Assessment of Flipped Classroom in Upper-Level Engineering Course

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Abstract

While flipped classrooms have been of interest in the last several years and anecdotally seem to offer a better means of engaging millennial students through active learning, there has been a lack of rigorous assessment regarding the impact of the flipped methodology on student learning gains. In particular, there have been few studies that have objectively examined student performance throughout the semester with a control group for comparison. This study serves as a means to fill that gap by comparing both objective performance and student perception of the flipped classroom with a control group experiencing the same upper level undergraduate engineering course in a traditional lecture-based format over the course of an entire semester. The main research questions for this study include: 1) are short-term student learning gains improved when comparing flipped vs traditional lecture methods, 2) what aspects of the flipped classroom are contributing to the difference in learning gains?, and 3) how do students perceive their learning gains in flipped vs traditional lecture styles? Comparison of quiz and exam grades will be used to address student performance. Weekly student recordings of the amount of time spent on different aspects of the course, student confidence surveys regarding the learning objectives one week prior to the two exams, as well as teaching effectiveness surveys twice during the semester will be used to investigate student perception. The results from this study combined with the minimal available literature will be used to provide insight on what, if anything, about the flipped classroom methodology is improving student learning gains and how that can be leveraged to improve the experience of students in other undergraduate courses.

Introduction

Active learning, meaning any activity that engages students in the learning process, has long been promoted as more effective than traditional lectures with several studies showing gains in student learning outcomes (Prince 2004). With the perceived benefits of active learning, the next question may be, “How do engineering faculty incorporate active learning in the classroom given the constraints of time and the amount of material that needs to be covered?” One potential answer to this question is the flipped or inverted classroom. The flipped or inverted classroom can be defined as one where students obtain content from technology and apply that content with help from the instructor in class (Margulieux et al. 2014). The flipped classroom provides a means of enabling the same amount of material to be covered by having students first interact with the content outside of the classroom and then spend class time actively engaging with the material they were introduced to prior to attending class.

With this solution in mind, several studies have been undertaken to evaluate the effectiveness of the flipped classroom. The majority of these are focused on student perceptions, not objective student learning outcomes, and do not use control groups for comparison (Bishop and Verlager 2013). There are a handful of studies that have attempted to use control groups or objective performance metrics.

One such study focused on comparing a traditional versus flipped version of a thermodynamics course (Lemley et al. 2015). While the author lists several advantages to implementing the flipped classroom, quantitative results are not statistically significant and could be due to a number of factors. In particular, the traditional and flipped classrooms were implemented in adjacent semesters which means the qualitative and quantitative improvements seen when using the flipped pedagogy could be a result of the instructor's ability to communicate the course content with increased familiarity. The two flipped courses also only contained 15 and 24 students respectively and the author concluded that the ability to work with students individually and hold them individually accountable was an advantage for several reasons in a flipped classroom. While seemingly beneficial, the particular techniques used by this author are not feasible in many large undergraduate universities due to class sizes and limited resources in terms of teaching assistants. As indicated by Chetcuti et al. (2014), approximately 20 students is the limit for one instructor when students are doing individual work in a flipped classroom.

A study by Mason et al. (2013) that compared a flipped upper level undergraduate engineering course to a traditional course showed instructors are able to cover more content, students performed either the same or better on 10 out of the 18 quiz and exam problems, and felt class time was used more effectively in the flipped classroom.

Day and Foley (2006) used a web lecture intervention in an upper level human-computer interaction course where online lectures were used to preface and supplement the traditional classroom experience. This is the one of the only studies (Bishop & Verleger 2013) that has examined student performance throughout a semester and compared it to a concurrent control section where they tried to ensure all topics, assignments, and time on tasks were the same. While this study showed improved student performance on all tasks in the flipped section, they did not provide enough results or methodology that was adaptable or generalizable to other courses.

The lack of semester long studies comparing both flipped and traditional pedagogy techniques and the need to further identify what about the flipped methodology is effective is the primary motivation for this study. While improved objective student performance is desired from any pedagogy change, there is also the hope of engaging students in higher order levels of Bloom's Taxonomy with the shift from lecturing to active learning during class time using flipped methods.

Research Design

Research Questions

This study is grounded in constructivist theory (Siemens 2005) and is a design experiment (Cobb et al. 2003) with the objective of determining if and how flipped classrooms help students learn and what attributes can and should be adopted in future course designs. In particular, this study aims to further understand the following: (1) Are short-term student learning gains improved when comparing flipped vs traditional lecture methods, 2) What aspects of the flipped classroom are contributing to the difference in learning gains?, and 3) How do students perceive their learning gains in flipped vs traditional lecture styles?

Course & Participants

The modified course is a senior level undergraduate elective at California State University, Sacramento that focuses on the design of steel structures for civil engineering majors. This course meets twice a week for 75 minutes and has 29 meetings over the 15 week semester. One class period is spent on the midterm exam and another 2 hour time period beyond the 15 week semester is spent on the final exam. The course covers content regarding the analysis and design of tension members, compression members, beams, beam-columns, and connections in steel structures. Students in both sections engage in an open-ended service learning project, complete nine in-class conceptual quizzes, are provided with suggested homework problem sets and solutions (not graded), and have access to examples with solutions for each topic.

Enrollment information for the two sections, treatment and control, both taught by the same instructor is listed in Table 1. While ethnicity data is not directly available, the university is a Hispanic-Serving Institution (27% of undergraduate student body) as well as an Asian-Pacific Islander-Serving Institution (21% of the undergraduate student body) with more than 50% of the students enrolled in the civil engineering department being minorities. For students declared as civil engineering majors as of Spring 2016, 51% are from low income families, 32.5% are first generation students, and 93.1% commute to campus.

While the students were not randomly selected, they did register for the different sections of the course prior to knowing that each section was going to be taught differently. To compare the performance of each section in this particular course, it is necessary to determine whether or not the two sections had significantly different past performance (based on average GPAs) when the course began. The control section's GPA was slightly higher as seen in Table 3, but the difference was not statistically significant based on a two-tailed t-test assuming unequal variances (source of p-values throughout unless otherwise noted).

Table 1: Demographics for Students in Steel Design I in Fall 2016

	Treatment Section	***Control Section***	***Total***	***Percent***
Female	11	11	22	25.9
Male	40	23	63	74.1
Total	51	34	85	

Test Section

The flipped classroom setup consists of students watching a 5 to 15 minute video of content prior to attending lecture. The videos were created by the instructor using Camtasia to record audio, highlighting, and additional images over Microsoft Powerpoint note slides. Students were given versions of the Powerpoint notes with missing information to fill in as they watched the video. The videos were hosted on the website Edpuzzle which tracked each students' progress in the video as well as the number of times each student watched various sections of the video. To encourage student engagement with the content and verify that they had watched the video in preparation for each class, each video contained anywhere from 1 to 12 questions that were either free response or multiple choice. The Bloom's Taxonomy level of these questions ranged from remember to evaluate. The percentage of students who watched the videos and answered all video questions ranged from 84 – 96% depending on the video. On average 92% of the class watched the video prior to coming to class and over the course of the semester, the average number of times each video was viewed per student ranged from 1.24 to 2.90 times.

Control Section

The control section is taught in a similar manner to past offerings of the course in a traditional lecture format. To accommodate the new addition of quizzes during class time, students are provided with partially blank lecture note handouts similar to those provided to students in the treatment section to reduce time spent copying material from the board. Due to time constraints, fewer examples are covered during lecture, but the control section has access to all examples and solutions through the course online platform that are worked on during lecture by the treatment section.

Limitations

While control and treatment sections were provided with the same content in different formats, there were some outside influences that were unable to be completely eliminated. The control section consisted of 34 students and was taught on Tuesday/Thursday at 9 AM in a classroom with 37 desks all facing towards the whiteboard. The treatment section consisted of 51 students and was taught on Monday/Wednesday at 7:30 AM with ten seats grouped around tables with half the class having their back to the main whiteboard. While the tables were conducive to letting students engage in individual and group problem-solving, they were not ideally set up for discussing the examples and solutions as a class.

There were many late arrivals and absences in the 7:30 AM course compared with the 9 AM course as shown in Table 2 below. This severely impacted quiz performance (since quizzes were given in the first 10 to 15 minutes). While scores of zero for students who did not take the quiz were not included in the average quiz score for each section, quiz scores from those who had less than the allotted time to complete the quiz were included. This tardiness issue was also prevalent for the midterm and final exams for the treatment section with several students arriving late and one student not even attending the final exam.

Table 2: Reported Average Weekly Attendance over 15 Weeks

	Treatment Section	*Control Section*
I attended 2 full lectures	*72%*	*85%*
I attended 2 lectures, but I arrived late to one of them	10%	5%
I attended 2 lectures, but I arrived late to both of them	2%	0%
I attended 1 full lecture	14%	9%
I attended 1 lecture, but I arrived late	1%	0%
I did not attend lecture this week	2%	1%

Students were free to communicate with students in the other section and may have even studied together for exams. While videos were locked down and only viewable to students in the treatment section through registered accounts, students in the control section could have gained access to them by viewing the videos with a student in the treatment section or using their log in credentials. The extent to which students communicated or enabled access to the lecture videos to control section students is unknown, but seems minimal in terms of video viewing given the hours at which videos were viewed and the fact that many students only viewed each video once.

Results

Are short-term student learning gains improved when comparing flipped vs traditional lecture methods?

The difference between the control and treatment section was only statistically significant on one quiz where the flipped classroom performed better on average. As seen in Table 3, the control section actually did better on average on every other assignment aside from the project, just not to a statistically significant degree. This would indicate that objectively, students perform to similar standards regardless of whether or not they experience the flipped classroom or the traditional lecture method. This is consistent with other reported findings by Papadopoulos & Roman (2010), Mason et al. (2013), and Bishop (2013).

Table 3: Performance for Students in Steel Design I in Fall 2016

	Treatment Section		***Control Section***	
	Average	**Std. Dev.**	**Average**	**Std. Dev.**
GPA	2.91	0.42	2.98	0.41
Quiz 1	16.1	2.88	16.9	2.77
Quiz 2	17.3	1.72	18.2	1.41
Quiz 3	17.5	2.71	17.8	1.60
Quiz 4	16.4	2.71	16.2	4.35
Quiz 5	14.8	2.81	16.0	2.48
Quiz 6	16.6	2.81	17.2	1.30
*****Quiz 7***	16.8	1.59	14.3	3.69
Quiz 8	17.0	2.09	17.1	3.40
Quiz 9rip	18.0	1.17	18.9	1.38
Midterm	72.0	12.7	73.0	13.5

Final	69.7	12.9	71.3	14.0
Project	90.3	6.02	90.0	5.55
Overall Grade	80.4	7.00	81.0	7.06

**Significance, two tailed: p<0.05, **p<0.01, ***p<0.001;*

One criticism of studies that quantitatively show increased performance for students experiencing a flipped methodology is that performance gains could simply be attributed to more time spent on with the material. To address this issue, students recorded the amount of time they spent on various activities for the course per week. As seen in Table 4, while the treatment section reported spending slightly more time on average on class prep (2.71 hours versus 2.39 hours), they spent less time on every other activity. The difference in the amount of time spent by each section on each activity was not statistically significant, however the average amount of time spent per week on the course was significantly lower for the flipped classroom.

Table 4: Number of Hours Spent on Different Class Activities

	Treatment Section		***Control Section***	
	Average	**Std. Dev.**	**Average**	**Std. Dev.**
Suggested Problems	2.62	1.94	3.10	2.21
Class Prep	2.71	1.44	2.39	1.67
Quiz Prep	2.44	1.51	2.88	1.85
Exam Prep	3.04	2.87	3.40	2.93
Office Hours	1.23	0.92	1.32	0.76
General	3.83	2.73	4.19	2.85

**Significance, two tailed: p<0.05, **p<0.01, ***p<0.001;*

What aspects of the flipped classroom are contributing to the difference in learning gains?

As part of their weekly time record, students were also asked what aspect of the course was and was not helpful. The top three aspects that were listed each week as helping students learn the course content were the in-class examples, working through suggested problems (homework), and notes from the lecture (control section)/video (treatment section). As shown in Figure 1, on average, half the class listed in-class examples as a helpful activity in both the control and treatment sections. The control section found the additional suggested problems more helpful than the treatment section while the treatment section found the lecture notes and videos more helpful. As topics became more difficult over the course of the semester, the control section found the suggested problems less helpful while the treatment section found the suggested problems consistently helpful throughout the semester. Of interest is the fact that students evenly attributed their learning of the material to the videos and in-class examples in the treatment section, while the control section indicated that the majority of their learning came from the in-class examples.

Despite statistically performing the same as the control section, the only aspect of the course that the treatment section spent more time on was preparing for class as seen in Table 4. This is consistent with the students weekly records that show students in the treatment section felt the

initial introduction from the video and subsequent in-class problem solving was the most beneficial in improving their understanding while students in the control section were first introduced to the content through problems in class and felt the need to spend more time on and claimed more benefit from the suggested problems.

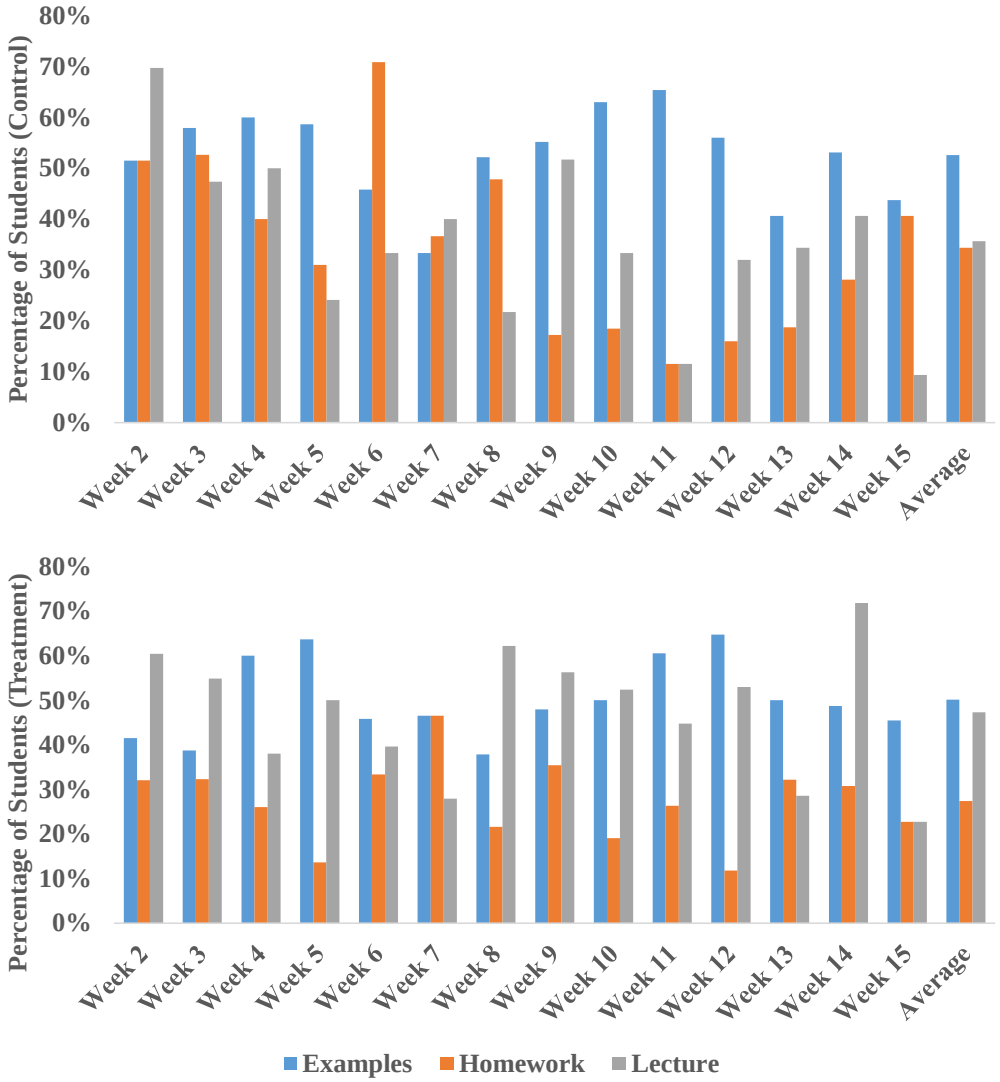

Figure 1: Helpful aspects of the course reported by students weekly

One anecdotal benefit of flipped classrooms and a positive aspect pointed out by students in several studies is the ability to watch lecture material multiple times and at their own pace (Velegol et al. 2015, Day and Foley 2006). While many students did watch segments of the videos or the entire video multiple times (on average each video was viewed 1.24 to 2.90 times), there does not seem to be any positive correlation between the number of times a student viewed the lecture and the overall grade. The student in Figure 2 who viewed the videos more than once on average but did not pass the course (overall grade 0.67 and an average of 3.29 views per video) is also one that seldom attended lecture (attended less than 20% of class meetings including exams) to receive the benefits of active problem-solving. The benefits of active learning in the classroom are made apparent by the fact that this individual achieved an average

of 82.5% on the quizzes they took (which were conceptual) and failed both the midterm and final exams (which required problem solving) with scores of 66% and 61% respectively.

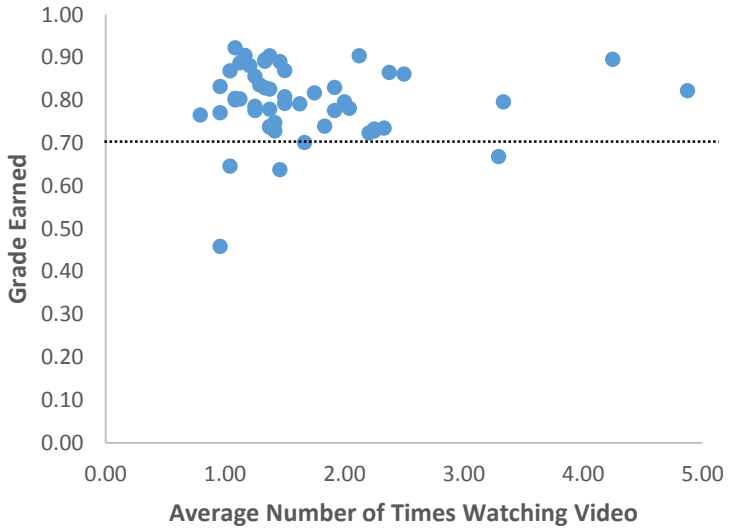

Figure 2: Relationship between overall grade for treatment section students and the average views per video

Identifying aspects that were not helpful varied more and included items such as working in groups, missing lectures, and difficulty with using the Steel Manual or handouts in class.

At the end of each video for the treatment section, there was a question that asked, "Do you have any questions you'd like me to answer at the start of class regarding the topics in this video (or anything else course related)?" This sort of question was also asked multiple times during the control section lecture as well. Qualitatively comparing typical question stems from the two sections, there were many more questions from the treatment section where students asked questions to analyze or evaluate the information that had been provided in the video. Many of these questions were then proposed to the class at large during the next class period to engage them in a discussion to try to critically think about their peer's question and arrive at one or more possible solution. This sort of discourse was infrequent, if not, nonexistent in the control section. One possible reason is students in the control section did not have time to absorb the material enough during lecture to produce these higher level questions and in turn there was not time to have students contemplate this type of question from one of their peers if it was asked.

How do students perceive their learning gains in flipped vs traditional lecture styles?

Students completed surveys during the week preceding the midterm and final rating their confidence on the topics covered. The results from the midterm survey are shown below in Table 5. For the midterm, students in the treatment section were more confident on average than students in the control section for 8 of the 10 topics they rated themselves on. Of the 40 topics that students rated their confidence on for the final, students in the flipped classroom were more confident on average for 22 of the topics. The first 10 topics that students rated their confidence

on for the midterm and final were the same. By the time of the final, students in the treatment section were more confident on average than students in the control section for only 6 of the 10 topics. The difference in confidence was not statistically significant for any of the topics.

Table 5: Pre-Midterm survey results indicating confidence levels of student (responses range from 1 = not too confident to 5 = extremely confident).

Question *Indicate your confidence in your ability to...*	*Treatment Section*		*Control Section*	
	Average (Midterm)	**Std. Dev (Midterm)**	**Average (Midterm)**	**Average (Final)**
Calculate factored loads using LRFD load combinations	3.52	0.85	3.88	0.93
Determine the strength of a tension member considering the Gross Section Yielding limit state	3.70	0.88	3.65	0.79
Determine the strength of a tension member considering the Net Section Fracture limit stat	3.48	0.85	3.35	0.93
Determine the strength of a tension member considering the Block Shear Failure limit state	2.70	1.06	3.18	0.88
Analyze tension members considering all limit states	2.91	0.90	2.88	1.05
Design a tension member	2.70	1.06	2.47	0.94
Determine the strength of a compression member considering the flexural buckling limit state	2.13	1.18	2.12	1.05
Calculate effective length factors for members in frames	2.39	1.12	2.06	0.97
Determine the strength of a compression member considering local buckling	2.17	1.19	1.71	0.85
Analyze compression members considering all limit states	2.04	1.19	1.76	0.75

**Significance, two tailed: p<0.05, **p<0.01, ***p<0.001;*

As part of the survey students were also asked what grade they expected to earn on the exam. Out of a traditional 4.0 scale, the treatment section estimated an average grade of 2.74 (approximately a B-) while the control section estimated earning a 3.12 (between a B and B+) on average for the midterm. Despite being less confident in their abilities, the control section had higher, and ultimately less realistic, grade expectations than the treatment section as both class averages were on the lower cusp of a B-. For the final exam, the treatment section estimated an average grade of 2.24 (Between a C and C+) while the control section estimated earning a 2.67 (approximately a B-) on average.

Students also completed a survey 8 weeks into the semester and another one at the end of 15 weeks. The questions on this survey were adopted from Tripod Surveys for grade levels 6-12 which have been developed and refined over the past decade and are considered reliable and valid measures of teaching effectiveness (Ferguson 2010). The results from the midterm and final surveys are shown in Table 6.

Many studies that investigate flipped classrooms indicate that students initially struggle with taking control of their own learning, but eventually come around to having to prepare for class and in some cases even show a preference for the flipped methodology (Velegol et al. 2015). Students in the flipped classroom of this study reported higher levels of not liking how they

learned in the flipped classroom, less interest in the course as the semester went on, and felt they had less control over how activities were done in the classroom compared to students in the traditional classroom. This is counterintuitive considering the main purpose of flipping the classroom is to increase engagement and interest in the material through active learning during traditional lecture time.

Table 6: Tripod Survey results indicating teaching effectiveness (responses range from 1 = totally untrue to 5 = totally true).

Question	*Treatment Section*		*Control Section*	
	Average (Midterm)	**Average (Final)**	**Average (Midterm)**	**Average (Final)**
My professor in this class makes me feel that she really cares about me.	4.51	4.36	4.71	4.62
My professor really tries to understand how students feel about things.	4.51	4.25	4.58	4.62
My professor seems to know if something is bothering me.	3.53	3.50	3.48	3.97
In this class, my teacher accepts nothing less than our full effort.	4.09	3.93	4.13	4.41
My professor asks questions to be sure we are following along when she is teaching.	4.85	4.43	4.68	4.79
My professor wants me to explain my answers – why I think what I think.	4.36	4.20	4.32	4.32
My classmates behave the way my teacher wants them to.	4.00	4.07	4.23	4.38
Our class stays busy and does not waste time.	4.68	4.52	4.90	4.79
When she is teaching us, my professor thinks we understand even when we don't.	2.74	2.86	2.48	3.38
If you don't understand something, my professor explains it another way.	4.28	4.07	4.52	4.53
My professor knows when the class understands, and when we do not.	3.98	3.64	4.10	4.12
I like the ways we learn in this class.	4.26	3.70	4.55	4.47
This class does not keep my attention – I get bored.	2.15	2.57	1.58	2.53
My professor makes lessons interesting.	4.04	3.77	4.19	4.29
Students get to decide how activities are done in this class.	2.66	3.02	2.74	3.24
My professor wants us to share our thoughts.	4.36	4.36	4.19	4.35
Students speak up and share their ideas about class work.	3.62	3.64	3.97	4.24
In this class, we learn a lot almost every class.	4.60	4.43	4.68	4.71
My professor takes the time to summarize what we learn each class.	4.17	4.14	4.19	4.47
The comments that I get on my work in this course help me understand how to improve.	4.51	4.41	4.61	4.53

**Significance, two tailed: p<0.05, **p<0.01, ***p<0.001;*

Conclusion

It is clear from this study that flipping the classroom does not necessarily correlate to improved student performance. Neither class performed better or worse than the other in a statistically significant manner other than one quiz in favor of the flipped methodology. One interesting result from this study is that students reported spending less time per week with the material in the flipped classroom and performed statistically the same as the traditional classroom. The major aspect of flipped methodology that enabled students to spend less time on the course with similar performance can likely be attributed to the pre-lecture introduction to the material. From instructor observation, as long as this pre-lecture activity was completed, students were able to more actively engage with the material when the instructor was there to support their first attempt at solving problems with the new content. Despite being provided with the same content and same problems, students in the control section struggled more during in-class examples and failed to ask insightful questions to better understand the course content and how it could extend to other problems. Students in the treatment section reported not needing to spend as much time outside of the classroom on additional problems to achieve the same level of problem-solving mastery as the control section.

Students from the flipped classroom on average reported higher confidence levels, had more realistic expectations of their performance on exams, and asked and answered higher level Bloom's Taxonomy questions. However, they reported being less satisfied with how they were learning, how much control they felt they had in the activities that occurred in class, and objectively performed the same as those in a traditional lecture course on quizzes and exams. Part of this could be attributed to the attendance issues and large class size that prevented enough one-on-one interaction with the instructor that has been touted as the most beneficial aspect of the flipped methodology in previous studies. While this study shows that the flipped methodology does not necessarily objectively improve student performance, it does indicate the potential for several notable benefits including more student engagement during in-class problem solving activities and more time in class to spend discussing topics in-depth or adding additional topics as shown by the shift in the types of questions students were able to ask about the material. Further exploration to quantify the number and types of questions based on Bloom's Taxonomy that students ask should be undertaken to determine if there is a significant difference in a flipped classroom.

Additional studies into the effectiveness of flipped classroom methodology will need to address the issues of student to instructor ratio and whether or not the technology aspect of the methodology (free streaming pre-lecture videos) used in this particular study is effective for students from a wide variety of backgrounds, particularly those who are economically disadvantaged and may not have easy access to technology or the time to spend preparing for class due to other obligations such as work.

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