It's Not Rocket Science: The Flipped Classroom in Space Mechanics

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Abstract

Flipping the classroom where the content previously taught in class is completed by students before coming to class has become a popular technique within higher education. This paper compares students' performance in an upper-level space mechanics flipped classroom to a more traditional classroom. Among three sections of the flipped classroom, the average final grade of students in the flipped classroom was 4.66, 8.82, and 9.93 percentage points higher than students in the traditional classroom.

Introduction

Successful educators relentlessly seek the best method to teach students. Often the "best" method depends on the course material, the students, the learning outcomes, and the instructor. Active learning and memory research suggest a learner-centered teaching (LCT) approach where the instructor becomes a facilitator.[1] LCT strives to create an environment that maximizes student engagement through "authentic, meaningful, and useful learning".[1]

Based on the idea that the person who does the work learns the material,[2] LCT can take different forms in the classroom including group work (e.g., a jigsaw classroom[3-5]), real-world problem solving,[5] and peer instruction.[5] Peer instruction, when a student teaches concepts to another classmate, requires deep (or semantic) processing where the instructing student must first understand the meaning, relationship, and importance of a concept.[6] In contrast, an instructor-centered classroom primarily uses direction instruction (i.e., lecture) where students observe but do not actively engage the course concepts which can lead to shallow processing and a weak memory trace.[6]

Beyond encouraging deep processing, peer instruction can lead to effective learning,[7] better team working skills,[8] deep-level questioning,[9] and increased motivation[10] which can boost student's attendance.[11] Peer instruction also lessens the common student response of "I understood it when you talked about it in class" because students must deeply process the course concepts.[12]

Learner-centered teaching and peer instruction commonly occur in the flipped classroom. The most straightforward definition of a flipped classroom is when students work on activities inside the classroom which would have normally been completed outside the classroom and vice-versa.[13] The flipped classroom model used for this study required students to watch video lectures before coming to class and to work on problems in class with an expert (the instructor) to guide them. The instructor, now transformed from a lecturer to a facilitator, creates in-class activities that prepare students for summative, graded assignments such as homework or exams. Furthermore, by transforming the classroom structure, the instruction changes from large-group instruction to individualized student instruction.[14]

Many previous flipped classroom studies have seen an improvement in student performance[15,16] resulting in positive student opinions and an increase in homework and exam scores.[17,18] However, few studies have compared a traditional and flipped classroom that cover the same

material for an entire semester[18,19] making it unclear how a flipped classroom influences students' learning relative to a more "traditional" classroom. In an earlier study, we examined student performance across two sections of an upper-level space mechanics course where one section was flipped, and the other section was a traditional structure.[20] Here, we continue that study with two additional sections of an upper-level space mechanics course with a flipped classroom design taught in the fall of 2017 by the same instructor. By extending this project for another semester, we can determine if our previous study was a coincidence, and we can provide strong evidence to support the effectiveness of the flipped class design.

Methods

The previous study was conducted in the spring 2017 semester with two sections of an upper-level space mechanics course taught by the same instructor at a small, private university. The student population was primarily full-time students coming directly from high school. The student body was 75% male and 62% white. After IRB approval, informed consent was obtained from all students. A total of 41 students participated (n = 21 in the traditional section and n = 20 in the flipped section). The traditional section (spring 2017) primarily used lecture with some active learning where students worked through group example problems during class. In the fall 2017 semester, two more sections of the same class taught by the same instructor were added to the study. Both fall 2017 sections were flipped, and a total of 66 students participated (n = 31 in section 1 and n = 35 in section 2). For the fall 2017 semester, two students from section 1 were removed because one student never submitted homework and another student stopped coming to class, submitting homework, and taking exams.

The flipped sections required students to watch a series of 5- to 7-minute videos on class concepts before coming to class. Students then spent the class period completing a worksheet on conceptual and numerical problems in groups. Both the flipped and traditional sections had the same content and used the same set of notes. However, compared to the traditional section, the flipped section completed part of the homework assignments during class. For example, a homework assignment in the flipped section required finding only one orbital property (angular momentum); while the homework assignment in the traditional section required finding four orbital properties (angular momentum, period, eccentric, and semi-major axis). An example of an in-class worksheet can be found in Appendix 1.

In the spring semester, both sections had 12 homework assignments that were broken into 3 parts consequentially having homework due each class. The first two homework assignments were low-stakes assignments and graded on completion. We are calling these assignments formative homework. The third homework assignment was graded on correctness (summative). The flipped section had shorter formative homework assignments than the traditional section since some of the homework problems were included in the daily worksheets. The formative homework assignments for the flipped section were often only one or two short questions. Furthermore, students in the spring flipped section reported that they did not have enough time to focus on the summative homework assignments with daily homework and videos. Thus, the formative homework assignments were dropped in the fall with the content migrating to worksheets or the summative homework leaving one weekly summative homework with a total of 12 homework

assignments. Across both semesters, the content of the summative homework assignments was unchanged.

Students worked in the same groups for the semester which were assigned during the second week of class. For both the traditional and flipped classrooms, students sat in these groups during class. Peer evaluations were conducted at the end of the semester. The peer evaluations were the same for all sections. Students were asked to give themselves and their groupmates a grade out of 100. The grades were averaged across the group for the final peer evaluation score.

During both semesters, students were assigned online multiple choice pre- and post-quizzes that were graded on completion, not correctness. The course assessment also included four exams which included the final. The grade weightings across semesters and class types are shown in Table 1. All exams included a group take-home exam worth 30% of the exam grade and an in-class individual exam worth 70% of the exam grade. The first three individual exams used similar problems across sections (e.g., one class might identify elliptical properties and the other would identify hyperbolic properties); while the fourth (final) individual exam and all group exams were identical for all sections. For the spring and fall semesters, the exams had the same weighting at 45%. The summative homework assignments were weighted at 15% in the spring and 25% in the fall because the formative assignments were removed in the fall. Class engagement for the flipped sections, which included the in-class worksheets as well as summative group quizzes, had the same weighting for the spring and fall semesters (15%). In the traditional section, class engagement (weighted at 5%) only consisted of the summative group quizzes. To remove the weighting differences across semesters and sections, the proportional percent students earned for each class element was multiplied by the corresponding number of points possible used in the fall semester. For analyses, the total course points (3150 points) were allocated as follows for class elements: homework (1200 points), class engagement (790 points), online quizzes (660 points), peer evaluations (100 points), group exam 1-3 (90 points), individual exam 1-3 (210 points), group exam 4 (30 points), and individual exam 4 (70 points). Individual and group exam 4 were separated from other exams because they were cumulative while the other exams were not.

Table 1: Grade Weightings for Spring and Fall 2017

	Traditional Spring	Flipped Spring	Flipped Fall
Individual Exams	31.5%	31.5%	31.5%
Group Exams	13.5%	13.5%	13.5%
Formative Homework	20%	10%	--
Summative Homework	15%	15%	25%
Class Engagement	5%	15%	15%
Online Quizzes	10%	10%	10%
Peer Evaluations	5%	5%	5%
Total	100%	100%	100%

Results

The data for each class element were normal and not skewed. Bivariate correlations were used to assess the relationship between continuous variables (see Table 1). For all sections, there were strong positive correlations between the points on the first three individual exams and the fourth group exam, the fourth individual exam, and homework. The homework was positively correlated with the fourth individual exam and online quizzes. Class engagement was positively correlated with the fourth individual exam, group exams 1-3, online quizzes, and homework. Online quizzes were positively correlated with individual exam 4. Peer evaluations were positively correlated with every course element. Finally, GPA was positively correlated with all course elements except the first three group exams and the fourth group exam. Generally, these results suggest that when students performed better on one class element (e.g., quizzes) they tended to perform better on other class elements (e.g., homework or individual exam 4).

Table 2: Correlations betweem Class Elements for All Four Sections

	Group Exam 4	Individual Exam 4	Group Exams 1-3	Individual Exams 1-3	Homework	Class Engagement	Online Quizzes	Peer Evaluations
Individual Exam 4	.01							
Group Exams 1-3	.09	.16						
Individual Exams 1-3	.30**	.36****	.19					
Homework	.16	.36****	.19	.25**				
Class Engagement	-.04	.26**	.23*	.16	.74****			
Online Quizzes	.17	.21*	.15	.17	.56****	.59****		
Peer Evaluations	.27**	.33***	.31***	.37****	.51****	.49****	.50****	
GPA	.10	.49****	.17	.46****	.46****	.35***	.40****	.40****

Note: *p<.05 ; **p<.01 ; ***p<.001 ; ****p<.0001

To determine whether the flipped classroom structure produced better student outcomes (e.g., higher grades) than the traditional classroom structure a series of ANCOVAs were conducted (results are shown in Table 3 and 4). GPA was used as a covariate because it was correlated with most class elements in Table 2. For significant main effects (refer to Table 3), Bonferroni pairwise comparisons were used. When variances were not equal (i.e., the homogeneity of variances test was failed), a type 1 sum of squares was used. There was a significant main effect for the points earned on the first three group exams [$F(3, 100) = 4.68$, $p < .01$, $\eta^2 = .12$], homework [$F(3, 100) = 5.20$, $p < .01$, $\eta^2 = .14$], class engagement [$F(3, 100) = 7.29$, $p < .001$, $\eta^2 = .18$], online quizzes [$F(3, 100) = 6.79$, $p < .001$, $\eta^2 = .17$], and total course points [$F(3, 100) =$

8.86, $p < .001$, $\eta^2 = .21$]. The effect sizes (partial eta squared) for the significant main effects were medium to large.[21] No other main effects were significant (refer to Table 4).

Bonferroni pairwise comparisons revealed that for the first three group exams, the flipped spring and fall section 1 obtained more points than the traditional section and the flipped fall section 2, but the traditional section and the flipped fall section 2 were not different. For the homework, class engagement, and online quizzes all flipped sections obtained more points than the traditional section, but the flipped sections were not different than each other. The traditional section obtained fewer total course points than the flipped fall sections 1 and 2; while, the flipped spring section's total course points were not different than any other section (see Table 3). No other pairwise comparisons were significant.

Table 3: Classroom Type Comparison of the Class Elements (Significant Effects)

	Traditional SP		Flipped SP		Flipped FA S1		Flipped FA S2				*Partial*
Measure	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*F*	*p*	η^2
Group Exams 1-3	82.3	1.23	84.9	1.24	84.6	1.06	80.0	0.95	4.68	.01	.12
Homework	870	31.4	1000	31.9	992	27.3	1020	24.4	5.20	.01	.14
Class Engagement	710	10.9	781	11.1	753	9.47	756	8.47	7.29	.001	.18
Online Quizzes	545	12.3	612	12.5	612	10.7	591	9.57	6.79	.001	.17
Total Course Points	2639	51.2	2790	52.0	2950	44.4	2920	346	8.86	.001	.21

Note: Variables in **bold** failed the test for homogeneity of variances and the type 1 sum of squares was used. GPA was used as a covariate. Mean (*M*) columns are estimated marginal means. For each row, different colors indicate a significant mean difference at $p < .05$. The same color or no color indicates no mean difference. For example, in the group exams 1-3 row, the traditional spring points were not different than the flipped fall section 2 points (indicated by green means). The flipped spring points were also not different than the flipped fall section 1 points (indicated by red means). However, the flipped spring and flipped fall section 1 had more group exam 1-3 points than either the traditional spring or the flipped fall section 2.

Table 4: Classroom Type Comparison of the Class Elements (Nonsignificant Effects)

	Traditional SP		Flipped SP		Flipped FA S1		Flipped FA S2				*Partial*
Measure	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*F*	*p*	η^2
Individual Exams1-3	176	2.93	173	2.97	181	2.54	180	2.27	1.80	.15	.05
Group Exam 4	27.0	0.70	26.6	0.71	27.6	0.61	26.8	0.54	.46	.71	.01
Individual Exam 4	49.2	2.35	47.5	2.38	49.7	2.04	43.9	1.82	1.83	.15	.05
Peer Evaluations	93.7	1.42	93.1	1.44	94.0	1.23	94.2	1.10	.14	.94	.004

Lessons Learned

Creating the videos and worksheets required more preparation time, but they can be re-used in subsequent semesters. The flipped section took approximately 2 to 3 hours of preparation for each 50-minute class period, but the course notes and many of the in-class exercises were adapted from previous semesters. An easy way to create the videos is to record the entire series of videos for the day, and then cut the video into 5- to 7-minute segments. For this study, the videos were screen captures created with Kaltura. Kaltura also has some basic video editing tools including trimming and chopping. During videos, students used guided notes,[5] or partially filled notes, provided at the beginning of each module. The guided notes created with the videos were posted, so that students could download their completed notes for class and/or homework.

To motivate students to watch the videos, the first day of class included a discussion on the benefits of watching the videos. Students also were required to take an online quiz which assessed the video's content. Furthermore, the in-class collaborative work encouraged students to at least look at the course material before coming to class.

The analytics in Kaltura specify how many times a user clicked play and the total number of minutes the videos were viewed which make the actual number of videos watched difficult to determine. In the spring, there were 107 videos for a total video length of ~9 hours. Around 30% of the students viewed all videos for more than the total video length (i.e. they watched some videos more than once). Around 20% of the class watched less than 30% of the total video length. The least amount of time a student watched the videos was just over 2 hours. However, the student who watched the fewest number of videos ended up with over 90% of the course points; whereas, a student who watched around 50% of the video length ended up with the lowest grade in the class. In the fall, the average viewing time was 6.4 hours with the total video length remaining approximately the same. In the fall, 17% of the students watched less than 30% of the total video time again with mixed performance. In this semester, the student who spent the least amount of time watching videos (14%) ended the course with an 81%; while, the student with the lowest grade in the class watched 27% of the total video length. The time spent watching videos was not always connected to a student's performance. However, correlations for the flipped classrooms revealed that as video view time increased so did the points on the individual final exam ($r = .24$, $p < .05$), homework ($r = .24=6$, $p < .05$), quizzes ($r = .28$, $p < .05$), and GPA ($r = .31$, $p < .01$).

When implementing a flipped classroom, it is recommended that the instructor be open and honest with the students about what they are doing and why they are doing it.[17] When first teaching a flipped class, it is useful to implement a feedback survey within the first few weeks of class. By modifying the class based on this survey (e.g., the time quizzes are due), the students have a voice in the class and are more willing to participate.[1] Beyond student buy-in, one of the hardest challenges for a flipped classroom design is creating in-class content that fits within the class period. However, adjustments can be made for subsequent semesters to remedy the problem.

Limitations and Future Research

With high final course grades (traditional spring = 82.67%, flipped spring = 88.96%, flipped fall section 1 = 95.28%, and flipped fall section 1 = 91.69%), it is possible that this study could have suffered from a ceiling effect. That is, there may be a larger difference between the flipped and traditional classrooms, but the measures used in this study were not sensitive enough to detect this difference. It is possible that the shorter homework assignments in the flipped classroom may have produced better performance than the longer homework assignments in the traditional classroom.

One may argue that homework and class engagement points can explain the total course point differences. However, when the points for homework and class engagement were removed from the total course points and analyses were re-run, GPA is no longer a significant covariate (meaning it did not explain the total course points), and the pattern of the results were similar to the ANCOVA reported above. The flipped fall section 1 obtained more total course points than the traditional spring section, and the flipped spring section obtained fewer points than flipped fall section 1 or 2. While this finding may suggest maturation, or the course improving over time, it does not suggest that the total point differences observed in this study can be explained by homework and class engagement points.

Additionally, it is possible that more students in the flipped classroom completed the online quizzes because they were required to watch videos before completing the online quizzes. Future research should examine student outcomes in a flipped space mechanics course while including more data from traditional classrooms. Further insights could also be gained from examining if class material is retained longer in a flipped classroom relative to a traditional classroom.

Conclusions

Flipped classroom research needs more studies with a control over an entire semester.[16] There is also a need for strong evidence to support the claim that the flipped classroom structure is more effective than the traditional classroom structure.[17] For two semesters, this study compared a control group (traditional classroom) to flipped classrooms taught by the same instructor. The flipped classrooms produced higher scores than the traditional classroom on the first three group exams, homework, online quizzes, class engagement, and most important - total course points. Regardless of semester, the flipped classrooms (spring = 88.96%, fall section 1 = 95.28%, and fall section 2 = 91.69%) consistently produced higher final course grades than the traditional classroom (82.67%). The increase in average class grade was statistically significant for fall sections and can account for a grade step. The grade differences in each classroom type (traditional and flipped) cannot be accounted for by GPA because the effects of GPA were held constant with the ANCOVA. Despite the quasi-experimental nature of this research (e.g., no random assignment), this study provides robust evidence that the flipped classroom structure is more effective than the traditional classroom, and if implemented in space mechanics courses, can enhance learning. Although it is not a panacea, the flipped classroom is an effective method to teach students.

Appendix

Class Engagement Worksheet for 1/27

1. If we know the semi-major axis, the eccentricity, and the true anomaly, how do we find the velocity? Share with your group.

2. Given the semi-major axis, and the eccentricity, find the angular momentum.

3. Let's say we are in a 400 km altitude orbit around the Earth with a velocity of 4 km/s. What is the semi-major axis?

4. If the spacecraft is descending and the eccentricity of the same orbit is 0.2, what is the true anomaly?

5. What is the flight path angle?

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