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Implementing a Flipped Learning Approach In Two Engineering Courses

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WIP: Implementing a Flipped Learning Approach in Two Engineering Courses

Introduction

The flipped learning approach is an innovative teaching technique that has been implemented in many university level engineering courses over the past 15 years. While elements of the flipped teaching method have been used since the late 1990's, two high school chemistry teachers, Jonathan Bergmann and Aaron Sams, are often credited with developing flipped learning in 2007. From their classrooms in Colorado, the technique has spread to the university level and across the world. [1], [2] This approach is based on flipping or inverting traditional classroom activities. In a traditional approach, students gain their first exposure to the material during the class meeting, usually in the from of a didactic lecture. Students then apply the concepts that they learned from the lecture to their homework, which is completed outside of the class meeting. In engineering courses, the homework often takes the form of a set of problems to solve. In the flipped learning approach, these activities are reversed. Students gain their first exposure to material in an individual setting by watching a video lecture or reading an assigned text. Consequently, the class meeting time is available for students to complete activities where they apply and practice what they learned before class. During the COVID-19 pandemic, the number of courses using the flipped approach increased rapidly, likely because the large in-person group lecture was unavailable to instructors and a synchronous video lecture session was unappealing to both instructors and students. [1], [3], [4] There is some evidence that flipped learning during the pandemic allowed student to perform as well as or better than in the traditional classroom setting [3].

Even before the pandemic, instructors were implementing flipped learning in engineering courses and implementation has continued to rise after the pandemic. Reports of student achievement in flipped engineering courses compared with traditional courses vary greatly and thus meta-analyses have been performed to gauge of the impact of flipped learning for engineering courses. In 2017, Karabulut-Ilgu et al. analyzed data from 30 studies that compared student learning in traditional and flipped classrooms and concluded that the flipped approach was at least as effective as the traditional one [5]. A few years later, Lo and Hew performed a similar meta-analysis, finding that the flipped approach promoted student achievement and students in flipped courses performed significantly better than those in traditional courses. The authors attributed these effects to the ability of learners to pause and rewatch lectures and increased problem-solving activities in the class meetings, including being able to get help from peers and the instructor. They also found that these effects were enhanced by a brief review of the topic in class before staring the problem solving session. [6] A more recent study has also found student performance is significantly improved in flipped learning settings [7]. Others have found that flipped learning improves student performance in STEM courses [8], [9], science courses [10], and higher learning courses across many disciplines [11]. In addition to academic gains, flipped courses have been shown to build students' interpersonal skills [11] and increase the performance of underrepresented students in STEM [12]. In attempt to realize these benefits and in hopes for deeper learning for my students, I began to implement flipped learning in some of my courses.

Over two years, I implemented flipped learning in two of the courses that I led at a small private university. The first course was EGE 210: Statics and Dynamics in the fall semester of 2023. This course is typically taken by students majoring in biomedical, civil, and mechanical engineering in the first semester of their second year. Prerequisites for this course include General Physics 1, Introduction to Engineering Design, and Calculus 2, which can be taken at the same time. The learning objectives for EGE 210 are shown in the left column of Table 1. In brief, the course covers particle and rigid body statics and particle dynamics and serves as a prerequisite for EGE 230: Thermodynamics and Fluid Mechanics 1, EGE 240: Mechanics of Materials, BME 412: Biomedical Transport. In fall 2023, twenty-nine students were registered for the course. The second course was upper-level biomedical engineering course, BME 412: Biomedical Transport, in the fall semester of 2024. This course, whose learning objectives are shown in the right column of Table1, had twelve registered students, all majoring in biomedical engineering in their third or fourth year of the program. The prerequisites for this course were Anatomy and Physiology 1, Differential Equations and Linear Algebra, Statics and Dynamics, and General Chemistry. Both courses were four credit hours. EGE 210 met for 65 minutes three times per week and was supported by a weekly 100-minute laboratory. BME 412 met for 100 minutes twice per week.

Table 1: Course Learning Objectives for the Two Flipped Courses

Learning Objectives for EGE 210: Statics and Dynamics	**Learning Objectives for BME 412: Biomedical Transport**
1. Apply the principles of static equilibrium to particles and rigid bodies 2. Analyze truss and frame structures 3. Apply the principles of equilibrium to analyzing beams 4. Analyze problems involving frictional forces 5. Apply the principles of kinematics and kinetics of particles for dynamic analysis	1. Correlate biological structures to the role they play in transport phenomena 2. Describe diffusion with and without convection and variables that influence the rate 3. Analyze transport in porous media and transvascular transport 4. Apply mathematical equations to model mass transport in biological systems 5. Use mathematical equations to describe fluid transport in biological systems 6. Explain design considerations for drug delivery and extracorporeal mass transport devices

From an academic perspective, both courses were successful in achieving the learning objectives. In EGE 210, the average numeric final grade was 82.85 ± 8.35% and the most frequently earned letter grade was B (Table 2). Furthermore, the Statics Concept Inventory was used to measure student learning in EGE 210. Students completed this concept inventory, which consists of 27 multiple choice questions that measure students understanding of nine statics concepts, in the first week of the semester and again in the twelfth week, after the statics portion of the course was completed. A paired t-test indicated that students answered significantly ($p=0.007$) more questions correctly on the post-test compared with the pre-test, indicating that their statics knowledge increased over the course of the semester. Finally, the course seemed to prepare students well for ensuing course work. All the EGE 210 students who took the next course in the sequence, EGE 240: Mechanics of Materials, earned A's and B's. They were also successful in the other courses that require EGE 210 as a prerequisite, EGE 230: Thermodynamics and Fluid Mechanics 1 and BME 412: Biomedical Transport, with only one student earning a score lower than C+ in either course. Taken together these scores indicate that students who completed the flipped EGE 210 were prepared to be successful in their future courses that built upon this one. Letter grades also indicate that students were academically successful in BME 412, where the average score was $87.73 \pm 5.14\%$ and the most frequently earned letter grade was B+ (Table 2). While the grades and other evidence suggest that students in both courses learned the content, student comments indicate that implementation of flipped learning in the biomedical engineering course was much more successful than in the statics and dynamics course.

Table 2: Final Student Grades in Flipped Courses

	EGE 210	**BME 412**
	n=29	n=12
Average	83%	88%
StDev	8%	5%
A	4	3
A-	4	2
B+	3	4
B	6	0
B-	2	1
C+	5	2
C	1	0
C-	0	0
D+	3	0
D	0	0
D-	1	0
F	0	0

Students in the biomedical engineering course expressed a much more positive attitude about the course and flipped learning than the statics and dynamics students did. Figure 1 shows the percent of students who made positive comments in the end of semester survey about flipped learning, negative comments about flipped learning, mentioned that they liked solving problems in-class or had to teach themselves content. About half of the BME 412 students left positive comments about the flipped modality in their end of semesters survey. Examples of these comments included “the flipped class was 100% the correct way to do it.”, “I liked the structure of the class. I recommend always having flipped learning where homework is done in class.” and “flipped learning was extremely beneficial”. Even more students, 75% of the class, commented on how much they liked using class time to work problems, including, “I liked being able to complete the homework problem in class so that when I had questions I could ask right away rather than waiting for office hours to ask the question.” Only one student mentioned disliking the flipped learning approach and having to teach themselves material. In contrast, about half of statics and dynamics students who left comments mentioned disliking the flipped modality and having to teach themselves content. Examples of these comments include, “I would have preferred that a math heavy course like this one not be taught with "flipped learning",” and “Flipped learning is not an effective or appropriate method of learning within engineering.” Only one EGE 210 student commented on enjoying solving problems in groups. In the following sections, I hope to share some factors that may explain these differences in the successfulness of implementing flipped learning.

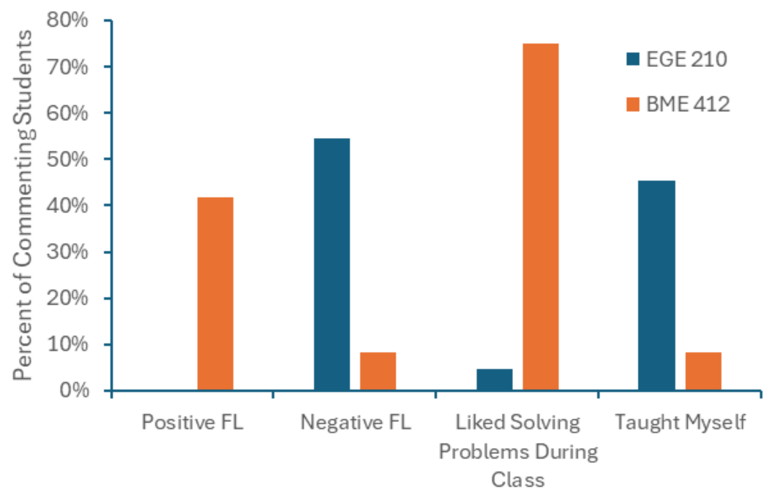

Figure 1: Analysis of End of Semester Survey Comments. For EGE 210, 22 of the 29 students left comments. For BME 412 all 12 of the students left comments.

Student Composition

The student composition of the two flipped courses differed. For EGE 210, most of the students were in their third semester of study and as a second-year student would typically be 19 or 20 years old. On the other hand, BME 412 students included three third-year students and nine fourth-year students, putting the average age over 21. Being older and having completed more college courses may have helped the BME 412 students be more prepared for and accepting of nontraditional pedagogies, like flipped learning. Additionally, there is some evidence that students view large, general courses less favorably than smaller courses within their majors [13]. Because EGE 210 had 29 students, which was relatively large for the university, and was categorized as general engineering, the students may have been predisposed to have negative feelings toward the course making them less accepting of flipped learning and producing the opposite effect for BME 412, a smaller course within the major. Furthermore, the BME 412 students were involved in the decision on the course structure and at the beginning of the semester voted unanimously to flip the class. Giving the students a voice in the decision likely helped make the flipped learning implementation more successful.

In flipped learning courses, students need to complete tasks independently and students with low self-regulation may be less accepting of flipped learning [5], [14], [15], [16]. Thus, being older and more experienced likely meant that the BME 412 students had developed stronger self-regulation skills than the EGE 210 students and this may have allowed flipped learning to be implemented more successfully in the upper-level course. Finally, Tomas et al. reported their experience on implementing flipped learning in a first-year science course. Their work indicated that while students reported watching the pre-class videos, they were not ready to take part in the planned collaborative learning activities without a significant in-depth review of the video content from the course instructor, concluding that flipped learning might not be the best choice for first year students. [17] My experience with second-year students was similar, in that even after completing the pre-class activities and having an example problem solved for them live in class, students still were not ready to attempt solving problems on their own. The upper-level students were much more willing to attempt solving problems after these same activities. Taken together, there is reason to believe that flipped learning will be more successful for upper-level students.

Pre-Class Activities

For both flipped classes, students' first exposure to a topic was in the form of a video lecture posted online. Students were asked to watch the lecture(s) before the first course meeting of the week. EGE 210 students also had online quizzes over the concepts in the video(s) that were due before the course meeting. EGE 210 included 32 videos with an average length of nine minutes and 39 seconds and BME 412 included 35 videos with an average length of fifteen minutes and thirty seconds. All the EGE 210 videos and 24 of the BME 412 videos were hosted on YouTube, set to unlisted so only those with the link could access the video, and analyzed with YouTube's video analytics. The remaining BME 412 videos were hosted on Microsoft Stream, which only recorded the number of views and thus these videos were excluded from the view duration analysis. Figure 2 shows the results of the video analytics. Despite having more and longer videos, the BME 412 students were more likely to engage with the online lecture. For BME 412, the average number of views per video was 22.5 ± 4.92. Because the class only had 12 registered students and the video links were only available to registered students, it seems that students were watching the videos more than once. It is possible that students used the video to prepare for class, then revisited it to study for exams, but it is more plausible that students were watching the videos across multiple viewing sessions because the average view duration was about 44.5% of the video. Allowing students to pause, restart, and review the lecture at times and at paces that are convenient for them is one of the commonly accepted benefits of flipped learning and video lectures. In contrast, the average number of views per EGE 210 video was 24.1 ± 6.64, meaning that at best only about 83% of the class accessed the videos. The actual number of students who watched the videos was probably lower than 83% because some students almost certainly clicked on the video link multiple times, either watching the video across multiple sessions or revisiting the material before an exam. Additionally, the average view duration per view was only about 30% of the video. So many EGE 210 students were only engaging minimally with the video lectures, while the BME 412 students were engaging with the to a much larger extent.

To investigate this difference further, I divided the total view duration for all viewers by the number of students in the class to calculate the percentage of the video watched per student. For BME 412, the average percentage of video watched per student was 86.9% but only 26.4% for EGE 210. Overall, the video analytics suggest that most of the BME 412 students watched the videos and played almost the entire duration of it, while a meaningful number of EGE 210 students probably did not access the videos and very few watched the entire duration of the videos. This result was particularly surprising because EGE 210 students had to take a pre-class quiz over the contents of the video lecture and BME 412 students did not. Therefore, it seems that the quiz was not an effective motivation to engage with the video lecture. In addition to watching the videos, EGE 210 had homework problem sets that were completed outside of class. These problem sets may have reduced the amount of time that students were willing to spend engaging with the video lectures. No matter the cause, this lack of engagement with the video lectures represented a considerable hinderance in EGE 210 and, in my opinion, was a large factor in the unsuccessful implementation of flipped learning in this course. My observations agree well with previous studies that show engagement with the video lecture is critical for students to benefit from flipped learning [6], [16].

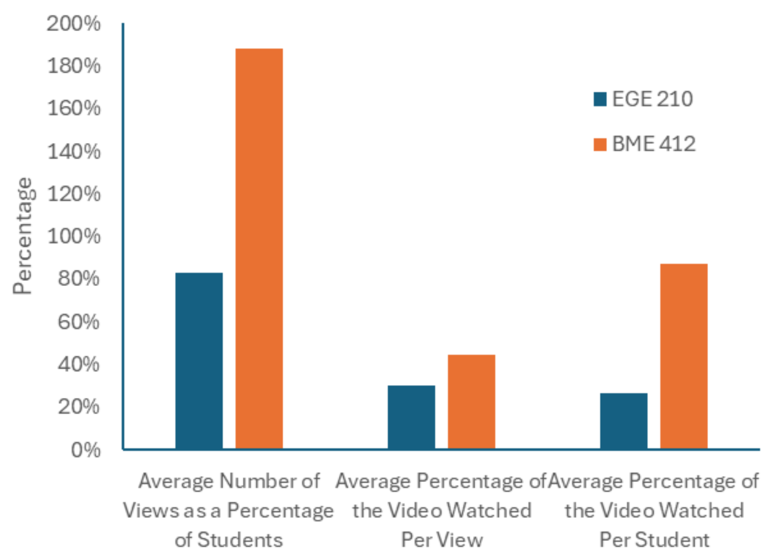

Figure 2: Pre-Class Video Analytics

In-Class Activities

In-person class meetings for both courses started with a brief introduction to the topic and working an example problem for the class. Then students worked in small groups to solve problems. Finally, EGE 210 ended with an exit quiz. The method for problem solving varied between the two courses. In Statics and Dynamics, students worked in instructor-assigned groups of three or four that rotated three times during the semester or after about 5 weeks. They also worked on their own paper or laptop/tablet talking to each other but recording answers individually. When they finished problem, they could either check their answer with the instructor or wait for the instructor to work the problem for the class. Students earned participation and attendance credit for attending the class session and did not earn additional points for solving the problems correctly. After class, students had an additional problem set for homework that was scored for correctness. The process was slightly different for Biomedical Transport meetings. After the example, students worked to solve the problems in randomly determined groups of three that rotated every week. Importantly, the groups were formed publicly and maintained only for the duration of one homework assignment. Another difference was that students worked problems on whiteboards, with one group at each of the room's four whiteboards and the entire group writing a single solution. Finally, the problems were scored for correctness and served at the student's "homework" score. The grading scheme did not include a separate category for attendance or participation.

As evidenced by the student comments, the BME students found their class time much more valuable, and this perception likely contributed to their acceptance of the flipped learning modality. It seems reasonable to assume that grading the class work for correctness added extrinsic motivation that made the BME students more invested in the in-class activities. However, I believe that the largest factor that impacted the class meetings was the change to working problems on whiteboard instead of paper or laptop. Having one whiteboard that the team shared forced students to collaborate and allowed me and other groups to see their work. This visibility was helpful because groups could check their answer with another group, and they often helped each other find mistakes. Teams could also look at the work of other groups for hints when their own group got stuck. I believe that being able to easily see the group's work and point out things on their board allowed me to be a more effective facilitator than was possible when students worked on their individual paper. While working on the whiteboards, students were less dependent on my intervention and could be efficient with their time, likely increasing their satisfaction. This observation is supported by Kayaduman's finding that increased student to student and student to instructor interactions can help achieve learning outcomes in flipped classrooms [18]. Furthermore, a large part of the value proposition of flipped learning for students is that they are doing the more difficult parts of the class with the support of their classmates and the instructor and working on the whiteboards enabled me to better deliver on this value proposition.

Conclusions

Comparing the implementation of flipped learning in the upper lever biomedical engineering course to the Statics and Dynamics course allowed me to identify factors that instructors may want to consider when deciding to flip a course. The first factor that I suggest considering is the level of the course. Upper-level courses tend to have older students who have more experience with university courses and better self-regulation skills, which may translate into better engagement with the pre-class materials. For flipped first and second year courses, I would consider providing students with a structured approach for engaging with the pre-class material. Something like guided notes that provide signals for important concepts, spaces to fill in key facts, and write down questions from the video lecture could help make this component of the course more active and provide an artifact that demonstrates individual student engagement with the pre-course material. This document could also be reviewed at the beginning of a class meeting to provide the type of extensive, in-depth review that Tomas et al. [17] implemented in their flipped first year science course. If possible, I would also strongly recommend giving the students a voice in deciding whether to implement flipped learning. As demonstrated by the end of semester comments, students who were a part of the decision to implement flipped learning were less likely to have negative feelings about it and more likely to observe the benefits. Next, I would think about if the number of students and the class meeting space is appropriate for the in-class activities. For me, this means that there are enough whiteboard spaces for students to work in small groups and the number of groups is manageable for me to serve as a facilitator or if there are too many groups to facilitate, could the course be supported by a teaching assistant. Instructors may also consider designing the in-class activities to maximize not only contact between the instructor and students, but also student to student contact. Finally, I would use the in-class activities as a scored component of the course and avoid assigning additional homework. Scoring the in-class work seems to provide better motivation for students to prepare for class than a quiz and avoiding other homework gives students ample opportunity to watch the pre-class videos. Implementing flipped learning in a course could provide students with the opportunity to deepen their understanding of the topic, increase their collaboration skills, and build self-regulation, but if the implementation is not successful, it could be a miserable experience for both the students and the instructor. It is my hope that this paper helps instructors who developing a flipped class.

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