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Design and Evaluation of Undergraduate Feedback-control System Course in Distance Learning

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Abstract

This paper is a work-in-progress (WIP) paper. COVID19 pandemic profoundly changed the way educators teach and the way students learn. Our institution, the New York City College of Technology, abruptly switched to distance learning mode in Spring 2020 and continues to offer all courses online in Fall 2020. This paper presents the redesign and evaluation of an undergraduate Feedback Control System course to adapt to distance learning. Feedback Control System course is the last required course for the Bachelor of Technology (BTech) program in Computer Engineering Technology (CET), which has a 3-hour lecture lesson and a 3-hour lab session every week. Due to our BTech students' diverse mathematical backgrounds, students think this course is demanding even in the traditional face-to-face teaching mode. Teaching such a mathematically involved class in the distance learning mode poses significant challenges to both the instructors and the students. This paper documents our re-structure and redesign process of both the lecture and lab components to facilitate students' remote learning experience, satisfy the ABET accreditation criteria and maintain our pre-set learning standard.

The online characteristic gives the instructors the freedom and a framework to teach classes in various delivery modes via synchronous lectures (like virtual meetings) and asynchronous online supplementary resources (for example, Blackboard). The arrangements we made to adjust to the distance learning mode include: a) decomposition of the course context into three modules and clear specification of the corresponding learning objectives of each module; b) combination of different technologies to create friendly and inclusive learning environment; c) frequent assessment of students' performance via online quizzes/tests; and d) carefully-designed laboratory assignments via MATLAB simulations that are able to demonstrate the entire feedback control process.

A comparison of students' performance under the traditional face-to-face learning mode and the new distance learning mode is conducted. Based on assessment results, we will evaluate the effectiveness of our current teaching methodology/plan developed for distance learning and possibly identify potential areas for further improvement.

Keywords: Engineering Education, Feedback control system, distance learning

1. Introduction

New York City College of Technology (City Tech) is one of the senior colleges of the City University of New York (CUNY), which is the nation's largest urban public university. City Tech is the largest public, baccalaureate college of technology in the Northeast and serves as a transformative engine of social mobility in New York City. [1] The department of Computer Engineering Technology (CET) is dedicated to preparing students with the fundamentals of electrical technology, electromechanical technology, computer hardware, software, networks, using engineering principles to integrate these technologies to control electromechanical devices and develop computer-controlled and embedded systems. Feedback Control System course is the last required course for the Bachelor of Technology (BTech) program in Computer Engineering Technology, which has a 3-hour lecture lesson and a 3-hour lab session every week. Due to our BTech students' diverse mathematical backgrounds, students think this course is one of the most challenging courses in our program.

In the spring semester of 2020, our institution abruptly switched from in-person teaching to distance learning. Distance learning continued into fall 2020. This paper is a work-in-progress (WIP) paper, reported our practice to adjust to distance learning in this course. In the next section, we present our efforts: a) decomposition of the course context into three modules (i.e., modeling, analysis, and design) and clear specification of the corresponding learning objectives of each module; (b) combination of various technologies and course activities to create inclusive learning environment; (c) frequent assessment of students' performance via online quizzes/tests; (d) carefully designed laboratory assignments via MATLAB simulations that can demonstrate the entire feedback control process. The last section presents the assessment results and comparison with in-person teaching mode.

2. Moving toward distance learning

Feedback Control System course introduces students to linear systems analysis and design in both the Laplace domain and time domain. This course starts by using differential equations to model systems on everyday applications, and Laplace transforms and transfer functions are used to study performance specifications, root locus, and frequency responses. The system design is introduced in both root locus technique and Bode/Nyquist technique. Because Engineering Technology students have relatively weak mathematics background, they feel challenging to grasp the relationship between mathematical models and physical applications and how to manipulate the mathematic model to generate desire response or controller. In the transition to distance learning, we want to emphasize on the big picture of feedback control system instead of making students lost in mathematic details. We also want to take advantage of available technologies, such as the flexibility and multiple methods to deliver information [2].

2.1 Decomposition of the course context

In our department, usually there are multiple sessions of this course opened at the same time. To give all instructors better guidance, we restructured the course content into three modules:

modeling, analysis, and design. The detailed content structure and important topics are shown in Table 1.

Table 1. Restructured course content

	Topics	
1	Review of math prior knowledge, such as complex number, Laplace Transform and Inverse Laplace Transform	**Modeling**
2	System Modeling: differential equation, transfer function and introduction to block diagram, use RLC circuits, Op-Amp circuits, electric motor as examples.	
3	Time Response of 1st-order and 2nd-order systems: general forms of output response, transient response, performance specifications (time constant, rising time, settling time, overshoot, peak time), second-order under-damped/ undamped/critically-damped/over-damped systems, natural frequency, damping ratio, steady-State Error (for unity feedback systems)	**Analysis**
4	Block Diagram Reduction: obtain transfer function of inter-connected systems.	
5	Stability Analysis: by pole locations and by Routh-Hurwitz criteria	
6	Root Locus: Introducing root locus Root Locus: Sketching root locus Root Locus: Refining root locus	
7	Introduction to Frequency Response Sketching Bode plot of 1st and 2nd order systems Gain Margin and Phase Margin Nyquist Plot and Nyquist Stability Criterion	
8	PID controller, effect on system response	**Design**
9	Root-Locus-Based Controller Design: PI Root-Locus-Based Controller Design: PD More examples on Root-Locus based PID controller design	
10	Frequency-Response-Based Design: Lead Frequency-Response-Based Design: Lag	
11	Introduction to MATLAB Control System Toolbox Control System Design: principles and case studies	

In the first module, modeling, we emphasize on the mathematic background and system modeling. Students review Laplace transform, which should be already covered in a pre-requisite course. Basic mechanical system, electrical system, and electro-mechanical systems are modeled using differential equations based on their physical principles; then Laplace transform is used to get transfer function. The second module, analysis, focuses on different aspects of transfer function from time response to stability, root locus, and frequency response. The last part is design, where students can use either root locus method or lead-lag method to design controller under certain specifications. In general, the first module is expected to finish in three to four weeks; the second module takes about five to six weeks; and the last module takes about four to five weeks depending on instructors. Based on the restructured course content, specific course learning outcomes that students are expected to achieve at the end of semester are presented in Table 2. These learning outcomes are consistent with each module and can be used as guidelines to assess students learning performance.

Table 2 Course Learning Outcome

Module	Learning Outcome
Modeling	1. Demonstrate the knowledge about mathematical models of dynamic systems described by time differential equations. 2. Construct a transfer function representation of a linear dynamical system. 3. Understand Laplace transform and the relation between different mathematic models.
Analysis	4. Understand the characteristics of feedback control systems, time response, and performance specifications. 5. Manipulate block diagrams and transfer functions. 6. Know what characterize stability in linear systems, and methods to analyze stability in feedback systems with controllers.
Design	7. Design control systems in the time domain using root locus techniques. 8. Design control systems in the frequency domain using Bode/Nyquist techniques. 9. Be familiar with the most common controllers in industrial use.
Lab	10. Integrate the concepts of feedback control systems with real-time simulation using MATLAB.

2.2 Create inclusive learning environment using different technologies

In distance learning, students can feel disconnected from instructor and their peers [3]. We explored various technologies to create a friendly and inclusive learning/teaching environment.

Zoom was used in synchronous virtual meetings. Professional zoom license was provided by the institution. Instructor and students hold synchronous weekly meetings according to the academic calendar. There are multiple software applications integrated into the synchronous virtual meeting. Microsoft PowerPoints was used to present slides; Microsoft OneNote was used as a whiteboard to solve examples and derive formulas in real-time with a writing tablet's assistance; MATLAB was used to do simulation and demonstration in class. Other features from Zoom, such as reactions, whiteboard, chat room, and poll, were used during the class to facilitate the discussion and communicate with students. Another significant advantage of Zoom is that it has an option to record a meeting on a password-protected cloud environment. This feature is beneficial because students can review these materials any time after the class.

Blackboard has been the official teaching platform used in our institution for many years. In general, it was used for posting course materials, such as lecture slides, homework assignments, and solutions. The role of Blackboard was expanded in distance learning. It was used to collect students' homework submissions, to conduct quizzes and exams. Instructors used Blackboard to give a clear course plan for each week and posted the link to recorded videos, so students did not feel disconnected from instructor. Because this is a course for senior students who are quite familiar with the functions of Blackboard, they did not have any problems using all these resources posted on Blackboard.

We tried virtual office hours and discussion forums to create a bond between instructor and students or between students. The instructor provides four-hour virtual office hours on Zoom every week, so students can stop by and ask questions or chat about their feeling. About 20% of students came to virtual office hours. To give students the opportunity to communicate with each other, the discussion forum on Blackboard was used to create a learning community where students can freely share some interesting topics. Every two weeks, a discussion thread was posted on the discussion forum. The subjects started from self-introduction, an interesting thing that happened during the pandemic, to some topics related to course materials, such as their preference on which mathematics model to describe a system. The topics usually were open-end questions; students were encouraged to do a web search or YouTube search to discuss their answers and share with other students. A study showed that engagement is crucial to student learning and satisfaction in online courses [4,5].

2.3 Frequent assessment of students' performance

CET4864 usually had three quizzes, one midterm exam, and one final exam in traditional in-person learning mode. Some students only submitted homework or reviewed materials before quizzes or exams. As a result, the learning effort was not consistent throughout a semester. This was a big concern for distance learning because students had less motivation to study. Another concern in distance learning was that students could be easily distracted during synchronous class. If students were unwilling to turn on their camera, the instructor did not know what they were doing during the class. To target these two concerns, online Blackboard quizzes were conducted weekly as low-stake tests in Fall 2020. As a result, quizzes gave students pressure to review, let students practice what they learned, and engage students during virtual synchronous meetings. Study shows that student learning is enhanced by frequent practice, and this is most effective when the practice is distributed across time and across tasks. [6] The quizzes were conducted at the end of each lecture in multiple-choice questions. Half of quiz questions came from the previous lecture requiring students to review before class, and the other half came from current lecture requiring students to pay attention during class. Questions usually focused on concepts and ideas without intensive calculations. These low stake quizzes can serve the functions of making students review materials and engaging students during a lecture. There were eleven quizzes conducted in fall 2020. All 20 students completed eleven quizzes, so we believe that weekly quizzes serve the designed purpose.

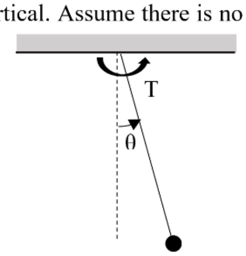
Multiple-choice questions are used in these low-stake quizzes because multiple-choice questions can easily test whether students grasp the correct concepts and basic knowledge. Another advantage of multiple-choice questions is that Blackboard system can automatically grade this type of questions without any error or confusion. On the other hand, it is hard to test students' problem-solving skills using multiple-choice questions only. Therefore, in both the midterm exam and the final exam, short-answer questions were also used to evaluate students' ability to analyze and logically solve a problem.

In Fall 2020, CET4864 still had one midterm exam and one final exam besides the weekly quizzes. The exams were high-stake tests [7], which assess students' general knowledge and emphasize logics, analysis, and computation. In face-to-face learning, the exams usually were conducted in closed-book, closed-notes, and in-class fashion. In distance learning, instructors cannot control whether students were closed-book or closed-notes. Another big challenge was to avoid plagiarism. The exams were restructured to have two parts. The first part was the multiple choices to test the basic concepts and knowledge; the second part was short answer questions that required analysis and computations. Students answered the second part on paper, then scanned, and submitted the answer sheets at the end of exams. To avoid plagiarism, the instructor generated a question pool for each topic, and students would get randomly selected questions from pre-designed question pools.

2.4 Collaboration with lab component

CET4864 is a 4-credit course with a 3-hour lecture and a 3-hour lab every week, so the lab is an essential component to this course's success. So far, all lab experiments were conducted in MATALB in both face-to-face learning and distance learning. No lab equipment was required. This made the transition from in-person teaching to distance learning relatively smooth. The lab learning outcome is listed in Table 2, integrate the concepts of feedback control systems

Pendulum is widely used in the traditional clock. It has a weight suspended from a pivot point by a massless cord. The weight has mass of m, the length of cord is L, T is the applied torque at moment t=0 (input), θ is the angle that pendulum swings away from vertical. Assume there is no friction in this process and zero initial conditions.



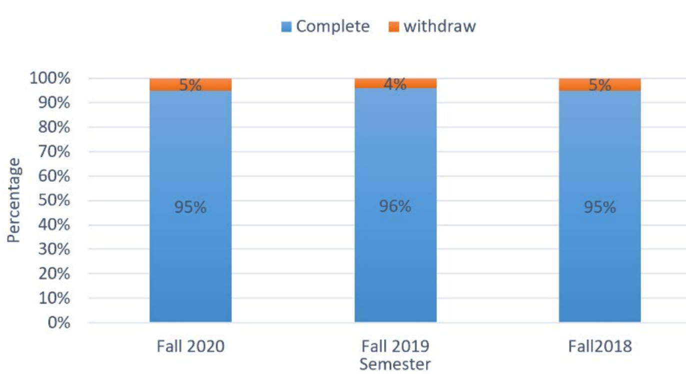
1. According to Newton's law for rotational motion, $M = I\ddot{\theta}$, where M is the sum of external moments, I is the mass moment of inertia ($I = mL^2$ for the ball), $\ddot{\theta}$ is the angular acceleration, write the dynamic model of pendulum. Assume the motion is small enough that $sin\theta \cong \theta$.
2. Do Laplace transform of differential equation, find the relation between $\Theta(s)$ and T(s).
   a. If m = 1kg, L=1m, g = 9.81 m/s^2, and T = 1N·m is a step input at moment t=0s. Calculate partial fraction expansion, then inverse Laplace transform by hand, find the response of the system $\theta(t)$.
   b. Write an m-file, use Matlab to calculate the inverse Laplace transform, show your results.
   c. Compare the results in a and b, plot the results from 0 to 10 sec. (plot θ in degrees, not radians.) What type of motion is this?
3. Discussion:
   a. What is the period and frequency of the plot in 2(c)?
   b. Change L=0.5m, plot the response again, what is the period and frequency?
   c. Can you design a pendulum with frequency of 1Hz?

Figure 1. Lab design example

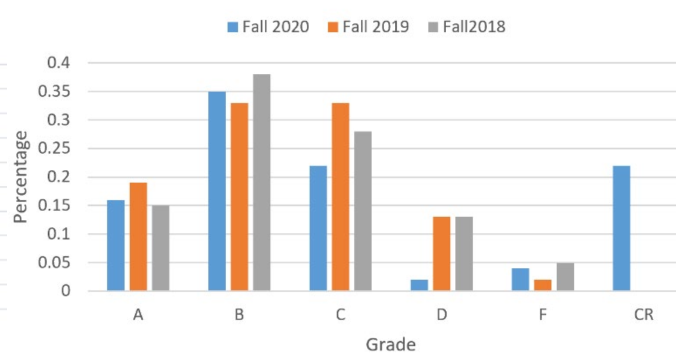
with real-time simulation using MATLAB. However, lectures and labs usually are taught by different instructors during the semester. In Fall 2020, we promoted the weekly communication between lecture instructor and lab instructor, and carefully designed laboratory assignments via MATLAB simulations to demonstrate the entire feedback control process. The lab serves as an extension of the lecture and emphasizes the connection between different parts. For example, one experiment, shown in Figure 1, was designed to model pendulum movement. Students start to model the system in differential equation using Newton's law for rotational motion in time domain, then get transfer function from differential equation, and discuss time response at the end. This lab connects dynamic model, differential equation, Laplace transform, transfer function, time response, and system design in one package. Students can connect these concepts, which they learned in lectures, to real-life applications. Formal lab reports are required, which can improve student's communication skills in both written and oral.

3. **Assessment and survey results**

In this section, we present the comparison of assessment results between distance learning and in-person learning. Fall 2020 was the first and only semester in which CET4864 was completely offered online; Fall 2019 and Fall 2018 were conducted regularly in in-person learning mode. Figure 2(a) shows the comparison between completion and withdrawal rate. All three semesters had very close completion rate, 95% in Fall 2020, 96% in Fall 2019, and 95% in 2018. Figure 2(b) displays the grade distribution among completed students. A and B grades in these three semesters were comparable; A was 16%, 19%, and 15% in Fall 2020, Fall 2019, and Fall 2018; B was 35%, 33%, 38% in three semesters. But C and D grades in Fall 2020 were much less than the other two semesters because our institution in Fall 2020 applied a temporary flexible grading policy to include a grade of Credit ("CR") or No Credit ("NC"). After instructors posted final grades, students can choose to convert the traditional letter grade they earned (any grade from B+ to D-) into a grade of Credit ("CR") or F to No Credit ("NC"). Unlike traditional letter grades, grades of Credit or No Credit will not factor into students' GPA. Some students earned a C or D in Fall 2020 and thought C or D grade hurt their GPA,



(a)



(b)

Figure 2. Assessment comparison between distance learning and in-person learning. (a) Completion rate; (b) Grade distribution

so they chose to convert to CR. If we combined C, D, and CR in Fall 2020, the total percentage was 46%, which was very close to the combination of C and D percentage, 46% and 41% in Fall 2019 and Fall 2018. The F grade in three semesters was 4%, 2%, and 5% in three semesters. Based on these results, we can conclude that students perform similarly under distance learning and in-person learning.

We conducted multiple anonymous surveys among students throughout the semester in one session of 20 students (n=20). Figure 3 showed the overall students' satisfaction with this class based on student evaluation of teaching (SET) conducted by our institution. The survey questions range from instructors' teaching style, communication, fairness, course environment, grading system, etc. Students give a score to each category with 5 as very satisfied, and 1 as very unsatisfied. In distance learning, the overall student evaluation score was 4.4 out of 5; in in-person learning, the overall score was 4.7 out of 5. These values are very close, which means students are equally satisfied in these two different learning modes. At the end of the Fall 2020 semester, we surveyed the effectiveness of distance learning in the same group of students. Students were asked to choose the five most effective teaching methods they like in distance learning from many options. The options were synchronous zoom lecture, provide lecture recording, solve problems step by step on whiteboard, provide power point presentation, weekly homework and solutions on Blackboard, weekly quiz and review, effectively answer questions during the class, effectively answer questions in email, virtual office hours, online resources, and discussion forum. The top five choices from students are presented in Figure 4.

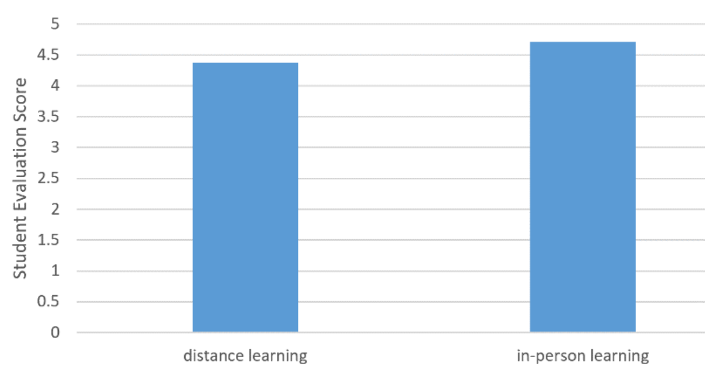


Figure 3. Comparison of student satisfaction rate

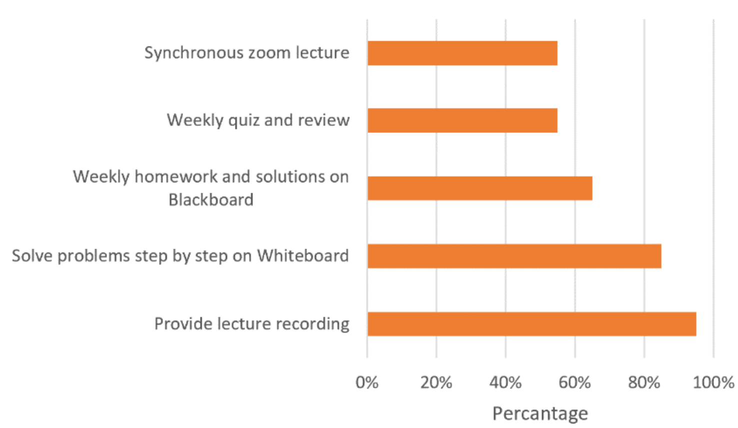


Figure 4. The five most effective teaching method in distance learning by students' choice.

95% of students chose lecture recording as the most effective method in distance learning, followed by solving problems step-by-step on OneNote during synchronous lectures at 85%. Weekly homework and solution were ranked number 3 at 65%. Weekly quizzes and synchronous zoom lectures are tied at 55%. These choices showed that students recognize the instructor's efforts and used all of the resources for their distance learning.

4. Conclusion and discussion

This work-in-progress paper presents our methods and arrangements that ensured a smooth transition from traditional in-person teaching to distance learning for an undergraduate feedback control system course. We restructured the course contents into three modules and developed corresponding learning outcomes for each module. These provided clear guidance for lecture and lab instructors. Different technologies and platforms were used to support distance learning and create an inclusive learning environment. Frequent in-class quizzes were conducted to motivate students to review materials promptly after each lecture and attract their attention during a synchronous meeting. Online tests were created with random questions to yield a reliable assessment of students' performance. Lecture and lab instructors worked to synchronize the course progress and develop the labs which integrate theories and applications. The assessment and survey results showed that students performed similarly between distance learning and in-person learning and gave positive feedback about their learning experience.

Teaching and learning during the pandemic have presented significant challenges to both instructors and students. For instructors, a tremendous amount of time was put into the preparation of distance learning. During synchronous zoom, instructors felt like talking to a computer or themselves if students did not turn on their cameras. On the other hand, students thought that they did not have enough control over how to learn in a synchronous meeting. One student repeatedly expressed that OneNote, the software used as a whiteboard for solving examples, is less effective than the real whiteboard in face-to-face learning. In OneNote, students can only read the parts displayed on the computer screen; in a real whiteboard in a face-to-face classroom, students can read and connect the materials written on different parts of a whiteboard. But most students agreed that more communications between students and the instructor could reduce these limitations of technologies.

In conclusion, we successfully transformed a mathematical intensive feedback control system course to distance learning in the Bachelor of Technology (BTech) program in Computer Engineering Technology (CET) and received similar assessment results compared to in-person learning. These data were collected from one session in Fall 2020. From these promising results, we plan to collaborate with other instructors and expand these arrangements to all (four) sessions of Feedback Control System classes in Fall 2021. The fall semester of 2021 will be a hybrid semester in our institution, with some courses offered on-campus and others still online. Specifically, the Feedback Control System course will continue to be offered online. We plan to collect more data in fall 2021 to further evaluate the effectiveness of our distance learning approaches.

Though online teaching poses challenges to both educators and students, it also forces educators to redesign course materials, re-think how the course should be taught, and take major steps toward improvement. We believe that our strategies will provide some valuable information for future practice, either in distance learning, in-person learning, or hybrid mode.

Reference:

[1]. College fact sheet, https://www.citytech.cuny.edu/about-us/docs/facts.pdf.

[2]. B. Pelz, "Three Principles of Effective Online Pedagogy," J*ournal of Asynchronous Learning Networks, Volume 14: Issue 1, 103-116, 2009*

[3]. H. Roediger, "Applying Cognitive Psychology to Education: Translational Educational Science," *Psychological Science in the Public Interest*. 14(1) 1-3 (2013)

[4]. F. Martin, D. Bolliger, "Engagement matters: Student perceptions of the importance of engagement strategies in an online learning environment," *Online Learning 22*(1), 205-222, 2018.

[5]. R. Kelly, "Creating a sense of instructor presence in the online classroom,". *Faculty Focus,* (2014).

[6] H. Roediger; P. Agarwal, K. McDermott, "Test-enhanced learning in the classroom: Long-term improvements from quizzing," *Journal of Experimental Psychology: Applied*, 17, 382-395 (2011).

[7] W. Au, "High-stake testing and curricular control: a qualitative synthesis," Educational Researcher, 36(5), 258-267 (2007).