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Redesigned Electrical Circuit Lab Course to Face the Challenges of Remote Learning

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Abstract

This paper presents our practice to adjust to distance learning in an electrical circuit lab course. Electrical Circuits (EMT 1150) is a first-year engineering gateway course for Electromechanical Engineering Technology (EMT) Associate in Applied Science (AAS) students. It is a five-credit course with a combined 4-hours lecture session and 3-hours laboratory session every week, which introduces students to the physical basis and mathematical models of electrical components and circuits. Laboratory work is performed on a breadboard using the digital multimeter, oscilloscope, and function generator. This course had a high failure and withdrawal rate in the regular in-person teaching mode, an average of about 30% in the past ten consecutive semesters.

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 our effort to redesign the contents, applications, and assessments of this course to face the challenges of teaching an online hands-on lab class. We also want to implement remote learning advantages, such as the flexibility and numerous methods to deliver information, into this course. The arrangements we made to adjust to the remote learning mode include: 1) redesign of the lab contents into 12 lab experiments in four modules; 2) integrate the connection between breadboard and Multisim simulation software; 3) combine various technologies to support online learning and create an inclusive learning environment. This paper will present student performance comparisons with traditional face-to-face teaching mode and summarize challenges throughout the semester and lessons learned. This paper will be of interest to any engineering educator who teaches hands-on lab class remotely or anyone interested in improving their current lab course with online resources.

Keywords

Engineering Education, Electrical Circuits, First-year Student, Hand-on laboratory

1. Introduction

The City University of New York (CUNY) is the nation's largest urban public university and serves as a transformative engine of social mobility in New York City. The New York City College of Technology (City Tech) is one of the senior colleges of CUNY. City Tech is the largest public, baccalaureate college of technology in the Northeast. [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. Electrical Circuits (EMT 1150) is a first-year engineering gateway course for Electromechanical Engineering Technology (EMT) Associate in Applied Science (AAS) students. It is a five-credit introductory engineering course with a combined 4-hour lecture session and 3-hour laboratory session every week, which introduces students to the physical basis and mathematical models of electrical components and circuits. Topics include basic engineering language, Ohm's Law, Watt's Law, resistance, series, parallel, series-parallel circuits, network theorems, equivalent circuits, capacitive and inductive circuits, and sinusoidal ac inputs. Laboratory work is performed on a breadboard using the digital multimeter, oscilloscope, and function generator. According to the data from College's Assessment and Institutional Research, the average enrollment for EMT1150 in the past ten consecutive semesters was around 144 students per semester. However, the percentage of students passing the course with a D or better was 73%, and the percentage of students passing the course with a C or better was only about 64%. [2] These results show that approximately a third of the students either failed or withdrew from the course. Because EMT1150 is the prerequisite course for most courses in the Associate degree program in EMT, students who do not pass this course either retake the course, transfer to other departments, or withdraw from the college. All these data were collected at in-person teaching mode.

In the spring semester of 2020, our institution abruptly switched from in-person teaching to remote learning. With support from the institution, department, and our students, this transition was achieved relatively smoothly. Remote learning continued into fall 2020. This paper is a work-in-progress (WIP) paper, reported our practice to adjust to remote learning in this electrical circuit lab course. In the next section, we present our efforts to redesign the contents, applications, and assessments of this course to face the challenges of teaching an online hands-on lab class. We want to overcome the limitations of remote teaching/learning of a hands-on lab class and implement the advantages of remote learning, such as the flexibility and numerous methods to deliver information [3], into this course. The major efforts were made on redesigning the lab contents, creating supporting learning activities, and building learning communities between students. The last section presents the assessment results and comparison with in-person teaching mode.

2. Adjustment to remote teaching/learning

Traditionally, EMT1150 lab class was conducted at an electro-mechanical laboratory equipped with power supplies, digital scopes, function generators, digital multimeters, and computers with circuit simulation software. Students were required to purchase a lab kit which included the circuit components, breadboard, jumper kit, and multimeter. The department provided the lab manual, which included thirteen experiments listed in Table 1 left column. In these experiments, Lab1 relied on circuit simulation software, Multisim, which was installed in lab computer; Lab 2 to Lab 8 depended on the DC power supplies to provide different voltages; Lab 9 needed to use a customed made circuit box for troubleshooting; Lab 10 to Lab13 relied on Function generator and digital oscilloscope.

Table 1 Electrical circuit lab schedules

Before Modification		After Modification	
1	Introduction to Multisim	1	Math review
2	Resistance	2	Introduction to Multisim
3	Ohm's law	3	Resistors and Multimeter measurements
4	Measurements in series circuit	4	Breadboard and basic circuit measurements
5	Measurements in parallel circuit	5	Ohm's Law Measurements
6	Measurements in series-parallel circuit	6	Measurements in series circuit
7	The Wheatstone Bridge	7A	Measurements in parallel circuit
8	Thevenin's theorem	7B	Measurements in parallel circuit comparison
9	Troubleshooting	8	Measurements in series-parallel circuit
10	Introduction to capacitors and inductors	9	The Wheatstone Bridge
11	Complex waves	10	Thevenin's theorem
12	Series AC circuits	11	Troubleshooting
13	Introduction to sine wave measurements	12	AC circuit

2.1 Redesign the contents of labs

As shown in Table 1, the lab schedule was heavily dependent on lab equipment, especially DC power supply, function generator, and digital oscilloscope before the pandemic. Students need to focus on their lab kits and use the resources available in their homes to adjust to remote learning. In the new lab kits, a 9V battery was included to serve as a primary power supply. Most students had a computer for their study, and our department provided the circuit simulation software, Multisim, for each student. Some students who were in financial hardship can loan a computer from our institutions' loaner program.

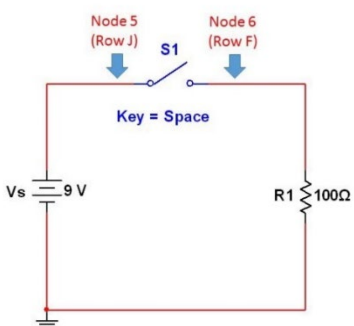
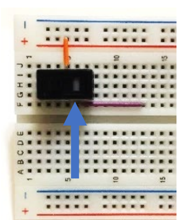
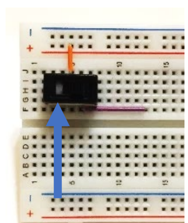
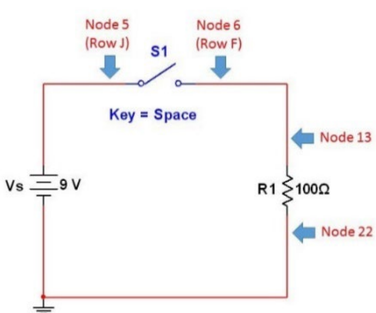
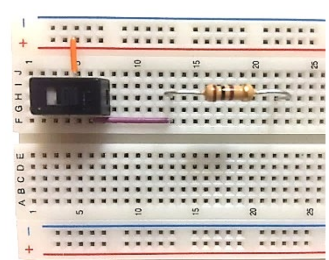
The lab schedule was redesigned based on their resources, as shown in the right column in Table 1. The lab contents were integrated into four modules. The first module was the introduction, including lab 1 and lab 2. This module helped students review the basic mathematic concepts used in this class and introduce them to Multisim circuit simulation software. This module also served as buffer-time for students to order and receive their lab kits. The second module was basic tools include lab 3 and lab4. Students learned how to use a multimeter to measure resistance, voltage, current, and basic breadboard connection in this module. These skills were the foundation of this lab course and were the most challenging part of distance learning. Lab 5 to lab 8 formed module

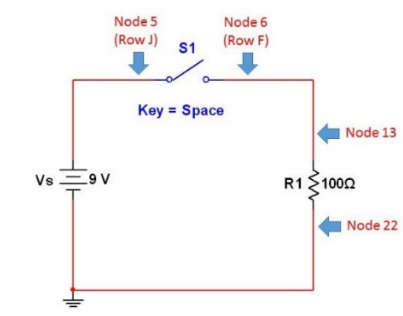
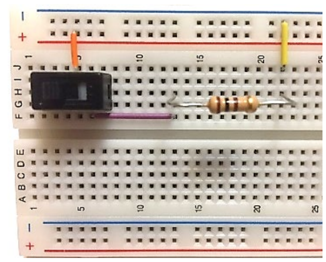
3 which focused on using a breadboard to connect different types of circuits and circuit analysis. Module 4 emphasized the circuit applications, which included lab 9 to lab 12.

Old lab manuals only included the lab procedures and depended on lab instructors to introduce the background knowledge and demonstrate operation details. The new lab manuals were updated for remote learning based on the new lab schedules. Each new manual included four parts. The first part was objectives and learning outcomes; the second part was a review of background knowledge used in this lab; the third part was the lab procedures and tables to record the experimental data; the fourth part was the questions for students to review after lab.

Important operation details were presented in pictures in each lab manual, so students can refer to these materials when they need to work on the lab by themselves. An example was shown in Table 2, which was a part of Lab 4, Breadboard and basic circuit measurements.

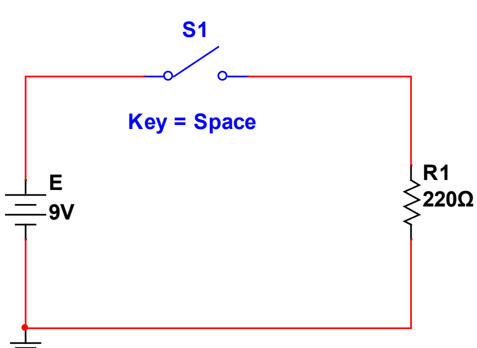
Table 2 Breadboard connection

Circuit Schematic	Description	Protoboard Connection	
	To build the circuit, we need to place the switch first. Put the middle leg of the switch in a node 5 and Row H, which needs to be connected to "+".The right leg of the switch needs to be connected to one side of R1. So put a jumper wire in a hole of "+" and in a node 5 and Row J. And put another wire between nodes 6 and 13 of Row F. It should be OFF when you slide the button to the left and ON when the button to the right.	Switch: OFF 	Switch: ON 
	Place R1 between nodes 13 and 22 of Row H.		

	Connect the other side of R1 to the Ground.	

2.2 Integrate Breadboard Measurements and Multisim simulation

When students use their lab kits to do experiments at home, there are some limitations. The biggest one is that there is only one voltage output, a 9V battery. In our lab manual before modifications, the laboratory DC power supply can provide a voltage at any designated values, which are valuable to observe any changing trend. For example, in the experiment of Ohm's law, students need to record the current change when voltage is changing and plot the voltage-current relationship in a graph. To overcome this limitation, Multisim simulation is integrated with breadboard measurements. Students can do simulations in Multisim when they need to observe the changing trend and compare the experimental measurements at 9V with simulations. One example is shown in Figure 1 where students need to measure different voltage inputs and corresponding currents, then use Ohm's law to calculate resistance and plot voltage-current curve.



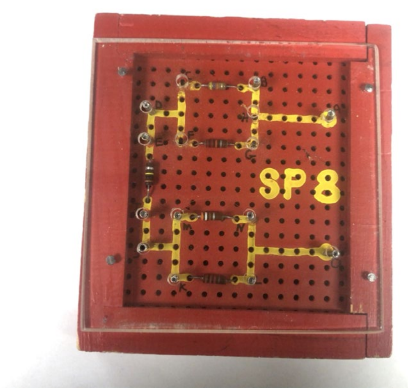
Complete simulation in Multisim, decrease the output of power supply to 8V, 4V, 2V, and 1V. Measure the current through R1 accordingly. Record data in Table 5. Build the same circuit on breadboard, measure the voltage and current on R1, record data In Table 5. Measure the resistance R1 using Multimeter directly. Plot the voltage-current curve based on your measurements.

Table 5

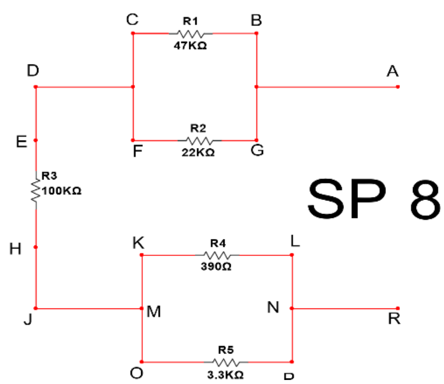
	E (V)	I(mA)	R=E/I (Ω)	P=EI (mW)
Multisim	1			
	2			
	4			
	8			
	9			
Breadboard				

Figure 1. Example of integration of Multisim simulation and breadboard measurements

Another example is our modification of Lab9, troubleshooting. In the past, students need to analyze three home-made circuit boxes to find any faults in the circuit boxes. One example is shown in Figure 2(a). Each circuit box has a build-in resistor network that includes one or multiple faults. The faults could be short connection, open circuit, or hidden resistor in the network. Students need to measure and analyze the circuit box, identify each fault. This is a popular lab because students can apply their knowledge about series, parallel, and series-parallel circuits in a realistic scenario, and this lab helps students develop problem-solving skills. However, during the pandemic, instructors and students did not have access to these home-made circuit boxes. We developed an alternative way to practice troubleshooting lab based on Multisim simulation. As shown in Figure 2 (b) and (c), a circuit schematic and some expected faulty measurements are given to students. Students need to build the circuit in Multisim and analyze one or multiple faults that can cause the measurements, as shown in Figure 2(c). The principle of analysis is the same; students still develop problem-solving skills. In the modified lab manual, the hands-on experiments based on breadboard counts 60% of total experiments comparing to 80% in face-to-face learning.



(a)



(b)

Points	Measured with no faults (Ω)	Measured with faults (Ω)	Difference (Ω)	Faults
BC		47K		
FG		47K		
EH		108K		
KL		0		
OP		0		
AR		155K		

(c)

Figure 2. The modification to troubleshooting experiment. (a) original circuit box; (b) Given circuit schematic; (c) Given measurements with faults.

2.3 Combine different technologies to support distance learning

In Spring 2020, our institution started distance learning. We tried various technologies to support online learning and create an inclusive learning environment. In Fall 2020, the following software and platforms were used.

Zoom was used in synchronous virtual meetings. A professional zoom license was provided by the institution. Instructor and students hold synchronous weekly meetings according to the academic calendar. During each class, the instructor first introduced the theoretical background of this lab in PowerPoint presentation. Because this was a lab class, the instructor set up a two-camera system to demonstrate the lab operation in real-time. Students can share their screen to ask questions or do troubleshooting with the instructor. Other features from Zoom, such as reactions, whiteboard, chat room, and poll, were used to facilitate the discussion and communicate with students. Another significant advantage of Zoom is that it gives the option to record presentations and lab demonstrations on a password-protected cloud service. Students can review these materials after the class.

Blackboard is the official teaching platform used in our institution. In general, it was used for posting course materials and collect students' work. We continued these practices in remote learning. Each lab has a content folder, including detailed learning objectives and outcomes of this lab, lab manual, the PowerPoint slides, the link of the recorded video, and lab report submission link. When students are familiar with this well-structured system, they feel comfortable accessing all information on the Blackboard.

A study showed that engagement is crucial to student learning and satisfaction in online courses [4,5]. We tried multiple methods to create an inclusive and friendly learning environment and create bonds between students and bonds between students to instructors. The instructor and students can directly interact during the synchronous class. However, we found that only 50% of students were willing to turn on their cameras and demonstrate their circuits. Another 50% only communicated in audio or chat box. The weekly virtual office was helpful to those students who need a one-to-one environment to ask questions. On Blackboard, the discussion forum was used to create a learning community for students to communicate on some interesting topics freely. Every two weeks, a discussion thread was posted on the discussion forum. The topics usually were some open-end questions related to their labs; students were encouraged to do a web search or YouTube search to find their answers and share with other students.

3. **Assessment and survey results**

Fall 2020 was the first semester in which EMT1150 Lab was offered entirely online, and the modified lab manual was implemented. It is relatively early to make a conclusive comparison on the efficacy between remote learning and in-person learning. In this work-in-progress paper, we present the comparison between the data from Fall 2020 and Fall 2019. The same instructor taught EMT1150Lab in both semesters with the difference of remote learning in Fall 2020 and in-person learning in Fall 2019. The instructor used different versions of lab manuals and graded the lab reports using the same standards. In Fall 2019, the students' sample size was n=18; in Fall 2020, the students' sample size was n=21.

Figure 3 showed the comparison of completion rates between two semesters. Students who attended some lab classes but didn't complete any lab reports and lab final exam are defined as Withdraw; students who completed less than five lab reports are defined as Incomplete; students who completed more than five lab reports and completed lab final exam are defined as Complete. In Fall 2019, the withdraw, incomplete, and complete rates are 17%, 28%, and 55%; in Fall 2020, the corresponding rates are 5%, 33%, and 62%. Fall 2020 has a 12% lower withdrawal rate, 5% higher incompletion rate, and 7% higher completion rate. Overall, these rates are relatively close.

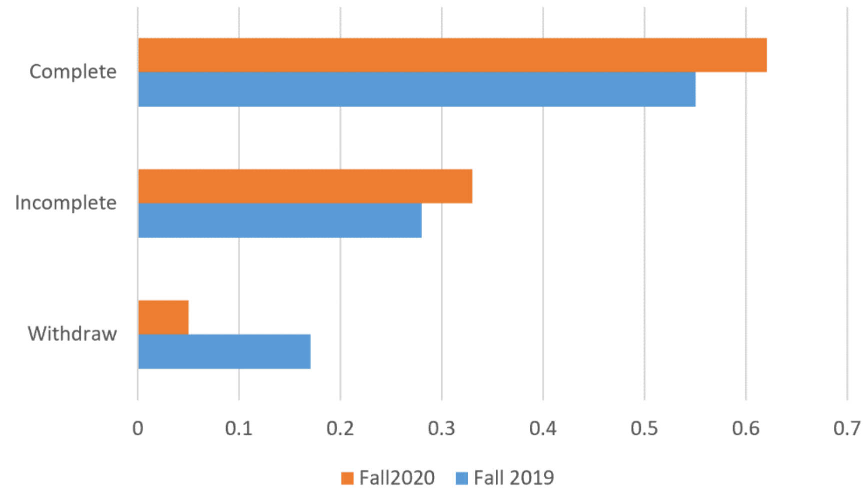


Figure 3. Completion rate comparison between Fall 2019 and Fall 2020.

In Figure 4, the average lab grades of students who completed the class were compared. The average grade in Fall 2019 was 76.33, and the average grade in Fall2020 was 82.43. They are comparable with Fall 2020 is slightly higher.

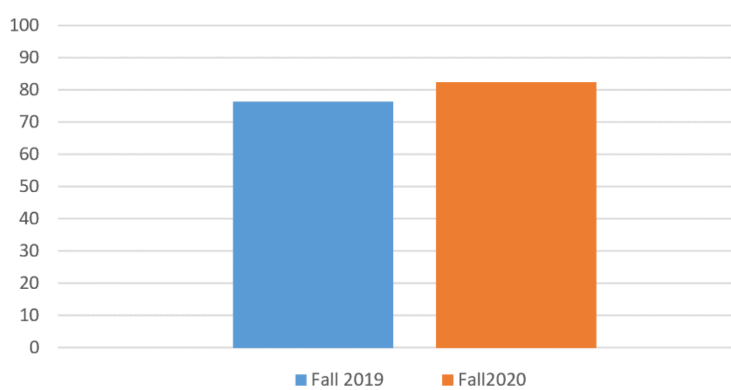


Figure 4. Comparison of average lab grades between Fall 2019 and Fall 2020.

In Figure 5, the overall students' satisfaction with this class was compared. Our institution conducts a survey of student evaluation to each class at the end of each semester. The survey questions range from instructors' teaching style, communication, fairness, course environment, etc. In Fall 2019, the overall rating was 4.48 out of 5; in Fall 2020, the overall rating was 4.39 out of 5. These values are very close, which means students are equally satisfied in these two different learning modes.

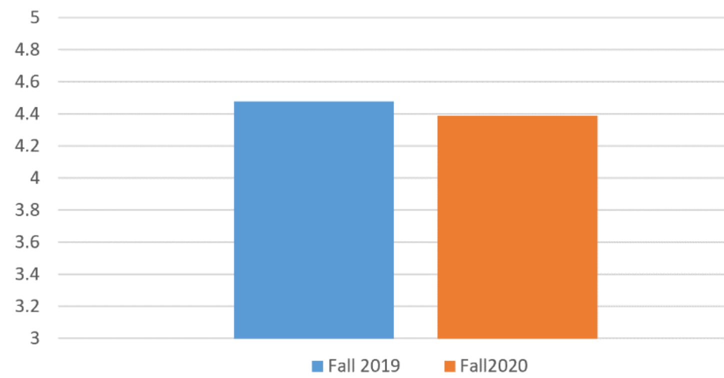


Figure 5. Comparison of student satisfaction rate between Fall 2019 and Fall 2020.

4. **Conclusion and discussion**

This work-in-progress paper presents our effort to transform a traditional in-person electrical circuit lab course into remote learning. The redesigned lab manual allowed students to complete electrical circuit experiments at home using their lab kits. The four-module design scaffolded students from basic circuit connection level to some important applications. The modified lab manual integrated breadboard connection and Multisim simulations, and maximum preserved hand-on breadboard practice. Various technologies were used to support distance learning and create an inclusive learning environment. Overall, our assessment and survey results showed that three parameters used for comparison, completion rate, average lab grades, and students' satisfaction rate, were very close with slight variations. Electrical circuit lab in distance learning showed a similar effect as this course in in-person learning.

Teaching and learning during the pandemic have presented significant challenges to both instructors and students. For instructors, the biggest challenge was that some students did not want to turn on their cameras and demonstrate their circuits and measurements. Because our institution has guidance to respect students' privacy rights, an instructor can't require students to demonstrate experiments, only can evaluate their work based on their lab reports. For students, their biggest challenge was time management. Some students attended synchronous class and did lab works, but they did not complete the lab reports. As a result, students did not get grades for this Lab. These were related to how to adjust to college life for first-year students. This is especially hard for freshmen students during the pandemic.

In conclusion, we tried to adapt a traditional electrical circuit lab course to remote learning. We hope these trials will provide valuable information for future practice when remote learning is no longer mandatory but optional.

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