FLIPPING LARGE CLASSES ON A SHOESTRING BUDGET

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ABSTRACT

Flipped learning, in which students watch video lessons outside the class time and the instructor uses the class time for instilling of knowledge through various active learning techniques, is often put forth as a more effective mode of instruction. While a number of educators in higher education have replaced their traditional lecture-based offerings with flipped classes, it is still debatable whether flipping can be scaled up to large core classes. In this paper, experiences are recounted from two consecutive flipped offerings of a junior-level signal processing class at Rutgers with an average enrollment of 122 students. These experiences suggest that, with some improvisations, large classes can be successfully flipped with minimal time, cost, and infrastructure overhead.

Index Terms— Active learning, flipped classroom, lecture format, online courses, project-based learning

1. INTRODUCTION

Much has changed in the world of academia since the medieval universities of the second millennium. But there is one thing that has remained largely unchanged: the mode of instruction. Despite several research studies pointing out numerous shortcomings of the lecture format [1–4], lecturing remains the dominant form of instruction in modern academy. The reason for this is simple: despite all its limitations, lecturing *is* the cheapest and quickest means of educating large numbers of students.

During the last decade or so, fueled in part by rapid technological advances, there has been a renewed interest in replacing lecturing with a more effective and scalable mode of instruction. Three modes of instruction that particularly stand out among the proposed alternatives are 1) project-based learning [5–8], 2) massive open online course (MOOC) [9, 10], and 3) flipped classroom [11–16]. Each one of these alternatives has, of course, its own sets of positives and negatives. Project-based learning is perhaps the most effective in overcoming socioeconomic, behavioral, and learning inequalities among students. But it is also the least scalable alternative to lecturing. On the other hand, MOOCs are perhaps the most scalable of all forms of instruction. Yet, the lack of face-to-face interactions with instructors make them pedagogically challenging for all but the most determined of students. Flipped classrooms (see Fig. 1) seem to be able to strike a balance between the scalability of MOOCs and the interactivity of project-based learning. Nonetheless, low-cost scalability of flipped offerings to hundreds of students remains an area of concern for academics. (We refer the reader to [17] for a more detailed comparison among these three forms of instruction.)

The goal of this paper is to add to the evidence that, with careful planning, flipped classrooms can be scaled up to hundreds of students at a fraction of the time, cost, and infrastructure overhead typically attributed to flipped learning. The impetus for this work comes from some of the earliest adoptions of flipped classrooms in engineering education [11–16]. The instructors of these flipped classrooms have been unanimous in their opinion that flipping seems to improve student learning outcomes. Nonetheless, most of the experimentation with flipped learning in engineering education has happened at the level of small (sometimes elective) classes. Among the documented flipped classrooms in electrical engineering, [12], [13], and [14] had enrollments of 30, 115, and 40, respectively. In particular, despite the documented success of large flipped classes such as [13], the conventional wisdom among engineering instructors has been that flipped learning is not easily scalable to core courses that enroll hundreds of students. In this paper, we provide evidence to the contrary that is based on two flipped offerings of a 15-week junior-level signal processing course at Rutgers University–New Brunswick in Spring 2016 and Spring 2017 with final enrollments of 133 and 111, respectively. We conclude by noting that many of the ideas discussed in this paper are explored in much greater detail in [17].

Organization: The rest of this paper is organized as follows. In Sec. 2, we discuss our reasonings for flipping the signal processing course. In Sec. 3, we describe the steps taken to implement flipping under time, budget, and infrastructure constraints. In Sec. 4, we describe the organization of our flipped offerings and discuss some of the learning outcomes. We conclude the paper in Sec. 5.

2. WHY FLIP AT ALL?

ECE 346: Digital Signal Processing is a required course at Rutgers for students majoring in electrical engineering. It is offered in every spring semester, with an average final enrollment of 100+ students in the last six years. Typically, more than two-thirds of the enrolled students are juniors who took *ECE 345: Linear Systems and Signals* in the immediately preceding semester, while the rest are seniors who did not or could not enroll earlier in the signal processing course for various reasons. We have been teaching this course since Spring 2012, with our first offering very much in the mold of traditional lecture and chalkboard format. This first offering would be considered a success by most standards; the course received an average rating of 4.33 (out of 5) from 56% of the enrolled students and there were more than a handful of students who had truly mastered the course material by the end of the semester. Despite its seeming success, this offering also laid bare many of the limitations of the lecture format, especially in relation to large core courses. In particular, the struggles of students who did not conform to the standard assumptions of the lecture format were all too apparent during the semester.

We made several tweaks to our first offering in the ensuing semesters in an attempt to make our offerings more equitable to students. These included experimenting with presentation slides in lieu

This work is supported in part by the NSF under grant CCF-1453073.

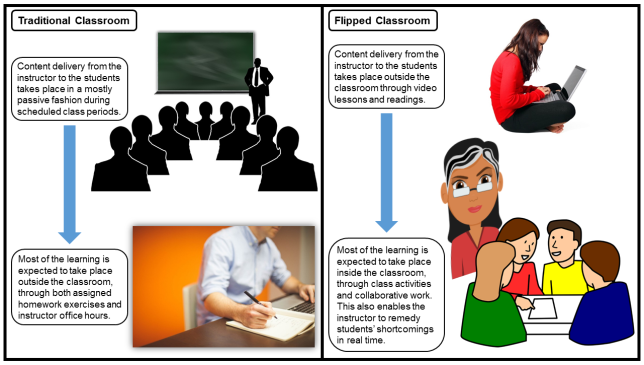

Fig. 1. A side-by-side comparison of a typical lecture-based classroom and a flipped classroom.

of chalkboard text, video archiving of class lectures, grade-based incentives for class participation, and different attendance policies. Some of these tweaks appeared to be helpful to students' learning (e.g., video archiving), while other tweaks seemed to have either little effect (e.g., mandatory attendance) or negative effect (e.g., presentation slides) on students' learning. And none of the tweaks seemed to directly confront the challenges of academic, behavioral, and learning variations among students. Concurrently, works such as [12, 13] were reporting remarkable effectiveness of *fully flipped* classrooms in improving learning outcomes. The only challenge that remained was figuring out how our large class could possibly be flipped using minimal time, cost, and infrastructure overhead.

3. LOW-BUDGET FLIPPING OF LARGE CLASSES

There were three major challenges that came to the fore when we examined the possibility of flipping our signal processing class. First, and this is perhaps the most daunting aspect of flipping, we needed to create engaging video lessons in a cost- and time-effective manner. Second, and as noted by other instructors [12, 13], flipping a course for 100's of students requires more than one person to guide students during in-class activities. A general rule of thumb for student–guide ratio in flipped classes is 20–30 students/guide, which means we needed a strategy to involve four to five additional guides in the flipped classroom without creating a budgeting crises for the department. The third challenge, often considered one of the biggest hurdles to adoption of flipped learning for *large* courses, is that the largest *active learning* classroom at Rutgers has a capacity of 90 students.[1] Since enrollment in our course at Rutgers often exceeded 100 students, we needed a plan that would enable students to reap the benefits of a flipped classroom in a lecture hall setting.

3.1. Low-overhead video lessons

Short, self-contained video lessons are the key to creating a flipped classroom. But planning, recording, and production of professional-looking videos can overwhelm even the most committed of instructors. Being cognizant of the risks of overcommitting, we initially opted for an acceptable compromise between overhead and quality of the video lessons. This compromise involved: (i) delivering lectures to students enrolled in our traditional offering of the signal processing class in Spring 2015 using a pen tablet (Wacom Bamboo Tablet) connected to a Windows laptop and Microsoft OneNote, (ii) capturing laptop's screen using a screencasting software (Camtasia Studio 8) and recording voice using an external mic (Logitech HD Webcam), and (iii) stitching, slicing, and deleting the recorded material using Camtasia Studio 8 to produce a set of 27 videos, each one of which covered a single topic and excluded classroom interactions and discussions with students. This piggybacking on traditional lecturing allowed us to limit the initial time overhead of video lessons to an average of approximately 2.5 hours per video. (This figure excludes both the lecture preparation and the lecture delivery times since we would have spent this much time regardless as part of the Spring 2015 offering.) The monetary overhead of these video lessons was also quite manageable, enabling our department to absorb the entire cost; in particular, an equivalent system comprising a pen tablet, an external mic, and screencasting and video editing software can be built as of this writing for approximately 400 USD.[2] Today, these videos—which are further divisible into subtopics of durations ranging from 10 to 30 minutes—undergo periodic improvements and are publicly available on our YouTube channel [18].

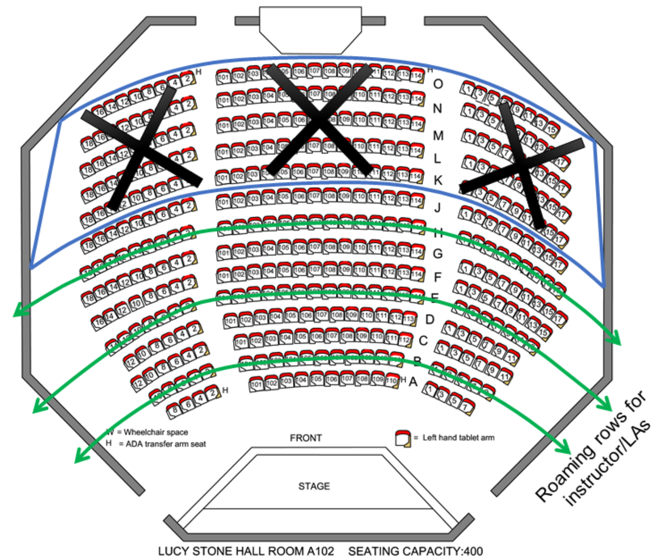

Fig. 2. A possible seating arrangement in a lecture hall for students in a large flipped classroom. This arrangement prohibits students from sitting at the very back of the hall (black crosses) and in three rows (green arrows), and enables instructor(s)/LA(s) to reach individual students by moving within the (green) restricted rows.

3.2. Low-cost in-class assistants

While having a person assisting every 20 to 30 students for in-class activities is critical to the success of a flipped classroom, most universities cannot financially afford such a high ratio of students to teaching assistants. The signal processing class at Rutgers, for instance, has historically been assigned one graduate teaching assistant (GTA). In order to balance the needs for financial prudency and in-class assistants, we resorted to the use of *peer* learning assistants (LAs). With the help of *Rutgers Learning Centers* (RLC), we recruited five students each year from our previous offering of the signal processing class to serve as LAs. Each one of these LAs spent two hours per week preparing for in-class activities and three hours

[1] Active learning classrooms are specialized, technology-rich physical spaces, typically comprising multiple round tables for student seating, that are often recommended in education circles for use in flipped learning.

[2] This figure excludes the costs of a laptop and note-taking software, both of which are considered integral for today's educators.

Table 1. Summarization of the main activities that comprised our flipped offerings in Spring 2016 and Spring 2017.

Step #	Activity Category	Activity Details	Grading Details
1-1	Home Activity	Viewing of assigned YouTube video lessons (∼30–70 minutes per class)	Ungraded
1-2	Home Activity	Completion of assigned textbook reading (if applicable)	Ungraded
1-3	Home Activity	Completion of online assessment (due by 7 a.m. on the day of each class)	4%–5% of the final grade
2-1	In-Class Activity	Review of key concepts by the instructor (∼10–15 minutes per class)	Ungraded
2-2	In-Class Activity	Short polling questions (∼2–5 questions, with each worth two points)	15% of the final grade (25% points for attempt)
2-3	In-Class Activity	Paper-and-pencil problems (∼1–3 problems, with each worth 4–12 points)	
3-1	Home Activity	Paper-and-pencil problems (∼1–3 problems assigned after some classes)	2%–3% of the final grade
4-1	Recitation Activity	Problem solving by the GTA (∼30–35 minutes and ∼3–5 problems)	Ungraded
4-2	Recitation Activity	Paper-and-pencil problems (∼3–5 problems, with each worth 4–10 points)	7% of the final grade

per week assisting students during class times. These LAs were formally coached in the art of pedagogy by RLC, and each one of them received a total of 1500 USD for the 14 weeks of instructions. Thus, for a meagre monetary overhead of 7500 USD (split among the university and the department), our flipped offerings in 2016 and 2017 resulted in student–guide ratios of 22 and 18.5, respectively.

3.3. Flipping in a lecture hall

While an instructor should ideally have access to an active learning facility for a flipped offering [12, 13], the capital cost associated with construction of such facilities—especially the ones that can accommodate 100's of students—means this is not always possible. We faced this very challenge for our flipped offerings at Rutgers. Rather than being deterred by it, we retooled our flipped offerings for large lecture halls. This retooling involved: (*i*) reserving a lecture hall for the flipped classroom whose capacity was at least twice the maximum expected course enrollment, (*ii*) dividing the lecture hall into contiguous groups of three rows each, and (*iii*) prohibiting students from sitting in the middle row of each group of rows. These empty middle rows enabled the instructor and the LAs to freely roam around the lecture hall, be able to physically approach all students, and assist them during in-class activities (see Fig. 2). While such a seating arrangement cannot be considered a replacement for an active learning facility, in which students themselves can also roam around and can utilize resources such as computers and writing boards, mid- and end-of-semester feedback from students suggested that the solution was an effective compromise between idealism and realism.

4. COURSE ORGANIZATION AND LEARNING OUTCOMES

Our flipped offerings of the signal processing class physically met for 80 minutes each at 8:40 a.m. on Mondays and Thursdays. In addition, enrolled students were divided into three recitation groups, with each group attending one 80-minutes recitation (led by the GTA) per week. There were three main categories of activities within this offering that fundamentally differentiated it from a traditional offering (see Table 1 for a bird's-eye view of these activities). These categories, referred to as *home activities*, *in-class activities*, and *recitation activities* in the offerings' parlance, accounted for 29% of a student's final grade. In order to achieve the learning objectives, which included comprehensive understanding of sampling theory, discrete-time processing of continuous-time signals, discrete Fourier transform, spectral analysis, and design of digital filters, we organized the three sets of course activities as follows.

4.1. Home activities

The category of home activities comprised tasks that students were required to complete outside the classroom. These tasks, the graded portion of which accounted for 7% of a student's final grade, were further subdivided into three groups. First, the students were regularly assigned *video lessons*, ranging in total duration from 30 to 70 minutes, and *textbook reading* that had to be watched and completed, respectively, before each class period. Second, each set of assigned video lessons and textbook reading was associated with an *online assessment* on a course management system (CMS) that the students had to complete by 7 a.m. on the day of the respective class. These online assessments comprised the simplest of short-answer, true-false, and multiple-choice questions and served as one of the main motivating factors for the students to watch the assigned videos and complete the assigned reading. There were two other aspects of the online assessments that gave students the opportunity to remedy some of the shortcomings in their understanding of the covered material. These involved giving ample time to the students to complete an online assessment (typically, an average of three to five minutes per question) and allowing students to retake an online assessment (with a different set of questions) in the case of unsatisfactory performance on the first attempt. Our flipped offerings in 2016 and 2017, respectively, had a total of 20 and 21 online assessments, which accounted for 67% and 59% of the grade for home activities. The final group of tasks that constituted home activities mostly consisted of paper-and-pencil exercises meant to reinforce students' understanding of the course material.

4.2. In-class activities

We divided each 80-minutes class period into two components. The first component, which typically lasted for 10–15 minutes, was used for a brief review of key concepts covered in the assigned video lessons. The second component, which covered the remaining class time and accounted for 15% of a student's final grade, comprised activities that helped students reflect on their understanding of the assigned video lessons and enabled us to take real-time remedial actions in response to widespread confusions. To this end, these activities were split into two categories, namely, *polling questions* and *paper-and-pencil exercises*. The polling questions part of in-class activities involved sequentially displaying short conceptual questions to students on a presentation slide and recording students' responses in real time using an online polling platform. (We used *Poll Everywhere* platform [19] in the class, which allows participants to respond using mobile devices.) The paper-and-pencil exercises part of in-class activities involved sequentially assigning longer problems to students and collecting students' works on loose sheets

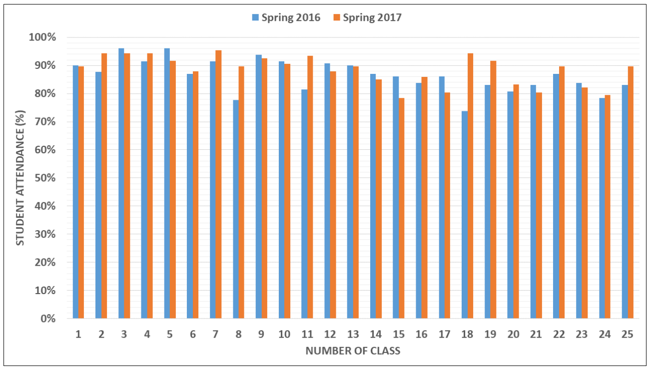

Fig. 3. The percentage of students attending each class period; average attendance = 86% (2016) and 88% (2017).

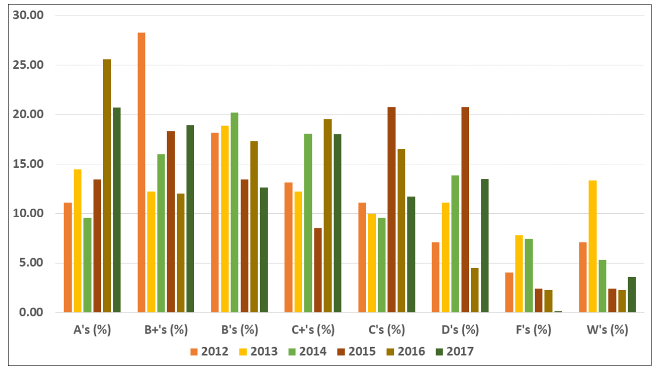

Fig. 4. Grade distributions for ECE 346 over six years (2012–2017).

of paper. A typical class period consisted of 2–5 polling questions and 1–3 paper-and-pencil exercises, with each polling question worth two points, each exercise worth anywhere between four and twelve points, and the students guaranteed 25% of the points for attempting an activity. The five LAs and we helped the students during each ongoing activity by roaming around the lecture hall and providing cues to struggling students. This looking over the shoulder of students and, in the case of polling questions, instantaneous access to students' responses gave us real-time insight into students' understanding of the covered material. This insight, which is one of the most important differences between a lecture-based offering and a flipped classroom, was then used to deliver a focused set of clarifying instructions to students at the end of each activity.

4.3. Recitation activities

Each one of the three recitation groups in the class attended one weekly 80-minutes recitation period led by the GTA. The activities in these weekly recitations were designed to enhance students' problem-solving skills. To this end, each recitation period was divided into two components. The first component, which typically lasted for 30–35 minutes, involved the GTA solving 3–5 problems on a chalkboard that reinforced the concepts covered in the last two sets of video lessons. The second component, which primarily distinguished the recitations in the flipped offering from those in a traditional offering, covered the remaining recitation period and accounted for 7% of a student's final grade. In this component, students were sequentially assigned 3–5 paper-and-pencil problems that specifically helped them master the *mechanics* of problem solving.[3] The students were given anywhere between four and ten minutes to solve each one of these problems on loose sheets of paper, with each problem worth anywhere between four and ten points. Further, the students were guaranteed 25% of the points for attempting a problem. The GTA, after assigning a problem to the students, roamed around the recitation room and helped students struggling with the problem. In addition, the students were encouraged to discuss the problems among themselves. Finally, the GTA capped off the assigned problems with collection of students' works and brief discussion of solutions of the problems.

4.4. Learning outcomes

The preceding discussion makes it abundantly clear that our flipped offerings were substantially different from a traditional lecture-based offering. *But did they result in better learning outcomes for the students?* Unfortunately, there are too many variables that affect students' learning abilities and a definitive answer cannot be given for this question without having the ability to control these variables. Some of these variables include students' academic preparation and command of pre-requisite material, their learning styles, their work habits, and their intellectual abilities. Since none of these variables could be controlled in our flipped offerings, only anecdotal evidence from the perspective of the instructor can be provided to ascertain the effectiveness of our flipped offerings.

There are four data points from our perspective that seem to suggest that our flipped offerings were a success. First, the number of students attending each scheduled class period (see Fig. 3) as well as the general body language of the students seemed to suggest the students were—on average—much more engaged in the flipped offering compared to our previous four traditional offerings. Second, the students' performance on in-class activities as well as the depth of their in-class queries suggested that the students internalized the course material better than in our previous offerings. Third, the sophistication of students' term projects in the flipped offering, on average, exceeded that of the projects in our traditional offerings. A possible explanation for this improvement is that students enrolled in the flipped classroom mastered the material better than in previous years. Finally, it used to be relatively straightforward for us in previous years to map students' numerical grades to letter grades. But the assignment of letter grades in the flipped offering became quite a chore due to the lack of significant gaps in the distribution of students' numerical grades. A possible explanation for this phenomenon, which has also been pointed out in [12], is that fewer students were being left behind in terms of their understanding as part of the flipped offering. In particular, the most noticeable aspects of our flipped offerings—in comparison to the previous four years—are the higher percentages of A grades and the lower combined percentages of D, F, and W grades; see Fig. 4 for grade distributions of our offerings from 2012 to 2017.

5. CONCLUSION

In this paper, we presented evidence that suggests large classes can be flipped at a fraction of the time, cost, and infrastructure overhead typically associated with flipped learning. We also discussed the effectiveness of these offerings in terms of learning outcomes from an instructor's perspective. Both the offerings also included comprehensive mid-semester and end-of-semester student surveys, excluded here due to space constraints, which also suggest the effectiveness of these offerings from students' perspective. We refer the reader to [17] for these survey results from the 2016 offering.

[3]This should be contrasted with the in-class paper-and-pencil exercises that focused on students' basic understanding of the course material.

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