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JUNE 22 - 26, 2020 #ASEEVC
Paper ID #29674

Student performance in partially flipped ECE laboratory classes

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Abstract

The flipped classroom is a relatively new pedagogical method that is based on outside-of-class video lectures and practice problems as homework, as well as active group-based activities in the classroom. This paper describes the partial flipping of two electrical and computer engineering laboratory courses and evaluates the students' performance under the flipped teaching approach. The primary motivation that drove the first author to flip these classes was the desire to tailor class time to students' needs, questions, and experimentation. Both partially-flipped courses are composed of equally challenging modules that cover different topics in digital signal processing and electronic circuit design. This study utilizes data collected from the two courses over the period from summer 2018 to summer 2019. In this paper, we analyzed scores from homework assignments, quizzes, and lab reports to assess the performance of the students on flipped modules versus their performance on regular lecture modules. Lab report quality is an essential measure that can indicate how well the students learned the module topic and their ability to interpret and analyze the results of the experiments. Assessment of lab report scores comparing flipped versus traditional instruction found a significant difference in favor of flipped instruction in both courses. Student interviews were used to measure perceptions of flipped learning, with indications that students positively perceived flipped and active learning techniques.

1. Introduction

The benefits and effectiveness of active learning for student problem solving, conceptual gains, exam scores, and engagement are well established [1]–[5]. Despite the known benefits of active learning, lecture-based teaching in STEM is still the prevalent approach, with active learning, in general, propagating at a slow rate [5]–[7]. But, with advances in technologies and ideologies, online education has gained more popularity and acceptance among students. This acceptance has encouraged instructors in different disciplines to adopt flipped instructions in their classes [8]. The flipped classroom is not equivalent to merely online videos; instead, the key point is the interactive activities done during class time when the instructor and students are face-to-face. It is not substituting a video for an instructor. It is not working unsystematically and is not students spending the entire course period in front of a computer. It is not a student studying alone [9], [10]. Instead, flipped instruction is a student-centered, more-involved form of active learning that aims to increase students learning and the quality of activities during the class period. The flipped classroom is a relatively new pedagogical method that is based on outside-of-class video lectures and practice problems for homework, as well as active group-based activities in the classroom [11]. This type of instruction may seem risky, as it puts the responsibility on the students to finish lectures before class time. However, some techniques (e.g., reliability quizzes) can be adopted to make sure that students complete the video lectures before the class. Also, previous research (e.g., [11]) suggests that student learning is improved for the flipped compared to the traditional classroom.

Despite being widely used, the flipped classroom approach still lacks consensus on its definition. Generally, in the flipped classroom, events that have traditionally occurred inside the classroom now happen outside classrooms and vice versa [12]. Therefore, and according to Strayer [13], we can think of the flipped classroom as a type of blended learning. Accordingly, Bishop and Verleger [11] defined flipped classroom as interactive, group-based learning activities occurring inside the classroom and direct, computer-based individual instruction occurring outside the classroom. Milman [14] defines it as an approach that enables higher efficiency of lessons by transferring knowledge to students via videos as well as by discussions, group work, and application during class. Toto and Nguyen [15] articulated that the flipped classroom is an approach that increases active learning and provides opportunities for students to use their knowledge in class with the guidance of a teacher.

Also, despite the relative popularity, there remains insubstantial empirical evidence and scholarly research determining the effectiveness of the flipped classroom to achieve higher engagement and learning outcomes [8], [11], [16]–[18]. This motivates researchers to conduct studies to qualitatively and quantitatively evaluate the effectiveness of the flipped classroom in different disciplines. The flipped classroom literature varies greatly in methodological rigor. However, most of the findings are consistently encouraging [11]. Much of the existing research assessing the effectiveness of the flipped classroom in higher education contexts (a) compares a flipped course to previous, more traditional iterations [19]–[21] (b) utilizes pre-post designs assessing changes from the beginning of the flipped course to the end [22]–[24], or (c) focuses on student perceptions and satisfaction with the flipped approach [25], [26]. In this paper, we present our study of the performance of students in two partially flipped electrical and computer engineering (ECE) classes, where we compare students' performance in the flipped modules to those in the non-flipped modules. This comparison enabled us to evaluate the potential impact of flipped instruction on student learning within a single course offering. Also, we studied the students' perspectives on flipped learning and the activities conducted during class time.

The elements of flipped classroom generally include (a) an exposure to the content prior to the class meeting, (e.g., video lectures), (b) a motivator for students to prepare for class, (e.g., pre-class or accountability quizzes), (c) a method to assess student understanding, (e.g., graded accountability quizzes), and (d) higher-level cognitive in-class activities that involve active learning, peer learning, and/or problem-solving [16]. In this study, we used short videos and pre-lab assignments, as well as accountability quizzes to present the material and motivate the students, respectively. Problem-solving, group discussions, and one-on-one student-instructor discussions were adopted as in-class activities. Finally, for the assessment of student learning, we used graded homework assignments, quizzes, and lab reports to assess the performance of the students on flipped modules versus their performance on regular lecture modules.

The various assessment and data analysis methods used in this paper to demonstrate the outcomes of the active learning are introduced and referenced in the Methods section, including methods for statistical analysis, qualitative data analysis, and structured classroom observation. Quantitative analysis of students' scores in flipped vs. non-flipped (regular) modules are presented and discussed in the results section. Also, student perspectives on the benefits and drawbacks of flipped classrooms are analyzed and discussed in the results section.

2. Course Description and Classroom Instructional Activities

Due to their nature, ECE laboratory courses are well suited for flipping. In this research, we partially flipped digital signal processing (ECE-1563), and electronic circuit design (ECE-1212) laboratory classes. The primary motivation that prompted the first author to flip these classes was the desire of tailoring class time to students' needs, questions, and experimentation. Each course is composed of equally-challenging modules throughout the course; therefore, we assessed the performance of the students on the flipped versus regular lecture modules within each course using homework assignments, quizzes, and lab reports.

The two courses provide hands-on experience in digital signal processing analysis and electronic circuit design, respectively. Both are junior/senior-level required courses for students pursuing a BS degree in electrical engineering (EE). Also, computer engineering (CoE) majors can enroll in either of these courses as a technical elective. The six lab modules covered in ECE-1212 included the following: frequency response of operational amplifiers, analog computation circuits, design of active filters, design of single- and multi-stage amplifiers, digital-to-analog conversion, and analog-to-digital conversion. In ECE-1563, sampling and reconstruction, system analysis using z-transforms, discrete-time Fourier analysis, discrete Fourier series and transforms, and design of digital filters were the main topics constituting four of the laboratory modules. For ECE-1212, three out of six modules were flipped in the summer semester of 2018 versus four modules in the summer semester of 2019. In the spring of 2019, the last two (out of four) modules in ECE-1563 were flipped. The amount of flipped material in ECE-1212, therefore, varied from one semester to another and was driven by student feedback and needs.

The video lectures for the flipped modules were recorded in the media lab at the University's Center for Teaching and Learning and were uploaded to the Panopto platform. The links to the videos were then posted on the class website. For ECE-1212, the video length ranged between 10 and 25 minutes, and for ECE-1563, the videos were 7 to 15 minutes long. Students were instructed to watch the videos before class time. In ECE-1212, students were required to submit a pre-lab homework assignment based on the materials they learned from the videos, where in ECE-1563, accountability quizzes were used. The accountability quizzes were mainly multiple-choice questions and were conducted using the course website (Blackboard). Therefore, students were able to get immediate feedback on their performance on that quiz.

During class, several active learning techniques were used. In ECE-1212, think-share, think-pair-share, one-on-one discussions, and group discussions were adopted to reinforce the materials in the videos and to supplement information needed when executing the lab experiment or writing the reports. The main goal of group discussions was to stimulate student thinking on how to analyze and implement the design circuits and discuss potential problems that may arise due to violation of simplifying assumptions. During the second part of the class, the students formed groups of two for analyzing and implementing the lab module. At that time, the instructor (i.e., first author) circulated around the classroom and observed the teams as they worked and also interacted with each team individually in a learner-centered fashion. The interactions with each team focused on their design evaluation, challenges they had, and achievement of the learning outcomes for their experiment. Also, these interactions enabled the instructor to assess student learning of the theory and to collect students' questions and concerns. Finally, after receiving all the students' concerns and questions, the instructor led another class discussion to address the concerns and questions. In ECE-1563, similar techniques to that in ECE-1212 were used as well as extended problem solving to practice the math of digital signal processing.

3. Assessment Methods

Various forms of assessment were conducted to determine the impact of partial flipping, including direct and indirect assessment of student performance and affective assessment that involved student perspectives on flipping and active learning.

3.1. ***Methods: Direct Assessment of Student Performance***

Since a portion of the material in each course was flipped, it was possible to compare student performance with the flipped versus non-flipped material within each course. Various assignments were assessed in each course for this comparison. For ECE-1212 (Electronic Circuit Design Lab), quizzes, pre-lab exercises, and lab reports were evaluated. This evaluation was done during two semesters (i.e., summer 2018 and summer 2019) for a combined sample size of n=35. For ECE-1563 (Signal Processing Lab), quizzes, homework assignments, and lab reports were assessed for one semester (i.e., spring 2019), with a sample size of n=35. The grader remained the same throughout the semester for each type of assignment in each course, and rubrics were used when grading all kinds of assignments (i.e., quizzes, homework, pre-lab exercises, and lab reports). The flipped and non-flipped materials in each course were of approximately-equal difficulty levels.

The comparisons within each course (i.e., non-flipped vs. flipped material) were done using paired samples t-tests as well as Glass' Delta effect sizes. In addition, the non-parametric analog to the t-test, the related-samples Wilcoxon signed-rank test, was run to corroborate the results of the t-test given the smaller sample sizes [27]. Glass' Delta effect sizes were calculated to determine the practical significance of the differences, with values below 0.50 considered small and values of 0.80 or above large [28], [29]. Glass' Delta is often used in the case of paired samples [30].

3.2 Methods: Assessment of Student Perspectives

Student perspectives on the use of simple active learning and flipped instruction were obtained in each course by conducting individual, semi-structured student interviews during class time. Participation in the interviews was voluntary. Human subjects' approval (PRO18060710) was secured for these various forms of student assessment. The interview questions used by the assessment analyst (i.e., second author) in both courses are shown in Table 1. For each item, the data from the two courses were combined to increase the sample size associated with each question. For the first question, 32 interview responses were collected and analyzed. For the second question, 33 responses were collected, and content analyzed.

A content analysis of the student interview responses was completed by two analysts to drive reliability [31]. The analysts independently content-analyzed the responses using coding schemes developed as part of previous research [32]–[34]. The analysts then discussed each response and the codes assigned to ensure consensus; thus, all responses were double-coded. For the first interview question in Table 1, the first-time inter-rater reliability score for the analysts indicated strong agreement beyond chance at Cohen's $\kappa = 0.86$ [27]. In coding the interview question about students' flipped classroom perspectives, the coding of the benefits resulted in a first-time inter-rater reliability score of $\kappa = 0.73$, indicating good agreement beyond chance [27]. The coding of the drawbacks resulted in $\kappa = 0.81$, indicating strong agreement beyond chance [27].

Table 1: Interview Questions

In this class, the instructor asks you to complete activities, discuss items, and in general participate. Can you discuss the impact of this instructional style on your learning and development?
In this class, the instructor asked you to do some learning on your own outside of class and then come to class prepared for hands-on work. Discuss your thoughts on this instructional method relative to learning and satisfaction.

4. Results and Discussion

4.1 Direct Assessment of Student Performance

4.1.1. ECE-1212 (Electronic Circuit Design Lab)

In ECE-1212, a significant difference was found for the lab reports when comparing the performance with the non-flipped versus flipped material. This difference was statistically significant based on both the parametric and non-parametric paired samples tests ($p<0.0005$ for each test), as shown in Table 2. The effect size was medium at Glass' Delta = 0.650. The differences in the other assignments (quizzes and pre-lab exercises) were not statistically or practically significant. When flipped instruction was used, there was more in-class time to discuss the experiment, the procedure, and the variability in results, potentially contributing to the significant change in lab report scores. Also, the instructor had more time to spend with each team individually, which may have also added to writing better lab reports, especially since most of the lab report grade focuses on interpretation and discussion of the results.

4.1.2. ECE-1563 (Digital Signal Processing Lab)

In ECE-1563, significant differences were found for the quizzes and lab reports in favor of the flipped method of instruction compared to the non-flipped approach. For quizzes, the difference was significant, based on both the paired samples t-test (p<0.0005) and its non-parametric analog (p=0.001), with a medium effect size of Glass' Delta = 0.605, as shown in Table 3. For lab reports, the difference was significant, based on both the paired samples t-test (p=0.005) and the non-parametric analog (p=0.009), with a medium effect size of Glass' Delta = 0.498. Recall that the difference in lab report scores was also significant for the other course (ECE-1212) in favor of flipped instruction. As in ECE-1212, there was more in-class time to discuss the experiment with the use of flipped teaching, possibly enhancing the lab scores. With the flipped instruction in ECE-1563, a portion of the class time was also used to solve additional problems, which likely improved the quiz scores. The instructor recalled that some students liked the quality of the flipped-instruction videos, were able to study the math content at their convenience and repeated the videos until the concepts were clear.

Table 2: ECE-1212 Comparisons

	Mean Score		***p***		**Effect Size**
	Non-flipped material (n=35)	Flipped material (n=35)	Paired Samples t-test (parametric)	Wilcoxon Signed Rank test (non-parametric)	Glass' Delta
Quizzes	7.66	7.66	0.98	0.87	0.005
Pre-lab exercises	9.01	9.03	0.87	0.49	0.021
Lab reports	89.63	93.75	<0.0005	<0.0005	0.650

Table 3: ECE-1563 Comparisons

	Mean Score		***p***		**Effect Size**
	Non-flipped material (n=35)	Flipped material (n=35)	Paired Samples t-test (parametric)	Wilcoxon Signed Rank test (non-parametric)	Glass' Delta
Quizzes	5.40	6.58	<0.0005	0.001	0.605
Homework	88.89	89.20	0.82	0.906	0.039
Lab reports	87.99	90.63	0.005	0.009	0.498

4.2 Assessment of Student Perspectives

4.2.1. Active Participation during Class

Based on a content analysis of the first interview question in Table 1, which gathered students' perspectives on being active and participatory during class, the vast majority of interviewees (81%) had a positive perspective on this. The most frequently-stated aspect of this positive experience for students was the in-class problem solving, practice, application, requests to think, and other activity, as stated by 81% of respondents. The ability to talk to and communicate with other students and/or the instructor during class, as well as the teamwork associated with an in-class active approach, were each stated by 16% of interviewees as a positive experience. Finally, thirteen percent (13%) of interviewees stated each of the following as positive aspects of this teaching approach: 1) promotion of liveliness, engagement, or attentiveness during class, and 2) repetition or reinforcement of material, sometimes aiding memory or leading to clarification of difficult material. These results are in line with the significant difference in the lab report scores in the two classes. With more communication and interactivity, students were able to ask specific questions, communicate their interpretations, and receive feedback from instructor and peers. This likely helped them to write clear explanations and discussions of their results in the lab report.

Table 4: Summary of Interview Responses Related to Flipped Instruction

Course	ECE-1212 (summer 2018)	ECE-1212 (summer 2019)	ECE-1563 (spring 2019)
Total Interview Responses	**12**	**16**	**23**
Benefits discussed	**8**	**15**	**20**
Alternative use of class time	5	8	6
Preparation, engagement & professional behaviors	3	4	1
Enhanced learning or learning processes	3	4	3
Convenience & flexibility	5	8	18
Drawbacks/Suggestions discussed	**6**	**2**	**11**
Don't use prefer flipped instruction or don't prefer	3	2	5
How class time used	0	1	2
Increased time, work, or stressors	1	0	1
Challenges with video-based learning	3	0	7
Benefits and Drawbacks both discussed	**2**	**1**	**8**

4.2.2. Flipped Style of Instruction

A content analysis of the second question in Table 1, which gathered students' perspectives on the flipped style of instruction, is presented in Table 4. Among the 51 student responses, 43 discussed the benefits of this type of teaching, and 19 discussed drawbacks or suggestions, with eleven responses discussing both benefits and drawbacks/suggestions. Students' mention of benefits was approximately equally distributed between the two courses. The most frequently-stated benefit to the flipped style was the convenience and flexibility of learning via videos, stated by 31 of 43 (72%) respondents who discussed benefits. Thus, students were able to reference the video lectures and learn the materials at their own pace. Alternative use of class time, including in-class problem solving, active learning, asking questions, one-on-one instructor support, and teamwork was stated by 19 of 43 (44%) respondents who discussed benefits. Almost one-quarter of responses (10/43) discussed enhanced learning or learning processes associated with flipped instruction. The least-frequently-stated benefit was the preparation, engagement, and professional behavior promoted by the flipped classroom, as stated by eight of 43 (18%) who discussed benefits. These benefits are summarized in Table 4. These results show that the flipped classroom was accepted by the majority of students, as it gave them flexibility and convenience in learning as well as engaging class activities that fostered their understanding of the topics.

More students in ECE-1563 discussed drawbacks/suggestions (i.e., 11 students) versus in ECE-1212 (i.e., 8 students in two semesters). Of the 19 responses that discussed drawbacks or suggestions, ten (~53%) indicated that flipped instruction should not be used or that students did not prefer it. Of the ten responses that indicated flipping should not be done, five were given by students in ECE-1563 (Spring 2019), and the other five were associated with ECE-1212 and were distributed over two semesters. The same number of responses discussed the challenges with video-based learning outside of class (10/19), with the majority of the responses coming from ECE-1563 (7/10). This can be understood by the nature of ECE-1563, which has more theoretical content compared to ECE-1212. Therefore, some students may prefer to have the theoretical basis presented in a traditional lecturing fashion to ask immediate questions rather than watching the videos. The other frequent drawbacks or suggestions were related to how in-class time was used in the flipped classroom (3/19); and the increased time, work, or stressors associated with flipped learning (2/17).

5. Conclusions

The flipped classroom has gained popularity in the past few years among different institutions, as it includes a more intense method of active learning and engagement. In this study, we evaluated the student performance in two partially-flipped ECE, and we determined students' perspectives on this approach of learning and on the class in-activities that were used in lieu of the traditional lecture. The direct assessment of student scores showed significant improvement in the report and quiz scores, which we believe was strongly correlated with the increased interaction and problem solving during class time. The student perspectives on video-based learning were also encouraging. However, due to the relative novelty of student-centered learning for many students, resistance to the flipped classroom approach may still occur, as we found from our interview results. This resistance may result in lowered participation in class activities, a belief that the course is disorganized, and/or increased feelings of stress to complete the work. Also, the results suggest that a proportion of students may tend to resist the flipped approach due to their preferences for lecture in-class as opposed to pre-class (i.e., via video). However, this should not discourage instructors from flipping their courses and evaluating them appropriately.

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