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Using a Flipped Classroom Approach to Enhance Student Engagement and Achievement in a Control Systems Course for Electrical Engineers

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Abstract

Control Systems is a core electrical engineering course. However, it remains a conceptually challenging course that requires students to integrate mathematical modeling, system analysis, and design principles. In Spring 2021, a junior-level Control Systems course at Stephen F. Austin State University was redesigned using a flipped classroom model to promote active learning, improve course pacing, and enhance student engagement. The course was organized into modular learning units delivered through the learning management system, each consisting of structured webpages, instructor-prepared lecture videos, embedded video quizzes, assignments, and module-level assessments. Pre-class modules emphasize self-paced learning and formative assessment, while in-class time is dedicated primarily to problem solving and guided discussion using active learning strategies. During the lecture, the instructor briefly reviews the module content before engaging students in solving carefully selected problems designed to reinforce key concepts. Students work individually or collaboratively, followed by an instructor-led discussion that emphasizes reasoning, interpretation, and conceptual understanding rather than procedural repetition. The effectiveness of the flipped methodology was evaluated using longitudinal Course Learning Outcome (CLO) assessment data collected from 2018 through 2025, allowing comparison between traditional and flipped offerings of the course. The results indicate that the flipped classroom model produced comparable or improved performance across most analytical and design-related CLOs, particularly those associated with system modeling, feedback analysis, and advanced formulation. Additionally, the flipped structure improved course pacing and enabled more consistent coverage of advanced topics that were previously difficult to reach within a single semester.

Keywords: Flipped Classroom, Control Systems, Active Learning, Engineering Education, Course Learning Outcomes

Introduction

Control Systems is a core course in most electrical and mechanical engineering curricula and is widely regarded as one of the more conceptually challenging subjects for undergraduate students. The course requires students to integrate mathematical modeling, system dynamics, and abstract representations of feedback behavior, often while simultaneously developing proficiency with computational tools. Traditional lecture-based instruction can limit students' opportunities to actively engage with these concepts during class time, frequently relegating higher-order problem-solving and conceptual integration to homework completed independently outside the classroom.

Flipped classroom pedagogy has emerged as a promising instructional approach to address these challenges by shifting content delivery outside the classroom and reserving in-class time for active learning. Prior studies in engineering education have shown that flipped instruction can improve student achievement, engagement, and conceptual understanding compared to traditional lecture-based models. An analysis by Lo and Hew [1] demonstrated a statistically significant positive effect of flipped classrooms on student performance across engineering disciplines, particularly when pre-class materials are reinforced with brief in-class reviews and structured problem-solving activities. Similarly, Bhat et al. [2] reported that flipped classrooms promote a shift from instructor-centered teaching to student-centered learning, increasing interaction, participation, and perceived learning quality. Chiquito et al. [3] further showed that flipped instruction can reduce performance variability and support inclusivity, with notable gains observed among female students in engineering courses.

Motivated by both the documented benefits of flipped pedagogy and the instructional constraints imposed during the COVID-19 pandemic, a junior-level Control Systems course at Stephen F. Austin State University was redesigned using a flipped classroom model beginning in Spring 2021. While the initial implementation was prompted by the need to support hybrid and remote instruction, the structure was intentionally designed to be sustainable beyond emergency teaching conditions. The course was reorganized into modular learning units that emphasize self-paced preparation, frequent formative assessment, and in-class active learning focused on conceptual reasoning rather than procedural repetition.

This paper presents the design, implementation, and outcomes of the flipped Control Systems course over multiple offerings from 2021 through 2025. This work examines the longitudinal impact of a consistently applied flipped structure on student engagement, performance, and confidence. The contributions of this paper include (1) a detailed description of a modular flipped course design tailored to Control Systems, (2) an active learning framework for in-class problem solving that emphasizes student reasoning and conceptual understanding, and (3) evidence of the effectiveness and sustainability of the flipped model in a post-pandemic engineering education context.

Course Structure

The Control Systems course is delivered using D2L Brightspace, the official learning management system at Stephen F. Austin State University. All instructional materials, assessments, and communication tools are centralized within the LMS to support a structured flipped classroom experience. The course is divided into nine instructional modules, each aligned with a corresponding chapter from Modern Control Systems by Dorf and Bishop. In addition to these content modules, a “Getting Started” module is provided at the beginning of the semester to explain the course expectations and the flipped methodology.

Each module is released on a predetermined date and remains accessible for the remainder of the semester, allowing students to revisit content as needed. The modular organization enables students to progress through the course predictably and consistently, reinforcing time management and self-regulated learning. Table 1 summarizes the module sequence and release schedule for the Spring 2026 offering. The Getting Started module serves multiple purposes. It introduces students to the instructor, course policies, the grading scheme, and the required textbook. It also explains how the flipped classroom methodology will be implemented throughout the semester. This module also includes a discussion forum in which students reflect on their post-graduation plans, including career goals and graduate school aspirations. These reflections help the instructor better understand students' motivations and professional interests early in the semester. Additionally, a syllabus and course outline quiz is included to ensure that students review and understand course expectations before engaging with technical content.

Table 1. List of Online Modules and Release Dates.

Topic	**Release Date**
Getting Started	January 14, 2026
Chapter 1 – Introduction to Control Systems	January 14, 2026
Chapter 2 – Mathematical Models of Systems	January 19, 2026
Chapter 3 – State Variable Models	January 26, 2026
Chapter 4 – Feedback Control System Characteristics	February 9, 2026
Chapter 5 – The Performance of Feedback Control Systems	February 16, 2026
Chapter 6 – The Stability of Linear Feedback Systems	February 23, 2026
Chapter 7 – The Root Locus Method	March 16, 2026
Chapter 8 – Frequency Response Method	March 30, 2026
Chapter 9 – Stability in the Frequency Domain	April 6, 2026

Each instructional module follows a consistent internal structure that guides students through the learning process. Modules include an introduction webpage, multiple content webpages, embedded lecture videos, video quizzes, assignments, assignment quizzes, a conclusion webpage, and a module checklist. The introduction webpage provides a brief overview of the module's topics and identifies the relevant Course Learning Outcomes (CLOs). Content webpages focus on specific concepts and present key equations and theoretical foundations. Embedded within these pages are instructor-recorded lecture videos that provide detailed explanations and worked examples. Video quizzes accompany each lecture video and assess student engagement with the material. In addition to conceptual questions, at least one question requires students to identify a keyword mentioned during the video, encouraging attentive viewing. Assignments are released concurrently with the module content, allowing students to preview and contextualize problem sets before attending class. Assignment due dates are typically scheduled for the day before the next module's first lecture. After submitting an assignment, students complete an assignment quiz focused on problem-solving and application of the concepts. Each module concludes with a summary webpage and a checklist that consolidates all required tasks and due dates. The checklist serves as an organizational tool to help students track progress and manage deadlines. Course announcements are regularly posted in D2L to notify students when modules open or when important deadlines approach. All due dates are also reflected in the D2L calendar.

Class meetings are primarily devoted to problem-solving and active learning. The instructor works problems using a Microsoft Surface tablet and OneNote, which is shared with students for viewing access. Students are provided with clean versions of the OneNote materials in both PDF and OneNote formats, allowing them to annotate problems using their own devices. Although the course was designed to function fully in a remote format, in-person attendance is strongly encouraged. Remote participation is permitted only under exceptional circumstances, such as illness, to maintain the integrity of the active learning environment.

Flipped Methodology Implementation Results

The effectiveness of the flipped classroom implementation was evaluated using longitudinal Course Learning Outcome (CLO) assessment data collected from 2018 through 2025. The Control Systems course includes fifteen CLOs covering modeling, analysis, design, computational tools, and broader contextual understanding of control systems. The list of these CLOs is in Table 2.

Table 2. Course Learning Outcome for the Control Systems Course

Course Learning Outcomes	
CLO 1	Model physical systems using differential equations and linear approximations.
CLO 2	Apply the Laplace Transform to model control systems.
CLO 3	Formulate a Transfer Function of Linear Systems.
CLO 4	Work with block diagram models.
CLO 5	Define the state variables for Dynamic Systems.
CLO 6	Construct the State differential equation.
CLO 7	Formulate the Transfer Function from the state equation.
CLO 8	Identify the characteristics of feedback control systems.
CLO 9	Evaluate the performance of feedback control systems.
CLO 10	Assess the stability of linear feedback systems.
CLO 11	Apply the root locus method.
CLO 12	Use MATLAB to design a system using root locus method.
CLO 13	Analyze control systems in the frequency domain.
CLO 14	Recognize how the field of control systems has impacted industry, and as a result how it has changed the way we live.
CLO 15	Identify the role of control systems in new technologies been introduced to the public.

CLO performance is assessed each semester on a five-point Likert scale, where higher values indicate stronger student achievement. CLO performance before implementation (traditional delivery) was compared with performance after the course was flipped in Spring 2021, to evaluate the impact of the flipped methodology. The following analysis focuses on CLOs 1 through 11, which correspond to the course's core analytical and design competencies. CLOs 12 and 13, which emphasize MATLAB-based design and frequency-domain analysis, were inconsistently covered before flipping due to time constraints and were therefore excluded from the comparative analysis. CLOs 14 and 15 address broader professional and societal outcomes. However, reliable assessment mechanisms for these outcomes are still under development and were not included in this evaluation.

Table 3 shows a breakdown of the CLO rating for the years 2018 to 2025, and Table 4 shows the average CLO rating comparing the traditional and flipped implementations. Overall, the flipped classroom resulted in improved or comparable performance across most core CLOs. Notable gains were observed in outcomes related to system formulation, feedback analysis, and advanced modeling. For example, CLO 7 (formulating the transfer function from the state equation) increased from an average of 4.54 under traditional instruction to 4.93 under the flipped model. Similarly, CLO 8 (identifying the characteristics of feedback control systems) improved from 4.46 to 4.77, and CLO 2 (applying the Laplace Transform) increased from 4.63 to 4.94.

Table 3. CLO Breakdown for the Control Systems Course by Year.

CLO	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
1	5.00	4.84	4.33	4.80	4.67	4.91	4.96	4.61
2	4.61	4.81	4.48	4.99	4.95	4.96	4.94	4.84
3	4.82	4.42	3.86	4.22	3.50	3.82	3.90	3.62
4	3.96	4.34	3.79	4.58	4.04	4.17	4.56	4.62
5	4.02	4.13	4.11	4.68	3.36	4.11	2.33	4.15
6	4.40	4.05	4.80	4.94	3.93	4.38	5.00	4.81
7	4.37	4.50	4.76	4.97	4.81	4.94	4.95	5.00
8	4.62	4.53	4.24	4.84	4.73	4.66	4.88	4.72
9	4.44	4.30	3.59	4.37	4.00	3.89	4.41	4.39
10	4.54	4.54	4.39	4.77	4.60	4.99	4.33	4.40
11	3.71	4.71	4.35	4.35	4.32	4.58	4.47	4.57
12	N/A	2.84	N/A	2.98	3.69	4.56	2.00	3.88
13	N/A	2.78	N/A	3.27	2.10	3.09	2.87	2.55
14	N/A	N/A	4.42	N/A	5.00	5.00	3.67	5.00
15	N/A	N/A	4.24	5.00	4.50	5.00	5.00	5.00

These improvements most likely are attributed to the reallocation of class time made possible by the flipped structure. By shifting content delivery to pre-class modules, students arrived in class better prepared to engage in higher-order problem-solving. In-class activities emphasized reasoning, interpretation, and conceptual validation rather than procedural repetition. The instructor frequently paused during problem-solving sessions to question students' assumptions and reasoning, fostering a deeper understanding of the underlying control principles.

Table 4. Average CLO Rating Comparing the Traditional Implementation Against the Flipped Implementation.

Average CLO		
CL0	Traditional	Flipped
1	4.72	4.79
2	4.63	4.94
3	4.37	3.81
4	4.03	4.39
5	4.09	3.73

6	4.42	4.61
7	4.54	4.93
8	4.46	4.77
9	4.11	4.21
10	4.49	4.62
11	4.26	4.46

While most CLOs showed improvement, a small number exhibited slight declines, most notably CLO 3 (formulating transfer functions of linear systems) and CLO 5 (defining state variables for dynamic systems). These outcomes rely heavily on mathematical abstraction and notation, suggesting that additional scaffolding or targeted in-class interventions may be beneficial for these topics. Nevertheless, performance in these areas remained above acceptable levels.

An important outcome of the flipped implementation was improved course pacing and coverage. Before flipping, it was challenging to consistently cover advanced topics such as root-locus design and frequency-domain analysis within a single semester. The flipped structure enabled more predictable progress through the syllabus, allowing consistent coverage of material associated with CLOs 11-13 in later offerings. This improved time management benefited both students and the instructor, reducing end-of-semester compression and improving instructional coherence.

Future Work

While the Course Learning Outcome assessment provides encouraging evidence of the effectiveness of the flipped classroom implementation, additional analysis is planned to further validate and strengthen these findings. Future work will focus on conducting a detailed statistical evaluation of the longitudinal data collected across multiple course offerings. This analysis will compare student performance before and after the implementation of the flipped methodology and examine trends across individual Course Learning Outcomes.

Planned statistical methods include hypothesis testing to determine whether observed differences between traditional and flipped offerings are statistically significant, as well as analysis of variance across semesters to evaluate consistency of the results. Additional metrics such as effect size, standard deviation, and confidence intervals will be used to quantify the magnitude and reliability of observed improvements. This approach will provide a more rigorous assessment of the flipped classroom model's impact beyond descriptive comparisons.

Conclusion

This paper presented the implementation and evaluation of a flipped classroom model for a junior-level Control Systems course first offered in Spring 2021. The course was intentionally designed as a sustainable instructional model, emphasizing modular content delivery, self-paced preparation, and in-class active learning. By shifting lectures to pre-class modules, in-class time was dedicated to problem solving, conceptual discussion, and student engagement. Longitudinal Course Learning Outcome assessments indicate that the flipped model resulted in comparable or improved student performance across most core analytical and design outcomes when compared to traditional instruction. The flipped structure also improved course pacing and allowed for more consistent coverage of advanced topics that were previously difficult to reach. While a small number of mathematically intensive outcomes showed modest declines, overall performance remained strong.

Overall, the results suggest that a structured flipped classroom approach can effectively support student learning and engagement in Control Systems. The modular design and active learning framework described in this paper offer a transferable model for other upper-level engineering courses seeking to promote deeper conceptual understanding and sustained student involvement.

References

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