Progressive Use of Active Learning in Electrical Engineering Courses

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Abstract

This paper describes my progression as a junior faculty member and instructor in terms of the use of various student-centered and active-learning techniques in electrical engineering (EE) lab courses. These techniques range from simple to more-involved techniques, and my objectives ranged from increasing interactivity during class to tailoring class time to students' needs and questions. These various techniques include think-share, think-pair-share, observe and comment, group discussion, and the flipped classroom. Active learning has been shown to be more effective than passive learning within a traditional lecture setting. In my courses, these methods have shown increased student understanding of the differences between mathematical models and physical realizations of systems. Adding active learning exercises to these laboratory courses has also increased interactivity among the students and addressed student difficulties in ways that are effective and generally enjoyed by the students. Additionally, an active learning workshop in the summer of 2018 motivated me to use more involved active-learning techniques, including the flipped classroom and inductive learning. Consequently, I flipped the last two modules of an electronic design laboratory in the summer as well as a signal processing lab in the fall of 2018. The effectiveness of these advanced techniques was formally assessed by comparing student work before and after the implementations, and these preliminary results will be discussed. Surveys and interviews were used to measure student perceptions of the teaching techniques, and these results will also be discussed, with promising indications these techniques were positively perceived by the students.

1. Introduction: Literature Review and Instructor Background

The benefits and effectiveness of active learning for student problem solving, conceptual gains, exam scores, and engagement are well established [1]–[5]. Active learning is defined as in-class work by students that goes beyond simply listening to the instructor and taking notes [6]. 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], [8]. For example, in electrical and computer engineering (ECE) departments, where the courses in the present paper are housed, a survey of U.S. faculty indicated that only 30% at the time were utilizing the very accessible and simple think-pair-share (TPS) technique that drives analysis and interactivity, with 54% of ECE faculty members having abandoned use of the technique after trying it [9].

Active learning is a learner-centered strategy, as students in a learner-centered environment, students are expected to *engage* with their learning and practice their skills [10], [11]. Another aspect of a learner-centered environment is sharing of power, whereby students can make some of the decisions related to their coursework [12]. For example, when feasible, students might be asked to set deadlines, identify assignments or content, or determine policies and procedures [12], [13]. Sharing control with students can positively influence their motivation and engagement [10], [14]. In one of the courses discussed in this paper, students were asked to vote on whether they wanted a flipped or traditional classroom, and this question was asked several times throughout the semester. On each occasion, the course proceeded according to the student vote. The instructor took this approach based on student feedback received after using flipped modules during the previous semester.

The various assessment and data analysis methods used in this paper to demonstrate the outcomes of the active learning will be introduced and referenced in the Methods section, including methods for statistical analysis, qualitative data analysis, and structured classroom observation. In addition, much has been written in the literature about the mixed nature of exam results with versus without various active learning techniques, in particular the flipped classroom, although other benefits may result [15], [16]. As will be discussed further, our preliminary exam results thus far have not shown definitive improvement, although students have qualitatively identified benefits with learning in an active environment.

Instructor Background

As an instructor, my adoption and use of various active learning techniques have progressed in time and complexity, starting with my career as a graduate-student instructor. My use of active learning started naturally, out of a need to focus students and drive their practice of the material. I started with and continue to use simple class activities so students better understand the concepts presented and gain self-confidence by sharing their thoughts and solutions with the rest of the class. Through various faculty workshops, I have gained additional perspectives on the use of active learning in the classroom, and this use of active learning has progressed and expanded, including from simple to more involved techniques, such as flipped instruction. Most recently, with the desire of increasing interactivity in my electrical engineering courses through the use of active learning, I joined a community of practice in my department that involves one-on-one mentoring and coaching of multiple instructors by two other faculty members to drive and support the implementation of active learning throughout the school. One of the coaches (i.e., second author) received an internal grant award from the Provost's Office to propagate active learning in the engineering school through this one-on-one mentoring and coaching approach. This community-of-practice and mentoring approach in the propagation of active learning has also been used elsewhere, with noted benefits [17].

During my first experience in teaching (and in the use of active learning), I taught a course with 70 students as a graduate student on microprocessor interfacing. Given the large number of students, I noticed that some started to lose their focus. As a result, I adopted a think-share method to increase student focus and involvement. Furthermore, I invited students to summarize the key points of the lecture at times or lead their peers in solving practice problems. Later, during my first semester as an assistant professor, I used similar activities, and the feedback from the students was positive and encouraging. Meanwhile, I started to attend several workshops on teaching and active learning methods. In my second semester as an assistant professor, I taught a laboratory class on signal processing. I implemented basic active learning techniques in this course and likewise received promising feedback from the students. However, given the nature of the class, I concluded that class time could be better utilized by one-on-one discussions with students to tailor the laboratory time to individual student needs. That was the first time I had thought of implementing a flipped classroom for signal processing, in which students could review material before class and

I could then address questions and follow up with individual students during class. That idea was solidified by my attendance at an in-house active learning workshop in the summer of 2018. The instruction offered at the workshop motivated me to implement the flipped classroom and more advanced active learning techniques in two courses offered in the summer and fall semesters of 2018.

2. Introduction: Course Descriptions and Classroom Instructional Activities

These two courses in which I implemented more-advanced active learning techniques (ECE-1212: Electronic Circuit Design Laboratory and ECE-1563: Signal Processing Laboratory) provide a hands-on experience in electronic circuit design and digital signal processing analysis, respectively. Both are junior/senior level required courses for students pursuing a BS degree in electrical engineering (EE). In addition, computer engineering (CoE) majors can enroll in either of these course as a technical elective. The lab modules covered in ECE-1212 include 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 are the main topics constituting four of the laboratory modules.

Several active learning techniques were used in these courses. In ECE-1212 (Electronic Circuit Design Lab), think-share, think-pair-share, one-on-one discussions, group discussion, and flipped modules were used throughout the summer semester of 2018. In ECE-1563 (Signal Processing Laboratory), one-on-one discussions, group discussion, and flipped instruction was used throughout the fall semester of 2018.

ECE-1212 For the first four (out of six) modules in ECE-1212, class began with a short presentation, during which the necessary background for the lab module was reviewed. During that presentation, I asked challenging questions and implemented think-share and think-pair-share activities with them. Group discussions were also implemented 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 class, the students formed groups of two for analyzing and implementing the lab module. At that time, I circulated around the classroom and observed the teams as they worked and 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 me to assess the student learning of the theory and to collect students' questions and concerns. Finally, after collecting all the students' concerns and questions, I led another class discussion to address the concerns and questions.

For the last two modules of ECE-1212, flipped instruction was adopted. A 25-minute video lecture was recorded for each module, and the students were asked to watch those videos and take notes before attending the class. Thereafter, during the first 30 minutes of class, I briefly reviewed the concepts from the video lecture and answered students' questions. The rest of the class was organized in a similar manner to that of the first four modules (i.e., team discussions, instructor-team discussions, and class discussion). It is worth mentioning that the video lectures 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.

At the end of each experimental module in ECE-1212 and regardless of the teaching style used, each group was asked to share their design and performance analysis. All responses were collected in one shared document such that each team could view other teams' designs and results. I then led a reflective debriefing class session to highlight the differences between the different designs, the discrepancies between results, and the factors that may have affected circuit behavior.

ECE-1563 Given the feedback from ECE-1212 on the flipped classroom, I was encouraged to use the same technique in another class, ECE-1563, during the fall semester of 2018. However, since flipped instruction was not the preferred learning approach for some of the students in ECE-1212, I decided to conduct an anonymous vote on which teaching method the students preferred (i.e., traditional vs. flipped). Before taking the votes, the two methods were briefly described to the students, and the pros and cons of each teaching style were clearly stated. Seventy percent (70%) of the votes preferred the flipped style so that style was adopted for ECE-1563 in a learner-centered fashion.

The videos used in ECE-1563 were obtained from a distance learning course on the same topic that was offered by the instructor's department in 2015. The material on the video lectures was similar to what I would cover in regular offerings of ECE-1563. The students were asked to watch two 45-minute video lectures per module. Each module took on average 3 to 4 weeks to be completed. Similar class activities to those used in the last two modules of ECE-1212 were applied for all modules of ECE-1563.

After one month and at another time mid-way through the fall semester, I conducted additional anonymous surveys to determine whether the students wanted to continue the flipped instructional method or preferred conventional lecturing. The one-month vote resulted in 63% of the students preferring to continue with the flipped instruction. However, from the one-on-one interaction activities, I recognized that some of the students were lagging behind because they had not watched the videos. Accountability quizzes were implemented, but problems in student understanding of the difficult material were still apparent. Therefore, to address this issue, conventional lectures were occasionally given to reinforce the core course concepts at various points in the latter half of the semester.

3. Assessment Methods

Various forms of assessment were conducted to determine the impact of the active learning techniques, including direct assessment of student performance, indirect and affective assessment involving student perspectives, and classroom observation.

3.1 Methods: Assessment of Student Performance

To directly assess student performance associated with the course changes, final exam scores were compared between semesters of each course. The final exam provided a particularly strong comparison, since the exam itself, the grader (i.e., instructor), and rubric remained the same across semesters. An analysis of covariance (ANCOVA) was conducted for the comparisons, with GPA at the start of the semester used as the control variable to take historical academic performance into account. Since the sample size was small (n=12) for certain comparisons, the non-parametric version of ANCOVA, known as Quade's test, was also run in those cases [18], [19]. The p-values based on the parametric and non-parametric analyses were generally in agreement, and examining both served to corroborate the results. Nonetheless, when run, the non-parametric result was used as the default. In addition, Cohen's d or Hedge's g effect sizes were calculated to determine the practical significance of the differences, with values below 0.50 considered small and values 0.80 or above large [20], [21]. Hedge's g is used for small samples [22].

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. 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 question, the data from the two courses was 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.

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.

A content analysis of the student interview responses was completed by two analysts to drive reliability [23]. The analysts independently content-analyzed the responses using coding schemes developed as part of previous research [15], [24]. 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 $\kappa = 0.86$ [25]. For the second question in Table 1, their agreement was good at $\kappa = 0.72$.

3.3 Methods: Classroom Observation

To assess the degree of active learning and interactivity during class time, the second author (i.e., assessment analyst) observed multiple class sessions of each course using the COPUS, or Classroom Observation Protocol for Undergraduate STEM [26]. Additional reasons for using the COPUS included the opportunity for very detailed and accurate formative feedback between the assessment analyst and the instructor as well as objective documentation of classroom occurrences and behaviors, both on the part of students and the instructor. The highly structured nature of the COPUS contributes to these benefits. With the COPUS, the class period is segmented into two-minute observation windows. For example, a 75-minute class has 38 observation segments. In each segment, the activities of the students and instructor, as given in the COPUS protocol, were recorded when observed. Thus, the percentage of segments with activities such as student questions and responses, active group work, and one-on-one instructor-student discussion could be calculated. The second author had used the COPUS protocol in previous assessment activities and achieved inter-rater reliability scores of $\kappa = 0.83$ and $\kappa = 0.96$ with other analysts, indicating her reliability in terms of strong agreement with other analysts [25].

4. Results

4.1 Results: Assessment of Student Performance

For each course, the assessment analyst compared the average final exam scores between semesters, with the latter semester containing additional elements of in-class activity and/or interactivity.

<u>ECE-1212 (Electronic Circuit Design Lab</u>) The interactivity with students and the linkage between theory and practice were higher in the latter semester (summer 2018), as more active learning, including flipped instruction, was used that semester. For ECE-1212, the final exam score for the more-active and interactive semester was somewhat lower as shown in Table 2, although not significantly so ($p = 0.12$) based on the non-parametric Quade's Test. The effect size was medium at $g = -0.55$. Although this aspect of the assessment does not show an improvement at this point, these results are also based on relatively small sample sizes at this point.

Table 2: Final Exam Score Comparisons in ECE-1212 (/100)

Adjusted Mean Score		***p***		**Effect Size**
Summer 2017 (*n*=22)	Summer 2018 (Increased Active/ Interactive) (*n*=12)	ANCOVA (parametric)	Quade's Test (non-parametric)	Hedge's *g*
78.2	72.6	0.13	0.12	-0.55

<u>ECE-1563 (Signal Processing Lab)</u> The flipped classroom format was used for most of the semester, in accordance with the student vote. As in ECE-1212, the final exam score for the semester with the flipped instruction was somewhat lower as shown in Table 3, although not significantly so ($p = 0.18$) based on the parametric ANCOVA. The effect size for the difference was also small at $d = -0.33$. Again, this aspect of the assessment is preliminary and has the potential to change with increased data.

Although the final exam scores were lower in classes with increased active learning, as has been described by others in the literature [15], [16], the discussion section in the lab reports submitted in these classes was superior to those submitted in the classes with little to no active learning activities. In summer and fall semesters of 2018, the students were able to write down solid and comprehensive discussions about their findings in each lab module. Moreover, their conclusions highlighted the shortcomings of simplifying assumptions and provided clear analysis for the discrepancies between their results and the expected results. However, the authors could not provide a quantitative measure for the report quality because different rubrics and different graders were used for different offerings of ECE-1212 and ECE-1563.

Table 3: Final Exam Score Comparisons in ECE-1563 (/100)

Adjusted Mean Score		***p***	**Effect Size**
Spring 2018 (*n*=38)	Fall 2018 (Flipped) (*n*=32)	ANCOVA (parametric)	Cohen's *d*
62.2	58.2	0.18	-0.33

4.2 Results: Assessment of Student Perspectives

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 great 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 was 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.

Flipped Style of Instruction A content analysis of the second question in Table 1, which gathered students' perspectives on the flipped style of instruction, produced mixed results. Among the 33 student responses, 18 discussed benefits of this type of instruction, and 17 discussed drawbacks or suggestions, with two responses discussing both benefits and drawbacks/suggestions. Students mentioning benefits were approximately equally distributed between the two courses, with eight in ECE-1212 and 10 in ECE-1563. The most frequently-stated benefit to the flipped style was the alternative use of class time, including in-class problem solving, active learning, questions and one-on-one instructor support, and teamwork, as stated by 10 of 18 (56%) respondents who discussed benefits. The next most-frequently-stated benefit was the preparation, engagement, and professional behavior promoted by the flipped classroom, as stated by nine of 18 (50%) who discussed benefits. One-third (6/18) discussed enhanced learning or learning processes associated with flipped instruction as well as the convenience and flexibility of learning via videos. These benefits are summarized in Table 4.

Of the 17 responses that discussed drawbacks or suggestions, nine (53%) indicated that flipped instruction should not be used or that it was not preferred by students. However, eight of these nine responses came from students in one of the courses (ECE-1563). More students in ECE-1563 discussed drawbacks/suggestions (i.e., 12 students) versus in ECE-1212 (i.e., 5 students). The other frequent drawbacks or suggestions were related to how in-class time was used in the flipped classroom (4/17); the increased time, work, or stressors associated with flipped learning (4/17); and challenges with video-based learning outside of class (4/17). These latter three drawbacks were fairly evenly-distributed between the two courses, unlike the drawback/suggestion related to not using flipped instruction (or not having a preference for it).

Table 4: Summary of Interview Responses Related to Flipped Instruction

Total Interview Responses	**33**	
Benefits discussed	**18**	
Alternative use of class time	10	56%
Preparation, engagement & professional behaviors	9	50%
Enhanced learning or learning processes	6	33%
Convenience & flexibility	6	33%
Drawbacks/Suggestions discussed	**17**	
Don’t use prefer flipped instruction or don’t prefer	9	53%
How class time used	4	24%
Increased time, work, or stressors	4	24%
Challenges with video-based learning	4	24%
Benefits and Drawbacks both discussed	**2**	

4.3 Results: Classroom Observation

ECE-1212 The assessment analyst (i.e., second author) observed ECE-1212 on two occasions during the summer 2018 semester containing the increased activity and interactivity. The assessment analyst observed this course for 152 minutes, or approximately 2.5 hours. After some initial lecture time, the students proceeded to work in groups on their lab-based problem assignment. Lecture occurred during just 20% of the observation segments. Student active work in groups occurred during 68% of the observation segments, as the instructor circulated among the students and had one-on-one conversations with them in approximately 57% of the observation segments. The interactivity was further highlighted by student responses to questions, with 18% of observation segments containing questions to students and 14% containing student responses. Students also asked questions or requested help in 45% of the observation segments, often as the instructor circulated to assist with the active learning.

ECE-1563 The assessment analyst also observed this course on two occasions during the fall 2018 semester with the flipped approach. She observed this course for 166 minutes, or approximately 2.75 hours. Although the course material was flipped and students were to watch videos outside of class, the instructor nonetheless lectured during 71% of the observation segments. This was in part due to the instructor’s assessment that the majority of students were not watching the videos as instructed. Although lecture did occur more than desired or expected, students still worked in groups on their lab assignments in 24% of the observation segments, as the instructor circulated and had one-on-one conversations with students in approximately 18% of the observation segments. However, in general throughout the course, lectures were limited to 40 minutes per session, and was in general dedicated to problem solving and demoing. The class met twice weekly for 110 and 170 minutes respectively.

5. Conclusions and Future Directions

As a junior faculty member teaching electrical engineering courses, I had the goal with this paper of describing my progressive use of active learning techniques so as to potentially inspire other faculty, in particular junior faculty, to do the same. I had used simple active learning as a graduate-student instructor and currently am using more advanced techniques and approaches, including the flipped classroom and learner-centered instruction. This progression has been supported and inspired by active-learning workshops as well as learning community participation. My involvement in a recently-formed learning community-of-practice has led to formal assessment and evaluation of my classroom efforts and ultimately publication of the outcomes via this paper. This assessment has shown our overall results at this point (i.e., student perspectives and performance) to be promising or on par with others' experiences and outcomes with the use of active learning, with our exam results still preliminary at this point. In addition, feedback data led me, in a continuous improvement fashion, to make changes with the Digital Signal Processing course (ECE-1563). In particular, I adjusted my approach to the flipped instruction in this course in the spring 2019 semester by pilot-testing newly-created custom videos for one of the topic areas – Fourier Analyses. The assessment analyst observed my spring 2019 classroom to offer formative feedback, interview students, and assist with evaluation of the custom videos – all as part of my community-of-practice involvement. In further extending the community of practice within our department, I shared my experience with fellow signals faculty. They agreed that lab classes in our department are well suited for the flipped style of instruction, and one of the faculty members actually decided to use flipped instruction in a programming course. We also discussed the possibility of flipping modules in non-lab based courses. The positive results from my own course revision of Digital Signal Processing will be discussed in my next publication on the use of active learning!

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