Strategies to Develop an Online/Hybrid Signals and Systems Course

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Dr. Buehrer has authored or co-authored over 50 journal and approximately 125 conference papers and holds 11 patents in the area of wireless communications. In 2010 he was co-recipient of the Fred W. Ellersick MILCOM Award for the best paper in the unclassified technical program. He is currently a Senior Member of IEEE, and an Associate Editor for IEEE Transactions on Communications and IEEE Wireless Communications Letters. He was formerly an associate editor for IEEE Transactions on Vehicular Technologies, IEEE Transactions on Wireless Communications, IEEE Transactions on Signal Processing, and IEEE Transactions on Education. In 2003 he was named Outstanding New Assistant Professor by the Virginia Tech College of Engineering and in 2014 Dr. Buehrer won the Virginia Tech College of Engineering Award for Teaching Excellence.

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Luke F. Lester, an IEEE and SPIE Fellow, received the B.S. in Engineering Physics in 1984 and the Ph.D. in Electrical Engineering in 1992, both from Cornell University. He joined Virginia Tech in 2013 as the Head of the Bradley Department of Electrical and Computer Engineering (ECE) and was named the Roanoke Electric Steel Professor in 2016. Prior to joining VT, he was a professor of ECE at the University of New Mexico (UNM) from 1994 to 2013, and most recently the Interim Department Chair and the Endowed Chair Professor in Microelectronics there. Before 1994, Dr. Lester worked as an engineer for the General Electric Electronics Laboratory in Syracuse, New York for 6 years where he worked on transistors for mm-wave applications. There in 1986 he co-invented the first Pseudomorphic HEMT, a device that was later highlighted in the Guinness Book of World Records as the fastest transistor. By 1991 as a PhD student at Cornell, he researched and developed the first strained quantum well lasers with mm-wave bandwidths. These lasers are now the industry standard for optical transmitters in data and telecommunications. In all, Dr. Lester has over 30 years experience in III-V semiconductor devices and advanced fabrication techniques. In 2001, he was a co-Founder and Chief Technology Officer of Zia Laser, Inc., a startup company using quantum dot laser technology to develop products for communications and computer/microprocessor applications. The company was later acquired by Innolume, GmbH. He was a US Air Force Summer Faculty Fellow in 2006 and 2007. Dr. Lester's other awards and honors include: a 1986 IEE Electronics Letters Premium Award for the first transistor amplifier at 94 GHz; the 1994 Martin Marietta Manager's Award; the Best Paper Award at SPIE's Photonics West 2000 for reporting a quantum dot laser with the lowest semiconductor laser threshold; and the 2012 Harold E. Edgerton Award of the SPIE for his pioneering work on ultrafast quantum dot mode-locked lasers. He has published 140 journal articles and some 250 other publications and is currently the Editor-in-Chief of the IEEE Journal of Selected Topics in Quantum Electronics.

Max Mikel-Stites, Virginia Polytechnic Institute and State University

Max Mikel-Stites is pursuing master's degrees in engineering mechanics and mathematics at Virginia Tech. He studies the biomechanics of hearing in parasitoid flies and is passionate about the physics of Marvel superheroes and scientific communication. His general research interests include biological modeling on both organismal and population scales, biological physics, and agent-based modeling. He graduated with degrees in applied mathematics and physics & astronomy from the University of Rochester.

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Kenneth Reid is the Associate Dean and Director of Engineering at the R. B. Annis School of Engineering at the University of Indianapolis. He and his coauthors were awarded the Wickenden award (Journal of Engineering Education, 2014) and Best Paper award, Educational Research and Methods Division (ASEE, 2014). He was awarded an IEEE-USA Professional Achievement Award (2013) for designing the B.S. degree in Engineering Education. He is a co-PI on the ”Engineering for Us All” (e4usa) project to develop a high school engineering course ”for all”. He is active in engineering within K-12, (Technology Student Association Board of Directors) and has written multiple texts in Engineering, Mathematics and Digital Electronics. He earned a PhD in Engineering Education from Purdue University, is a Senior Member of IEEE, on the Board of Governors of the IEEE Education Society, and a Member of Tau Beta Pi.

Strategies to Develop an Online/Hybrid Signals and Systems Course

Abstract

This paper describes a sophomore-level "Signals and Systems" core course in electrical engineering and computer engineering at Virginia Tech. Over the course of four offerings (Spring 2021 – Fall 2022 semesters), we aimed to increase the student response rate to a course-wide survey by asking students to self-report their attainment of the course learning objectives and to increase the percentage of students who rate their ability to achieve the course learning objectives as either "Good" or "Excellent." In the Spring 2022 offering of the section, we introduced "student-produced digital media submissions", referred to as "student podcasts", to increase student engagement with the course material and course learning objectives. A podcast is a digital audio files made available for streaming or download on either a computer or a mobile device. The podcast questions are introduced as quiz questions in the course learning management system. The paper discusses that following the introduction of the student podcasts, students report an increased attainment of the course learning objectives. The willingness of the student populations to provide online course-end feedback is viewed as a potential indicator of increased engagement in response to the introduced interventions. Results show that the percentage of students who respond to the online course-end student survey increased from 38% in the Spring 2021 offerings of the course to 45% in Fall 2021, 54% in Spring 2022, and 57% in Fall 2022 offerings respectively.

Introduction

Online course offerings greatly facilitate the expansion of an electrical and computer engineering (ECE) department's pool of potential students, making them an important asset in an administrator's enrollment management toolbox. At the same time, the convenience and enhanced access of online courses make them popular with many students. From a faculty perspective, the flexibility in work location and time management afforded by online courses is a significant employee benefit. All of these positive factors contribute to the persistence and desirability of online courses. There are also challenges to online learning, and these challenges are what motivates the desire to increase engagement. Even more so, the past two and a half years have motivated many universities to temporarily transition from traditional in-person instruction to mostly virtual instruction. This transition involved developing new approaches to pedagogy as well as student assessment. During this same time period, there has been an unprecedented growth in student usage of online support materials and support services. This paper focuses on how Virginia Tech, a large mid-Atlantic university is developing a signals and systems course in online, hybrid, and in-person modalities.

Due to its nature, online education can take advantage of digital media, such as podcasts and chat platforms (including one-to-one and group social media communication), both of which can be used by learners and instructors to reach and engage broader audiences. A podcast is a digital audio files made available for streaming or download on either a computer or a mobile device. In particular, the popularity of podcasts is extremely high amongst our undergraduate learners (and beyond).

Given that young learners feel very comfortable using videos, chats, and podcasts to communicate their ideas, feelings, and status, it is expected that the use of digital media can and will be an integral part of their undergrad learning journey, even if not formally integrated into instruction. Here we aim to include the use of digital media in the course as a way to encourage students to use formats with which they are most comfortable as a way for them to express their understanding of course concepts in oral form, and at the same time, through this mode of expression, the students experience what it is like to teach others about the concepts.

This paper is concerned with the online education environment within the context of engineering education focusing on a signals and systems course. Undergraduate engineering students at Virginia Tech intending to major in computer engineering and electrical engineering normally enroll in several fundamental base courses in their first two years of undergraduate studies. Typically, the students take their first course on signals and systems in their second year. At Virginia Tech, students who enroll in their first course in signals and systems are second-year students intending to major in electrical engineering and computer engineering. In this course, students learn "mathematical methods for the analysis and design of continuous and discrete linear, time-invariant systems" [1]. The five course learning objectives are shown in Table 1. Topics covered include continuous and discrete signals and their properties, linear time-invariant systems, Fourier series, Fourier transforms, and filtering [1].

Table 1. Learning Objectives for Course

LO Number	Learning Objective (LO) Short Name	Learning Objectives [1]
1	LO 1	"Describe a given system using a block-level description and identify the input/output signals" [1].
2	LO 2	"Mathematically model continuous and discrete linear, time-invariant systems using differential and difference equations, respectively" [1].
3	LO 3	"Analyze the use of filters and their interpretation in the time and frequency domains and implement standard filters in hardware and/or software" [1].
4	LO 4	"Apply computations of the four fundamental Fourier transforms to the analysis and design of linear systems" [1].
5	LO 5	"Demonstrate professional communication through formal documents that communicate solutions to problems and document projects within the domain of signals and systems" [1].

This paper describes a case study focused on visual and written approaches for assignments and exams that we are taking in four semesters of a signals and systems base course. The term "base" refers to the course as one of eight "base courses" in the ECE department that each student is required to pass (with at least a C grade) in order to proceed to subsequent departmental courses at the 3000-level or 4000 level.

In this paper, we focus on the use of podcasts and videos in the course as additional media for assessment. We aim to show that the use of activities of this type also promotes student engagement, increases broader participation, and prepares students for their educational journey for "just-in-time training" and future professional development.

Podcast and video assignments are produced by the students as a question in weekly quizzes. The quizzes are administered in the course learning management system (Canvas). Quiz questions are multiple choice except for the last question that is the podcast question. The last question in a quiz asks the student to select from any of the previous quiz questions, create a 2-minute podcast in MP4 format, and upload the podcast to the learning management system. In the 2-minute podcast, a student narrates their solution to the quiz. Some students record an audio file. Other students record a video file of themselves speaking. Yet other students record their voice with slides showing their work. Other students record themselves speaking along with their work and slides showing the question and solution to the problem. Some students incorporate the learning objectives in their discussion. The specification for the podcast question is the following [2]:

> "Select one of the problems in this quiz and prepare a 2-minute video presentation in mp4 format in which you explain the problem and your solution. You may use a VT Presentation Template posted to the Files folder. Then, upload your video presentation using the box below." [2]
>
> "Please state your name and date in the presentation." [2]
>
> "This question helps class achieve ECE2714 Learning Objectives LO 3 and LO 5 for the course:
>
> 'LO3. Analyze the use of filters and their interpretation in the time and frequency domains and implement standard filters in hardware and/or software.' [1-2]
>
> and
>
> 'LO5. Communicate solutions to problems and document projects within the domain of signals and systems through formal written documents.' [1-2] "

The podcast assignments offer students the opportunity to explain their solutions (also referred to as video logs or vlogs for students who add visual components to their podcasts). The podcast assignments aim to: (a) motivate students to submit answers in an enjoyable way, (b) increase time and effort that the students are encouraged to devote to a project, and (c) improve course outcomes.

Background and Overview

The students in the "Signals and Systems" base course (ECE2714) are enrolled in the undergraduate engineering program in the Bradley Department of Electrical and Computer Engineering at Virginia Tech [1]. Emphasis was placed on analytical solutions to differential and difference equations as well as facility in solving problems in both the time and frequency domains. Prior knowledge includes basic circuit analysis, differential equations, complex numbers, and computational methods [3-5].

The majority of the students taking the course are sophomores and juniors. The Fall 2021 cohort is composed of students who took Math online during first semester of COVID.

Table 2 shows questions that students are asked in the Student Perceptions of Teaching questionnaire ("SPOT") surveys following the course regarding their attainment of the learning objectives [6]. Figure 1 shows the percentage of the students who responded "Good" or "Excellent" to survey questions regarding their attainment of the learning objectives. The aim of the course is to receive at least 70% of students who respond either "Good" or "Excellent" for each LO. Figure 2 shows the Response Rate increases from Spring 2021 to Fall 2022. Tables 3-5 show the course modality, grading structure, and approximate mapping of the learning objectives (LOs) to the course structure, respectively.

Table 2. End-of-course survey questions [6] regarding attainment of Learning Objectives

LO #	LO Name	Learning Objective (LO)
1	LO 1	**"At the end of this course, how do I rate my ability to:** Describe a given system using a block-level description and identify the input/output signals" [6] (**Poor, Fair, Good, Excellent, N/A**).
2	LO 2	**"At the end of this course, how do I rate my ability to:** Mathematically model continuous and discrete linear, time-invariant systems using differential and difference equations respectively" [6] (**Poor, Fair, Good, Excellent, N/A**).
3	LO 3	**"At the end of this course, how do I rate my ability to:** Analyze the use of filters and their interpretation in the time and frequency domains and implement standard filters in hardware and/or software" [6] (**Poor, Fair, Good, Excellent, N/A**).
4	LO 4	**"At the end of this course, how do I rate my ability to:** Apply computations of the four fundamental Fourier transforms to the analysis and design of linear systems" [6] (**Poor, Fair, Good, Excellent, N/A**).
5	LO 5	**"At the end of this course, how do I rate my ability to:** Demonstrate professional communication through formal documents that communicate solutions to problems and document projects within the domain of signals and systems" [6] (**Poor, Fair, Good, Excellent, N/A**).

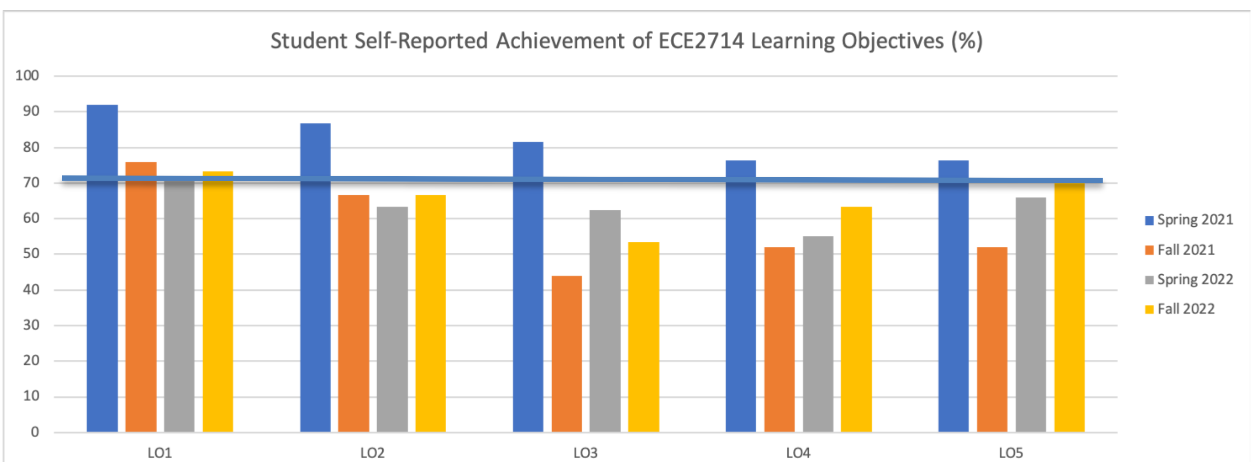

Figure 1. Percentage of students who self-reported their achievement as either "Good" or "Excellent" for each of the ECE2714 learning objectives in end-of-semester surveys. The horizontal blue line indicates the 70% department target for each LO.

Table 3. Course Modality and Student Preparation

Semester	Delivery of Lectures	Delivery of Exams	Student preparation
Spring 2021	Online using Zoom	Exam 1, 2, Final Exam: Online	In person (Pre-COVID) mathematics
Fall 2021	Online using Zoom	Exam 1: Online; Exam 2, Final Exam: In person	Online mathematics (COVID)
Spring 2022	Online using Zoom	Exam 1, 2: In person; Final Exam: In person	Online mathematics (COVID)
Fall 2022	In person in "small group classroom" with whiteboards	Exam 1, 2, Final Exam: In person	Online mathematics (COVID)

Table 4. Course grading structure

Week	Exam 1	Exam 2	Final Exam	Project/ Labs	Class Participation	Homework/ Quizzes	Total
Spring 2021	20%	20%	25%	5% Project	10% **(ARWs, EQs)**	20% HW	100%
Fall 2021	20%	20%	25%	5% Project	10% **(ARWs, EQs)**	20% HW	100%
Spring 2022	25%	25%	30%	5% Labs (3)	5% **(ARWs, EQs)**	10% Quizzes	100%
Fall 2022	25%	25%	25%	10% Labs (3)	5% **(ARWs, EQs, Attendance after Exam 2)**	10% Quizzes	100%

Table 5. Mapping of course LOs to course structure

Week	Exam 1	Exam 2	Final Exam	Project/Labs	Class Participation (ARWs, EQs)	Homework/Quizzes
Spring 2021	LOs 1, 2	LO 3, 4	LOs 1-4	LO 5	LOs 1-4	LOs 1-4 HW
Fall 2021	LOs 1, 2	LO 3, 4	LOs 1-4	LO 5	LOs 1-4	LOs 1-4 HW
Spring 2022	LOs 1, 2	LO 3, 4	LOs 1-4	LO 5	LOs 1-4	LOs 1-5 Quizzes
Fall 2022	LOs 1, 2	LO 3, 4	LOs 1-4	LO 5	LOs 1-4	LOs 1-5 Quizzes

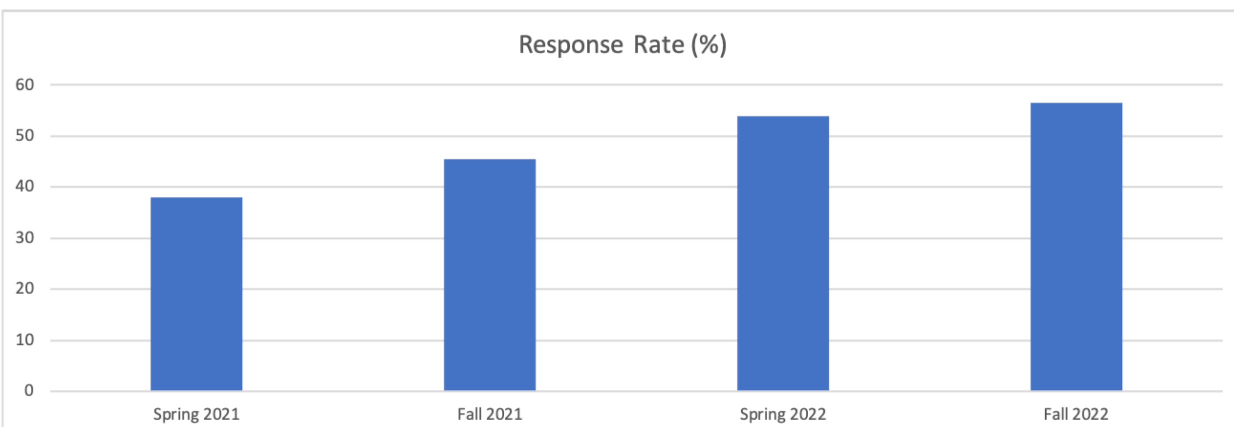

Figure 2. Response rate to end-of-semester student surveys about attainment of ECE2714 learning objectives

Figure 3 and Table 6 show the grade distributions (percentage). The percentage of the class that does not achieve the minimum (C or above) is shown (that is, C-, D+, D, D-, F).

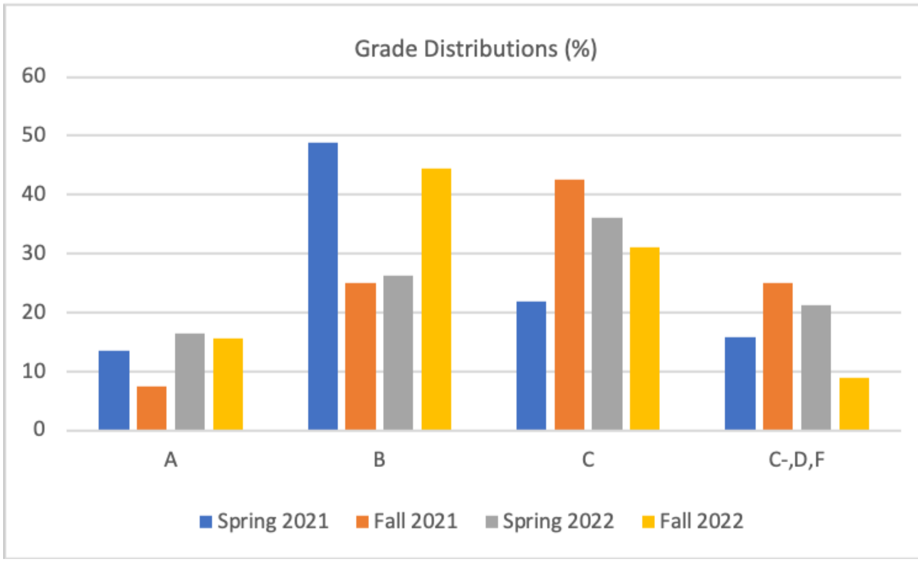

Figure 3. Grade distributions (in percentages)

Table 6. Grade Distributions

	Spring 2021	Fall 2021	Spring 2022	Fall 2022
A (A, A-)	13%	7.5%	16%	15%
B (B+, B, B-)	49%	25%	26%	44%
C (C+, C)	22%	42.5%	36%	31%
C-, D+, D, D-, F	16%	25%	21%	9%

Figure 4 shows the percentage of honor code violations in each semester. There were zero honor code violations in Fall 2022, compared with 21% in Spring 2021 and 22% in Fall 2021.

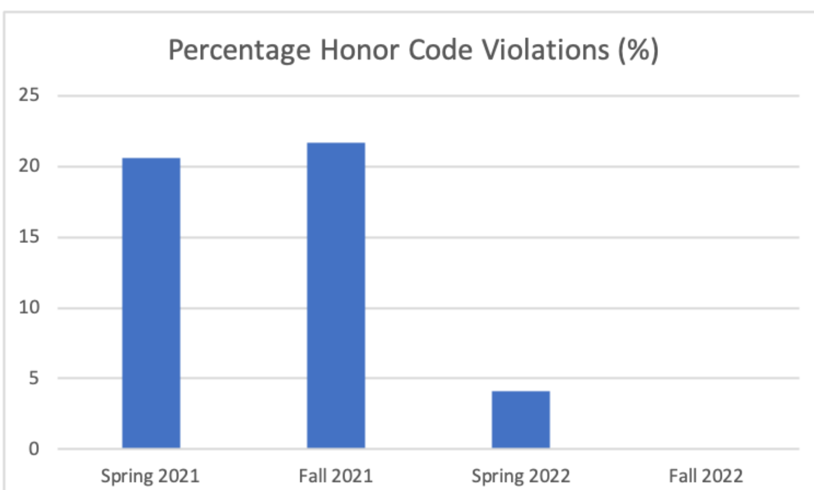

Figure 4. Percentage of honor code violations (%)

Instructional Approach and Four Categories of the Learning-Centered Teaching Techniques (A) through (C) in One Online Section

In the online section, principles of "Constructive Alignment," "Practice and Feedback," and "Balance" guide the instructional approach design [7-11]. The online section implemented learner-centered teaching techniques (Table 7) in the following four categories: (A) Course setup, (B) Course delivery, (C) Formative assessment, and (D) Summative assessment [7-11].

Table 7. Course Elements

	Element	**Spring 2021**	**Fall 2021**	**Spring 2022**	**Fall 2022**
(A) Course Setup	Graphic organizer (concept map)	X	X	X	X
	Learning objectives	X	X	X	X
(B) Course Delivery	Online (live) Zoom lectures	X	X	X	
	In-person lectures with "small group classroom" with whiteboards, dual screen projection, and wall displays				X
	Active Reading Worksheets (in Excel/Canvas)	Excel	Excel	Canvas	Canvas
	Lectures with Circuit Examples	X	X	X	X
	Engagement Questions (in Excel/Canvas)	Excel	Excel	Canvas	Canvas
	Breakout Sessions (Zoom)	X	X	X	
	Mapping topic learning objectives to exam problems	X	X	X	X
	Meme Competition	X	X	X	X
	Monthly visits to Blacksburg	X	X	X	
	Students offered choice in some assessments		X	X	X
	Tent cards for student names (in class)				X
	Equation Sheet			X (Final Exam)	X
	Weekly Modules in course Learning Management System with 'before class', 'during class', 'after class' topics, learning objectives, assignments	X	X	X	X
(C) Formative Assessment	Course check-in surveys	X	X	X	
	MidSemester Feedback				X
	Reaching out to students who missed each assignment with individual emails requested by the department			X	X
	Reaching out to students who missed each class with individual emails requested by the department (after attendance was tracked)				X
	Homework (for credit)	X			
	Homework (extra credit)		X	X	X
	Quizzes		X	X	X
	Quizzes with podcasts				X
(D) Summative Assessment	Mid-Term Exam 1 Online	X	X		
	Mid-Term Exam 1 in person			X	X
	Mid-Term Exam 2 Online	X			
	Mid-Term Exam 2 in person		X	X	X
	Final Exam online	X			
	Final Exam in person		X	X	X

(A) Course Setup

1) *Graphic organizer for one online section*

In an online section, a graphic organizer (Fig. 5) was developed because these graphic organizers (also referred to as “concept maps”) “preview material to be covered in class and/or summarize what was covered and put it in a broader context” [10]. Concept maps are also discussed in [12].

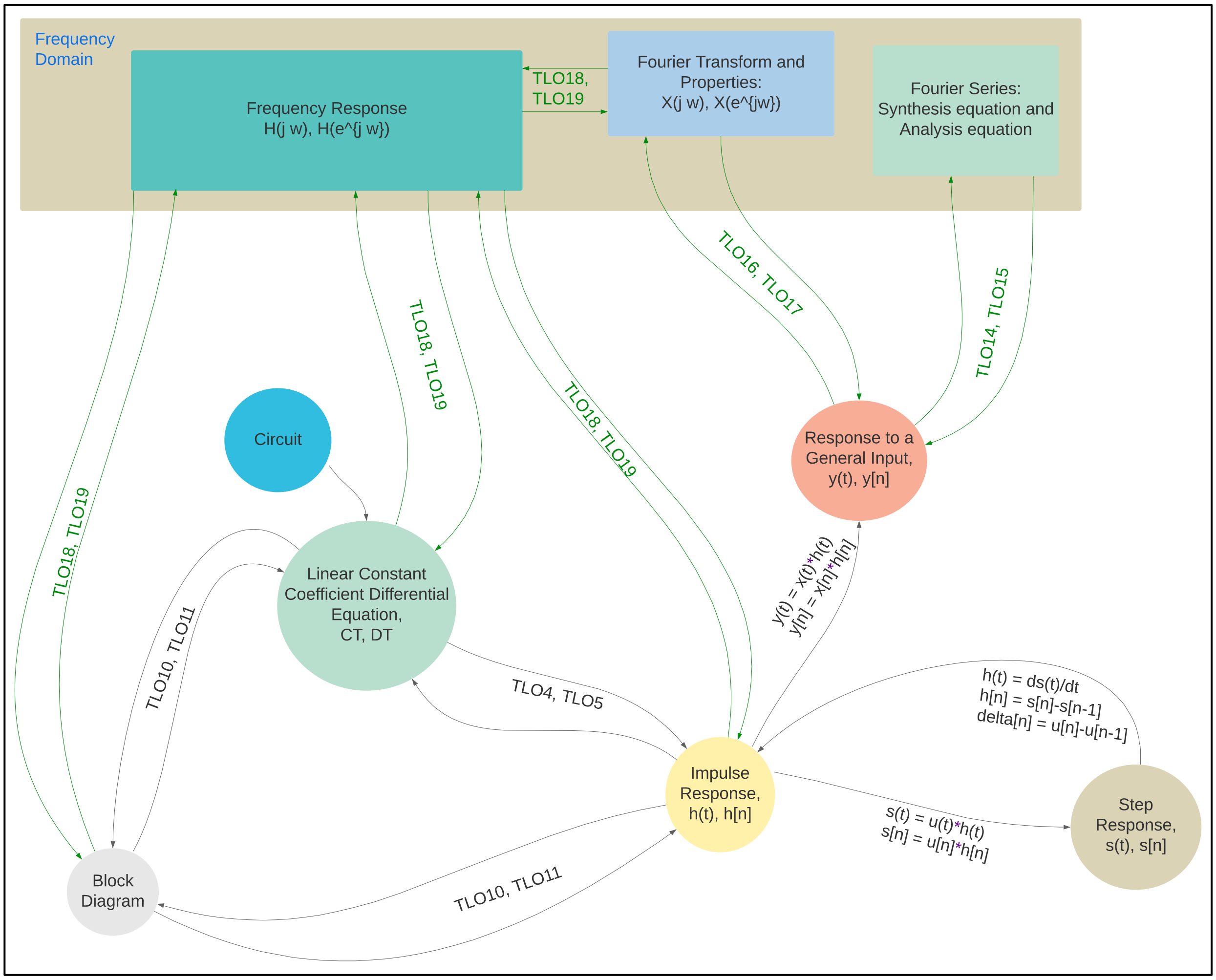

Figure 5. Graphic organizer

2) *Learning objectives*

Like the approach in [9], for each problem set (homework), each MidTerm Exam, and the Final Exam, students are given a table on the first page of the exams mapping problems to the Topic Learning Objective(s), or “TLOs” (Table 8) on a cover sheet. The cover sheet also lists the assignment instructions.

(B) Course delivery of one online section

3) *Lectures with Circuit Examples*

The lectures are organized as two 75-minute class meetings on Tuesdays and Thursdays. Several TLOs include circuits examples that relate the associated TLOs to material covered in prerequisite courses. Examples include circuits that can be described by first-order and second-order differential equations.

Table 8. **Topic Learning Objectives (TLOs) for the Course**

TLO Number	Topic Learning Objective (TLO) Number and Name
1	TLO 1: Course Introduction
2	TLO 2: Continuous-time (CT) signals
3	TLO 3: Discrete-time (DT) signals
4	TLO 4: CT systems as linear constant coefficient differential equations
5	TLO 5: DT systems as linear constant coefficient difference equations
6	TLO 6: Linear time invariant CT systems
7	TLO 7: Linear time invariant DT systems
8	TLO 8: CT convolution
9	TLO 9: DT convolution
10	TLO 10: CT block diagrams
11	TLO 11: DT block diagrams
12	TLO 12: Eigenfunctions of CT systems
13	TLO 13: Eigenfunctions of DT systems
14	TLO 14: CT Fourier Series representation of signals
15	TLO 15: DT Fourier Series representation of signals
16	TLO 16: CT Fourier Transform
17	TLO 17: DT Fourier Transform
18	TLO 18: CT Frequency Response
19	TLO 19: DT Frequency Response
20	TLO 20: Frequency Selective Filters in CT
21	TLO 21: Frequency Selective Filters in DT
22	TLO 22: The Discrete Fourier Transform
23	TLO 23: Sampling
24	TLO 24: Reconstruction

4) *Active Reading Worksheets (ARWs)*

Active reading worksheets (ARWs) [14] were implemented in the online section and hybrid sections as questions to be completed by students before class. In Spring 2021 and Fall 2021, the ARWs were delivered using Microsoft Office Forms. In Spring 2022 and Fall 2022, the ARWs were written using Canvas Quizzes. The ARWs are typically 4-5 questions that ask students about concepts, figures, and equations that are discussed in the reading assignment in the textbook, *Signals and Systems* by Oppenheim and Willsky [15].

In the Spring 2022 hybrid section and Fall 2022 in-person section with hybrid delivery, the ARWs were implemented in Canvas with the quiz function. These questions were typically multiple-choice questions and were graded by Canvas. The ARWs were required to be submitted by the start time of each class lecture. The hybrid section offered 5-6 weekly Canvas-graded timed open-note quizzes. Quizzes used the same questions with different values of the constants in some of the questions (such as $a = 3$) to maximize (as much as practical) variability between student quizzes without impacting difficulty.

In Week 10 of the Fall 2022 section (October 18, 2022), a discussion of the course to obtain **Mid-Semester Feedback** was held at the end of class by the Center for Excellence in Teaching and Learning (CETL) [16] at the instructor's invitation. For approximately 15 minutes, CETL led the class in a discussion of mid-semester formative evaluation. Students were asked to respond to the following prompts:

> (1) "What aspects of the class do you believe **should be changed**? How should these aspects be changed? (Please be as specific as possible)" [17];
> (2) "What aspects of class are **working well**? What are the strengths of the class? What aspects of the class are having a positive impact on your learning?" [17];
> (3) "What aspects of the class are **working poorly**? What are the weaknesses of the class? What aspects of the class are having a negative impact on your learning?" [17].

Following mid-semester feedback in Fall 2022, CETL delivered a Mid-Semester Feedback report to the instructor. The instructor held a discussion with class at the start of the following class. Based on this discussion, the following changes were made to the course: (1) solutions and answers to quizzes were posted for the rest of the semester; (2) full credit was given for quizzes when students submitted their own work as a PDF and when students submitted a video podcast (no points were deducted for wrong answers on quizzes); (3) attendance at each class was tracked, and class voted on the number of points to receive for attendance.

5) *Engagement Questions and Breakout Sessions*
Engagement questions (EQs) [18] are implemented in the online section as a method to take attendance and encourage students to log in to the class Zoom meeting.

In Spring 2022 and Fall 2022, the engagement questions were also implemented in Canvas with the quiz function in Canvas. These questions were typically multiple-choice questions and were also graded by Canvas. The EQs were required to be submitted by 11:59 PM after each lecture.

6) *Meme Competition*
A meme competition [19] is held in the online section to encourage students to apply the concepts they have learned throughout the course. The meme competition is held in the last few weeks of the course. Students have the option to submit memes to a webpage on padlet [20]. Students earn class participation bonus points (up to 1% over the participation maximum) to submit a meme.

7) *Monthly visits to the main physical campus requested by the department*
Monthly visits were requested by the department for the instructor to visit the main physical campus in Blacksburg in Spring 2021, Fall 2021, and Spring 2022. Visits were requested to teach class in person and to hold office hours.

8) *Students offered choice in some assessments*
In Fall 2021, following discussion with the department, students were offered a choice of problems to solve in MidTerm 2 (top six out of eight questions counted toward the grade) and Final Exam (top eight out of ten questions counted toward the grade).

In Spring 2022, students were offered two multiple-choice problems with multiple parts in the exams. For correctly completing enough parts of these questions, the students receive full credit.

In Fall 2022, students were offered problems with choice on MidTerm exams 1 and 2. Two multiple-choice problems were offered on the Final Exam.

9) *Homework questions and exam problems are mapped to Topic Learning Objectives*
In each semester, the homework questions and exam problems are mapped to the Topic Learning Objectives in the course.

(C) **Formative assessment**
10) *Course Check-in Survey, Course Check-in Survey (Open-ended), Midterm Survey, Week 13 Course Check-in Survey 2, Week 13 Course Check-in Survey 2 (Open-ended), Week 13 Midterm Survey 2 in one online section*
Six times in the semester in the online section, optional online surveys are offered in the learning management system to request student feedback. These surveys were implemented through Canvas in the middle of the semester (3 surveys) and in Week 13 (3 surveys). Student feedback was collated into a PowerPoint presentation and discussed in the next week. Afterward, changes were discussed and made in coordination with other instructors in the course.

In Fall 2022, a Mid-Semester Feedback session was held in class by invitation of the instructor. The Center for Excellence in Teaching and Learning (CETL) [16, 17] visited class during Week 10 to collect anonymous feedback and prepare a report. The feedback was discussed with the class, and following the discussions, changes were made to the course.

11) *Reaching out to students with individual emails requested by the department*
To further increase student engagement, in Spring 2022, the department requested that instructors of all base courses reach out to students with a copy of the email to each student's assigned departmental Undergraduate Academic & Career Advisor regarding missed graded events. The suggested note is:

> *"Dear Student (insert name here),*
> *I was reviewing the grades in ECE XXXX and noticed that you were not able to complete assignment XXX. Is there anything our support team for the class can do to help you keep on track in the class? I am happy to have you in this class and want to see you succeed. I understand that we all face demands outside of the classroom that can impact our class performance. If you would like to meet to discuss a plan moving forward in this course, please come to my office hours at your earliest opening or if they conflict with your schedule, please reach out to our assigned GTA for assistance."*

12) *Video Quizzes (podcasts)*
Video quizzes [21] offer students an opportunity to explain course concepts in their own words (podcast) with the option of preparing slides (video quiz). Students are at the center of the content creation. In this way, the students feel like engineers and are exploring their sense of belonging in the engineering community.

Portions of the Video Quizzes (podcasts) are adapted from projects described by Joseph P. Hoffbeck in 2012 at the ASEE *Annual Meeting* [22] and from problems in a Digital Signal Processing textbook by Tan and Jiang [23]. In these quizzes, students are provided with MATLAB code and encouraged to run the code and use their critical thinking skills to analyze the results.

(D) **Summative assessment**
Two mid-term exams and one final exam were given.

Results: Student Participation

Figure 6 shows the percentage of the class who completed the Active Reading Worksheets.

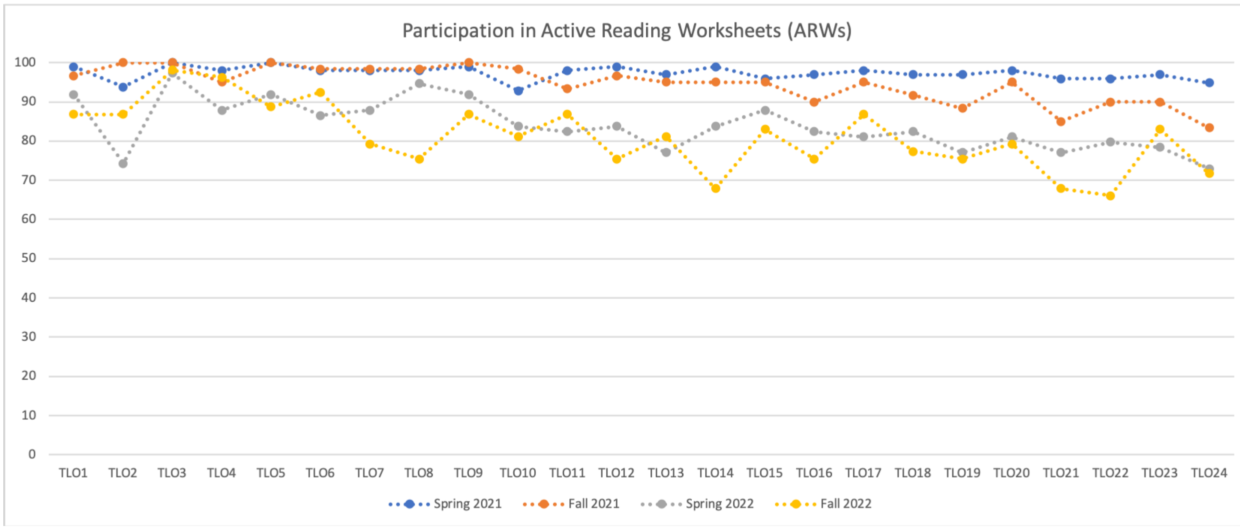

Figure 6. Participation of the class (%) who completed daily Active Reading Worksheets

Figure 7 shows the percentage of the class who completed the daily Engagement Questions (EQs).

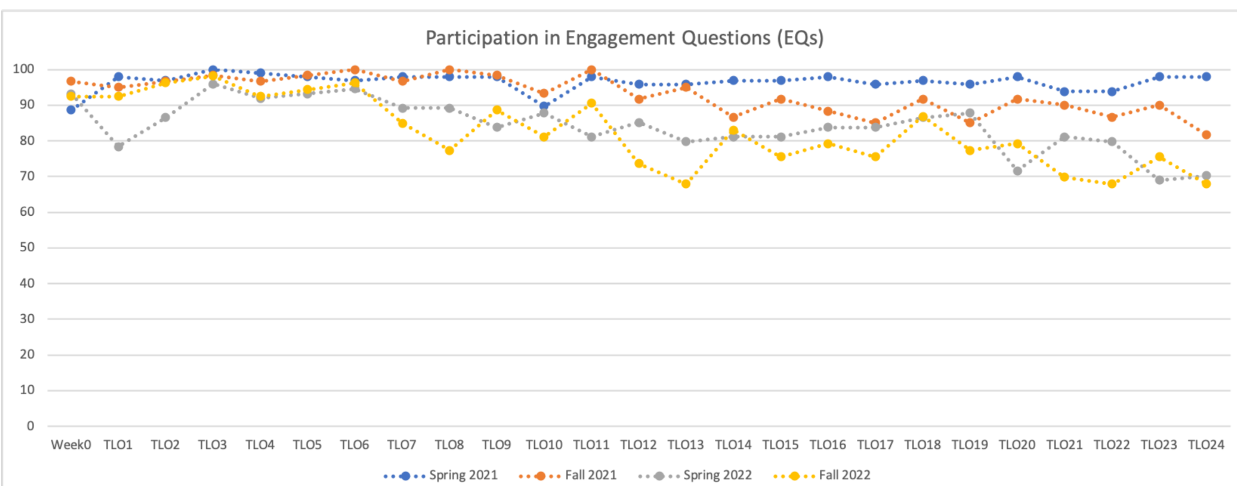

Figure 7. Participation of class (%) who completed daily Engagement Questions

Figure 8 shows the percentage of the class who submitted Quizzes in Spring 2022 and Fall 2022. There were 1-2 quizzes each week assigned at 1:00pm after the second class of the week and due on Saturday night at 11:59pm. The quizzes were assigned and graded in Canvas on Sunday and Monday in order to give students graded feedback before the following week's classes.

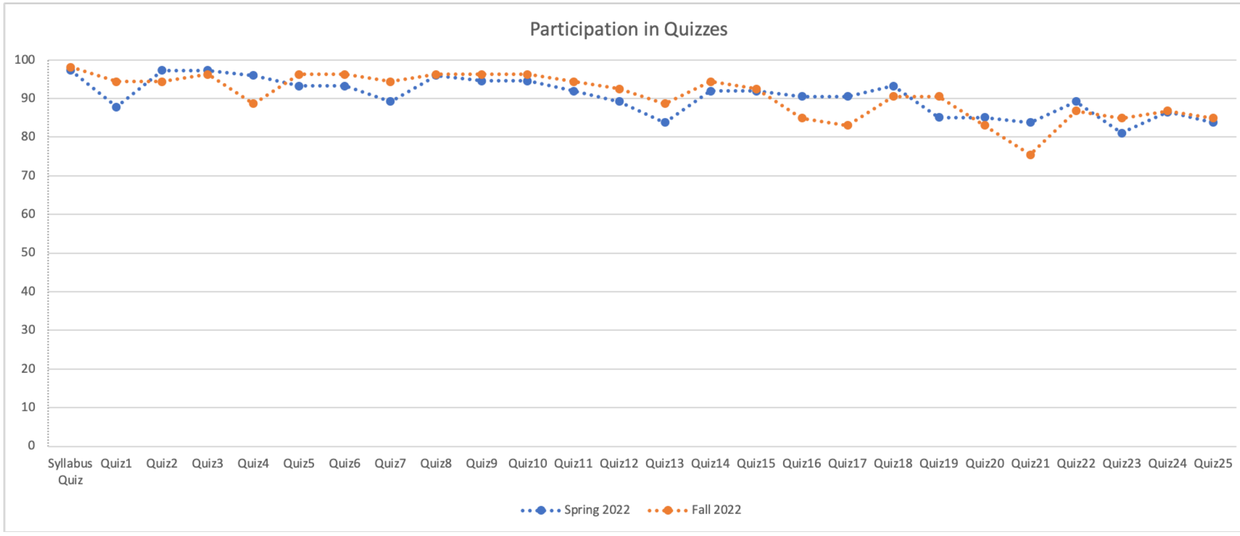

Figure 8. Participation of class (%) who completed Quizzes

Figure 9 shows the percentage of the class who attended class after Mid-Semester Feedback starting after exam 2 with TLO17 until the end of Fall 2022 semester.

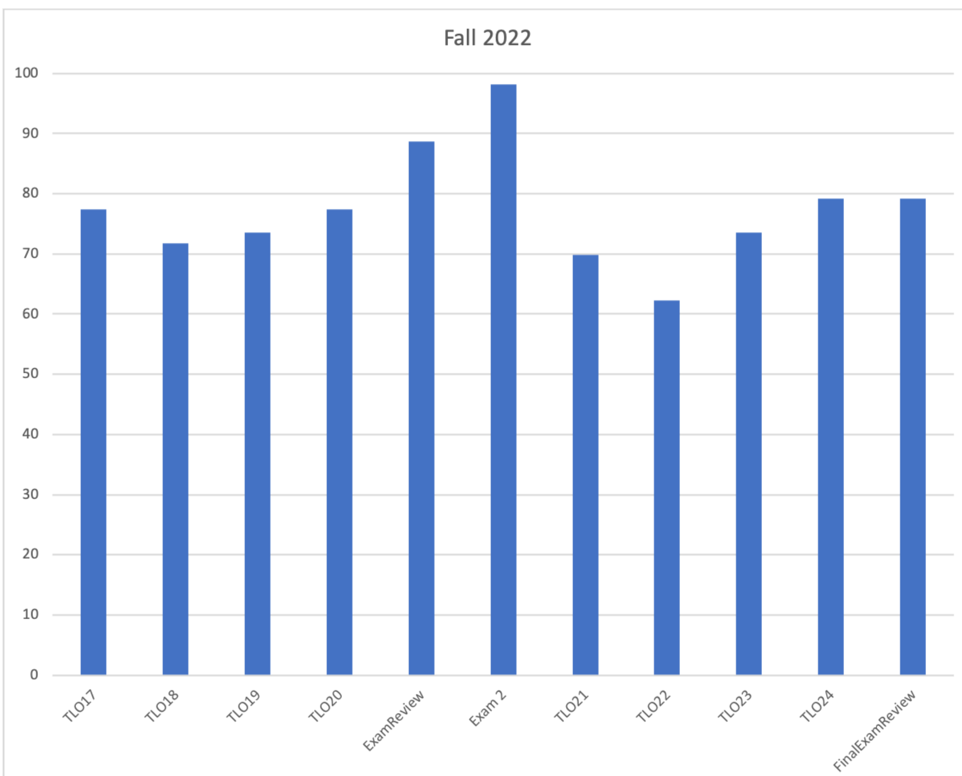

Figure 9. Attendance (%) after Mid-Semester Feedback when attendance is tracked in Fall 2022

Figure 10 shows the percentage of the total missed assignments across all categories (for that week) as a function of time.

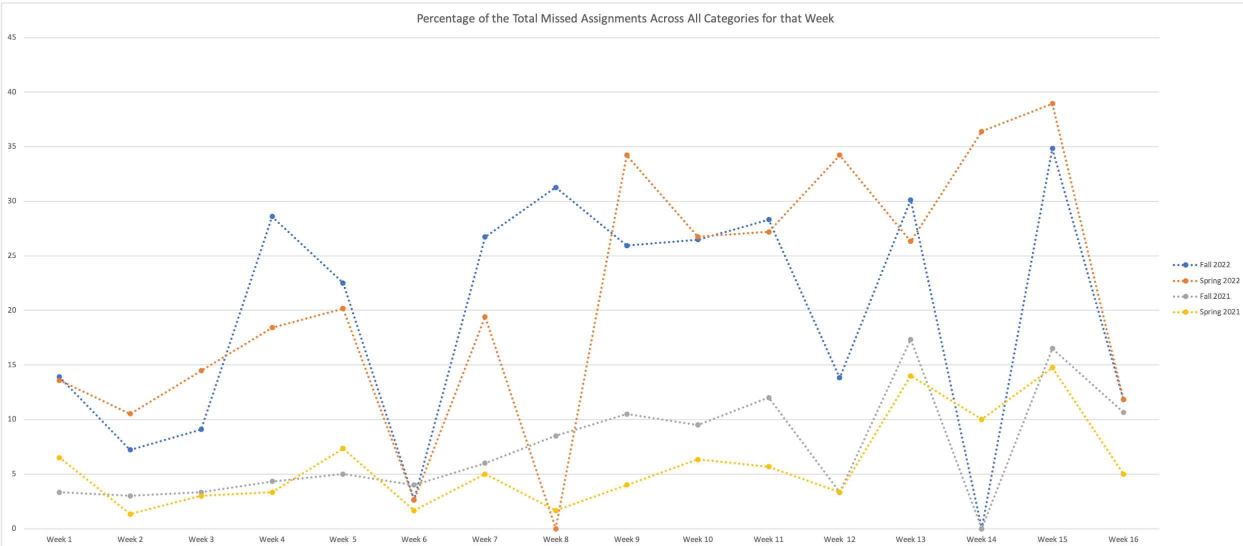

Figure 10. Missed assignments as a function of time

Results: Two Department Metrics

The department requests students to self-report regarding student attainment of the five course LOs (LO1-LO5) as discussed in Fig. 1. Students are asked the extent to which they feel that they have attained the course LOs. The five choices use a Likert scale and are: “Excellent” (4 points), “Good” (3 points), “Fair” (2 points), “Poor” (1 point), and “N/A” (0 points).

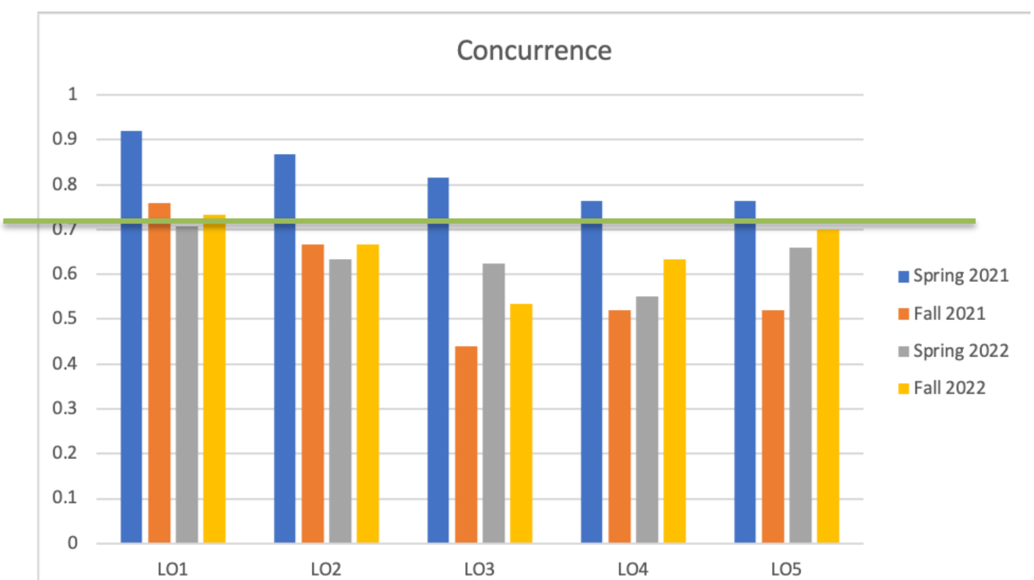

Figure 11. Concurrence Scores

Two metrics are derived from the self-reported student attainment. Failed concurrence is stated when there are fewer than 70% of respondents who indicate “Good” or “Excellent” regarding the attainment of the LOs (LO1-LO5). Concurrence score is reported by the department as a fraction. A “Failed” Mean Opinion Score (MOS) occurs when the weighted average score is less than 2.6 out of 4.0 regarding attainment of the LOs (horizontal green lines in Figs. 11 and 12).

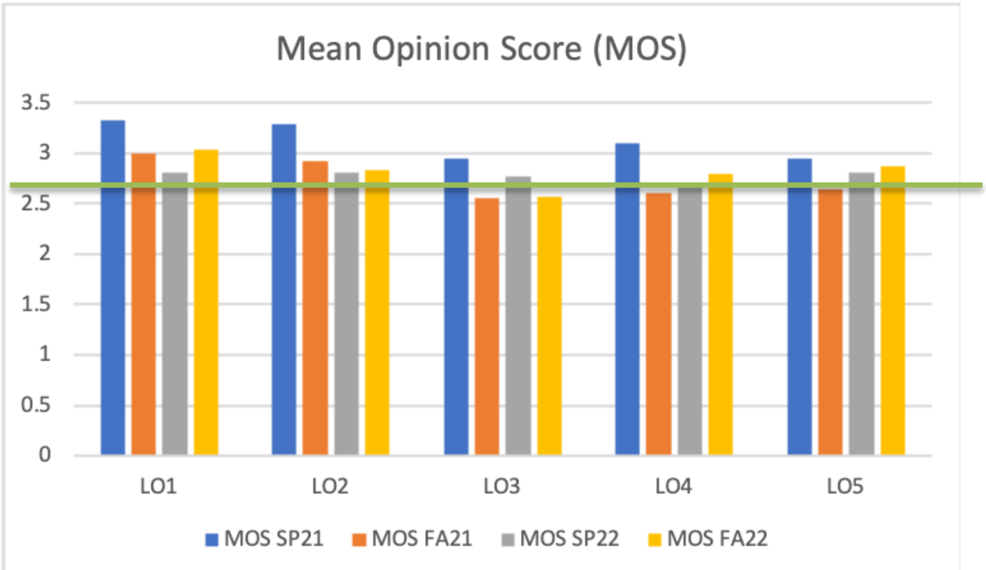

Figure 12. Mean Opinion Scores (MOS)

Results: Student self-reported feedback

Student feedback about the techniques and course development are shown in Table 9. The comments discuss learner-centered teaching techniques in anonymous end-of-semester surveys.

Table 9. Some anonymous student comments in end-of-semester Student Perceptions of Teaching (SPOT) Surveys

	Student Comments
Spring 2021	“She provided great notes that were helpful in all of the assignments”
	“Every class is very carefully prepared”
	“Office hours, examples, more examples, and even more examples, handouts literally everything she does helps you learn”
	“She is very patient with me and she always encouraged us to do better during every class”
	“Good ARW and engagement stuff”
Fall 2021	“Provides worked out solutions to previous course materials. And also worked out problems during class”
	“Supplied a multitude of resources to look at the supplemented the course”
	“She presented the lecture information in a clear and concise manner”
	“The course was online, so in terms of the online lectures, they were presented clearly. There was never a major issue when it came to lectures. As for the in-person exam, it was okay. The room wasn’t fantastic and it didn’t seem like the workspace for the students was properly prepared.”
	“In person would be better”
Spring 2022	“She summarized key points from the reading on her notes and presented in a very clear and concise manner. She was always open to feedback and responded very promptly to it.”

	"Professor Lanzerotti had a LOT of materials for students to learn the course material. Everything from creating her own quizzes to not allow the students to sink too much tie into the problems to the practice exams to the feedback on allowing us to still do the in-person classes homeworks. Not a single other professor I've had at Tech has given the students so many opportunities to do well."
	"The well-organized handouts and lecture notes aided me in understanding the course concepts."
	"Notes provided were clear to understand and color coded to help with clarify. Professor Lanzerotti would also give us helpful tips on how to solve certain problems that would later help for other assignments. Because of this, this allowed students to take any given problem and be able to solve it."
	"I enjoyed taking the course, and my interest in signal processing has increased after taking it. I appreciate the instructor's responsiveness to student questions and feedback."
Fall 2022	"The quizzes and Course Director Materials were very extremely helpful for understanding course content, and the test review sessions were very helpful as well. The mandatory attendance was also a good policy."
	"I liked all the worked out problems in the TLOs and notability notes."
	"The design of the course was better when there was more board time. I know everyone said otherwise but I think this is dense material to lecture on and given more time on boards would have meant more time for Dr. Lanzerotti to help work through issues students had, which, in my experience, is an excellent skill she has."
	"She really cares her students and welling to do adjustment to help student study more efficiently."
	"Professor was extremely organized from beginning to end, and also allowed students to give her feedback to better help us learn in the class. Treated us with a lot of respect and made the class feel welcomed."

Conclusions

The results show that the changes to increase course engagement succeeded as everyone is learning how to learn during COVID and in post-COVID environments. The percentage of students who respond to the online course-end student survey increased from 38% in the Spring 2021 offerings of the course to 45% in Fall 2021, 54% in Spring 2022, and 57% in Fall 2022 offerings respectively. The percentage of students with failing grades decreased to 9% in Fall 2022, from 16% (Spring 2021), 25% (Fall 2021), and 21% (Spring 2022), respectively. The percentage of honor code violations in each class decreased to 0% in Fall 2022, from 21% (Spring 2021), 22% (Fall 2021), and 4% (Spring 2022), respectively.

The pedagogical approach that we are adopting has the advantage of increasing student engagement in the course. The strategies to increase in-person engagement may be helping to improve the students' performance. We observe that the additional strategies, including the Equation Sheet and the mapping of topic learning objectives to the course graded event problems, may also be helping to improve the students' performance. We will continue these strategies, including podcasts, in the future.

The podcasts worked very well as a way to engage the students in the course. Students enjoyed the opportunity to present the material in their own words and present live to a virtual audience (the instructor) who listened to the podcasts.

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Committee for information about the calculation of the assessment of the course learning objectives using Mean Opinion Score (MOS) and Concurrence Score.

Glossary

ARW	Active Reading Worksheet
CETL	Center for Excellence in Teaching and Learning
CT	Continuous time
DT	Discrete time
ECE	Electrical and Computer Engineering
EQ	Engagement Question
LO	Learning Objective
MOS	Mean Opinion Score
SPOT	Student Perception of Teaching
TLO	Topic Learning Objective
VT	Virginia Tech

References

[1] ECE 2714 – Circuits and Systems. [Online]. Available: https://ece.vt.edu/undergrad/courses/2714.html.

[2]. ECE 2714 – Online/hybrid section. Question specification in the Online/hybrid section of ECE2714 with podcast questions.

[3] ECE 2024 – Circuits and Devices (3C). [Online]. Available: https://ece.vt.edu/undergrad/courses/2024.html.

[4] ECE2544 – Fundamentals of Digital Systems (3C). [Online]. Available: https://ece.vt.edu/undergrad/courses/2544.html.

[5] ECE2514 – Computational Engineering (3C). [Online]. Available: https://ece.vt.edu/undergrad/courses/2514.html.

[6] Virginia Tech Student Perceptions of Teaching (SPOT). [Online]. Available: https://aie.vt.edu/institutional-effectiveness/spot.html.

[7] Richard M. Felder and Rebecca Brent, *Teaching and Learning STEM: A Practical Guide*, 1st Ed., New York, NY: Jossey-Bass, March 7, 2016.

[8] Rebecca Brent, Michael Prince, Richard Felder, "Promoting and Managing Student-Student Interactions in Online STEM Classes," *Int. Jnl. Eng. Educ.,* vol. 37, no. 3, pp. 797-813, 2021.

[9] Michael Prince, Richard Felder, Rebecca Brent, "Active Student Engagement in Online STEM Classes: Approaches and Recommendations," *Adv. Eng. Educ*., vol. 8, no. 4, Fall 2020.

[10] Richard M. Felder and Rebecca Brent, “Effective Teaching: A Workshop.” National Effectiveness Teaching Institute (NETI).

[11] Mary Yvonne Lanzerotti, Christopher I. Allen, Michael Doroski, Curtis Medve, Michael Seery, P. Len Orlando III, Farid T. Khafizov, “An Electrical Engineering Graduate Course Sequence in Integrated Circuits Targeted to Real-World Problems in Industry, Defense, and Security,” 2017 *American Society of Engineering Education*, Columbus, OH. June 25-28, 2017. Paper ID# 17791.

[12] Cristiane Tolentino Machado and Ana Amélia Carvalho, “Concept Mapping: Benefits and Challenges in Higher Education,” *The Journal of Continuing Higher Education*, vol. 68, no. 1, 2020, pp. 38-53.

[13] Chelsea Jalloh, Benjamin Collins, Danielle Lafleur, Joss Reimer, and Adrienne Morrow, “Mapping session learning objectives to exam questions: How to do it and how to apply the results,” *Medical Teacher*, vol. 42, no. 1, pp. 66-72, 2020. https://doi.org/10.1080/0142159X.2019.1652261.

[14] Active reading worksheets, David Kashinski, personal communication re: PH384/Applied Optics, 2020.

[15] Alan Oppenheim and Alan Willsky, *Signals and Systems*, 2nd Edition. New York, NY: Pearson, 1996.

[16] Virginia Tech Center for Excellence in Teaching and Learning. [Online]. Available: https://teaching.vt.edu/.

[17] “Using the Feedback-Best Practices”, Samuel Browning, personal communication, October 19, 2022.

[18] Engagement questions, David Phillips, personal communication re: PH205/Physics 1, 2020.

[19] Meme competition, Corey Gerving, personal communication re: PH205/Physics 1, 2017-2020.

[20] Padlet: You are beautiful. [Online]. Available: padlet.com.

[21]. Valerie Denney, Embry–Riddle Aeronautical University, personal communication, 2022.

[22]. Joseph P. Hoffbeck, “Enhance Your DSP Course with these Interesting Projects,” 2012 *American Society of Engineering Education* (*ASEE*) *Annual Meeting*, AC 2012-3836, San Antonio, Texas, 2012, pp. 1-15.

[23]. Li Tan and Jean Jiang, *Digital Signal Processing: Fundamentals and Applications*, Second Edition, Waltham, MA: Elsevier, Inc., 2013.