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Undergraduate Performance in Embedded Systems Technical Electives: Comparison of Course Pre-Requisite Format

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Introduction

The delivery format of courses at all levels lies on a spectrum with live face-to-face at one end, asynchronous virtual delivery at the other, and all other hybrid formats between them. One hybrid format along the spectrum is the flipped classroom. The flipped classroom ”inverts the traditional classroom model by introducing course concepts before class allowing educators to use class time to guide each student through active, practical, innovative applications of the course principles” [1]. The driving motivator of this approach is the potential to increase student learning of course materials and subsequent improvement in performance using and applying them.

To date, there has has been significant research evaluating if the flipped-class does lead to improved learning outcomes with survey's and meta-analyses of these works presented by Lo et al., [2] and Strelan et al. [3]. In the meta-analysis by Strenlen et al., the authors reviewed 198 studies across disciplines and levels (primary, secondary, tertiary) and concluded that flipping the classroom is likely to improve student performance with the strongest effects reported for humanities, teaching, and engineering disciplines [3]. Similarly, in their meta-analysis of 29 flipped engineering courses Lo et al. also concluded that the flipped classroom promotes student achievement in engineering education [2]. Specific to engineering education Lo et al. identified that the six major benefits of the flipped class were self-paced learning, multiple exposures to course materials, preparing students for class, more problem solving activities, peer-assisted learning, and instructor support [2]. Overall, these results support the use of the flipped class to improve student performance in engineering courses.

Within the electrical and computer engineering disciplines the flipped classroom approach has been used to teach electrical circuits for non-majors [4], microcomputers [5, 6], digital logic design [7], analog circuit design [8], and signals [9]. While this is not an exhaustive list of electrical and computer engineering related courses that have been flipped, it does highlight that this format of course is being implemented across domains in the discipline.

Often, the research on this topic evaluates student performance between sections of the same course that has been offered in different formats [6, 10]. This is incredibly useful for evaluating student learning during the course but does not provide details to evaluate if there are differences in long-term retention related to the course format. This provides the motivation for this research which explores how electrical and computer engineering students perform in subsequent computer engineering courses after taking the pre-requisite course in either a flipped-style or lecture format. The underlying hypothesis is that students who completed the flipped-style pre-requisite will perform better (e.g. have a higher course grade) in subsequent courses than their peers who completed the pre-requisite course in the traditional lecture style because of the previously discussed benefits of the flipped class.

To test this hypothesis, this study uses a retrospective analysis of student data from the University of Alabama. As some background, at the University of Alabama a microcomputers course has been delivered in two modalities (traditional lecture style and flipped-style) during the same semesters for multiple years. These courses cover the same topics and use the same laboratory experiments (but have different instructors, assignments, and tests). After completing this course students can take embedded systems and computer architecture technical electives in later semesters. These electives have only one section with a single instructor and are taught using a traditional lecture style. This provides an opportunity to evaluate if there are differences in students' performance in the later technical electives based on the format (traditional or flipped) of the pre-requisite microcomputers course students completed.

The specific research question (RQ) that this study aims to answer is:

- **RQ:** Did undergraduate electrical and computer engineer students who successfully completed a microcomputers course in a flipped-style / high-flex format perform better in subsequent computer architecture and embedded systems courses than their peers who completed microcomputers in a traditional lecture format?

This work will provide a quantitative comparison of student overall performance in the microcomputers course based on format and a comparison of student performance in the embedded systems and computer architecture technical electives when grouped by pre-requisite format. The following sections will provide a summary of the microcomputers course and delivery formats, the study methods, data, analysis, and subsequent discussion of the results. These details are expected to advance understanding of how pre-requisite class format (flipped-style vs. lecture) impacts performance in subsequent computer engineering courses.

Summary of Embedded Systems Courses at the University of Alabama

Undergraduate engineering students in the Department of Electrical and Computer Engineering at the University of Alabama have required and elective courses covering digital design and embedded systems topics. All students in the department are required to take a microcomputers course (ECE 383) typically in their 3rd year of study. This course is a pre-requisite for further technical electives on Computer Architecture (ECE 484) and Embedded Systems (ECE 486). The academic calendar description of these courses at the University of Alabama are below:

- **Microcomputers (ECE 383):** Microprocessors, microcontrollers, assembly-language programming, interrupts, polling and hardware interfaces. Computing proficiency is required for a passing grade in this course. Includes laboratory experiments.
- **Computer Architecture (ECE 484):** Basic computer organization, computer arithmetic, assembly language, machine language, simple and pipelined central-processor organization, memory system hierarchy, and measuring computer performance.

- **Embedded Systems (ECE 486):** Integration of microprocessors into digital systems. Includes hardware interfacing, bus protocols and peripheral systems, embedded and real-time operating systems, real-time constraints, networking, and memory system performance.

Both ECE 484 and ECE 486 are optional technical electives for students completing an Electrical Engineering undergraduate degree. For students completing a Computer Engineering undergraduate degree ECE 484 is a required course and ECE 486 remains an optional technical elective.

Typically all of these courses have been delivered using the traditional lecture style (approximately 150 minutes of in-person lectures per week for 15 weeks) supplemented by assignments and (for ECE 383 and ECE 486) laboratory activities outside of lectures. Student performance is assessed using individual examinations at 2-3 timepoints during the semester and a final examination. Since Fall 2021, ECE 383 has been offered in lecture style and/or flipped-style formats based on the preference of instructors assigned to those courses. The transition of ECE 383 to the flipped-style has been previously reported for interested readers [6]. Over this period, the lecture-style has been offered 9 times and the flipped style 5 times. Regardless of the delivery style, each section of ECE 383 covered the same topics and used the same set of 8 laboratory activities. These laboratories were completed by students in pairs (self-selected) with approximately 2 hours of weekly assistance available during a scheduled lab period with a laboratory instructor.

In the flipped style delivery, course lectures were provided asynchronously as pre-recorded online digital videos available in the learning management system. Then scheduled lecture times were used as work periods to support students in completing the course assignments, work-period activities, and/or labs activities. Students were given the option to: i) watch lecture content prior to scheduled course times and use in-class time to complete posted work-period questions (on topics related to the lecture) or assignments/labs with instructor support; ii) attend the scheduled course times and watch the video lectures (with option to ask questions of the instructor); or iii) watch the lecture content on their own time and attend lectures only when they had further questions.

As noted previously by Freeborn[6] option i) meets the criterion of Bishop and Verleger[11] to be classified as a flipped classroom (e.g. out-of-class activities must include required video lectures and in-class activities must be required and involve interactive learning activities), options ii) and iii) are better considered as high-flexibility, traditional approaches. The intent of the three-option approach was to provide students the flexibility to engage with the course in their preferred style. For this reason, this is format is referred to as flipped-style instead of flipped-classroom. Beyond the class sessions, the students had access to instructor support with the course materials at weekly office hours. This flipped-style ECE 383 course was previously analyzed to determine if there were differences in student performance comparing the delivery style (when taught by the same instructor), reporting no statistically significant differences on the final examination between traditional lecture and flipped-style iterations [6]. This was attributed to similar levels of engagement with course materials resulting from most students in the flipped-style opting for the high-flexibility option. However, the performance of students in future classes after completing the flipped-style course has not yet been explored and motivates this work.

Methods

For this work, the final letter grade of students in ECE 484 and ECE 486 is used as the comparison metric of their course performance. In both courses final grades are based on student achievement on assignments and examinations and it is expected to be an appropriate metric of each students individual overall performance in the course. It should be noted that ECE 486 has an optional lab course (ECE 487), but only the ECE 486 grade is used in this comparison.

For the analysis in this work, the deidentified individual final letter grades for students who had completed ECE 484 and students who had completed ECE 486 in any semester from Fall 2022 to Spring 2024 were collected. Additionally, their ECE 383 final letter grade and the specific semester/section that they had completed each course was collected. This period (Fall 2022 to Fall 2025) was selected to limit ECE 484/486 data to the time period after the first offering of ECE 383 in the flipped-style (Fall 2021). This yielded datasets with 119 and 146 students for ECE 484 and ECE 486, respectively. Next, the datasets were cleaned to remove students with ECE 484 or ECE 486 grades of Withdrawal (W), Incomplete (I), or Pass (P). These were removed because these grades do not provide sufficient detail on the level of student performance. Similarly, students with an ECE 383 grade of P (Pass) or no grade at all (indicating the ECE 383 pre-requisite was met by transferring credit from another institution) were removed. After cleaning, the ECE 484 and ECE 486 final datasets contained 116 (3 removals) and 141 (5 removals), respectively.

Next, all final letter grades were converted to a numerical value where A+ = 4.3, A = 4.0, A- = 3.7, B+ = 3.3, B = 3.0, B- = 2.7, C+ = 2.3, C = 2.0, C- = 1.7, D+ = 1.3, D = 1.0, D- = 0.7, and F = 0. Then each data pair was labeled as either 'Flipped-Style' or 'Lecture' based on the ECE 383 semester/section of that student. Based on this grouping, 44 students in the ECE 484 dataset completed the flipped-style of ECE 383 with 72 completing the lecture version. In ECE 486, 37 students in the dataset completed the flipped-style with 104 completing the lecture version.

The Mann-Whitney U test was selected as the statistical test to determine if there were differences between the median final grades of the students. This specific test was selected because the final letter grades are ordinal data and not continuous data. The statistical testing in this work was completed using SPSS Statistics v29 (IBM Corp., New York).

Results

The average (with their standard deviation) and median final grades for the students in ECE 484 and ECE 486 (from Fall 2022 to Spring 2024) are given in Tables 1 and 2, respectively. The median ECE 383 grades are above 3.3 (B+) for all students who completed ECE 484 and ECE 486, suggesting that students taking Computer Architecture and Embedded Systems demonstrated very good understanding of the material in the pre-requisiste microcomputers course.

Focusing initially on ECE 484, a Mann-Whitney U test was run to determine if there were differences in ECE 383 grades based on lecture format for students enrolled in ECE 484. Distributions of the final grades for flipped and lecture formats were similar as assessed by visual inspection. The median final grade (3.3 for flipped-style, 3.5 for lecture) was not statistically significantly different between formats, $U = 1239.5$, $z = 1.813$, $p = 0.070$. This suggests that

Format	Students	ECE 383 Average	ECE 383 Median	ECE 484 Average	ECE 484 Median
Flipped-Style	44	3.18 ± 0.826	3.3	3.54 ± 1.03	4.0
Lecture	72	3.42 ± 0.789	3.5	3.43 ± 0.896	3.7

Table 1: Final Grade Average ($\pm$ standard deviation) and Median for ECE 484 students grouped by ECE 383 Class Format

Format	Students	ECE 383 Average	ECE 383 Median	ECE 486 Average	ECE 486 Median
Flipped-Style	37	3.31 ± 0.762	3.3	3.69 ± 0.529	4.0
Lecture	104	3.57 ± 0.778	4.0	3.48 ± 0.925	4.0

Table 2: Final Grade Average ($\pm$ standard deviation) and Median for ECE 486 students grouped by ECE 383 Class Format

there was not a performance difference in ECE 383 based on course format for those students who completed ECE 484.

Next, a Mann-Whitney U test was run to determine if there were differences in ECE 484 grades based on ECE 383 lecture format. Again, distributions of the final grades for flipped and lecture formats were similar as assessed by visual inspection. The median final grade (4.0 for flipped-style, 3.7 for lecture) was not statistically significantly different between formats $U = 1725.5$, $z = 1.119$, $p = 0.263$.

Turning attention to ECE 486, a Mann-Whitney U test was run to determine if there were differences in ECE 383 grades based on lecture format for students enrolled in ECE 486. Distributions of the final grades for flipped and lecture formats were similar as assessed by visual inspection. The median final grade was statistically significantly higher for the lecture format (4.0) compared to the flipped format (3.3), $U = 1456.5$, $z = -2.230$, $p = 0.026$.

Next, a Mann-Whitney U test was run to determine if there were differences in ECE 486 grades based on ECE 383 lecture format. Again, distributions of the final grades for flipped and lecture formats were similar as assessed by visual inspection. The median final grade (4.0 for flipped, 4.0 for lecture) was not statistically significantly different between formats $U = 2071.5$, $z = 0.709$, $p = 0.478$.

Discussion

Based on the reported final letter grades students in ECE 484 and ECE 486 demonstrated excellent understanding of the course material which is reflected in the median grades for all groups being greater than 3.7 (A-). However, the comparison of the median final grades in both ECE 484 and ECE 486 indicate there was no statistically significant differences in student performance based on the ECE 383 pre-requisite class format. This does not support the initial hypothesis that students who completed the ECE 383 flipped-style course would perform better in ECE 484 and ECE 486 than their peers who completed the lecture-style course due to the expected flipped-style benefits of self-paced learning, multiple exposures to course materials, more problem solving activities, peer-assisted learning, and instructor support.

This could be a result of how the ECE 383 flipped-style class was implemented. Recall that students were given three options to engage with the course: i) watch lecture content prior to scheduled course times and use in-class time to complete posted work-period questions (on topics related to the lecture) or assignments/labs with instructor support; ii) attend the scheduled course times and watch the video lectures (with option to ask questions of the instructor); or iii) watch the lecture content on their own time and attend lectures only when they had further questions. The specific option that each student pursued was not captured, but it was noted that across three iterations of the flipped-style (from Fall 2021 to Spring 2023) that only one-third of students attended 50% or more of in-class work-periods (option i) [6]. If this same proportion of students who completed ECE 383 then enrolled in ECE 484 and ECE 486, then the majority of students likely did not engage in the flipped-style activities that would have promoted higher-engagement with course materials in comparison to a traditional lecture style format. This could account for the similar median grades for both groups in this study.

Another factor that could be limiting differences may be the use of laboratory elements as active learning components in ECE 383. Students in all course formats complete a set of 8 laboratories beyond the lecture periods. This requires students to spend up to 2 hours each week in an instructor supported lab period and additional time outside of the lab periods to finalize. These labs require active engagement with course material and with a student peer to complete. Students must breadboard their microcontroller hardware and then write code, debug code, and demonstrate the correct operation of the system to achieve various measurement, computation, and control tasks. These activities foster much greater engagement with the course material than if there was only a lecture component. This element could have a much greater impact on the students learning than the course format (and highlights an interesting site for further research).

It is also important to note the limitations of this retrospective analysis and how the analysis has been conducted. This analysis has not considered temporal aspects, that is how (if at all) does the length of time after completing ECE 383 before completing a subsequent technical elective effect course performance? Also, the metric used for comparing student performance (final letter grade) may not be the most appropriate. While it is a representation of the overall performance there are expected to be confounding variables (e.g. are assignment grades an accurate representation of individual student knowledge/performance when completed in uncontrolled environments and how could this influence the analysis?). These cannot all be answered with the current dataset but does indicate future areas of potential research.

While there were no performance differences in ECE 484 and ECE 486 based on ECE 383 lecture format, it is positive that all students demonstrated a high-level of proficiency in follow-up courses. This suggests that students were well-prepared for the following courses. Though this this may be an artifact of selection bias (especially for ECE 486). As an optional technical elective, students taking ECE 486 are likely students who have a demonstrated interest in these topics which may mean that they have invested significant time in them previously and continue to prioritize engaging with them (resulting in their high performance).

Conclusion

There was no statistically significant difference in the median final grade of undergraduate electrical and computer engineering students in computer engineering technical electives (Embedded Systems and Computer Architecture) based on the format of the pre-requisite course (lecture or flipped-style) in this study. This is attributed to limits of students engaging in the flipped elements (opting for high-flexibility vs. complete flipped participation) and the presence of high-impact active learning elements (hands-on laboratories) in both formats. While there was no difference, students from both groups showed very high performance in their technical electives.

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