# Collaborative Problem Solving and Achievement in a Discrete-Time Signals and Systems Course

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***Abstract*— Aggregated research evidence suggests that active learning and student-centered instruction are positively associated with student achievement; however, context-specific studies in engineering classes indicated inconsistent results. To further investigate the effects of classroom environment and the amount of active learning on student achievement, we conducted a quasi-experimental study. We compared student achievement in two Discrete-Time Signals and Systems classes: one taught in an active and collaborative environment, and one taught in a lecture classroom. To assess student learning, we used three exams and the Signals and Systems Concept Inventory. The results showed that students in the lecture classroom outperformed their peers in the active classroom on midterm 1 but scored lower on midterm 2. No difference was found in performance on the final exam and the concept inventory. Additionally, for the active classroom, we examined students' attitudes towards the classroom environment, as the literature suggests that this factor may contribute to achievement. However, no relationship was found between attitudes and student achievement.**

***Keywords—active learning; student-centered instruction; student achievement; conceptual understanding; signals and systems; electrical engineering; undergraduate education.***

## I. Introduction

Active learning and student-centered instruction are topics of significant current discussion and research in science, technology, engineering, and mathematics (STEM) education. Aggregated research evidence supports the benefits of such instruction for improving student learning, engagement, and retention [1]. In response to these results, colleges and universities have begun to construct active learning classrooms designed to support student-centered approaches and various implementations of flipped-style instruction [2]. However, while research shows that on average active learning positively influences student achievement, context-specific studies in engineering courses indicated inconsistent and inconclusive results. These results, in combination with our own interest in determining the most effective ways of teaching in undergraduate signals and systems courses, motivated us to explore the effect of the classroom environment and amount of active and collaborative learning on student achievement in signals and systems.

In this study, we compared two signal and systems classes taught by the same instructor in two different formats: (1) predominantly student-centered with a substantial amount of collaborative problem solving in an active learning classroom, and (2) predominantly instructor-centered with a small amount of collaborative problem solving in a conventional lecture classroom. The results of the study may provide insight for instructors of signal and systems classes about how the classroom environment and the amount of active learning affect student achievement in fundamental signals and systems topics such as system properties, convolution, Fourier series, sampling, and the z-transform. We also anticipate that these results will inform the design of future research studies that aim to examine best practices for student learning in signals and systems courses.

## II. Literature Review

While aggregated evidence suggests that active learning is positively associated with undergraduate student achievement in STEM [1], [3], effects of different active learning practices and student-centered instruction vary. For example, Yelamarthi and Drake found that students in an active (flipped) first-year digital circuits course scored consistently higher throughout the course than their peers in a traditional lecture class [4]. However, Mason, Shuman, and Cook showed that students in an active (flipped) control systems course were more successful than students in the traditional lecture course only on some topics [5]. Finally, Self and Widmann in their study of introductory dynamics classes did not observe any differences in student achievement between active and traditional classrooms [6]. The amount of active learning practices in class may also affect student performance. In a study of chemical engineering classes, Kelly found that spending more than 25% of class time on active learning does not make a difference in student achievement [7]. Additionally, a number of studies claimed that active learning positively influences student conceptual understanding of the material (see [8] for a study in physics and [9] for a study in signals and systems). However, these large-scale studies may have used data collected from classes taught by different instructors. As a result, the difference in conceptual understanding may be attributable in part to the instructor. Furthermore, inconsistent effects of active learning on student achievement may also depend on students' attitudes toward the active learning classroom environment [10]. Evidence suggests that students might need time to adapt to a new environment [11] and to adjust their study habits [5].

To provide further, more comprehensive evidence of the effect of classroom environment and the amount of active learning on student achievement, we conducted a context-specific quasi-experimental study in which multiple measures of student achievement were utilized. We concentrated on a single electrical engineering course (Discrete Time Signals and Systems) taught by the same instructor (the second author) in different semesters using different teaching approaches. Having the same instructor teach the studied classes might eliminate the instructor effect on student achievement. We aimed to answer the following research question: Is there a difference in student achievement between an active/collaborative learning environment and a predominantly lecture environment, controlling for students' initial knowledge? For the active/collaborative classroom, we also examined students' attitudes towards the classroom environment over time and as related to their achievement. We hypothesized an increase in attitudes over time and a positive relationship with achievement.

## III. Context

This study was conducted in a junior-level discrete-time signals and systems course. The course is required for students pursuing a BS in electrical engineering and serves as one of several possible electives for students pursuing a BS in computer engineering. It follows a continuous-time signals and systems course that is typically taken in the sophomore year. Only one section of the course is offered each semester; therefore, students do not have a choice of the instructor and/or classroom environment unless they take the class in a different semester. The coverage of the discrete-time course includes convolution, system properties, discrete-time Fourier series, discrete-time Fourier transform, sampling and reconstruction, the z-transform, and a brief introduction to the discrete Fourier transform. Given that students have been exposed to many of the concepts (convolution, impulse response, Fourier series, Fourier transform, pole-zero analysis, etc.) in the continuous-time prerequisite course, one of the goals of the discrete-time course is to help cement these concepts, in addition to extending the concepts and procedures for application to discrete-time signals and systems. Beyond extensions of concepts introduced in the continuous-time course, the discrete-time course also places significant emphasis on sampling and reconstruction, particularly on understanding the effects of these operations in both the time and frequency domains.

We analyzed two offerings of this course taught in two different formats: predominantly instructor-centered with a small amount of collaborative problem solving in a conventional lecture classroom (referred to as the lecture class in this paper) and predominantly student-centered with most of the class period devoted to collaborative problem solving in an active/collaborative learning classroom (referred to as the active class in this paper). The lecture class was taught in a traditional classroom that held approximately 80 students in several rows of fixed, stadium-style seating. The core of each class period was traditional lecture, delivered by the instructor at the front of the room using a document camera to display hand-written notes that were created in real-time as the lecture progressed. Lecture was interspersed with short active learning elements. Specifically, students were asked to work in groups to solve problems related to the lecture material. These problems typically required 5-10 minutes to solve, and 1 to 3 problems were included in each class period. Many problems were multiple choice, and students submitted their answer via iClicker. Thus, even though they were encouraged to work in groups, answer submission was individual. The groups in the lecture class were not assigned or fixed; students were asked to work with the people sitting near them. Students received half credit for submitting an answer and full credit for submitting a correct answer. In-class problems comprised 5% of each student's overall grade in the course.

In a later semester (the active class), the course was taught in a specialized Active Learning with Technology (ALT) classroom [12] that supports active and collaborative learning with flipped style instruction. The ALT room contains eight round tables and has a capacity of 72 students. Whiteboards cover all walls of the room. Because the class material is primarily applied math and heavily focused on mathematical procedures and problem-solving, the ALT room provides a natural venue for allowing students to work collaboratively on more complex problems and receive feedback in real time. Rather than lecturing with short in-class problems interspersed, as was done in the lecture class, nearly all of each class period in the active class was spent on collaborative problem solving. Students in the active class were assigned reading to prepare for each class period and were given a short quiz at the beginning of each class period to provide motivation and accountability. The quiz was completed individually, and answers were submitted via iClicker. Quiz scores comprised 5% of each student's overall course grade.

Following a brief review of the quiz, the instructor typically provided a very short (no more than five minute) overview of the topic for the day and then gave the students a multi-stage problem to solve. Students were asked to solve problems on the wall-to-wall whiteboards in assigned groups of approximately three students. While students worked, the instructor and teaching assistants circulated among the groups asking questions, answering questions, and giving frequent individualized feedback. After some time (usually 15-20 minutes), the instructor brought the class back together to discuss the problem and its solution. The class period continued with more problems solved in a similar fashion. After the class ended, students were required to submit pictures of their whiteboard solutions to the instructor to receive credit for their work. In-class group problem solving contributed 7% to students' total course grade. Group problem solutions were graded almost entirely for completeness and effort rather than for a correct solution.

## IV. Methods

### A. Participants

Participants for this study were undergraduate students, predominantly juniors or seniors, majoring in electrical engineering. The data analyzed in this work-in-progress paper were collected from 51 students in the lecture class and 43 students in the active class.

## B. Measures

A number of measures of student achievement were used to provide a comprehensive assessment of student knowledge. The measures include scores on the three exams (midterm 1, midterm 2, and the final exam) and scores on the pre and post administration of the Signals and Systems Concept Inventory (SSCI) [9]. Through students' exam grades we aimed to formally assess their achievement throughout the semester. The SSCI scores served as a measure of students' conceptual understanding of the course material; the scores on the pretest were also used as a measure of students' initial knowledge of the course material for the purposes of this study.

Prior to the data analysis, we compared questions on the exams administered in the two classes; only the exam questions that assessed students' knowledge of the same concepts were used in this study. Thus, midterm 1 covered system properties, convolution, and discrete-time Fourier series; midterm 2 covered sampling, continuous-time Fourier series (as used in sampling), plotting of discrete-time signals, and the z-transform; the final exam covered system properties, discrete-time Fourier transform properties, frequency analysis, the z-transform, sampling/reconstruction, and filter specifications. We also compared the items on the SSCI and extracted those that corresponded to each exam. Thus, SSCI 1, SSCI 2, and SSCI 3 consist of all items on the SSCI that correspond to topics on midterm 1, midterm 2, and the final exam, respectively. SSCI 1, SSCI 2, and SSCI 3 represent students' initial conceptual knowledge of the exam material; SSCI pretest is the overall score on the pretest administration of the inventory. For ease of interpretation, all scores were converted into percentages of the maximum score of each measure.

Additionally, at the end of the semester students in the active class were asked to reflect on the past semester and indicate via a survey their attitudes toward the classroom environment at four points in time (at the beginning of the semester, before midterm 1, before midterm 2, and before the final exam). Attitudes were measured using a 6-point Likert scale where 1 was extremely negative and 6 was extremely positive. These data were used to answer the research question of how attitudes are related to student achievement in the active class and how they change throughout the semester.

# V. Results

To test the hypothesis that there is no difference in student achievement (measured by exams and a concept inventory) between the active and lecture classes controlling for students' initial knowledge (measured by the SSCI pre-test) four ANCOVA tests were conducted. Prior to that, the assumptions for all tests were tested. The assumptions of normality, linearity, and homogeneity of regression slopes were satisfied for all tests. The assumption of independence of the covariate (SSCI 1, SSCI 2, SSCI 3, and SSCI pretest) and the independent variable (class) was also satisfied ($t\ (92) = -0.215$, $p = 0.830$, $t\ (92) = 0.203$, $p = 0.839$, $t(79.2) = -0.933$, $p = 0.354$, and $t(92) = -0.853$, $p = 0.396$ respectively). In other words, students in the active and lecture classes did not differ in their initial knowledge, as measured by SSCI 1, SSCI 2, SSCI 3, and SSCI pretest. Descriptive statistics on each measure are presented in Table I. The assumption of homogeneity of variance was violated for the ANCOVAs that tested the difference between the two classes on midterm 2 and the final exam controlling for SSCI 2 and SSCI 3, respectively. However, with nearly equal numbers of participants in each class, as in our study, the effect of this assumption violation is negligible. Additionally, partial $\eta^2$ was used as a measure of effect size for all tests and interpreted according to [13].

Four ANCOVA tests were conducted to determine whether students' achievement on the three exams and the SSCI differed based on the class they were in while controlling for prior knowledge. SSCI 1 was evaluated at 65.96, SSCI 2 at 47.57, SSCI 3 at 53.26, and SSCI pretest at 56.00. Descriptive statistics on each measure are presented in Table I. The results for midterm 1 showed a statistically significant difference between the two classes ($F\ (1, 91) = 13.978$, $p = 0.000$) with a medium effect size (partial $\eta^2 = 0.133$). In other words, students in the lecture class had higher scores on midterm 1 than did their peers in the active class when controlling for initial knowledge. The results for midterm 2 also indicated a statistically significant difference between the two classes ($F\ (1, 91) = 8.572$, $p = 0.004$) with a small to medium effect size (partial $\eta^2 = 0.086$). In other words, students in the active class did better on midterm 2 than did their peers in the lecture class when controlling for initial knowledge. The results for the final exam showed no statistically significant difference between the two classes ($F\ (1, 89) = 2.606$, $p = 0.110$), meaning that students in the lecture class did not differ from their peers in the active class in their scores on the final exam when controlling for initial knowledge. The results for the SSCI posttest indicated no statistically significant difference between the two classes ($F\ (1, 89) = 0.051$, $p = 0.821$); thus, students in the lecture class did not differ from their peers in the active class in their scores on the posttest administration of the concept inventory when controlling for initial knowledge.

TABLE I. DESCRIPTIVE STATISTICS FOR MEASURES OF STUDENT ACHIEVEMENT

| Measure | Lecture Class | | Active Class | |
|---|---|---|---|---|
| | *Mean (SD)* | *N* | *Mean (SD)* | *N* |
| Midterm 1 | 83.72 (11.64) | 51 | 74.59 (15.11) | 43 |
| Midterm 2 | 75.58 (16.97) | 51 | 83.74 (11.47) | 43 |
| Final Exam | 81.62 (14.43) | 50 | 78.86 (10.73) | 42 |
| SSCI posttest | 75.92 (15.02) | 50 | 78.10 (14.76) | 42 |
| SSCI 1 | 65.60 (17.47) | 51 | 66.39 (17.91) | 43 |
| SSCI 2 | 47.90 (17.10) | 51 | 47.18 (17.23) | 43 |
| SSCI 3 | 51.63 (14.11) | 51 | 54.78 (17.92) | 43 |
| SSCI pretest | 54.75 (14.89) | 51 | 57.49 (16.28) | 43 |

Additionally, for the active class, a One-Factor Repeated Measures ANOVA was used to analyze students' attitudes toward the classroom environment over time. Descriptive statistics for each time point are presented in Table II. Since the assumption of sphericity was violated, the Geisser-Greenhouse conservative F test was used. The results indicated a statistically significant effect of time on students' attitudes ($F(13.727, 60.981) = 8.121$, $p = 0.002$). Multiple comparison procedures with a Bonferroni correction revealed that only the attitude at the beginning of the semester differed from the attitudes at other points of the semester. In other words, while at any time of the semester students' attitudes toward the classroom environment were positive, at the beginning of the semester students liked the active learning environment slightly less than during the semester. However, students' attitudes toward the classroom environment did not appear to be related to their achievement. No correlation was found between attitudes prior to midterm 1 and achievement on midterm 1 ($r = -0.143$, $p = 0.371$), attitudes prior to midterm 2 and achievement on midterm 2 ($r = 0.181$, $p = 0.259$), and attitudes at the end of the semester and achievement on the final exam ($r = -0.078$, $p = 0.630$).

TABLE II. DESCRIPTIVE STATISTICS FOR ATTITUDES TOWARDS THE CLASSROOM ENVIRONMENT (N=41)

| Time | Mean (SD) |
|---|---|
| At the beginning of the semester | 3.80 (1.66) |
| Prior to Midterm 1 | 4.32 (1.17) |
| Prior to Midterm 2 | 4.61 (0.97) |
| Prior to Final Exam | 4.73 (1.07) |

## VI. DISCUSSION

The results of this study showed that students in the lecture class outperformed students in the active class on midterm 1, while students in the active class outperformed students in the lecture class on midterm 2. No difference was observed in student performance on either the final exam or the concept inventory. We hypothesize that the difference on midterm 1 might have occurred due to the time needed for students in the active class to become used to the new classroom environment, which is consistent with the literature [5], [11]. The difference on midterm 2 might be attributed to the effect of the active/collaborative learning environment and a substantial amount of time devoted to collaborative problem solving. In other words, being unfamiliar with the ALT classroom environment, students in the active class scored lower on midterm 1, but when the adjustment period was over, they scored higher on midterm 2 than did their peers in the lecture class.

By the end of the semester, the type of class instruction and classroom environment appeared not to matter any longer. Toward the end of the semester, students could have changed their focus from problem solving to larger projects and other end-of-term assignments, which may explain why students in the active class did not score higher on the final exam than did their peers in the lecture class. Furthermore, the amount of collaborative problem solving did not appear to affect student performance on the concept inventory, despite evidence of its effectiveness from the other studies [8], [9]. This result might have been observed in part because the problem solving in the active class emphasized mastery of procedures more than mastery of concepts. Another possible reason for this result lies in the amount of collaborative problem solving incorporated in the two classes. Consistent with [7], above a certain threshold, the amount of active learning may no longer impact student achievement.

Examining the active learning classroom environment more deeply, we found that students' attitudes toward the classroom environment were lower at the beginning of the semester compared to their attitudes throughout the semester; however, at any point in the semester, their attitudes were positive. While this finding does not support concerns about student resistance toward active learning presented in the literature [10], it might indicate that students come to active/collaborative learning classrooms with some degree of skepticism and/or caution. Nevertheless, student achievement throughout the semester does not appear to be attributable to student attitudes, as no correlation was found between these two variables.

The main limitation of this study was the use of non-identical exams in the two semesters, with the exception of the concept inventory, which was consistent across the two semesters. Though we tried to make our exam measures as similar as possible by excluding problems for which no corresponding problem (topic) could be found in the parallel exam from the other semester, non-identical achievement measures might be a source of error. In other words, any differences in student achievement on the exams might be attributed not to the differences in class instruction, but to the differences in the exams themselves. The relatively small sample sizes used in our study also limits the validity and generalizability of the results.

## VII. CONCLUSION

This study aimed to explore the differences in student achievement in two Discrete-Time Signal and Systems classes taught in different formats: predominantly active/collaborative problem solving and predominantly instructor-centered lecture. We used multiple measures of student achievement, employed at different times throughout the two semesters. To exclude the possibility that any observed results can be explained by students' initial knowledge of the material, we statistically controlled for initial knowledge using scores on a concept inventory. Our results indicated that students in the predominantly active class scored lower on the first midterm and higher on the second midterm than did students in the predominantly lecture class. However, no difference was observed in student performance on the final exam or on the concept inventory. Further investigation is needed to develop a more comprehensive picture of student achievement, as well as to identify possible explanations of the observed differences and/or similarities in student achievement across different measures. Larger sample sizes and the same measures of achievement across classes are needed for more rigorous investigations.

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