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Lessons Learned from Two Years of Flipping Circuits I

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Introduction

A "target point" is a vulnerable transition, or perhaps even an undesirable climate, that impacts the preparation steps toward becoming an engineer [1, 2]. According to the NSF Engineering Directorate, "one of the most critical "target points" to successful professional formation of engineers is the engineering "core," the middle two years of the four-year undergraduate experience". During these middle years, students take a bulk of courses in engineering fundamentals. These technically focused courses are critical junctures and are often the primary points of attrition. Uninspiring teaching, abstract content with seemingly little connection to "real" engineering [3], and lack of effective use of best teaching practices are frequently cited as obstacles in learning in these years [4]. Instructional interventions that engage the students and improve student success as well as retention at this target point are therefore vital.

Various pedagogical tools and methods have been developed and adopted to foster student-centered learning to address this problem. For teaching Circuits I – a representative core course in electrical and computer engineering – in particular, examples include traditional lectures supplemented with interactive software [5] or web-based materials [6], complete online delivery of content [7], and problem-based learning [8-10].

The flipped classroom is a pedagogical approach where traditional in-class (synchronous lectures) and out-of-class activities (asynchronous homework) are reversed: Group learning activities take place inside the classroom, and direct instruction is delivered online outside the classroom. The distinguishing features of the flipped classroom from other formats are the delivery of content via pre-recorded video and the face-to-face interaction with the instructor.

Benefits of the flipped format has been shown by many studies. These include flexibility for the instructor in presenting the material [11, 12], i.e., tailoring the delivery format to student learning style and background. Bland et al. [13] found the flipped approach was well-received by engineering students and motivated them to become self-learners.

In this paper, we present the results of a study on teaching a fundamental engineering course. Over a period of 2 years, Circuits I was taught in the traditional lecture format, then in the flipped format for five consecutive semesters. This is a continuation of a prior study [14] that had reported on the first two semesters only. This paper describes changes made to the flipped class, adds new data and discusses new results from the semesters that followed.

Highlights of the key results are significantly improved student performance and retention. When Circuits I was taught in the traditional way, on average only 54% of the students that started the semester received the marks required (a "C" in this case) to take further courses in the curriculum. This number includes the 28% that dropped the course during the semester. In the first iteration of the flipped classroom, that numbers of students who received a "C" or better jumped to 83% and only 2% of the enrollees dropped the class.

We also measured student perceptions in terms of learning preferences, engagement, and learning of course concepts. These evaluations were based on student surveys (mid-term reflections, course evaluations) and student work products (assigned homework, quizzes, exams).

Initial Implementation

The Department of Electrical and Computer Engineering at the University of Florida offers two separate circuits courses: EEL3111C - Circuits I and EEL3003- Elements of Electrical Engineering. EEL3003 uses the textbook "Basic Engineering Circuit Analysis" by Irwin and Nelms [15] and does not have a laboratory component. All electrical and computer engineering (ECE) and biomedical engineering (BME) students are required to take EEL3111C. All other engineering majors are required to take EEL3003. The course used in this study is Circuits I.

Circuits I is typically taken at the same time as differential equations and has both semesters of Physics with Calculus as a prerequisite. Students have had the traditional exposure in Physics to energy, work, voltage, current, and simple voltage laws. The enrollment in this course is 160 each in the Fall and Spring semesters and 60 in the Summer. These numbers include transfer students from community colleges who are prospective ECE or BME majors. In Fall and Spring, classes meet three times a week for 50 minutes and are supported by a once-a-week laboratory experience of three hours. Summer classes meet three times a week for 65 minutes and are supported by a once-a-week laboratory experience of three hours. The course uses the textbook "Electric Circuits" by Nilsson and Riedel [16] and covers chapters 1-8 and 10. Topics covered include sources, Ohm's law, nodal and loop analysis, source transformation, superposition, Thevenin's theorem, Norton's theorem, op-amps, capacitors, inductors, first-order transients, diodes, phasors, impedance, filters, Bode plots, AC circuit analysis, and AC power.

In the years past, including Fall 2012, Circuits I was taught traditionally. Lectures were given in each class period on the material. Homework problems were assigned every week. Students were assessed using weekly 15-minute quizzes, three mid-term exams, and a comprehensive final exam. The Fall 2012 students served as the control group for this study.

Since Spring 2013, Circuits I has been taught in the flipped format. In the flipped format, students are expected to watch the pre-recorded lectures online and come to class prepared to work in small groups. The lectures were recorded in a studio classroom furnished with audiovisual equipment. The same professor who taught Fall 2012 Circuits I created the videos. In all, 35 videos were produced. Topics were presented in the same order as the traditional lecture. As in the traditional lecture, the professor used the chalkboard to introduce concepts and demonstrate their applications by working out example problems. Each video was 50 minutes long. Instead of one large class, we offered nine sections with maximum enrollment of 20. Students were broken into groups of four and worked together on problem solving (Figure 1). This approach was chosen based on literature that showed that guided problem solving was critical to the success of the students [17, 18]. Students were assessed the same way, except for the addition of a daily quiz to ensure students come to class prepared [19, 20]. The lab was kept identical to Fall 2012. Historically, there has been little difference between the Fall and Spring semester in student performance. The only real difference between Fall 2012 and Spring 2013 offerings was how class time was spent.

Figure 1: Setup of the flipped Circuits I class. Students were enrolled in small sections and worked in groups of four.

Changes Made in Flipped Circuits I

In the subsequent iterations, changes were made to the flipped classroom, as summarized in Table 1. The first was the increase of section size from 20 to 40 students in Fall 2013, which reduced the section number from nine to four. To maintain the level of attention paid to each student group, a graduate teaching assistant was recruited. The teaching assistant was trained to facilitate the discussions to guide students' thinking process, rather than to provide immediate answers.

In Fall 2013, we made the comprehensive final exam optional since all the topics were covered by the time the scheduled third test was due. In the time that freed up, we chose to cover more examples and provide demonstrations with the Digilent Analog Discovery (Figure 2: a USB-powered portable oscilloscope, function generator, spectrum analyzer, network analyzer, voltmeter, and power supply [21]) kit connected to a laptop to reinforce the concepts rather than to introduce new material.

Figure 2: Digilent Analog Discovery – a USB-powered portable oscilloscope, function generator, spectrum analyzer, network analyzer, voltmeter, and power supply

In Spring 2014, ECE Department's curriculum-wide adoption of the Digilent Analog Discovery in courses with a laboratory component opened the door to meaningful experiential hands-on learning anywhere for Circuits I students. Instead of replacing the existing Circuits I laboratory all at once, we decided to incorporate Digilent Analog Discovery modules from the company's free full online tutorials, "Real Analog [22]," into homework assignments.

Summer 2013 and 2014 have remained the same in terms of section size due to the small enrollment typical for that time of the year. Summers are taught by a different instructor team, so weekly quizzes were not given (Table 1). The only change made was the incorporation of Digilent Analog Discovery modules in the homework assignment in Summer 2014.

	Fall 2012	Spring 2013	Summer 2013	Fall 2013	Spring 2014	Summer 2014
Format	Traditional	Flipped	Flipped	Flipped	Flipped	Flipped
Lab	no change	no change	no change	no change	no change	no change
Instructors	S	S, K, L, P	K, T	S, K, Teaching Assistant	S, K, Teaching Assistant	K, T
Enrollment - Class Size	145	168 - 20 per section	58 - 20 per section	160 - 40 per section	150 - 40 per section	52 - 20 per section
In-Class Activity	Traditional	Group Problem Solving	Group Problem Solving	Group Problem Solving	Group Problem Solving	Group Problem Solving
Daily Quiz	No	Yes	Yes	Yes	Yes	Yes
Weekly Quiz	Yes	Yes	No	Yes	Yes	No
Test 1	Yes	Yes	Yes	Yes	Yes	Yes
Test 2	Yes	Yes	Yes	Yes	Yes	Yes
Test 3	Yes	Yes	Yes	Yes	Yes	Yes
Final Exam	Yes	Yes	Yes	Optional (11 students took the final)	Optional (12 students took the final)	Yes
Homework	assigned, but not graded	assigned, but not graded	assigned and graded	assigned and graded	assigned and graded, added Digilent kit assignments	assigned and graded, added Digilent kit assignments

Table 1: Iterations of Circuits I class over six semesters from Fall 2012 to Summer 2014. Fall 2012 class was taught in the traditional lecture format and used as the control group in the study. All subsequent semesters were taught in the flipped format with slight variations.

Results and Discussion

A student needs a "C" or better grade to successfully complete the course and continue further into the curriculum. In Fall 2012, only 54% of the students that started the semester received the marks required to take further courses in the curriculum. This number includes the 28% that dropped the course during the semester. It should be noted that the course is not designed to be a weed-out. Given the highly selective nature of the admission process and given their prior success in calculus and physics, nearly all students should be successful in this course.

Almost all of the dropped cases were due to poor performance that led students to recognize that they were unlikely to make a passing grade. It is not clear how many of these students subsequently changed major due to the experience, but it is likely that some students were discouraged enough to no longer pursue ECE or BME as a major. Therefore, we were motivated to make the change to engage the students, improve student success, and student retention. We measured the effectiveness of the flipped Circuits I by evaluating student performance, student retention, and student perception.

Student Performance and Retention

Table 2 summarizes the results from the course on the four major exams. Except for Summer 2013, the same team of instructors designed the exams for the flipped class. The instructor for Fall 2012 was part of the team and oversaw the design of the exam as well as the grading rubrics. This was to ensure consistency in the level of difficulty of the exams and how partial credit would be given. For the three mid-term exams, the average was higher in the flipped version of the course. With each exam, the difference became smaller. More impressive is the reduction in standard deviation (Figure 3).

In our previous work that compared the traditional Fall 2012 and flipped Spring 2013 performance [14], we noted the first two exam averages showed large and moderate effect sizes, while the third exam and final exam showed negligible effect sizes. Analysis revealed the decrease in effect size could be attributed to higher retention (Figure 4). In Fall 2012, the students that did poorly on the early exams dropped the course and did not take the final exam. With the much higher retention in the flipped class, it was conceivable that the population that took final exams in the two semesters were different. Detailed discussion can be found in Kim et al. [14]

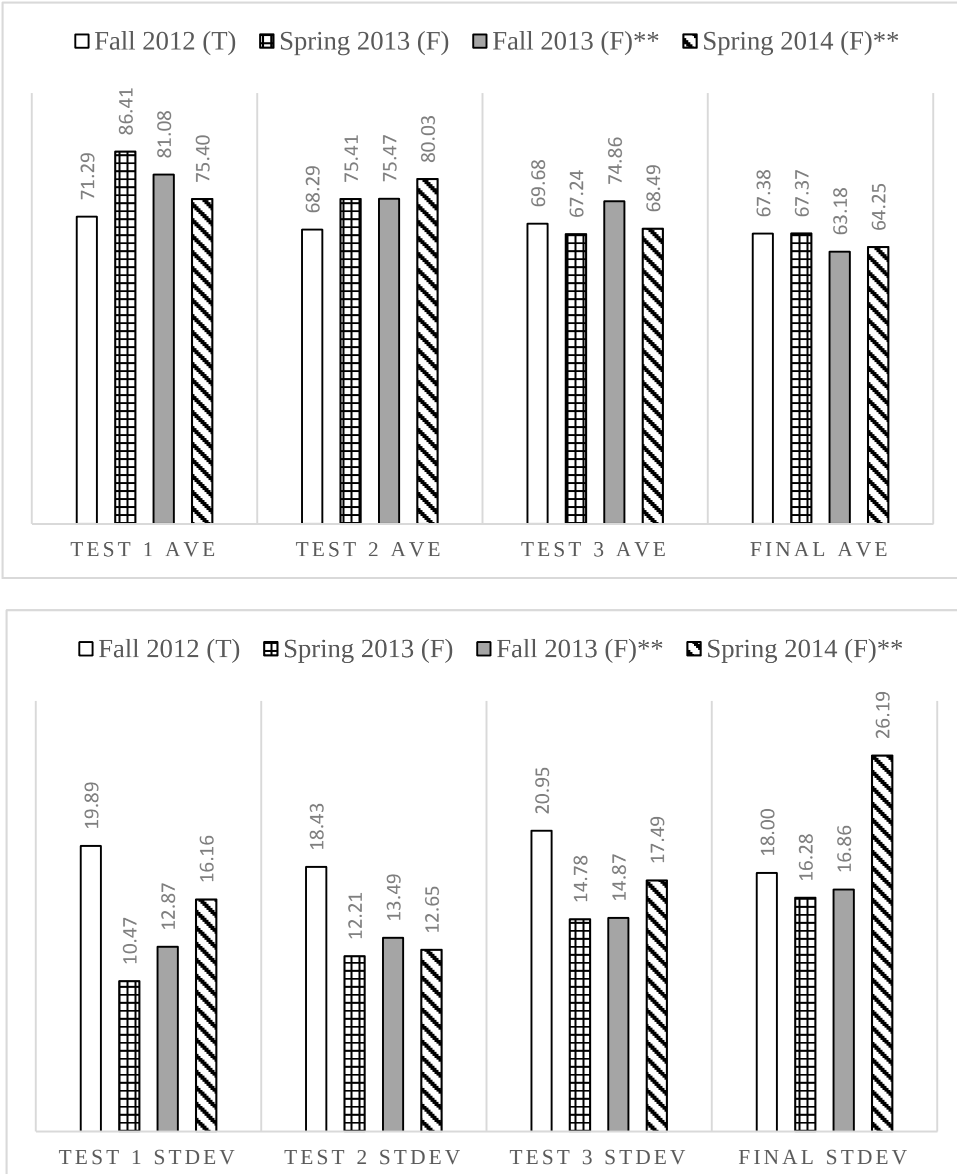
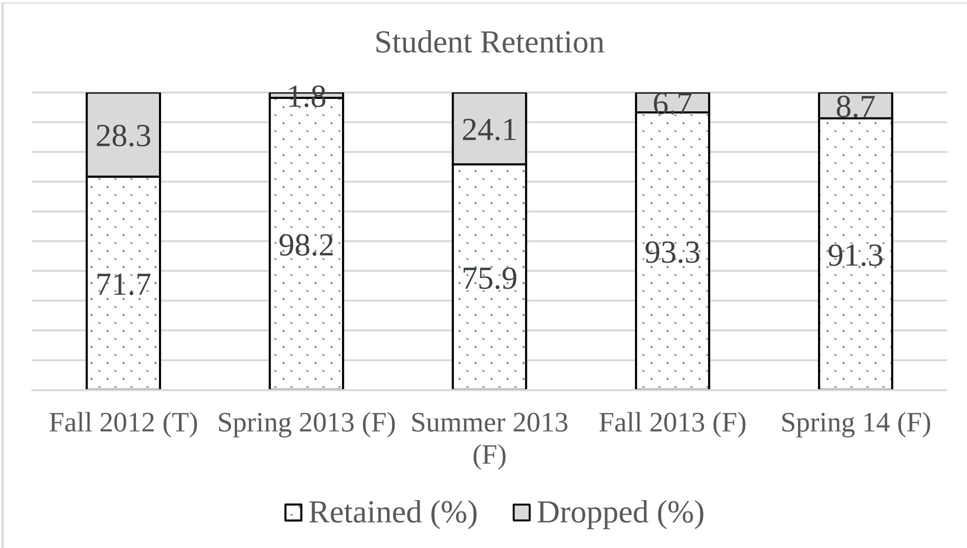


Figure 3: Student Performance – Exam Results. Top bar graph shows the test score averages out of 100 points and the bottom bar graph shows the standard deviations of each test. Fall 2012 was taught in the traditional format (T). Other semesters were taught flipped (F). Summer 2013 tests were written by a different set of instructors and was excluded from the analysis.

**As pointed out in Table 1, the final exam in Fall 2013 and Spring 2014 were optional. Only students who did poorly on the previous three tests and fell under a set threshold were allowed to take the final exam.



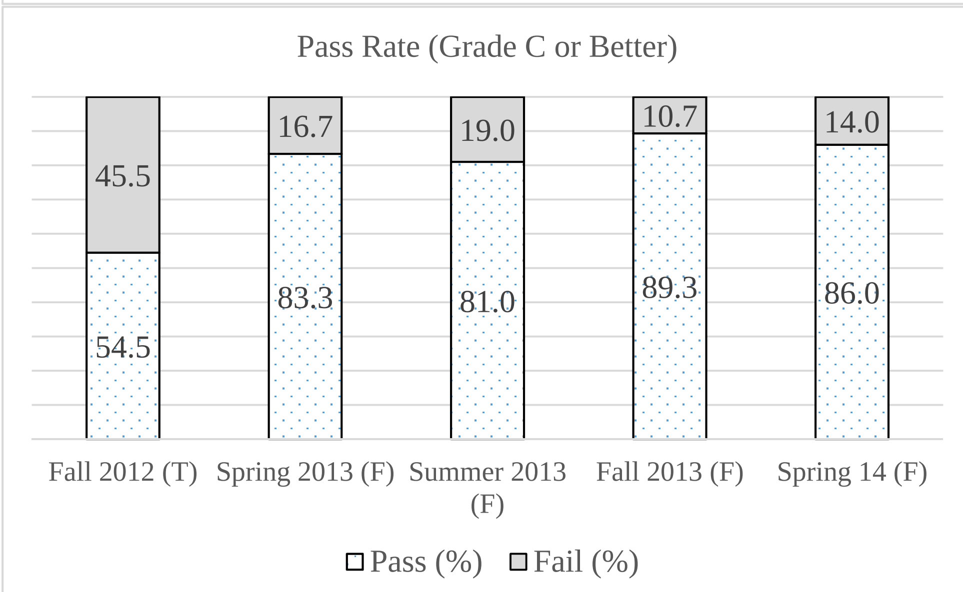


Figure 4: Circuits I Flipped Classroom Outcome. Fall 2012 was taught in the traditional format (T). Other semesters were taught flipped (F). Student retention and performance markedly improved in the flipped version of the course.

The flipped class consistently showed a significant improvement in student performance over the traditional class - over 80% of the students received a “C” grade or better. The improvement in student performance and retention has continued in subsequent flipped semesters (Figure 4).

Student Perception

Student perception surveys were conducted at week 6 and week 12 of the flipped semesters. This was separate from the course evaluation surveys conducted by the university at the end of the semester. Students were asked to respond to a series of 12 statements on a 5-point Likert scale and were provided room for open-ended comments. Later, the results from the week 6 and week 12 survey were paired for each student. Results of the survey are summarized in Table 3.

Previous studies on flipped classroom have shown contradicting results when it comes to time spent outside the classroom for the class. While Papadopouls et al. [23] reported that students spent more time studying when the class is flipped, Mason et al. found that flipped format class does not require students to spend significantly more time than does a traditional format [24]. Our survey results seems to agree with the latter study. Open-ended comments indicated the daily quizzes and weekly quizzes kept the students constantly on their toes. Also, students remarked using class time to practice problem solving got them out of the habit of "equation shopping," i.e., trying to fit the numerical answer to the formula discussed in class, rather than understanding the concepts first.

In response to "I prefer the format of this class compared to traditional lecture only format," Students strongly favored the flipped approach to spending class time. Representative comments attached to this question included "It was great that the lectures were available to view online so I could go back to previous lectures if I was confused on some subject," and "I really like that the course is taking a different path from normal lecture courses. I think sit-and-watch lecture courses with very little active involvement are not only extremely ineffective, but generally mind numbing and boring. Student involvement drastically increases the amount learned in a class, and allowing us to take charge of our own learning is fundamental to allowing us to really learn and reason." Some students pointed out that the class format worked because it was not a one-way online delivery of content, but supplemented with face-to-face time with the instructor, with whom they could clear questions and misconceptions.

Transfer students from community colleges strongly endorsed the class activity involving working in groups, which helped them socialize with their new classmates and integrate them into the course.

The students felt the recorded lectures were well structured. This was notable, because each video was 50 minutes long and unedited. Ideally, the lectures would be edited to 5-10 minute segments and cover concept introduction, example problem application, and lab segment.

The lab part was where students expressed major discontent. The biggest complaint about the lab was the modules being "too straightforward." This suggested student expectations for the lab were set higher now that they felt more confident about their conceptual understanding. This was somewhat alleviated with the introduction of the Digilent kit in the homework. However, for the implementation to be meaningful, it may be necessary to incorporate the Digilent kit into the in-class activities, rather than assign a project as homework.

Question	Spring 2013		Summer 2013		Fall 2013		Spring 2014	
	Week 6 Mean (SD)	Week 12 Mean (SD)	Week 6 Mean (SD)	Week 12 Mean (SD)	Week 6 Mean (SD)	Week 12 Mean (SD)	Week 6 Mean (SD)	Week 12 Mean (SD)
The workload (time spent outside the classroom) for this course is fair.	3.94 (1.17)	4.21 (1.05)	3.73 (0.83)	4.33 (0.65)	3.79 (0.94)	4.18 (0.73)	3.71 (0.78)	4.24 (1.02)
I prefer the format of this class compared to the traditional lecture only format.	4.14 (1.11)	4.21 (1.05)	3.98 (0.89)	4.48 (0.81)	4.08 (1.29)	4.43 (0.55)	4.22 (1.03)	4.10 (0.71)
The in-class time devoted to problems is helpful for my learning.	4.03 (1.05)	4.13 (0.75)	3.99 (1.23)	4.20 (0.35)	4.10 (0.72)	4.18 (1.24)	4.08 (0.95)	4.15 (0.63)
Collaborating with my peers on problems in-class is helpful.	4.61 (0.63)	4.60 (0.52)	4.40 (0.67)	4.25 (0.45)	4.51 (0.88)	4.38 (0.50)	4.42 (0.81)	4.71 (0.73)
The online lectures are well structured.	4.38 (1.14)	4.24 (0.75)	4.22 (1.11)	4.02 (0.80)	4.18 (0.83)	4.01 (0.55)	4.31 (1.21)	4.25 (0.76)
The in-class activities are well organized.	3.67 (1.03)	4.03 (0.93)	3.89 (0.33)	4.18 (0.62)	3.85 (0.68)	4.11 (1.00)	3.90 (0.64)	4.15 (0.69)
The lab helps my understanding of the in-class material.	3.40 (0.70)	3.51 (1.03)	3.41 (1.14)	3.55 (1.01)	3.43 (0.88)	3.62 (1.11)	3.60 (1.05)	3.78 (0.98)
The in-class discussions help my performance in the lab.	3.52 (0.87)	4.05 (1.18)	3.60 (0.23)	3.98 (0.35)	3.57 (1.07)	3.88 (0.46)	3.48 (1.10)	4.01 (1.41)

Table 3: Student Perception Survey Results. Likert scale used to rate the statements were: (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree. After each question, a space was provided for open comments.

Conclusion

The flipped format of Circuits I significantly improved student performance, student retention, and was well-received by the majority of students. Some of the key lessons from this 2-year study are:

- While students miss the interactive nature of a live lecture, they prefer working with their peers and receiving guidance tailored to their individual learning needs. Shortcomings of the one-way delivery of the online videos are compensated by learner-centered activities in the classroom.

- Initial resistance to the new format is to be expected. The course needs to be carefully structured and expectations must be established early to facilitate student buy-in. Daily quizzes not only ensured students came to class prepared, but also helped the students adapt to the flipped format.

- The preparing for a flipped format class can be more consuming for the instructor. However, video production is not necessarily the rate-determining step in the implementation of the format. With our unedited 50-minute recording of a traditional lecture, we were still able to reap the benefits of the flipped classroom. The videos, despite their length, were generally well-received by the students.

- As a previous study pointed out [25], the flipped format can free up class time that can be used for additional activities. We made the comprehensive final exam optional since all the topics were covered by the time the scheduled third test was due. In the freed-up time, we chose to cover more examples and provide demonstrations on the Digilent kit to reinforce the concepts rather than to introduce new material.

We are working on revising the laboratory to match the new flipped style of learning, editing the lectures, and revising the homework assignments to enrich students' experience. We also have an NSF Improving Undergraduate STEM Education (IUSE) grant application pending to enhance and expand experiential learning modules in the domains of circuits analysis, biosignals and systems analysis, and experimental design in collaboration between the BME Department of Northwestern University and ECE Department of University of Florida. Future plans include assessing whether students who have benefitted from the flipped classroom continue to be successful in further courses in the curriculum.

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