Successfully Flipping a Fluid Mechanics Course Using Video Tutorials and Active Learning Strategies: Implementation and Assessment

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Successfully flipping a fluid mechanics course using video tutorials and active learning strategies: Implementation and Assessment

Abstract

This paper investigates the use of a flipped classroom pedagogy to lower the repeat rate in a bottleneck upper division mechanical engineering course. Over two quarters (Winter 2017 and Spring 2017), two sections of the fluid mechanics course were taught back-to-back by the same instructor at California State Polytechnic University, Pomona; one section was flipped (n = 63), and the other was taught in a traditional lecture style (n = 64). Both sections met twice-a-week for 75 minutes. In the flipped classroom, the course material was divided into weekly modules with each module focusing on a different topic. Students completed the following activities for each module: (a) Prior to the first in-class meeting, students were required to watch a series of videos totaling approximately 15-60 minutes; (b) At the first in-class meeting, students were given a concept quiz to ensure they watched the videos, and the remaining class time was dedicated to reviewing the solutions to the quiz, reviewing the concepts in the videos, and solving example problems; (c) After the first in-class meeting, students were provided with an optional zero-credit practice quiz to prepare them for a second, more challenging quiz at the beginning of the second in-class meeting; (d) After taking the challenging quiz and reviewing the solutions during the second meeting, the remaining class time was dedicated to an active learning exercise called a "Team Battle" in which students competed in teams to complete problems as quickly as possible. Students in the traditional lecture classroom also had access to the videos, but were not required to watch them; class time consisted of students hearing lectures on new material and discussing example problems. Both sections were assigned readings and homework problems through the McGraw-Hill Connect platform as a prior study [1] demonstrated its potential benefit in boosting student performance in the course.

The impact of the flipped classroom pedagogy on students' academic performance and attitudes was assessed by comparing the flipped and traditional lecture sections' performance on similar quizzes and exams, Connect assignments, concept inventories, psycho-social scales, and focus groups. Students in the flipped class had a much lower repeat rate (D and F combined = 11.1%) than the control group (34.4%). Though individual assignments and exams tended to not reflect statistically significant differences, overall course scores were significant even when controlling for major, GPA in major, and overall GPA. Significant differences in positive changes in psychosocial variables between the traditional lecture and flipped groups highlighted possible explanations for differences in overall course performance, as the flipped group reported greater confidence, feeling more supported and successful, and rated the course more positively.

1. Introduction

Over the last decade a plethora of technological innovations have facilitated a wider range of course delivery models and offered new pedagogical tools. During this same time, the Mechanical Engineering Department at California State Polytechnic University, Pomona (Cal

Poly Pomona) faced the challenge of a bottleneck upper division course with a high repeat rate (ME 311: Fluid Mechanics I) – historically, approximately one-third of ME 311 students earned a D or F, forcing them to repeat the course. In order to alleviate the bottleneck, a variety of technological innovations were employed and assessed with some success prior to this study [1]. After researching best practices, the instructor, with the support of the Mechanical Engineering Department and in conjunction with assessors from the Psychology and Sociology Department, decided to experiment with a flipped classroom.

1.1 What is flipped learning?

Flipped classrooms are part of the educational movement toward student-centered and problem-based learning [3]. In a flipped classroom, more of the traditional didactic portion of the class takes place online, often using video tutorials. The videos are ideally much shorter and more focused than typical in-class lectures [4]-[6]. This frees up class time to engage in higher-order learning strategies, rather than the more basic transfer of and review of information. The classroom is used to foster connections and active learning, with students engaging in hands-on activities, projects, and/or problem solving [3],[7]-[11]. Students spend more time learning as student-to-student and student-to-teacher interactions increase [10],[12]. Faculty can provide immediate feedback to students, obtain more nuanced gauges of student comprehension, and focus on areas of deficit in a flipped classroom [12]. Since areas of deficit may differ among students, sections, or groups, this allows more flexibility in focus and use of classroom time. Certainly, for an increasingly diverse student and faculty body, being able to have more flexibility is generally considered advantageous [10].

It is important to note that a “flipped class” is not an online class. Technology is used to facilitate learning, and face-to-face time is used more for practical hands on learning activities rather than lecture. In addition, presents material in a variety of formats to reinforce learning. For example, closed captioning may assist students who engage better through reading text than hearing content. Students have access to the background material at all times, allowing them to review material at their leisure. Students report being able to review material multiple times as one key advantage over traditional lecture pedagogy [13].

1.2 Student performance and attitudes in flipped classrooms

Studies have demonstrated flipped classes are effective at improving student grades and student learning outcomes [7],[9],[12],[14]-[18], as well as the classroom experience [17],[19]. This has been demonstrated explicitly for engineering classrooms [4],[13],[18],[20], although the literature specifically investigating flipped fluid mechanics courses is limited and has shown mixed results [21],[22].

Students report improved levels of satisfaction in studies of flipped classrooms [9],[23] and specifically in engineering courses [4],[13]. Research has shown a student preference for the flipped class model relative to traditional models [9],[24]-[27]. Student engagement within the classroom setting and with peers is also facilitated by the flipped class model [23]. Interestingly, some research suggests high-performing students benefit more than weaker-performing students from a flipped class [27]. In addition, flipped classrooms have been shown to be impactful for retaining people of color in STEM [28].

1.3 Why did we attempt a flipped class?

While the flipped classroom approach may not be appropriate or effective for all types of courses, instructors, or students [20], the upper division fluid mechanics course discussed in this paper seemed to be ideal for this style of instruction. The course requires students to apply engineering concepts to solve many problems. It also has a relatively low student to instructor ratio (≈ 30:1) per section.

Additionally, in previous quarters we assessed and found potential positive impacts to using the publisher's integrated learning system [29] and deployment of video tutorials on student performance and perceptiona. Futhermore, in focus groups students explicitly requested more class time devoted to problem solving and demonstrating applications [1]. Hence, this intervention specifically addresses student concerns.

Flipped classes are most effective when class time is used to answer questions, demonstrate how to approach and work problems, and to work cooperatively [8],[30],[31]. In our experiment, the instructor followed these best practices by using class time to, solve problems, have students work collaboratively on problems in a "fun" game format, and, assess comprehension. Student academic performance in the course, satisfaction with the course, and a series of psycho-social variables were measured to compare the flipped and traditional versions of the course.

2. Methods

The flipped classroom experiment took place over two quarters (Winter 2017 and Spring 2017) at Cal Poly Pomona. In each quarter, an experimental section (flipped) and a control section (traditional lecture) met twice-a-week for 75 minutes and were taught back-to-back by the same instructor. The typical class size for ME 311 was 30-35 students. Because both experimental sections were taught in a similar manner over the two quarters, as were both control sections, the data from both quarters were combined in order to analyze a larger sample size – i.e., the data from the two flipped sections were combined ($n = 63$ total) and the data from the two traditional lecture sections were combined ($n = 64$ total). Data from each quarter was also analyzed separately to ensure the results were consistent. Though students in Spring quarter had a lower repeat rate (6.2%) compared to winter (16.1%), results on regression equations, psycho-social variables, and concept inventories, were consistent, suggesting the data could be analyzed in the combined form.

In the flipped section, during every week of the 10-week course (except week 1) students took a concept quiz on Tuesday that was based on videos they were required to watch outside of class. The remainder of the Tuesday section was devoted to discussion, demonstrations, and example problems. Between the meeting on Tuesday and Thursday, students had access to an optional, zero-credit quiz that was more challenging and meant to help prepare them for meeting on Thursday. On Thursday, students took a longer quiz that involved significant calculations and was more difficult than the concept quiz. The rest of Thursday was dedicated to collaborative

“Team Battles” where small amounts of extra credit could be earned. A Team Battle is an active learning exercise designed by the instructor that involves group problem solving and has been used successfully by the instructor in the past for a different flipped course [2]. In this course, the instructor split the class randomly into teams of four, provided each team with two problems related to the week's topic, then had students work in pairs to solve the problems. When a team believed they solved both problems correctly, one representative wrote the team name on the whiteboard and the instructor checked their answers. If one or both answers are wrong, the team was given a three-minute timeout in which they could continue to work on the incorrect problem(s) but could not write their team name on the board. When half of the teams obtained the correct answers, a representative from each team came to the front of the room and clicked a random number generator program that selected a prize consisting of some combination of candy and extra credit for each team member (Figure 1).

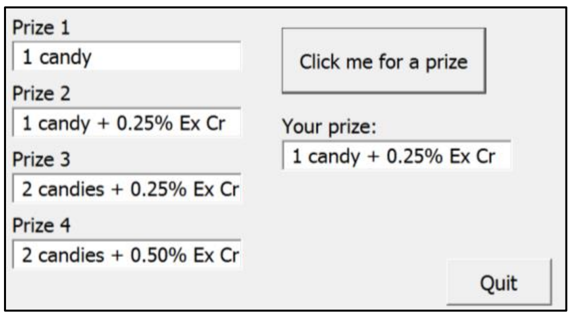

Figure 1: Screenshot of the random generator program used to determine prizes for winners of the Team Battle.

During the Team Battle the instructor floated around the room answering questions related to the problem statements. However, the instructor did not provide guidance on how to solve the problems – students were required to turn to their teammates for assistance. Students were permitted to use whatever resources they brought to class, including a laptop or phone to access the eBook and internet. At the end of the Team Battle, the instructor discussed the solutions to the two problems. The total amount of time for the Team Battle was approximately 30 minutes. Both accountability and meaningful active learning activities are crucial to succeeding with a flipped course [3],[32]. Team Battles held students accountable in a “fun” format that included solving problems in a mildly stressful, time-pressured situation. Team battles also provided immediate feedback and incentive to prepare beyond the quizzes, factors that improve flipped class efficacy [33]. Quizzes, combined with examples and the engaging Team Battles, created a flipped class that was responsive to student requests for more examples, held students accountable for watching videos outside of class, and motivated and engaged students with active collaborative learning activities.

The control group had access to the video tutorials used in the flipped section, but the course was taught in a traditional lecture format. Class time was used primarily for lecturing on new topics and discussing example problems.

Both sections were assigned readings and end-of-chapter problems in the McGraw-Hill Connect platform accessed online. The readings involved the use of SmartBook, which is an interactive eBook that tests students’ reading comprehension through the use of frequent concept questions. The end-of-chapter problems were generated using the Question Bank tool in Connect. Question

Bank automatically varies parameters within each problem, effectively giving each student a unique set of problems. This prevents students from simply copying the solution manual. A previous study by the authors found that the use of both SmartBook and Question Bank in this course seemed to help students' overall performance [1].

The percentage value of each component of the final course grade and the criteria for the overall letter grade is shown in Table 1. Students were able to boost their course grade in a few other ways as well. For both sections, if a student received a 90% or greater on the final exam, which was cumulative, the worst grade they would receive is a B+. This policy was designed to encourage students who struggled early in the quarter to not give up. Additionally, both sections had the opportunity to earn 0.75% for participating in a focus group. In the experimental section, the worst concept quiz and worst calculation quiz could be dropped, and there were opportunities to earn small amounts of extra credit in weekly Team Battles. At the end of the course, the instructor added roughly 2% to the experimental sections' overall scores before assigning letter grades. However, the instructor added roughly 3.5% to the control sections' overall scores before assigning letter grades to help level the playing field – it was determined that the Team Battle bonus opportunities and dropping of quizzes helped the experimental section by about 1.5% on average.

Table 1: Percentage of course grade for each assessment and criteria for overall course grade

Assessment	Control section (traditional lecture)	Experimental section (flipped)	Overall course grade
Question Bank problems (Connect)	5% (5)[a]	5% (5)	90% ≤ A
SmartBook readings (Connect)	5% (5)	5% (5)	80% ≤ B < 90%
concept quiz	N/A[b]	10% (8)	70% ≤ C < 80%
calculation/application quiz	20% (4)	40% (8)	60% ≤ D < 70%
midterm exam	30%	N/A	F < 60%
final exam	40%	40%	

[a] Number in parentheses indicates the number of assessments given in that category
[b] N/A = does not apply to this section

To assess the impact of the flipped classroom, the authors examined student's performance in the course, scores on a pre-course and post-course concept inventory, and scores on a pre-course and post-course assessment of a variety of psycho-social variables. Focus groups with the experimental and control groups were also conducted by the student co-authors, under the direction of the first and second authors. The focus group transcripts were de-identified and faculty did not have access until the quarter concluded. IRB approval was obtained prior to beginning the research.

3.1 Results – Students' academic performance

The primary goal of this project was to reduce the failure rate in a bottleneck course, so students' overall course performance was a key metric of success. Figure 2 demonstrates that 34.4% of the control group did not receive a passing grade, compared to just 11.1% of the experimental group. Additionally, the experimental group had many more A's compared to control group (41.3% vs 14.1%, respectively).

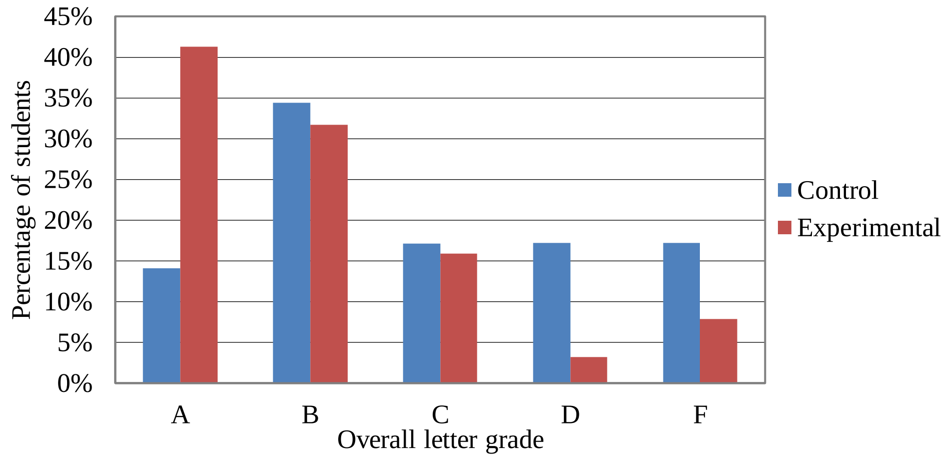

Figure 2: Overall course letter grades for the control group (traditional lecture) and experimental group (flipped).

Overall, the student performance in the course on all assignments and assessments provided some evidence that the flipped format improved success. On the vast majority of assessments, results were in the expected direction of the experimental group outperforming the control group, although the results were not always statistically significant. It seems that a small difference in average scores add up. In other words, it wasn't that students in the experimental section *significantly* outperformed the control group on a specific assignment or exam, but rather that they *slightly* outperformed them on most, indicating a global classroom impact.

The overall course percent (mean percentage of total points earned by the end of the course) was 82% for the experimental group and 71% for the control group, and this difference is highly statistically significant ($p < 0.001$). One irresolvable methodological challenge was the fact that the course requirements for the experimental group and control group were not entirely the same. Specifically, the control group that had only four calculation/application quizzes and one midterm, the experimental group had eight calculation/application quizzes, eight concept quizzes, but no midterm.

On the final exam, the experimental group had a higher mean score (74.55%) than the control group (73.30%), but the difference was not statistically significant. It is possible that the results were influenced by factors such as the final exam taken on different days (meaning one group had more time to study), by student motivation (one group might have felt more pressure to do well on the final exam because they did not do well on the midterm), and by the questions on the exam which were designed to be similar but not exactly the same.

On the Connect assignments, students in the control group performed statistically significantly better on only two of the thirteen Connect assignments, but the experimental section demonstrated statistically significantly better performance on four of the assignments. Additionally, students in the experimental section outperformed students in the control group on four other Connect assignments but the difference was not statistically significant. Hence, students in the experimental section had higher average scores on the majority of Connect assignments. While each difference was small, they added up to a significantly improved pass rate.

Performance on a concept inventory (a 13-question test which was designed to capture student understanding of key concepts covered in the course but did not count in the course grade) was compared. At the beginning of the quarter, students in the control group earned a mean of 7.0 out of 13 possible points (54%), significantly outperforming the experimental group who earned a mean of 6.0 out of 13 points (46%) on the pre-test ($p < 0.05$), which indicates that perhaps the control group entered the course with greater ability. At the end of the quarter, there was no longer a significant difference between the control group and experimental group – the mean post-test score was 9.6 out of 13 points (74%) for the control group versus 9.0 out of 13 points (69%) for the experimental group ($p > 0.05$). Because the experimental group went from performing statistically significantly worse to there being no statistically significant difference by the end of the course, this suggests the intervention may have had a positive impact.

To control for factors that could impact overall course performance, regression equations were created that controlled for major, student abilities prior to entering the course (testing both GPA and GPA in major separately), and gender. ME 311 is a required course for both mechanical and civil engineering students and based on discussions with engineering faculty who taught this course in the past, civil engineering majors sometimes fared worse in the course than mechanical engineering majors. We also assumed that there could be an external factor that resulted in stronger students being more likely to end up in one section or the other, which is why we controlled for grade point average in one equation, and grade point average in major in a second equation. Previous research suggests gender could impact the success of students in engineering [34] and their experience [35],[36]. Similar to other studies that explored race and gender [35],[36], we created dummy variables for race and gender, but no significant relationship was found for either in our analyses. With overall course score (total score in the course at the end of the course) as the dependent variable, we ran a regression with campus grade point average, gender, major, and experimental versus control group. We also ran the equation using GPA in major. Similar results emerged. The results clearly demonstrated a statistically significant impact for being in the experimental group, even when major and prior abilities were controlled for. The results of the regression indicated the three predictors explained 53.5% of the variance (R-squared =.535): GPA in major, being in the experimental section, and the major of the student (generally mechanical engineering versus civil engineering) ($p < 0.001$).

3.2 Results – Students' perceptions from surveys

Given that the students in the control group actually started out with a stronger conceptual understanding of the fluid mechanics (as indicated by a statistically significant difference between the control and experimental groups on the pre-test of the concept inventory), what are some factors that could explain the stronger performance of the students in the experimental group? One possible explanation is the more positive experience students often report in flipped classes [4],[13]. A survey was administered at the beginning and end of the course which instructed students to provide psycho-social ratings. Students indicated their attitudes about the course by making selections on a 7-point scale between two extreme descriptors such as "satisfying/unsatisfying." We compared the values at the beginning and the end of course (Table 1), and the change in those values (Table 2).

The experimental group showed statistically significant differences in improved favorability (from week 1 to week 10) toward the psycho-social ratings for the course over the control group for the variables friendly ($p < 0.01$), satisfied ($p < 0.05$), prepared ($p < 0.001$), enjoyable ($p < 0.05$), confident ($p < 0.001$), supported ($p < 0.001$), hopeful ($p < 0.001$), successful ($p < 0.001$), better than other courses in the major ($p < 0.05$) and the value of the course ($p < 0.01$). We also tested results for week 1 and week 10 separately to interpolate our results. It is striking to us that regardless of significance, the experimental group has more positive ratings for the class on all the psycho-social variables by week 10. This tells us that students in the experimental section were having a more positive classroom experience overall.

Table 1. Students' psycho-social rating of the course and instructor at the start and end of the quarter: Means, standard deviations (SD), and *t* values for merged Winter/Spring 2017 data

Variable	W1 Mean Exp	W1 SD Exp	W1 Mean Control	W1 SD Control	*t*	W10 Mean Exp	W10 SD Exp	W10 Mean Control	W10 SD Control	*t*
Stimulating	5.33	0.908	5.23	1.16	-0.521	5.83	1.060	5.52	1.064	-1.574
Friendly	5.67	1.012	5.80	1.166	0.663	6.44	1.003	5.91	1.048	-2.734**
Satisfied	4.72	1.240	4.77	1.383	0.207	5.65	1.416	5.03	1.256	-2.430**
Prepared	4.54	1.026	4.97	1.064	2.252*	5.72	1.295	5.16	1.320	-2.272*
Useful	6.02	0.957	5.95	1.257	-0.324	6.13	1.229	6.03	1.025	-0.446
Cooperative	4.74	1.290	4.80	1.492	0.260	5.33	1.401	4.79	1.321	-2.100*
Enjoyable	5.20	0.980	5.16	1.200	-0.165	5.96	1.149	5.53	1.030	-2.073*
Confident	4.25	1.350	4.97	1.169	3.155***	5.72	1.250	5.12	1.226	-2.550**
Supported	5.13	1.258	5.48	1.026	1.656*	6.09	1.103	5.51	1.071	-2.828**
Hopeful	5.26	1.168	5.84	0.986	2.932**	5.98	1.189	5.40	1.294	-2.446*
Successful	5.12	1.027	5.44	1.009	1.762*	5.93	1.195	5.14	1.302	-3.307***
Better than	4.89	1.002	4.82	1.148	-0.336	6.15	1.204	5.61	1.065	-2.479**
Value Course	5.69	0.923	5.97	0.951	0.580	6.07	1.007	5.63	1.175	-2.126*

W1 = Week 1 of the course. W10 = Week 10 (final week) of the course. Exp = Experimental section. Control = Control Section.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ with a one tailed test.

Table 2. Changes in students' psycho-social ratings from Week 1 to Week 10 of the quarter and section comparison for Winter/Spring 2017 (ΔT)

Variable	Mean Exp	Mean SD	Mean Control	SD Control	*t*
Stimulating	0.52	0.97	0.20	1.23	-1.50
Friendly	0.73	1.16	0.05	1.32	-2.82**
Satisfied	1.00	1.68	0.25	1.86	-2.15*
Prepared	1.18	1.19	0.26	1.74	-3.18***
Useful	0.17	1.10	0.07	1.24	1.42
Cooperative	0.41	1.54	-0.07	1.56	-1.62
Enjoyable	0.77	1.08	0.38	1.03	-0.87*
Confident	1.52	1.44	0.15	1.58	-4.66***
Supported	1.09	1.27	0.07	1.15	-4.30***
Hopeful	0.75	1.28	-0.45	1.43	-4.56***
Successful	0.92	1.15	-0.37	1.24	-5.55***
Better than	1.28	1.32	0.83	1.38	-1.72*
Value Course	0.39	0.90	-0.07	1.07	-2.44**

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ with a one tailed test.

At the end of every quarter at Cal Poly Pomona, the university obtains feedback about all instructors by deploying student evaluations to every course. Because Cal Poly Pomona is a primarily undergraduate institution, these student evaluations play an important role in determining whether faculty obtain tenure and promotion. Students rate the instructor's performance in nine areas on a five-point-scale, with 1 being "very good" and 5 being "very poor." Table 2 shows the instructor's overall score (averaged over all nine questions) in the four sections taught during the study. While the instructor received respectable marks for the control sections (1.39 and 1.29), the instructor's scores for the experimental section were near perfect (1.09 and 1.07), giving another indication that students perceived the flipped classroom experience very positively.

Table 2: Instructor's overall score on university-issued student evaluations

Quarter	Experimental section	Control section
Winter 2017	1.09[a]	1.39
Spring 2017	1.07	1.29

[a] All four scores are an average based on student responses to nine questions.
1 = very good, 2 = good, 3 = satisfactory, 4 = poor, 5 = very poor

3.3 Results – Students' perceptions from focus groups

Toward the end of each quarter, students in both the control and experimental sections were invited to participate in focus groups run by the student co-authors of this paper. Students who attended the one-hour focus groups received 0.75% extra credit to their overall course score and snacks. The focus groups provided us with further evidence that the flipped class format was both useful and preferred. Students in the experimental group noted the high engagement level in the course and the value of time for more example problems. In contrast, the control group lamented the lack of time for examples in class.

Experimental group quotes	Control group quotes
• *This class is more involved.* • *This class we have team battles, and you get more practice in class.* • *There are more examples and you learn more from examples than from the lecture.* • *With technology, I like how he records his lecture. His notes are good, his examples are pretty relevant and what you expect on quizzes and exams.*	• *I would like to see more examples.* • *Sometimes, he only does one example for each topic. It is a little frustrating.* • *We have classes for only an hour, and sometimes it goes by so fast, we don't get enough examples.* • *I feel like I learned more in his past class because he actually reviewed the concepts and did more examples. It's the main problem that I have for this class - he only shows one problem and it doesn't show the different variations that happen in the problem.*

The students in the experimental group provided more positive feedback about the professor and the course compared to control group.

Experimental group quotes	Control group quotes
• *You so can tell that he applied technology very well in this class!* • *Anytime I ask him a question, he is very good at explaining it. He takes some time to explain it.* • *This guy is really nice and makes me want to come to class even though it's hard.*	• *You have to watch examples on YouTube and ask friends for help.* • *[For this class you have to] learn not to rely on your actual class; you have to learn on your own.*

Students in the experimental group highlighted the established benefits of flipped classes: flexibility, pacing, interaction with peers, and ability to access resources.

Experimental group quotes	Control group quotes
• *I think it helps me because it's more realistic … I have someone to work with. I feel like it's really beneficial of me for learning because even though it's more traditional to learn in lecture, I think it's really helpful because you have different methods of learning. I also formed a strong connection with my group.* • *Thursday's work really reinforces the work for me.* • *The recorded lectures are really helpful because I get to re-watch them and go on my own pace.* • *I think it's helpful because I get another perspective on how the problem is done. I think the interaction with my peers is really helpful if I am stuck.*	• *It's intimidating that the final and the midterm make up 70% of your grade.* • *I'd rather have the quizzes right away they're a little bit too spaced out.* • *We don't get as much resources as [the other section] so I see their examples and that helps.* • *I often zone out. I walk out of this class often that I feel like I didn't learn anything.* • *Most of my learning happens outside the classroom.*

The co-authors of the present paper who administered the surveys and conducted the focus groups noted the improved classroom dynamic and more positive peer interactions in the flipped section compared to the traditional lecture section, as suggested by the literature [10],[12]. The students in the experimental groups seemed more connected with each other, and were more willing to participate in, and excited about, the focus groups. The control groups seemed to interact among themselves less and were less enthusiastic regarding our project. Students' description of the classroom experience during the focus groups supports the idea that the Team Battle experience created a more "easy" dynamic among students, who were used to working together on a task in pressure-filled situations. Students also saw the Team Battles as helping them succeed in the areas most important for success in the course, such as problem solving under time pressure.

<u>Experimental group quotes regarding Team Battles</u>

- *Team battles make us work faster and harder.*
- *Team Battles… Very helpful. If you mess up in the quizzes, and then you go back [in the Team Battle] and feel bad about it, but when you see what you did and you know to do it right next time.*
- *The quizzes are very conceptual whereas the Team Battle and homework is harder. So it builds up your confidence on a quiz.*
- *I like the group battles because you're forced to interact and it results in the class being more active and involved in the lecture.*

4. Conclusions

It would seem that for upper-division engineering courses, and we would argue that for other courses with similar challenges, a flipped class model can improve both student performance and student experience in the classroom. The Team Battles were notably impactful for students, which is consistent with literature that suggests flipped classes are most impactful when activities foster peer and instructor interaction [10],[12]. While gamification of courses has been critiqued for undermining performance and experience [37], this problem was avoided in this case because the Team Battles were more perceived as a fun learning experience rather than a high-stakes course-long competition. Moreover, the Team Battles and structure of the flipped course directly addressed a perceived student need [1].

The main goal of our project was to reduce the repeat rate (Ds and Fs) in a challenging bottleneck engineering course. With the flipped class model, the repeat rate dropped from 34% to 11%. Yet, the concept inventory demonstrates relatively similar rates of overall concept comprehension at the end of the course (although the experimental group did appear to have greater gains from week 1 to week 10 compared to the control group). To some degree, the increased success may be explained by the positive student experience in the flipped class, as demonstrated by the scores on the psycho-social variables. In both quarters, the flipped class was "more engaged" than the traditional lecture class. In part, we believe the program was successful because the intervention matched student need, created a more positive classroom environment and fostered peer relations. Students in the control group, and in a previous study [1], explicitly requested that more class time be used for examples, as occurred in the flipped version of the course. A handful of students in the control group viewed their peers in the experimental group at an advantage because of the "extra time to interact with the professor." In addition, Team Battles actively engaged students in more example problems with support from peers. As one student stated, "with a peer you're able to better communicate how you got stuck on a problem and it's more relatable." Finally, Team Battles and quizzes forced students in the experimental section to stay engaged with course material more regularly, whereas students in the control section reported being most likely to review and engage with material before their less frequent quizzes and exams. A student in the experimental group expressed his fondness of the Team Battles, "*It sets up a competitive environment and it makes you want to do well. And if something didn't click with you in the lecture it has to click with you now if you want the extra credit."* Though students did not have statistically significantly better performance on many assignments, having slightly better performance overall translated to statistically significant differences in overall performance and an improved (lower) repeat rate.

References

[1] P. Nissenson, F. L. Wachs, J. L. Fuqua, Y. Zhao, S. Pedroza, A. C. Shih, "Impact of an Online Learning Environment on Student Performance and Perceptions in a Fluid Mechanics Course," in *Proceedings of the 2017 American Society of Engineering Education Annual Conference & Exposition*, Columbus, OH, USA, June 25-28, 2017.

[2] P. Nissenson, "Impact of a hybrid format on student performance and perceptions in an introductory computer programming course," in *Proceedings of the 2015 American Society of Engineering Education Pacific Southwest Conference*, San Diego, CA, April 10-11, 2015.

[3] J. L. Bishop and M. A. Verleger, "The flipped classroom: A survey of the research," in *Proceedings of the 2013 American Society of Engineering Education Annual Conference & Exposition*, Atlanta, GA, USA, June 23-26, 2013.

[4] S. Zappe, R. Leicht, J. Messner, T. Litzinger and H. Lee, "Flipping the classroom to explore active learning in a large undergraduate course," in *Proceedings of the 2009 American Society for Engineering Education Annual Conference & Exposition*, Austin, TX, USA, June 14-17, 2009.

[5] P. Johanes and L. Lagerstrom, "Online Videos: What every instructor should know," in *Proceedings of the 2016 American Society of Engineering Education Annual Conference & Exposition*, New Orleans, LA, USA, June 26-29, 2016.

[6] D. Bolliger, S. Supanakorn, and C. Boggs, "Impact of podcasting on student motivation in the online learning environment," *Computers & Education*, vol. 55(2), pp. 714-722, 2009.

[7] D. Berrett, "How 'Flipping' the Classroom Can Improve the Traditional Lecture," *Education Digest*, vol. 78(1), pp. 36-41, 2012.

[8] J. Bergmann and A. Sams, *Flip Your Classroom: Reach Every Student in Every Class Every Day*, Eugene, OR: International Society for Technology in Education, 2012.

[9] M. J. Lage, G. J. Platt and M. Treglia, "Inverting the classroom: A gateway to creating an inclusive learning environment," *Journal of Economic Education*, vol. 31(1), pp. 30–43, 2000.

[10] E. Brunsell and M. Horejsi, "Flipping Your Classroom in One 'Take,'" *Science Teacher*, vol. 80, 2013.

[11] D. Riendeau, "Flipping the classroom," *The Physics Teacher,* vol. 50(8), pp. 507, 2012.

[12] B. Alvarez, "Flipping the Classroom: Homework in Class, Lessons at Home," *Education Digest,* vol. 77(8), pp. 18-21, 2012.

[13] J. Foertsch, G. Moses, J. Strikwerda and M. Litzkow, "Reversing the Lecture/Homework Paradigm Using eTEACH Web-based Streaming Video Software," *Journal of Engineering Education*, vol. 91(3), pp. 267-274, 2002.

[14] J. A. Day and J. D. Foley, "Evaluating a web lecture intervention in a human–computer interaction course," *IEEE Transactions on Education*, vol. 49(4), pp. 420-431, 2006.

[15] J. S. Lewis and M.A. Harrison, "Online delivery as a course adjunct promotes active learning and student success," *Teaching of Psychology*, vol. 39(1), pp. 72-76, 2012.

[16] B. McNally, J. Chipperfield, P. Dorsett, L. Del Fabbro, V. Frommolt, S. Goetz, J. Lewohl, M. Molineux, A. Pearson, G. Reddan, A. Roiko and A. Rung, "Flipped classroom experiences: student preferences and flip strategy in a higher education context," *High Educ*, vol. 73(2), pp. 281-298, 2017.

[17] S. Wilson, "The flipped class: A method to address the challenges of an undergraduate statistics course," *Teaching Psychology,* vol. 40(3), pp. 193-199, 2013.

[18] N. Lape, R. Levy, D. Yong, K. Haushalter, R. Eddy and N. Hankel, "Probing the inverted classroom: A controlled study of teaching and learning outcomes in undergraduate engineering and mathematics," in *Proceedings of the 2014 American Society of Engineering Education Annual Conference & Exposition*, Indianapolis, IN, USA, New Orleans, LA, USA, June 15-18, 2014.

[19] K. Wong and D. Chu, "Is the flipped classroom model effective in the perspectives of students' perceptions and benefits," in *Proceedings of the 7th International Conference on Hybrid Learning Conference,* Shanghai, China, August 8-10, 2014.

[20] G. S. Mason, T. Rutar Shuman and K. E. Cook, "Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course," *IEEE Transactions on Education*, vol. 56(4), pp. 430-435, 2013.

[21] C. McClelland, "Flipping a large-enrollment fluid mechanics course: Is it effective?" in *Proceedings of the 2013 American Society of Engineering Education Annual Conference & Exposition*, Atlanta, GA, USA, June 23-26, 2013.

[22] D. Webster, D. Majerich, and A. Madden, "Flippin' fluid mechanics - Comparison using two groups," *Advances in Engineering Education*, vol. 5(3), 2016.

[23] R. F. Swinburne, B. Ross, R. Laferriere, A. Maritz, "Flipped Learning, Flipped Satisfaction, Getting the Balance Right," *Teaching & Learning Inquiry*, vol. 5(2), pp.114-127, 2017.

[24] R. Bachnack and S. Maldonado, "A Flipped Classroom Experience: Approach and Lessons Learned," in *Proceedings of the 2014 American Society of Engineering Education Annual Conference & Exposition*, Indianapolis, IN, USA, June 15-18, 2014.

[25] J. Mclaughlin, L. Griffin, D. Esserman, C. Davidson, D. Glatt, M. Roth, R. Mumper, "Pharmacy Student Engagement, Performance, and Perception in a Flipped Satellite Classroom," *American Journal Of Pharmaceutical Education*, vol. 77(9), pp. 196, 2013.

[26] N. Sarawagi, "A flipped CS0 classroom: applying Bloom's taxonomy to algorithmic thinking," *Journal of Computing Sciences in Colleges*, vol. 29(6), pp. 21-28, 2014.

[27] J. Tague and G. R. Baker, "Flipping the classroom to address cognitive obstacles," in *Proceedings of the 2014 American Society of Engineering Education Annual Conference & Exposition*, Indianapolis, IN, USA, June 15-18, 2014.

[28] C. Talley and S. Scherer, "The enhanced flipped classroom: Increasing academic performance with student-recorded lectures and practice testing in a "Flipped" STEM course," *The Journal of Negro Education,* vol. 82(3), pp. 339-347, 2013.

[29] McGraw-Hill Connect informational website. Available at: http://www.mheducation.com/highered/platforms/connect.html

[30] W. Redekopp and G. Ragusa, "Evaluating flipped classroom strategies and tools for computer engineering," in *Proceedings of the 2013 American Society of Engineering Education Annual Conference & Exposition,* Atlanta, GA, USA, June 23-26, 2013.

[31] N. Soundarajan, S. Joshi and R. Ramnath, "A Novel Approach to Collaborative Learning in the Flipped Classroom," in *Proceedings of the 2014 American Society of Engineering Education Annual Conference & Exposition*, Indianapolis, IN, USA, June 15-18, 2014.

[32] C. Brame, "Flipping the classroom," Vanderbilt University Center for Teaching, 2013. [Online] Available: http://cft.vanderbilt.edu/guides-sub-pages/flipping-the-classroom/. [Accessed February 1, 2018]

[33] M. Kim, "The experience of three flipped classrooms in an urban university: An exploration of design principles," *The Internet and Higher Education*, vol. 22, pp. 37-50, 2014.

[34] N. M. Else-Quest, J. S. Hyde and M. C. Linn, "Cross-National Patterns of Gender Differences in Mathematics: A Meta-Analysis," *Psychological Bulletin*, vol. 136(1), pp. 103-127, 2010.

[35] R. W. Lent, M. J. Miller, P. E. Smith, B. A. Watford, R. H. Lim, K. Hui and K. Williams, "Social Cognitive Predictors of Adjustment to Engineering Majors across Gender and Race/Ethnicity," *Journal of Vocational Behavior*, vol. 83(1), pp. 22-30. 2013.

[36] E. Litzler, C. Samuelson and C. Lorah, "Breaking it Down: Engineering Student STEM Confidence at the Intersection of Race/Ethnicity and Gender," *Research in Higher Education*, vol. 55(8), pp. 810-832, 2014.

[37] M. Hanus and J. Fox, “Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance,” *Computers & Education*, pp. 152-161, 2015.