed the students' completion of the course objectives. For all courses, the objectives were satisfactorily met, which is defined as a solid majority of students (greater than 70%) achieving at least a C-level on an assessment of that specific course objective.

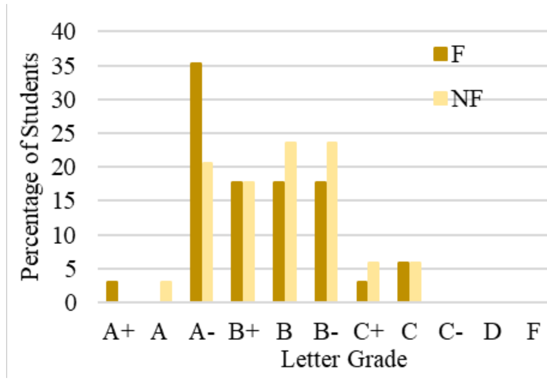
It is worth recognizing the 3rd year civil engineering majors who took the CE380 course flipped in the Fall of 2020 also took the CE371 course flipped in the Spring of 2021. This may demonstrate that the students began to develop better study skills needed to succeed in a flipped classroom which led to the higher performance. The 4th year civil engineering students who took the flipped CE483 may have also been more prepared to efficiently manage the unstructured time in flipped classroom in order to be successful in the course, while the 2nd year civil engineering students in MC364 had a more difficult transition into a different mode of learning.

Table 2: Overall student performance comparison between flipped and not flipped classes

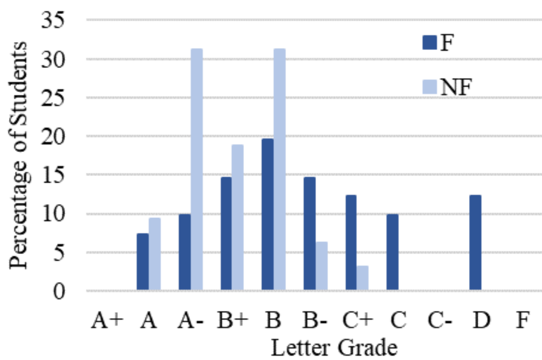
	Mechanics of Materials MC364		Soil Mechanics & Foundation Design CE371		Hydrology and Hydraulic Design CE380		Design of Reinforced Concrete Structures CE483	
	Not Flipped	Flipped	Not Flipped	Flipped	Not Flipped	Flipped	Not Flipped	Flipped
Number of Students	144	118	34	34	32	41	34	41
Avg. Incoming GPA	3.32	3.37	3.08	3.07	3.29	3.07	3.1	3.27
Avg. Outgoing GPA	3.53	3.32	3.06	3.21	3.33	2.78	2.86	3.48
Change in GPA	0.21	-0.05	-0.02	0.14	0.04	-0.3	-0.25	0.21
Avg. Final Grade	90.1%	87.8%	85.3%	87%	88.2%	82.8%	83.6%	89.6%
Std. Dev. Final Grade	5.4%	6.4%	4.8%	5.2%	4.1%	7.6%	6.3%	5.8%



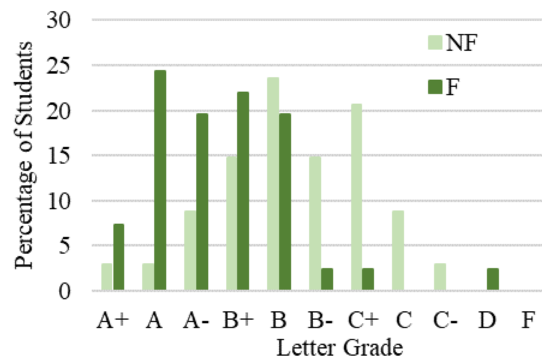
(a) Mechanics of Materials



(b) Soil Mechanics and Foundation Design



(c) Hydrology and Hydraulic Design



(d) Design of Reinforced Concrete Structures

Figure 5: Letter grade distribution comparison between flipped and non-flipped course – a) Mechanics of Materials, b) Soil Mechanics and Foundation Design, c) Hydrology and Hydraulic Design, and d) Design of Reinforced Concrete (F=Flipped, NF=Not Flipped)

Performance on Final Examination

The authors recognize that using grades as an indicator of impact of the flipped classroom may be subjective due to a wide variety of factors. However, the final examinations administered in each course are historical graded events taken by students each semester. No changes were made to individual questions on the examination to provide consistency between each year, however the overall length of the examination was reduced from 3.5 hours to 2.5 hours due to restrictions on classroom availability and social distancing requirements. When grading the exams, a standard grading scheme was applied to ensure uniformity between different semesters and instructors. The final exam will provide a better assessment of student performance than the letter grade distribution, which may be confounded by additional changes to the course structure. Therefore, a statistical analysis was conducted on the student performances on the final exam in the flipped classroom and non-flipped classroom. A Bayesian varying intercept model was developed to isolate the treatment effect of the flipped classroom on final examination performance. Bayes Theory states that the posterior distribution of a parameter (θ) given experimental results (d) is proportional to the prior distribution of the parameter times the likelihood of the parameter given the experimental results, as shown in equation 1.

$$P(\Theta|d) \propto P(d)P(d|\theta) \tag{1}$$

The Bayesian model assumed that final test scores were a normally distributed, which is a conservative statement about the data requiring only a mean and standard deviation of the samples and is the maximum entropy distribution for repeated measurements from a large sample size [24]. The test data for each course was standardized to have a mean of zero and a standard deviation of 1 to put each sample on the same scale and prevent the model from overfitting to a specific set of data. Data was partially pooled between the treatments and courses to assist with differing sample sizes, overfitting, and shrink the estimates towards the true sample means, providing more accurate out of sample predictions. The varying intercept model took the form of:

$$Exam\ Score \sim Normal\ (\mu_i, \sigma_E,) \tag{2}$$

$$\mu_i = \alpha_{course[i]} + T_{Treatment[j]} \tag{3}$$

$$\alpha_i \sim Normal\ (\bar{\alpha}, \sigma_\alpha) \text{ for i = 1-4} \tag{4}$$

$$T_j \sim Normal\ (0, \sigma_T) \text{ for j = 1-2} \tag{5}$$

$$\bar{\alpha} \sim Normal\ (0,1) \tag{6}$$

$$\sigma_\alpha \sim Exponential\ (1) \tag{7}$$

$$\sigma_T \sim Exponential\ (1) \tag{8}$$

$$\sigma_E \sim Exponential\ (1) \tag{9}$$

Where the mean of the final exam score is a linear combination of two varying intercept terms, α and T. α is the unique intercept for each course, and T is the unique intercept for each treatment effect, flipped and not flipped. Each intercept is assumed to have a prior distribution that is normally distributed with an underlying mean for each course ($\bar{\alpha}$) and a standard deviation ($\sigma_\alpha\ and\ \sigma_T$) that is estimated from all of the data for each course and each treatment. This approach results in an estimate of the underlying mean of each course and the portion of the final test scores that can be attributed to the treatment effects. Further, each parameter estimate is a probability distribution that quantifies relative uncertainty in each measurement, which is pooled from all of the data providing a total estimate of the treatment effects from the flipped classroom.

In order to approximate the posterior distribution, Markov Chain Monte Carlo sampling was used to draw samples from the posterior in proportion to the distribution of each parameter. Hamiltonian Monte Carlo with No U-Turn sampling was implemented using the program Stan [25]. Four chains of 1000 samples were run, with 50% of samples in each chain utilized for adaptive warm-up of the sampler. Each chain converged with an effective sample size of over 800 sample for each parameter and an R-hat convergence diagnostic of 1.00. Trace plots showing the convergence of the parameters are shown in Figure 6. Each of these diagnostics indicate that the model sampled effectively and that the results are compatible with the data given the model structure selected.

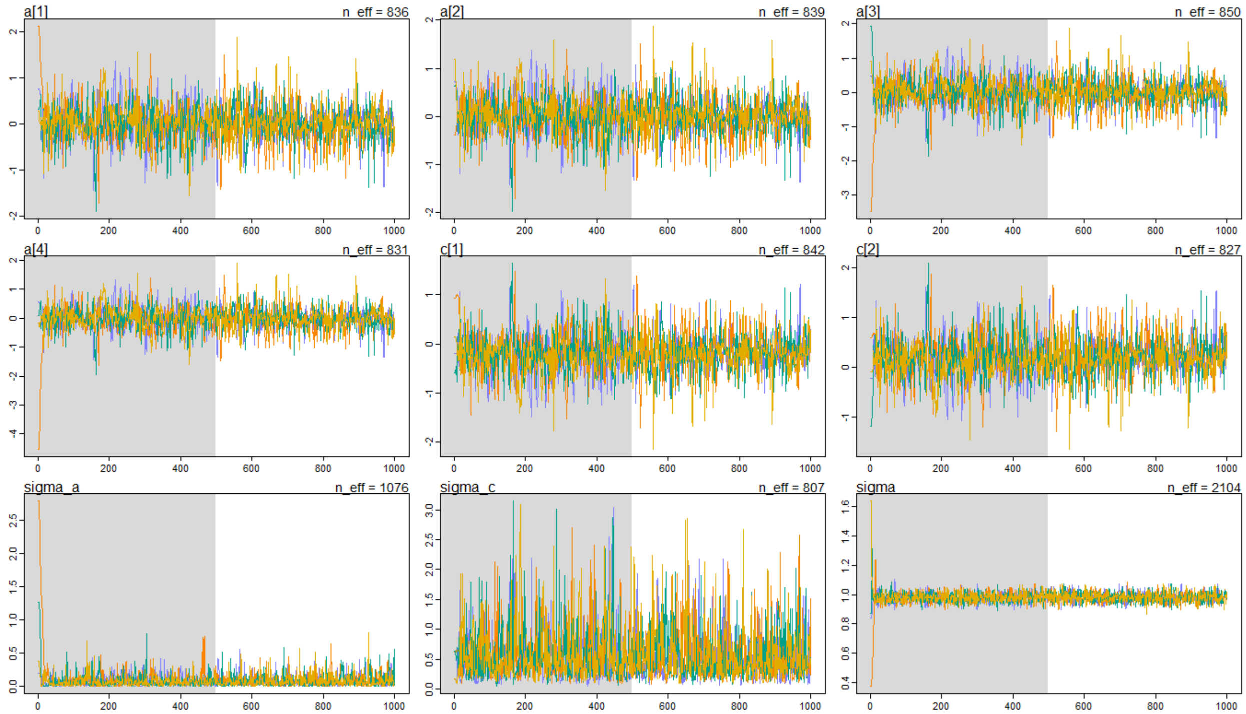


Figure 6: Trace plots of four Markov chains for each model parameters and number of effective samples showing convergence of the model and effective sampling from the posterior distribution.

As expected for standardized data, the model predicted that the underlying mean for each course to be approximately zero with a standard deviation (σ) for all courses of approximately 1. The effect of the flipped classroom treatment on each course was on average slightly negative with a posterior mean of -0.17 and standard deviation of 0.35. The effect of the not-flipped treatment was slightly positive on average with a posterior mean of 0.21 and standard deviation of 0.35. Interestingly the pooled standard deviation of the treatment effects has a posterior mean of 0.55 and a 95% credible interval of between 0.15 and 1.30. This implies a wide variation in the effect of the treatment on individual students. This variation of the treatment effects is significantly higher than the effect of each specific class (σ_A), or the data itself (σ). Posterior distributions of the model parameters with 95% credible intervals are shown in Figure 7.

Overall, the model indicates that the treatment of flipping the classroom had minimal effect on student end of term exam performance from previous years and that on average, the flipped classroom had a slightly negative effect on this student sample.

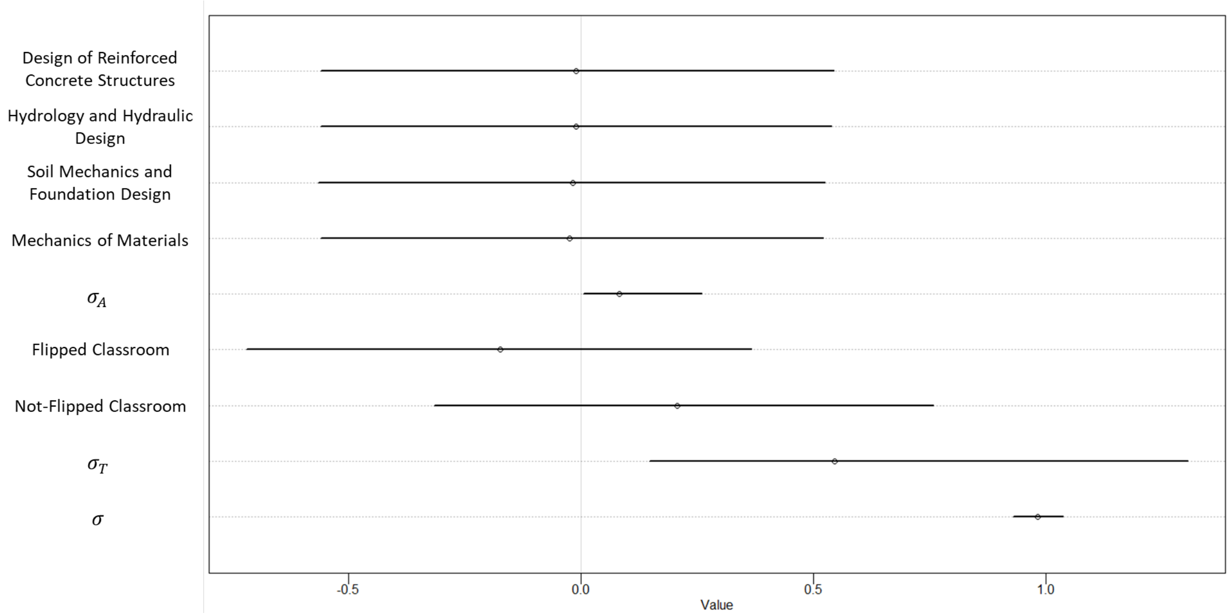


Figure 7: Posterior means of model parameters with 95% credible intervals. Variation in treatment effects is significantly higher than other parameters.

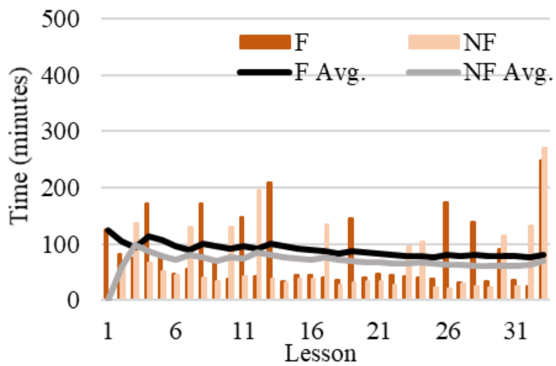
Time Spent Preparing for Class

The Civil and Mechanical Engineering Department at the U. S. Military Academy requires all students to track their time spent on all activities including preparing for each individual academic course. These self-reported times are typically reported at the start of each lesson and may be greatly influenced by the due date of graded requirements and the personal schedules of each student. Students are expected to spend up to double the length of a lesson preparing outside of class. For example, for a 55-minute lesson, students are expected to spend approximately 110 minutes preparing for class. Table 3 presents the average time spent preparing for a lesson over the entire semester. Students spent more time preparing for three out of the four flipped courses compared to the non-flipped course. The students in CE380 reported spending on average 22% less time preparing for the flipped class compared to the non-flipped. CE380 was the only flipped course where students were not required to attend each lesson in-person. A limitation of the CE380 data is that time survey information was only collected from the students 10 times over the semester. The lower performance in CE380 may be attributed to the students not dedicating time to attend the non-required recitation periods to clarify any misconceptions. Two of the courses, CE371 and CE483, exceeded the guidelines for time spend out-of-class. However, the additional time spent engaged with the material resulted in better performance in both courses.

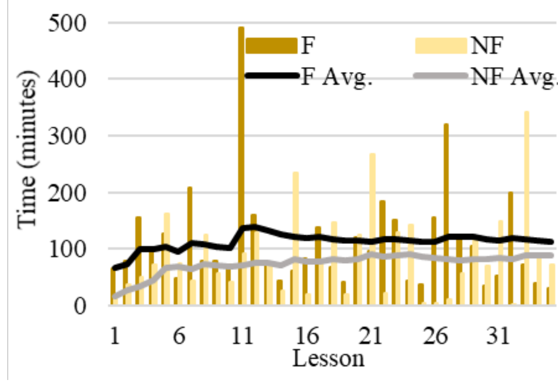
Figure 8 shows the distribution of time over the semester. MC364 has the most uniform time spent per lesson due to the impact of having reading quiz assessments at the start of approximately 70% of the lessons. These assessments forced the students to consistently engage with the material outside of class. The other three courses had inconsistent averages for each lesson primarily due to the significant time required for students to complete comprehensive homeworks. These assignments take a significant amount of time and effort and coupled with the requirement to watch the lesson videos prior to attending class is the primary reason for the increased time surveys in CE371 and CE483.

Table 3: Self-reported student time spend preparing for a lesson

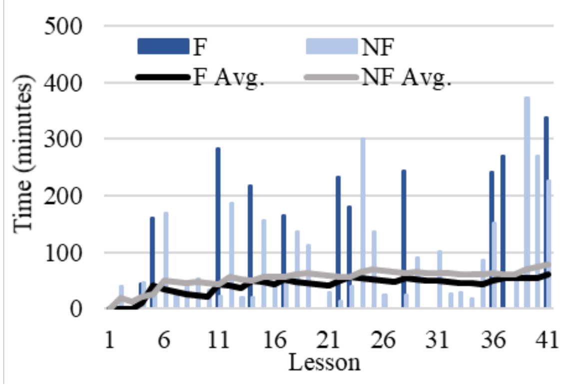
Avg. Time Preparing for a Lesson (minutes)	Mechanics of Materials MC364	Soil Mechanics & Foundation Design CE371	Hydrology and Hydraulic Design CE380	Design of Reinforced Concrete Structures CE483
Not Flipped	69	88	78	121
Flipped	81	112	61	130
10-year Average	60	74	64	90



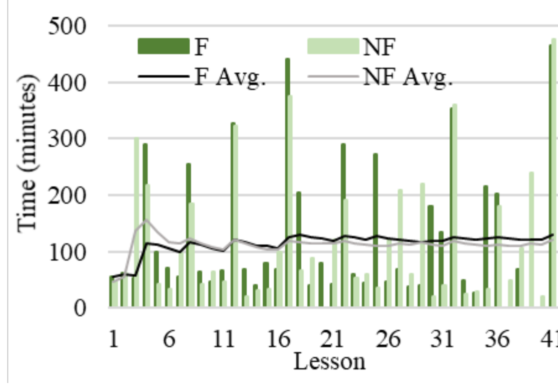
(a) Mechanics of Materials



(b) Soil Mechanics and Foundation Design



(c) Hydrology and Hydraulic Design



(d)Design of Reinforced Concrete Structures

Figure 8: Self-reported student time preparing for each lesson for the flipped and non-flipped course – a) Mechanics of Materials, b) Soil Mechanics and Foundation Design, c) Hydrology and Hydraulic Design, and d) Design of Reinforced Concrete (F=Flipped, NF=Not Flipped)

Student Course-End Feedback

Student course-end feedback was collected at the end of the semester for all four courses in the flipped and non-flipped format. Select survey questions used to assess the implementation of the flipped classroom are shown in Table 4. The results of the student course-end feedback are shown in Figure 9. Questions 1-3 related directly to the instructors' impact on the students both in and out of the classroom. For the most part, student feedback in all four classes indicated the flipped classroom had minimal effect (<5% change in student feedback) on the instructors' encouragement of the student to take responsibility for their own learning, the instructors' plan for each lesson, and the instructor's execution of effective teaching and learning techniques. However, two exceptions were identified. First, students in CE371 indicated there was less organization of the instructors' plan for each lesson in the flipped classroom compared to the non-flipped classroom. The CE371 in-person flipped classes were primarily spent working on homework with instructor oversight opposed to executing in-class lesson activities. Second, students in MC364 indicated their instructor did not use effective techniques for learning inside and outside of the class. Overall, there was a very split perception from students on the flipped classroom pedagogy. Figure 10 shows the results of a separate survey given to MC364 students, which showed that 47% of students strongly agreed or agreed the flipped class format was effective, while 23.5% did not agree or strongly disagreed that it was effective. 91% of students did agree working problems in class was effective in helping them learn, but 36% of students would have preferred out-of-class homework assignments in lieu of reading quizzes.

The results for question 4 (Q4) showed students in all four courses preferred the classroom environment in a traditional class compared to a flipped class. Students may have been uncomfortable in the flexible flipped classroom environment, where the students are more in control of the in-person lesson than the instructor.

Questions 5-7 inquired about student time spent on the course material. The in-class and out-of-class assessments for all four courses remained relatively unchanged in the flipped class. However, all four classes introduced video lesson content, which the students were expected to watch outside of class. For MC364, the students perceived that they did not have enough time to complete assignments, reflect on the material, or adequately prepare for optimum performance, however the students self-reported time survey information collected each lesson was an average of 81 minutes, 26% lower than the 2:1 guideline, but 17% greater than the non-flipped class. In MC364, the students' out-of-class time was spent watching the lesson videos (average of 35 minutes/lesson), preparing for reading quizzes and examinations, and completing four laboratory reports. For CE371, the students indicated they did not have enough time to prepare, reflect, and complete assignments compared to previous semesters. The students in CE371 completed similar out-of-class assignments, had to watch the videos outside of class, and spent the class period with the instructor. This resulted in a 27% increase in self-reported time spent due to the added out-of-class requirements. This may be due to an inefficient use of in-class time to work on out-of-class assignments. For CE380, the students perceived having enough time to prepare and reflect due to the flexibility of not being required to attend all lessons. For CE483, despite a 7% increase in self-report time, the students reported that the flipped classroom allowed them more time in their personal schedule to engage with the material. This could be a direct result of the increase maturity of 4^{th} year civil engineering majors to manage unstructured time and the restriction of not being able to travel during the semester due to the Pandemic.

Table 4: Student Course-End Feedback Questions

	Question
Q1	My instructor encouraged students to be responsible for their own learning
Q2	My instructor had a structure or plan for every lesson's learning activities
Q3	My instructor used effective techniques for learning, both in class and for out-of-class assignments
Q4	The classroom environment (e.g. desk setup, boards, technology, lights, etc.) had a positive impact on my ability to learn
Q5	The homework assignments, papers, and projects in this course could be completed within the time guidelines of 2:1 ratio of out-of-class time versus in-class time.
Q6	My personal schedule allowed me enough time to reflect on the material I learned in class
Q7	My personal schedule allowed me enough time to adequately prepare for my optimum academic performance

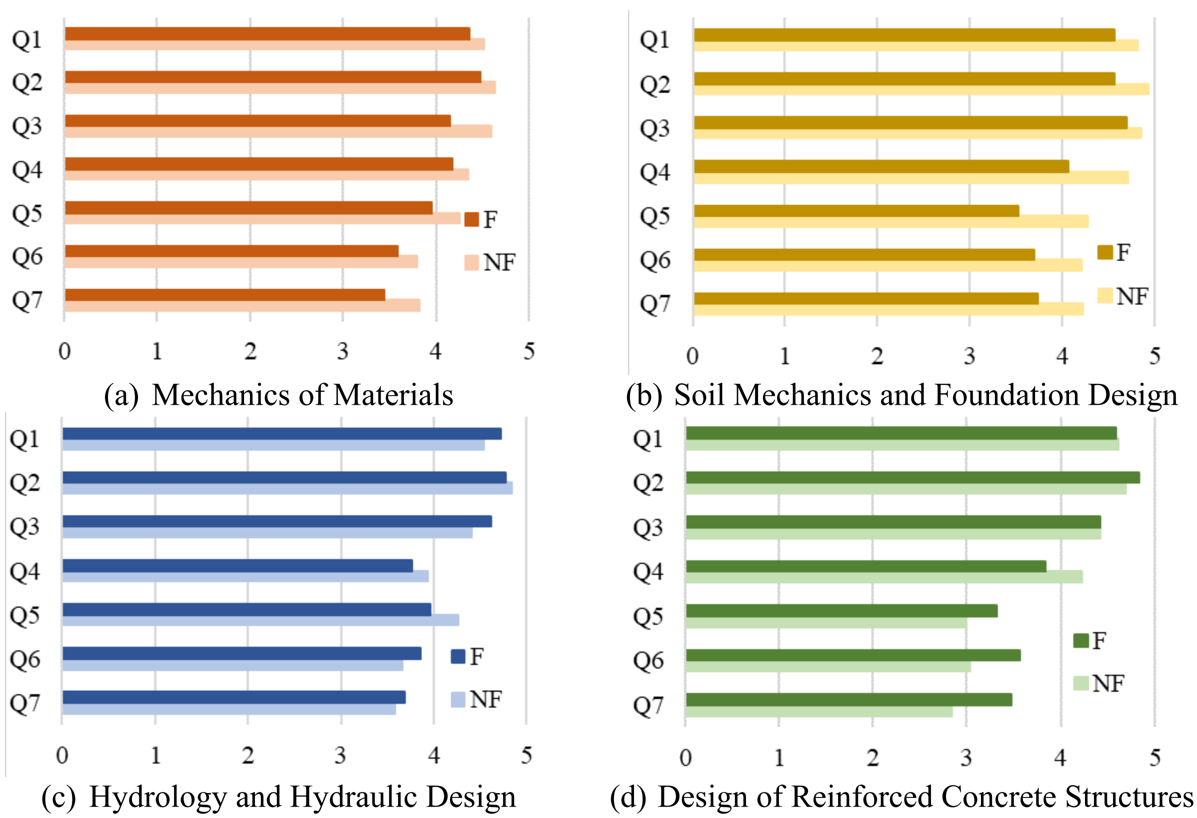


Figure 9: Student course end feedback comparison between flipped and non-flipped course – a) Mechanics of Materials, b) Soil Mechanics and Foundation Design, c) Hydrology and Hydraulic Design, and d) Design of Reinforced Concrete (F=Flipped, NF=Not Flipped)

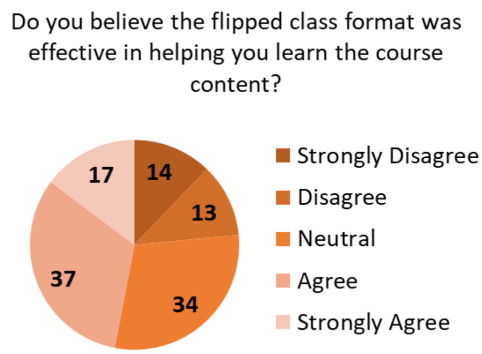


Figure 10: Results of MC364 survey on student perception of flipped class

Open-end course-end feedback was also collected for each course regarding comments on the delivery of the course and the instructor. Selected comments from students who took the flipped courses are below:

MC364 – Mechanics of Materials

- "The reading quizzes, while difficult, did force the student to be responsible for his own learning."
- "I really appreciated the ability to take boards much more in this course. Last semester, in 'Statics', I would fall asleep in the class since there was little participation and I was not able to engage in the learning."
- "The videos were perfect for learning the material, the quizzes were motivation to learn on our own, and class time was practice problems and clarification from instructor. Brilliant organization."
- "Working board problem and especially receiving feedback in real time from my instructor and classmates made understanding how to solve problems much easier."
- "Throw me into the deep end and I will learn how to swim! Especially, when the lifeguard is walking around."
- "Flipping the class was not helpful. It would be more beneficial to do practice problems together as a class with the instructor taking the lead. This would allow students to take notes and have something to refer to after class. The lack of notes I have from this class was not helpful at all."
- "The flipped classroom is a terrible teaching strategy. The efficacy of teachers comes from their ability to take complex topics from the textbook and explain them in easily understandable ways. By giving students videos, you lose this benefit and force them to grapple with complex concepts with inadequate explanation: the videos are not the same as an in-person lesson."

CE371 – Soil Mechanics and Foundation Design

- "The best resource for preparing for 'Exams' were the homeworks and class videos. Doing an example problem in the lesson videos also helped with my learning."
- "The homeworks were very effective at preparing me for the 'Exams'"

- “The labs were great! I think 95% of my learning occurred during these times.”
- The flipped course design worked well; however it would be helpful to cover more complicated problems in class in addition to videos.
- “Good course design. It would be best to spread the labs out. More than one lab per week makes the homeworks too much.”
- “The high volume of homeworks required a pace that was difficult to maintain during certain parts of the semester.”

CE380 – Hydrology and Hydraulic Design

- “The recitation periods were nice. it made it feel like we were still in the "in-person" learning environment which helped me to better understand the material.”
- “The course was challenging but fair. Teachers and program made learning easier with the remote challenge.”
- “Love this course! Great stuff! Video learning was easy and effective - preferable to doing the same thing but in class (because I could do it from the comfort of my room or library).”
- “A hybrid course style would be a good replacement of the online videos with recitation periods.”

CE483 – Design of Reinforced Concrete Structures

- “I enjoyed the flexibility in switching to working on homework in class, it shows that you are constantly managing time we spend in and out of class on assignments. In my opinion this class was most effective classrooms for learning in the COVID environment.”
- “The course was well executed. The shift from moving towards more independent learning influenced my willingness to learn effectively.”
- “I love both the recorded videos and the setup of the (Microsoft) Teams page, Very accessible.”
- “The videos were excellent resources for the future and should always be available for future semester (i.e. Publish after lesson, even in non-COVID environment)”
- “The desk arrangement made it very hard to communicate with my group to do group work. I usually just did work on my own because of it.”
- “I like instructor lesson videos, but not when they replace in-class teaching. It should be one or the other. I do not have enough time to watch the videos outside of the lesson to learn the objectives.”
- “Some pre-class videos could have been a little shorter.”

Instructor Feedback

The instructor feedback was fairly consistent across all four courses. The main theme was that creating the video content required a significant amount of effort. However, now each of the courses has a library of videos for each topic in the course that can be used as supplemental learning resources even in a traditional class. The videos provided the instructors with a large amount of flexibility to execute in-person learning. They were not restricted by time constraints to ensure all the lesson content was covered during the class period as students could refer to the video content on their own time. Another common sentiment across instructors was the need for shorter videos. The students seemed to prefer videos that were less than 10 minutes even if more were included for each lesson.

In MC364, the instructors used the class period to challenge their students to tackle complex problems. The ability to provide students with immediate feedback was ideal for enhancing their learning and ensuring they did not develop "bad habits." In this type of classroom environment, it is critical that the instructor and students have a good rapport. It could be incredibly difficult for the instructor to assess all the students work especially if one or two students are really struggling. Students must take responsibility for their own learning having watched the videos prior to class and arrived with any questions. The instructor is also responsible for empowering the high-performing students to take a leadership role in the flipped classroom to help their peers.

In CE380, the instructor did not require attendance for every lesson, but noted the students who did attend most of the recitation periods greatly benefited. By making the recitation periods optional, the courses never had a situation where the number of students exceeded the classroom capacity restrictions. Thus, allowing the course to be executed effectively in a hybrid environment even with the added restriction.

The instructors in CE483 used the flexibility of the flipped classroom to change their primary in-person classroom activities halfway through the semester. The instructors recognized the time required to watch videos outside of class plus no change to the homework requirements was a much higher time demand on the students than the 2:1 guideline. They then transitioned to allow students to complete their homework in class, which was found to improve student interest, engagement, and reduced out-of-class time.

Overall, the instructors did not see a large impact on student achievement of the course objectives due to implementation of the flipped classroom. Variations were consistent with typical year-to-year changes and is most likely a direct result of differences between student populations.

Conclusions & Recommendations

The U.S. Military Academy had not developed a fully flipped civil engineering course prior to the Pandemic. This study analyzed the implementation of the flipped classroom for the four courses during the COVID-19 Pandemic during the 2021 Academic year. Analyzing the results showed minimal impact on the student performance and varied results on the time required by students to be successful in the course. Students who embraced the flipped classroom performed well, while students who preferred an instructor led classroom environment performed more poorly. This may be a direct result of the rapid transition of these courses from the traditional instructor-led format to a flipped classroom. Transition to a flipped classroom required a significant amount of effort from instructors to develop videos and prepare new in-person content.

Reflecting on the student feedback, implementing the flipped classroom format during remote/hybrid learning may have been viewed by most students as a "double load" with the instructor expectation that students attend in-person class and watch out-of-class video lectures in addition to completing all assignments. The timing of the transition to the flipped classes may have been too rapid; occurring at an inopportune time. One student in MC364 stated "After a year of remote classes because of COVID, it would have been nice to get in-person instruction rather than just doing example problems that we could do on our own." The results of the study confirmed a deliberate design approach and planning is required for implementation of a flipped classroom. This is more than simply rearranging the order of learning activities. To effectively execute a flipped course, it is recommended that instructors gradually introduce new learning resources such as videos and in-class active learning activities to create the high-quality teaching products necessary to encourage students to take responsibility for their own learning. Similar to the results of previous studies, it is critical that short videos are provided to the students; no longer than 15 minutes. Now that higher-education is transitioning back to normal in-person learning, three of the four courses have reverted to their original instructor led course delivery but continue to utilize the video resources for students interested in receiving additional instruction. The instructors of Mechanics of Materials have continued to refine and update the flipped classroom approach to improve students learning.

The authors recognize that there are limitations to this study and confounding factors that may have impacted the results. In addition to the transition from the traditional class format to the flipped classroom format, the results of this study may have also been impacted by different instructors who taught the courses, different demographics of the student populations each semester, and different course materials provided to the students. The authors also acknowledge that the results are unique to the students and instructors at the US Military Academy, and it may be difficult for other institutions to replicate the results.

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