

Flipping Calculus for Engineering Students: Pre-class Assignments and Readiness Assessment Strategies

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1. Introduction

In the last ten or so years there has been a great deal of attention and interest in the flipped classroom model of instruction, with early discussions starting at least as early as 2000¹. The buzz around flipped classrooms has likely been fueled by the attention it has received in popular media, such as the U.S. News and World Report article in 2014 extolling the virtues of the flipped classroom model to strengthen STEM students' learning². A recent survey by Campus Technology found that 55 percent of the faculty they surveyed (~500) were flipping either some or all of their classes³. The popularity of the flipped classroom has led to the establishment of the Flipped Learning Network (flippedlearning.org), and the recently published Best Practices For Flipping The College Classroom⁴. In spite of the attention and interest, the flipped classroom model is still not clearly defined, and its virtues are often based on anecdotal evidence and student survey results¹. Though small, there is a growing body of scholarship on flipped classroom model.

The basic approach of the flipped classroom model is easy to understand and communicate: in a flipped class – what students traditionally do inside the classroom they do outside the classroom and what students traditionally do outside the classroom they do inside the classroom⁵.

However, there remain inconsistencies in what various publications consider to be a flipped class. In fact, many of the papers on flipped classrooms fail to provide significant details about the in-class activities that make up the flipped class. Often those same papers rely on student surveys to evaluate the impact of the flipped class. The flipped classroom model of instruction is generally viewed as having positive impacts on student learning, even though very few studies have rigorously compared flipped versus traditional classrooms using objective measures of learning. Interestingly, two reviews of the literature^{6,7} both identified that improvements from flipped classrooms may result from the active learning techniques that usually accompany a flipped class. There is significant scholarship to support that active learning does increase student performance^{8,9}.

A number of studies specifically focus on flipping college mathematics classes. Sahin, Cavalazoglu, and Zeytuncu¹⁰ flipped three out of the ten content sections in a college calculus course. They found a statistically significant difference on quiz scores between the flipped and non-flipped sections, with quiz scores for the flipped sections being higher. They also found strong student preference for video rather than reading assignments in preparing for the flipped classes. Talbert¹¹ provides substantial details about how a first semester calculus course was flipped. Talbert found that over 90% of the students completed the pre-class assignments and Talbert also reported that an Entry Quiz average for the class between 73% and 78% indicated that students were moderately successful at achieving a basic understanding of course content independently. Tague and Baker¹² briefly describe their implementation of a flipped differential

equation class. Evaluation of the flipped class included only student. In the surveys students reported that the pre-class material related to the in-class materials. Lape et al.¹³ found no significant differences in measures of student achievement in a flipped Introduction to Differential Equations course.

In these and other studies it appears, though it is not often explicitly stated, that this was the first time the class had been taught using a flipped class approach, and often the first time the instructor had used a flipped classroom design. It could be argued that instructor's first flipped class is at a greater disadvantage than their first traditionally taught class because instructors typically have significant past experience as students in traditionally taught courses but little or no experience as students in flipped classes. This does not in any way discount the importance of these and other studies on flipped classes, only that an instructor's prior experience (or lack of) with the flipped class model of instruction is a factor that should be taken into consideration. Mostly, it identifies the need for more scholarly publications that discuss both the details of discipline specific flipped class implementations and changes or adjustments an instructor made based on initial efforts and observations.

This paper discusses how one instructor applied the flipped classroom model to mathematics classes taken by engineering students at a large research institution, located in the Southeast. The classes were offered over the course of three semesters. The first class roughly corresponds to calculus II, from this point forward referred to as CALC-II-1T (for calculus II first time). The next semester, the instructor taught a course roughly corresponding to calculus III; call this course CALC-III. In the following (third) semester, the instructor taught the same calculus II course, call this course CALC-II-2T (for calculus II second time). Section 2 describes the flipped or inverted classroom model of instruction in more detail. Section 3 presents and discusses implementation details for each class. Some preliminary analysis of data from the courses is presented and discussed in section 4. Conclusions are discussed in section 5.

2. The flipped classroom model of instruction

Descriptions of the flipped classroom model of instruction are many and varied^{6,7,11,14}. These misconceptions have arisen from the many and varied descriptions of flipped classes that exist in the literature. The flipped learning network provides a definition of flipped learning in an attempt to counter misconceptions about flipped classes.

“Flipped learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter.”

-- Flipped Learning Network (<http://flippedlearning.org/definition-of-flipped-learning/>)

Recognizing that the flipped classroom model is an instructional design model, juxtaposing it with a more traditional instructional design model is useful in understanding the flipped

classroom. In a traditional instructional design model, the one familiar to most of us, there are three phases in the instructional design for a given unit. 1) select the concepts (and write learning objectives), 2) use class time to present information on the main topics and concepts, and 3) have students work outside of class on activities intended to bring about mastery of the content (learning objectives)¹¹. An alternative approach to the traditional model might be: 1) select the concepts (and write learning objectives), 2) give students structured out-of-class assignments where they initially encounter the concepts and topics on their own, and 3) use class time to have students work on activities during class that assess their basic knowledge and assimilate the concepts and topics by constructing their own knowledge of the topic¹¹. In this alternative, items 2 and 3 from the traditional model have been switched or flipped, hence the name flipped classroom.

This alternative or flipped approach is attractive because students are in the classroom with subject matter experts when they are wrestling with mastery of the topics rather than hearing about them for the first time. Some definitions of flipped classroom are explicit about the use of technology for implementation of phase 2 (give students structured out of class assignments where they initially encounter the concepts and topics on their own)¹⁴. While technology for content delivery is not a prerequisite for flipped classes, in practice it has been information technology that has driven exploration of flipped classes, with Kahn Academy style videos and pod casts making creation and delivery of video or interactive multi-media content cheap and easy to make and distribute. The myriad of technologies that can be used to deliver content probably makes the flipped classroom attractive to instructors, and many times it is this aspect that gets the most attention from instructors and in the literature. While the use of technology to deliver content is both interesting and powerful, it is that classroom time, now freed up from lecture-based encounters with basic concepts and content, that has the greatest potential to transform how students learn in a given class.

3. Flipped CALC-II and CALC-III Implementation Details

3.1 Classrooms and Contact hours

Flipped classes are undoubtedly taught in a variety of different physical spaces, however, many of the articles describing flipped classroom studies make almost no mention of the physical classroom space^{7,10,11,14}. All of the classes, CALC-II-1T, CALC-III, and CALC-II-2T met in an active learning classrooms (ACL)¹⁵ at least three days a week. Active learning classrooms typically feature tables with monitors or screens that students can use when they work in small groups. Often there are personal white board and lots of white board space on the walls for students to use as well.

CALC-II and CALC-III are 4 credit hour classes, which meet five days a week. There were two sections of CALC-II-1T, CALC-III, and CALC-II-2T. Sections meet for 50 minutes on Monday, Wednesday, and Friday, and both sections met together on Tuesdays and Thursdays. The Monday, Wednesday, Friday classes met in an active learning classroom that seats 50

persons. On Tuesday and Thursday the classes met in a standard lecture hall classroom, and exams were always administered on either Tuesday or Thursday. Some Tuesday and Thursday class meetings of CALC-II-2T meet in a new ALC on campus. 59% of the students in CALC-II-1T also took CALC-III.

3.2 The Flipped Class Redesign Plan

After reviewing literature on flipped classes, specifically Talbert¹⁶ and Bishop and Verleger¹⁴ the instructor set about developing a flipped classroom redesign plan for CALC-II and CALC-III. Content and learning objectives already existed for these courses and were familiar to instructor. What remained was to establish a structure for the courses that followed the flipped class model. Content was divided into units, and each unit was further divided into lessons. The lesson then became the instructional unit for these courses. Each unit lesson (UL) was intended to prepare students for a single class meeting. During class, students would participate in class activities designed to engage them further and deeper with the material in the lesson assigned for that day. Class activities would be small-group problem solving activities. The homework problems used in the traditionally taught class would be the starting point for developing the class activities. All the course components and a brief description are in table 1. In planning each course, the instructor spread days with no assigned lesson across the semester, providing time and opportunity to address situations when the class clearly needed additional work on a lesson topic. Table 2 shows the number of units and number of lessons for each of the three courses. A web-based, online, multi-media content system provide by the textbook publisher was used to assign lessons and homework. The system provides algorithmically generated questions with the ability to score those questions automatically even when answers are mathematical expressions.

Students were assigned a score for each course component and a weighted sum determined their class weighted average, which in-turn was the basis for the course grade. These weights are shown in Table 1. The 10% weight for class activities (CA) is due the instructor's concern that students might easily dismiss the importance of attending class since "traditional" class materials were available on-line. By including both UL and CA in the weighted average students were motivated to complete these activities. That also required a finding a way to score these items. The development of ULs and CAs and methods for scoring them were the focus of the flipped class development for CACL-III1T, CALC-III, and CALC-II-2T. Section 3.3 discusses the unit lessons and the class activities in detail for CALC-II-1T. Section 3.4 and 3.5 describe relevant changes made in CALC-III and CALC-II-2T.

Table 1. Flipped class course components, their description, and the weight assigned to each component.

Course Component	Description	Weight		
		CALC-II-1T	CALC-III	CALC-II2T
Semester Exams	Closed notes, closed book, and without a calculator pencil-and-paper semester exams were administered throughout each course.	25%	25%	25%
Final Exam	Cumulative final exam that follows the same format as the semester exams, twice as long.	60%	60%	60%
Unit Lessons (UL)	Pre-class work designed to be completed by students before coming to class. Each lesson includes multimedia content and practice exercises. Multimedia content includes links to the etext book, publisher provided video content, and instructor created video content	5%	3%	3%
Class Activities (CA)	Cooperative learning and structured problem solving activities designed to engage students with the lesson material.	10%	10%	10%
Homework (HWK)	Practice problems to be completed after class.	-	2%	2%

Table 2. Number of units and lessons for CALC-II-1T, CALC-III, CACL-II-2T.

Course	Units	Lessons per Unit	Total Number of lessons	Number of Semester Exams
CALC-II-1T	13	3	39	13
CALC-III	6	3 to 9	33	6
CALC-II-2t	13	3	39	7

3.3 CALC-II-1T Implementation details

The goal for each unit lesson (UL) was for students to gain initial fluency with the lesson content. Pragmatically speaking, each lesson took the place of an in class lecture. The primary element of each lesson was a video lecture. Most of the lesson lecture videos were created by the instructor using Microsoft OneNote™ and screen capture software. Lesson lectures were stored as MP4 files on a web server and students were provided a link to the lesson video in the lesson assignment. In addition to the lesson lecture, lesson assignments include publisher provided multimedia content and practice problems. Each lesson contained between seven and twenty-five practice problems. The problems were selected by distributing the homework questions traditionally assigned for a given unit across the lesson assignments. Each lesson had a due date, this allowed students to know what lessons would be the focus of a given days class activities. Students were told by the instructor to first read the etext section and watch the videos and then attempt some or all of the practice problems before class. Students were allowed, and encouraged, to continue to work problems in the lesson assignments and no scoring penalty was applied for late work. Each media assignment was worth one point, and each practice exercise was worth one point. The lesson assignment for Unit 4 Lesson 1 is shown in figure 1. The first item, Unit 4: Prepared Lecture Notes is a link to the instructor created lesson video. The next item is a links to the publisher etext section related to the lesson material and following that is a link to the publisher provided video for the etext section above. To receive credit for those items students only had to open the item link. The remaining numbered items are practice problems.

For the class activity (CA) part of the class, students worked together with other people in the class as part of team or group. Teams were pseudo-randomly assigned at the beginning of each class meeting by shuffling cups with the student's names on them and then clustering the cups on tables in the active learning classroom. Student worked on problems that the instructor selected, primarily from the set of homework problems typically assigned in a traditionally lecture-based course. Students worked in groups and the instructor visited the student groups to check in with students. If a misconception or question came up in more than one group, the instructor would get the classes attention re-state the question and then give a short mini-lecture style answer to the entire class. The instructor also gradually revealed solutions to the problems as the class worked, usually not revealing a solution until most of the groups were done or nearly done. After class, the instructor shared their notes from class with the entire class. The selected problems for the Unit 4 Lesson 2 Class Activity are shown in figure 2.

View Question Details



Unit	4
Assignment name	Unit 4 Lesson 1
Chapter coverage	12
Displays with chapters	12
Total points	21
Estimated time:	27m 24s+
Metrics-based assignment difficulty	Easy (0), Moderate (5), Hard (8), Very Ha
History ID	92692_H_317335377_2

Link to instructor created video

Link to appropriate section of the etext

Link to publisher provided video content.

#	Question ID / Media	Objective / Book Association	Estimated time	Numeric Answer Tolerance	Credit for Unsimplified Answers	Tries within Each Question	Student to show work	# Points
	Unit 4 Prepared Lecture Notes 12.3: Natural Logarithms							1
	7.2 Natural Logarithms 12.3: Natural Logarithms							1
	Lecture: Derivative and Integral forms 12.3: Natural Logarithms							1
↓ 1	12.3.1	Use the properties of logarithms.	2m 51s				No	1
2	+ (12.3) [102]-U04-B02A	none specified					No	1
↓ 3	12.3.3	Use the properties of logarithms.	2m 3s				No	1
↓ 4	12.3.9	Find derivatives of logarithmic functions.	1m 25s				No	1
↓ 5	12.3.13	Find derivatives of logarithmic functions.	48s				No	1
6	+ (12.3) [102]-U04-B03A	Find derivatives of logarithmic functions.					No	1
7	12.3.15	Find derivatives of logarithmic functions.	1m 46s				No	1
8	12.3.21	Find derivatives of logarithmic functions.	2m 13s				No	1
9	12.3.23	Find derivatives of logarithmic functions.	1m 23s				No	1
10	+ (12.2) [102]-U04-B04	Evaluate integrals.					No	1
11	12.4.93	Find integrals of exponential functions.					No	1
12	12.3.65	Use logarithmic differentiation.	3m 36s				No	1
13	12.4.93	Find integrals of exponential functions.					No	1
14	12.3.39	Evaluate integrals.	1m 37s				No	1
↓ 15	12.3.41	Evaluate integrals.	2m 41s				No	1
↓ 16	12.3.45	Evaluate integrals.	1m 22s				No	1
↓ 17	12.3.51	Evaluate integrals.	3m 20s				No	1
↓ 18	12.2.85	Evaluate integrals.	2m 19s				No	1

Figure 1. Unit 4 Lesson 1 assignment for CACL-II-1T

Solve $e^{\sqrt{t}} = x^5$ for t
Find the derivative of y with respect to x for $y = e^{(6\sqrt{x}-8x^2)}$
Find $\frac{dy}{dx}$ given $e^x - 8 \ln x = \cot(y)$
Solve the equation $\ln e - 7 * 2^{-2\log_2 x} = \frac{4}{x} \log_{12} 1728$
Evaluate the integral: $\int 18^{t^8} e^{-t^9} dt$

Figure 2. CALC-II-1T Unit 4 Lesson 2 class activity problems.

Scoring for the class activities was largely participatory, as long as students came reasonably prepared and were not observed off-task, then they got full credit for that days class activities. The level of preparation for class was measured by the current score for each student on the unit lesson assignment for that day. Since students could continue to work after class on the lesson assignments, a perfect score of 100% was not required. In fact, students were told that they should watch or read the multimedia material in each lesson thoroughly, then attempt as many questions as they could. It was made clear that students did not need to score 100% before coming to class, but that 10% was not an acceptable score. In the hour before the class met, the instructor ran a report in the online system to see all the students' scores for the current lesson assignment, sorted in descending order. Based on this the instructor decide on a minimal score that was needed to get full credit for that days class activity score. Table 3 shows how class activity (CA) scores were assigned. The instructor selected this scoring approach because they felt coming to class was important and they wanted to encourage students to do so, even if they did not prepare for class that day. The minimum threshold score varied greatly from day to day. At the end of the semester the lowest five class activities scores were dropped before computing the class activity score for final grade calculation.

Table 3. Class Activity Scoring for CALC-II-1T.

Description	Class Activity (CA) score
Students attending class with a corresponding unit lesson score above the instructor defined minimal score for that day's lesson.	100%
Students attending class with a corresponding unit lesson score below the instructor defined minimal score for that day's lesson.	80%
Students attending class with a zero or no score on the corresponding unit lesson score for that day's lesson.	60%
Students who did not attend class on that given day	0%

3.4 CALC-III

Three important changes were made in the flipped CALC-III course based on the instructor's observations and evaluation of the CALC-II-1T course: 1) changes to the lesson assignments problems and scoring regime were made, 2) skeleton notes to accompany lesson lecture videos were provided, and 3) readiness assessment tests (RATs) were added.

In CALC-II-1T the instructor noticed that students appeared to struggle with the overlap between Unit Lesson practice problems and class activity problems. The initial thought had been that students would be able to successfully work a few practice problems before class as part of the lesson preparation. During class, students would work additional problems, all of which were also in the unit lesson assignment. After class they could return to the unit lesson assignment, with the knowledge and ability to work many of these problems relatively quickly, and then spend time with the problems that were not worked during class. Instead students seemed not to connect the problems worked during class to the lesson assignment problems, sometimes even asking questions about the lesson assignment problems when that was a problem worked during class. It also appeared that many, if not all, of the lesson assignment questions were too difficult, and successful completion of them before class usually involved looking at the provided learning aides, such as show me an example. To address this, the number of problems in the lesson assignments were reduced, and (relatively) easier questions were selected. The learning aides were turned off in these assignments and students were limited to two attempts for each practice question. Finally, students were allowed to continue to work on the lesson assignments but with a 50% penalty applied to any additional work they did during the semester. This was intended to encourage students to complete assignments on time. Allowing access after the due date prevented the instructor from having to open up assignments so students could access the lesson materials if they failed to do the assignment on time. For each unit a small set of homework problems was added. These were a select few of the more challenging homework questions that were originally in the unit lessons in CALC-II-1T. These homework questions were due the day of the exam covering that unit.

In CALC-III skeleton notes for each lesson were created in Microsoft OneNote™. The notes included important figures, definitions, and setup for example problems worked in the lesson video. Students had not particularly complained in CALC-II-1T that they needed skeleton notes. However, when the instructor taught these classes using in a more traditional model, they used DyKnow™, a classroom tablet software system that allows students and faculty to share digital white space. This system allowed the instructor to provide skeleton notes for students in real-time. It seemed reasonable that students would benefit from having something similar for the lesson videos. Creating these was not difficult, the instructor just took the OneNote™ pages made during video creation and removed the content that they did not want in the skeleton notes. The OneNote™ pages contained the topic of the lesson, some figures and statements of the learning objectives in that lesson with example problem questions and a link to the instructor's video presentation for that lesson. OneNote pages were exported and stored on a web server,

then, in the online lesson assignment, rather than a link to the lesson video, the instructor provided a link to the OneNote page.

The final, and probably most substantial change was the addition of readiness assessment test (RATs). It seemed to the instructor that students were not quite achieving the desired level of preparation for class. Using the lesson assignment completion level was giving a very poor indication about the level of preparation, and it occurred to the instructor that students would need better feedback about their preparation if they were to improve it. The goal of the RATs was to provide the instructor a better gauge of how well students were prepared, and provide students with meaningful feedback about how their preparation for class aligned with the instructor's expectations. RATs were administered as a paper handout at the beginning of each class meeting. The RAT asked basic questions, usually little computation was needed, and the instructor really tried to probe for basic initial comprehension of the material. Appendix A is the Unit 2 Lesson 6 RAT. Completely correct answers were not required to receive full credit for the RAT, just sufficient work to show that students had read the appropriate sections in the text, and attempted the practice questions. The rubric used to score the RAT was included on the RAT, and can be seen in the appendix. A graduate student and the instructor scored the RATs for each day and recorded that as the class activity score for that day in the online gradebook. After the RAT, the instructor quickly reviewed the RAT questions and answers, and give a short mini-lecture on that day's lesson material. The remainder of the time students worked in small groups solving more difficult problems related to that lesson or previous unit lessons. The Unit 2 Lesson 6 Class Activity handout is shown in Appendix B. If the instructor felt that a specific student was not working productively during class, they could lower the class activity score for that day, and students were warned of this. The instructor had to warn a few students, but never had to alter a class activity score.

3.5 CALC-II-2T

Three changes were made to CALC-II-2T: 1) the number of semester exams was reduced by almost 50%, and 2) the instructor switched to an online system for administering RATs and 3) a team component was added to the RATs.

The number of semester exams was reduced because the instructor saw that each day most of the students were fully engaged with trying to understand the material and master solving the problems assigned to be worked during class. The frequent testing, one exam every week, was an implementation artifact from a more traditionally taught class. In a more traditionally taught class it is easy for students to postpone any studying until just before an exam. Providing frequent assessment, in the form of a weekly test, helps keep students on-track. What the instructor realized was that in the flipped class, students were genuinely working on the material in every class meeting, and possibly didn't need the extra motivation of weekly exams.

Therefore, the instructor reduced the number of test by 50% by having an exam every two weeks instead of every week.

Another substantial change was the switch from paper to an online system for RATs and the addition of a team component to the RATs. The RATs in this class were delivered using a recently developed online classroom response system¹⁷ available as part of the textbook publisher's companion online multimedia package. This online system allowed the RATs to be scored automatically. It also supported team-based learning, where all the students complete the RAT individually first, then in a second team round they can see each other's answers and answer the question again, perhaps with a completely different answer. In the team round they are told if the answer is incorrect and can answer again, but with a scoring penalty. After an instructor specified number of incorrect answers they are told the correct answer. The system also allowed the final score pre student to be based in part on the individual score and part on the team score. For this class the percentage was 30% individual and 70% team. The instructor had to develop RAT questions for each class meeting and code them into the on-line system. There were already a suite of problems for each lesson that were used in CALC-II-1T. The instructor used those as a starting point, modifying some to be "easier" by changing them to set up not solve. The instructor also added some new, more conceptual questions as well. Each RAT started with the easier, usually multiple choice questions, then later questions were often the practice problems exactly as they were in CALC-II-1T. Students were informed that it was not necessarily possible to complete the individual round of the RAT before the instructor moved them to the team round. Nonetheless each day students would have a class activity score based on their online RAT score. To address the fact that on many RATs, no student would even approach 100%, the class activity score used in the grade calculation was determined by summing all the class activity scores for each student over the semester and finding the maximum number of points had by any one student. Any student with more than 75% of the maximum number of points attained by any student received a 100% class activity score when calculating their grade. A similar approach was done with above 60% earning a 90%, and above 48%, earning a 70%, and anyone with a score at all earning a 50%.

4. Preliminary Analysis of Unit Lessons and Class Activities

There are a variety of aspects of the flipped class model of instruction. Two important aspects that are immediately apparent are: getting students to attend class, and when they do, motivating and evaluating that they have sufficiently prepared for class (i.e., that they have faithfully attempted to engage with the basic content assigned to them for that class meeting). Getting students to attend class is not unique to the flipped classroom, but in the flipped classroom model it does have unique challenges. Specifically, with content delivery moved outside of class (particularly when that content is video lectures), students can easily, but mistakenly, see class time as superfluous, because what they once went to class to get is now available online. It is easy to see how, in a flipped class, students might be inclined to view coming to class as an unnecessary burden, rather than an opportunity for learning. The effectiveness of flipped classes also requires that students have achieved some minimal level of preparation. Whether the issue

is preparation or attendance, when they don't prepare or attend there is little chance for the claimed benefits of the flipped classroom to occur.

4.1 Methods

Section 3 presented several different approaches that were used to assess students' level of preparation and reward their attendance in three flipped classes, CALC-II-1T, CALC-III, and CALC-II-2T. We generalized those different approaches into two categories: Unit Lessons (UL) and Class Activities (CA). In all the classes discussed above there were numerous lesson assignments and class activity scores throughout the semester, the character of these assessments and how they were scored is described in Sections 3.3 through 3.5. This study was approved by our Institutional Review Board (IRB), reference number 639441. For each student in each class we created a unit lesson score (UL score) by finding the average of all unit lesson scores for that class and a class activity score (CA score) by computing the average of all class activity scores. We also computed each student's mean exam score in each class; the final exam score was included in the average, but all exams were weighted equally. The lowest unit lesson scores and class activity scores were dropped when computing student's final weighted average, but in this analysis all scores were used. Multiple regression analysis was used to test if the CA and UL scores predicted students' mean exam scores. Several of the data had to be transformed because they violated the assumption of normality and homoscedasticity.

CALC-II-1T

For the model used for CALC-II-1T, the original data for the CA scores violated the regression assumption of normality and homoscedasticity because the CA scores were negatively skewed. The CA scores were negatively skewed because they are the representation of the class activities the students did in class. The authors corrected these violations by reflecting and square root transforming the CA scores. The data was tested for normality after reflecting and transforming the data, and the normality was met to run a regression analysis with the transformed data.

CALC-III

CA scores in CALC-III violated the regression assumptions of normality and homoscedasticity. The CA scores were negatively skewed. To correct these violations, the CA scores were reflected and square root transformed. Normality was met after transforming the data.

CALC-II-2T

For this model, the original data for UL scores violated the regression assumption of normality. The UL scores were negatively skewed. To correct this, the data were reflected and then square root transformed. After reflecting and transforming the data, the violations of regression assumptions were corrected for the model.

4.2 Results

CALC-II-1T

Multiple regression analysis was used to test if the CA and UL scores predicted students' mean exam scores. It was found that CA and UL scores explain a statistically significant amount of variance in mean scores on exams, $F(2,87) = 17.214, p < .001, R^2 = .284, R^2_{Adjusted} = .267$. The analysis indicated that UL scores did not significantly predict mean exam scores (Beta = .151, $t(88) = 1.634, ns$), however CA scores did significantly predict mean exam scores (Beta = -.485, $t(88) = -5.257, p < .001$). The beta score was negative for the CA data because of the combination of transformation of the data and that fact that it was negatively skewed.

CALC-III

A multiple regression analysis was conducted to test if CA scores, and UL scores predicted mean scores on exams. Analysis indicated CA scores and UL scores together predicted a statistically significant amount of the variance, $F(2,97) = 50.372, p < .001, R^2 = .509, R^2_{Adjusted} = .499$. Both the CA scores (Beta = -.347, $t(98) = -4.086, p < .001$) and UL scores (Beta = .463, $t(98) = 5.456, p < .001$) were significant predictors of mean exam scores. Both the negatively skewedness of the CA data and transformation of the CA data contributed to the negative beta.

CALC-II-2T

Multiple regression analysis was used to test if CA scores and UL scores predicted mean scores on exams. It was found that CA scores and unit scores explain a statistically significant amount of variance in mean scores on exams, $F(3,55) = 43.938, p < .001, R^2 = .706, R^2_{Adjusted} = .690$. UL scores did significantly predict mean exam scores (Beta = -.597, $t(57) = 2.592, p < .05$) as did CA scores (Beta = .428, $t(57) = 3.460, p < .001$). The negative beta on the UL scores was due to the transformation and negative skewedness..

Table 4. Regression analysis results for CALC-II-1T, CALC-III, and CALC-II-2T.

Class	N	R ²	R ² _{Adjusted}	Model Significance
CALC-II-1T	89	.284	.267	$p < .001$
CALC-III	99	.509	.499	$p < .001$
CALC-II-2T	58	.706	.690	$p < .001$

Discussion

The analysis found that students' UL and CA scores in CACL-II-2T explained a greater percentage of the variance in exam average than did the UL and CL scores in CALC-III and CALC-II-1T. The analysis also showed that UL and CA scores in CALC-III explained a greater percentage of the variance in exam average than did the UL and CA scores in CALC-II-1T.

One of the operating assumption of the flipped classroom is that when students come to class prepared and then work productively and authentically during class they will have better or deeper learning, which should be reflected in their exam scores. So the objective of the unit lessons is to prepare students for class, with the score indicating how well prepared the student is for class. Similarly the objective for the class activities is to create opportunities where students engage more deeply with the topics and really fortify and extend the understanding acquired before class, possibly correcting misconceptions as well. Again, class activity scores need to measure or indicate the degree to which that happened.

Many factors might have contributed to the observed increase in r^2 values for the later UL and CA scores. One of these certainly is the difference between the class activity scores in the three classes. In CACL-II-1T, class activity scores were really based on two fairly course gained measures: attendance and unit lesson score threshold, with attendance being weighted more. CALC-III, the instructor implemented a completely new method (to them) for the class activity scores – the readiness assessment test (RAT). While still being scored generously, the question on the RATs tried to draw out the key concepts and highlight common misconceptions, and did so without requiring lots of calculations, which exams often do.

In CALC-II-2T the instructor again used RATs, but this time deployed using a new classroom response system. The further increase in r^2 values of the UL/CL score prediction of variance in exam average might be mostly attributed to the online system's more fine grained score reporting, compared to the rubric and paper RATs from CALC-III. That the r^2 went up in this class is interesting, since in this class, class activity scores were based on computer graded class assignment, were as exams were hand graded pencil and paper.

5. Conclusions

Over the course of three semesters an instructor was able to continuously improve the design of flipped class to enhance student learning. The instructor's revisions from semester to semester show how developing a flipped class is an iterative process that must be informed by experience as well as the literature. For administrators and department chairs, this work shows how it can take multiple semesters to flip a class. Certainly faculty can start farther along the path when they well research the literature, however the individuality of student body, college, and course content make every attempt to flip a class unique in ways that matter a lot to the faculty teaching the course.

The next steps in this research is to begin to look for evidence of efficacy. While exam performance and course grade are one possible measure, there are other, possibly more potent, measures. One such measure is performance in other, traditionally taught courses for which the flipped course or courses are prerequisites. Another interesting area to investigate is what effect a student's first flipped has on future flipped classes they might take.

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Appendix A

Unit 2 Lesson 6 Readiness Assessment Test

ENGR-201-U2L6RAT.docxs Last, First: _____ Section: _____

#1 For $z = f(x, y)$

$\vec{\nabla}f$ is called the _____ of f

For Instructor Use

- 5 – Well prepared for class
- 4.5 – Adequately prepared for class
- 4 – Somewhat prepared
- 3 – Not at all prepared or late.

$\vec{\nabla}f =$ _____

(give the formula)

#2 For $z = f(x, y)$

$\left(\frac{df}{ds}\right)_{\hat{u}, P_0}$ is called the _____ of f

at P_0 in _____

$\left(\frac{df}{ds}\right)_{\hat{u}, P_0} =$ _____

(give the formula)

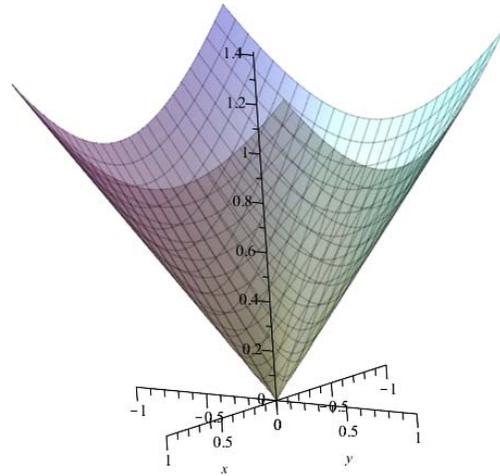
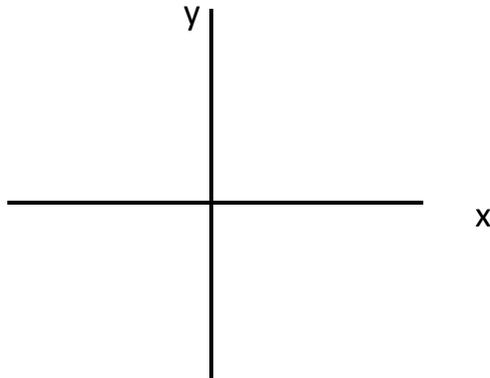
#3 What is the direction of $\left(\frac{df}{ds}\right)_{max}$?

Appendix B

ENGR-201-U2L6-GroupActivity.docx

Instructions: Work in pairs to complete the problems that follow. Work together by first making sure you both understand how to proceed, then checking each other's work at intermediate points, making sure both persons understand both their own work and the other person's work.

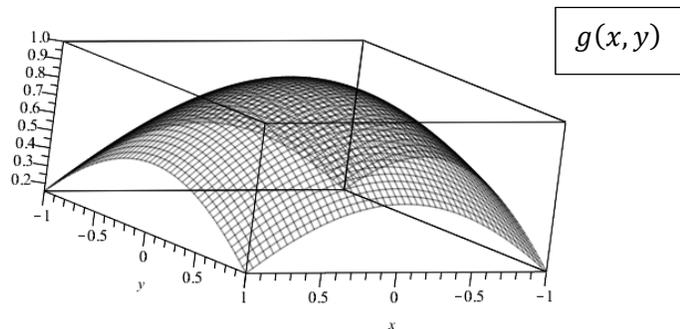
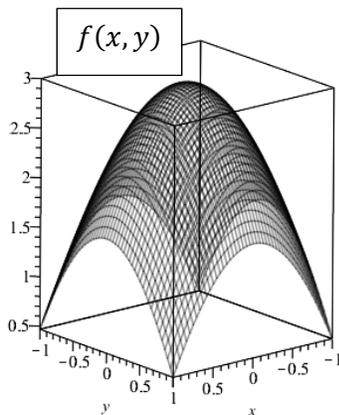
#1 The Surface $z = f(x, y)$ is shown to the right. On the provided xy axis, draw the gradient vector, $\vec{\nabla}f$ at $P_1(1,1)$, $P_2(-1,1)$, $P_3(-1, -1)$, and $P_4(1, -1)$



Discuss with your partner.

#2 Find the gradient of $f(x, y, z) = \ln(xyz)$.

#3 The surface $z = f(x, y)$ and the surface $z = g(x, y)$ are shown below:



At the point $P_0(1,1)$ in the direction $-\hat{i} - \hat{j}$ which is greater $\left(\frac{df}{ds}\right)_{\hat{u}, P_0}$ or $\left(\frac{dg}{ds}\right)_{\hat{u}, P_0}$ and Why?

Discuss with your partner.

#4 Find the directional derivative of the function $f(x, y, z) = -9e^x \cos(yz)$ at $P_0(0,0,0)$

in the direction of $A = -\hat{i} + \hat{j} + 4\hat{k}$