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Instructing Lab Courses Virtually

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Abstract

Hands-on learning has always been essential in our educational culture. Most engineering lectures are accompanied with lab courses. The 2020 COVID-19 pandemic forces almost all lab courses to be taught virtually. Students can no longer access on-campus facilities and work with classmates in-person; instructors cannot deliver face-to-face instructions. Worse yet, the transition happened so quickly that it overwhelmed both the students and the faculty members.

The main challenge was to convert lab courses to their virtual formats while maintaining the quality of the labs and meeting learning objectives. In particular, this paper addresses the issues of student outcomes, *e.g*., how are they affected? and how do we deal with the challenges? In the presentation, problems will be addressed, followed by the approaches and strategies taken to attack the problems. The discussed methods are then demonstrated using three example lab courses. Finally, lessons learned from this experience will be presented.

Index Terms — Lab courses, learning environment, hands-on learning, online simulation, microelectronics circuits lab, computer network lab, digital circuit design lab.

1. Introduction

As John Dewey, a well-known educational theorist, emphasized[1], "hands-on learning such as lab experiments are essential in education experience." This principle was challenged when providing remote/virtual mode of instructions due to the COVID-19 situation was forced. This was stated in Alexander et al.'s report [2], "Higher education is no longer simply being asked to change. Change will be forced on it, and not just from the impact of Covid-19."

The challenges on the lab courses were highlighted by Woodley et al. [3], "The challenge is to move lab courses quickly online and still meet the learning objectives, which exists in all phases of online course design." To meet the needs for all students, as addressed in Thomas Tobin and Kristen Behling's book, "reach everyone, teach everyone" [4], different teaching strategies have been proposed [5-6]. With regard to the lab courses, finding appropriate resources, delivering clear instructions, and creating labs without being physically present are the crucial issues.

The purpose of this paper is to share our experiences in meeting learning objectives while teaching lab courses virtually. The learning objectives impacted by the transition will be highlighted, following by a discussion on the affected student outcomes. Our approach to attack the problems will be presented and example lab courses will be used to share the experiences and demonstrate the results.

1.1. Learning Objectives and Student Outcomes Impacted

The learning objectives defined by our department, include the followings that are related to lab courses: provide solid theoretical and hands-on knowledge, understand the challenges of a dynamically and globalized changing world and are willing to adapt, and master effective communication skills to obtain success either working individually or within a team environment.

Based on the learning objectives, student outcomes were defined. Out of the seven student outcomes, the following two are identified that mostly affected by the situation.

- Communicate effectively with a range of audiences.
- Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

1.2. Challenges and Approaches

According to the above discussions, communication and experimentation are the two areas that need to be focused.

With regard to communication, the issues include (1) peers communication, (2) virtual instructions, and (3) remote demonstration. Fortunately, these problems can be handled through proper software applications. In particular, Zoom and Blackboard are the vehicles adopted for giving instructions. For students to demonstrate their works, video recording can be performed and posted to YouTube.

Regarding experimentation, equipment is essential. If the experiment is school provided such as oscilloscope, function generator etc., then simulating software such as PSpice, MATLAB etc. are used. If the experiment uses equipment owned by individual students, such as breadboards, FPGA (Field Programmable Gate Array) boards, or microcontrollers, then conducting experiment can be done remotely. If the experiment is purely software based, then students can use the share screen feature provided by video conference applications such as Zoom to demonstrate.

In this paper, three lab courses will be presented to demonstrate the uses of the above approaches/strategies. For the Microelectronics circuits lab, on-campus facility is the only equipment that is available. Therefore, simulation tools are taught and used. For the Computer network lab, the students were asked to purchase the microcontrollers with RF (Radio Frequency) capability, where the microcontrollers are connected via USB (Universal Serial Bus) to computers to develop code and then download code. For the Digital circuits design lab, FPGA boards are purchased individually by each student and so they can conduct experiments remotely and record the demonstration.

1.3. Lab Courses Demonstration

The three core lab courses taught in the sophomore, junior and senior levels are discussed in this paper, listed below:

1) ECE 2200L is electronic hardware lab using oscilloscope, function generators, and lots of electronic parts like diode and transistors.

2) ECE 4303L consists of experiments on both network software and microcontrollers. Network software experiments were not converted virtually due to timing (but conceivably was easy), and microcontrollers network experiments with two or more microcontroller (like Arduino or Raspberry Pi) networked were converted virtually effortlessly.

3) ECE 3300L is digital hardware lab on FPGA (Field Programmable Gated Array) board and also Verilog hardware design language and software like Xilinx or Cadence.

The first example shows how to transit the labs using online simulation tools such as Personal Simulation Program with Integrated Circuit Emphasis (PSpice). PSpice allows students to conduct the labs remotely. Online simulations provide the learning environments for students to explore concepts, and collect/store/transmit data. Moreover, students can verify their predictions without purchasing anything beyond access to the website. This experience shows that proper online simulations resources can provide a robust alternative to in-person labs.

The students in the other two labs were already using their own equipment prior to the pandemic lockdown. In particular, the computer network lab uses Arduino, Raspberry Pi, or some other microcontrollers with radio frequency (RF) wireless capabilities. The digital circuit design lab uses Xilinx FPGA board. For these labs, conducting labs can be done individually and remotely. Labs demonstrations can be recorded and posted online through video-sharing platform such as YouTube. With the Video conference application such as Zoom, the labs instructions are conducted in real time and students adapt to the transition smoothly.

2. ECE 2200L Microelectronics circuits lab

Twenty-one college students participated in the lab course ECE 2200L in spring 2020 (from January 18 to May 8).

2.1 Lab course description

2.1.1 Lab content

a) Traditional lab

The lab course aims to train students in the design, construction and characterization of microelectronic diode and transistor circuits with an emphasis on large signal performance. The project key technical components include characteristics of the PN Junction and Diodes, transient response and some applications of the diodes, bipolar Junction Transistor, MOS Field Effect Transistor, Junction Gate Field Effect Transistor Characteristics and application. All students who took this lab have a background in Electrical and Microelectronics Circuit through taking ECE 1101L (Electrical Circuit Analysis I Laboratory) and ECE 2200 (Microelectronics Circuits). They learned the fundamental laws of electric circuits, applications to circuit analysis, matrix methods; the behavior of semiconductor devices including diodes and MOSFETS, and the application of large signal models to single stage amplifiers to determine voltage transfer curves.

This lab course was scheduled to meet once a week, on Thursdays from 4:00 PM to 6:50 PM in ECE 9-431 operating systems laboratory. There were 13 experiments in the lab for the total of 13 weeks related to design, construction and characterization of microelectronic diode and transistor circuits with an emphasis on large signal performance. The most current course information was kept on Blackboard, such as the syllabus with week by week labs spelled out and parts list clearly. The lab rules and safety were also covered.

b) Transitioning to Virtual Lab

To move a lab course quickly online, Instructor designed the virtual mode of instruction of ECE 2200L including three parts:

- Teach the content at the beginning of the lab.
- Use simulation tools (such as PSpice) to model each circuit.
- Show the simulation results through sharing the screen.

Instructor modified the previously planned labs associated with the simulation so that students can perform it at home. Instructor also prepared for each virtual lab a To-Do list that serves as a very good pre-lab for the students. The To-Do list helps the student to better meet their learning objectives for the course. Instructor can control the instructions for the lab and post them in Blackboard.

2.1.2 Hardware and software for lab

a) Traditional Lab

The ECE 9-431 operating systems laboratory houses 13 laboratory benches equipped with Agilent DSO-X 2022A Oscilloscope 200MHz, Agilent Technologies U3401A Digit Dual Display Multimeter, Keysight E3630A 35 W Triple Output DC Power Supply and Keysight 33210A Function/Arbitrary Waveform Generator on each bench.

The supplies include PN diodes LED, Zener Diode, Schottky Diode, Laser Diode, Germanium Diode, BJT transistors, MOSFET transistors, JFET transistors, a variety of resistors, capacitors, Operational amplifier, and transformer. Students can find some of the supplies from the department stockroom for free, and/or purchase the unavailable supplies from an electronics store for all of the experiments. They are usually low cost items (resistors, capacitors, diodes, and transistors) totaling a few dollars at most and available from electronic stores like Digi-Key, Mouser Electronics or etc.

The laboratory also provides software for simulating electrical circuits, and software for analyzing data from electrical circuits.

b) Transitioning to Virtual Lab

Student access to on-campus labs are limited by the spring 2020 semester according to COVID-19 restrictions. To instructing this lab course virtually, we use PSpice / Ltspice to simulate electrical circuits. The Oscilloscope, Power Supply, and Waveform generator can be instructed virtually using simulation. To simulate the Power Supply and Waveform Generator, we require students to add parts from SOURCE library, such as VSIN (Sinusoidal Voltage Source), VSRC (Simple voltage source), ISRC (Simple current source), and IDC (Simple DC current source) to a circuit. To simulate the passive supplies, we require students to add parts from ANALOG library, such as R (resistor), C (capacitor), D1N4002 (diode), and 1N4372 (Zener Diode) to a circuit. To simulator the transistors, we require students to add parts from BIPOLAR, BREAKOUT, and JFET libraries, such as Q2N2222 (BJT), MbreakN (NMOS), MbreakP (PMOS), J2N3819 (JFET). Then student wire a circuit together, use probes, set up a simulation profile and choose the simulation option, run the simulation. Then they can display the circuit performance, generate waveform plot and optimize the experiment design without the breadboard and equipment such as oscilloscope and Digit Dual Display Multimeter.

2.2 Course learning outcomes and grading procedure

Students are evaluated according to course learning outcomes (CLO) based on 100-percent (100-point) grading scale. The CLO and the respective grade credits are defined in Table 1 (traditional lab) and Table 2 (Virtual lab). The grading procedure was included in the course syllabus and provided to all participated students at the beginning of the course and at the before the virtual lab instruction.

Table 1 Course learning outcome and credits – Traditional lab

#	**Course learning outcomes**	**Credit, %**
1	Design, construct and characterize common microelectronic diode and transistor circuits to meet specifications for large-signal performance.	15
2	Use standard test equipment to characterize circuit performance and to ensure that the experiment works properly.	70
3	Document and report on procedures and results that follows a defined template.	15
	Total	**100**

Table 2 Course learning outcome and credits –Virtual lab

#	**Course learning outcomes**	**Credit, %**
1	Design, construct and characterize common microelectronic diode and transistor circuits to meet specifications for large-signal performance.	15
2	Use PSpice / LTspice as an analysis and verification tool.	70
3	Document and report on procedures and results that follows a defined	15

	template.	
	Total	**100**

2.3 Implementation

The lab course has been completed by early May 2020. The instructor normally lectures for 30 to 45 minutes before each experiment. Instead of showing the lab equipment in physical, the instructor showed online images and videos of each equipment through Zoom. Instructor demonstrated the experiment PSpice simulation with sample data, interpreted the experiment data, and ask students to complete the experiment design and analysis the data themselves. Students are required to read the description of next experiment in advance so that they come to the laboratory prepared. Each student needs to turn in a Lab Report in a week after the experiment. Weekly reports are to be short, normally 3-5 pages (more or less) plus data. Each report will be neat, clear, and concise, and will include the following elements: an Executive Summary, a brief Objective, Diagrams, Data (reduced in tabular and/or graphical form), and Analysis. The report will be judged not by its length but by its contents and quality.

To move a lab course quickly online, Instructor start to find the right resources. Online simulations can let students explore concepts and test their predictions without purchasing anything beyond access to the website. All the simulations resources discussed here provide a robust alternative to in-person labs.

1) Free OrCAD Academic licenses: https://www.orcad.com/orcad-academic-program
2) Analog Devices LTspice: https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html
3) Other Circuit Simulator Applet: http://www.falstad.com/circuit/

Instructor used the first 30 to 45 minutes for detailed instruction such explaining the circuit and measurement techniques, deriving the equations, asking the students questions and demonstrate the lab, then left the time to students to conduct the experiment, and helped the students on solving the problems. For example, for the objective of designing, constructing, measuring and evaluating FETs and BJT analog building blocks and simple digital gates. Instructor drew circuit diagram of the BJT inverter on the board, together with the diagram of how the input voltage is converted to output voltage, how the collector current changes with the base current. After the instruction, students perform an experiment; each student submits individual report which is due at the beginning of class on the next week. Instructor spent individual time in the Zoom meeting with different students. Students shared their screen, and instructor answered their questions.

During the Zoom class session, if the internet becomes unstable and glitch, the session will be ended and restarted later. Instructor will also post the class activities on Blackboard for student to do.

Reflective activities: The instructor encouraged, supported and mentored the students. Our students interacted using chat in Zoom to post questions for instructor to answer. Students were able to answer one another's questions, to share screen, show the results or the malfunctioned circuit, debug. Students can work together for trouble shooting too. More students engaged in the lab tasks, before, during, and after the online lab period.

2.4. Outcomes

2.4.1 Comparison of the lab scores of 2019 (traditional) and 2020 (half virtual)

The students developed the microelectronics circuit experiments, performed the lab tasks, completed and submitted the lab reports. No student failed the lab class. The learning outcomes are still fulfilled in general.

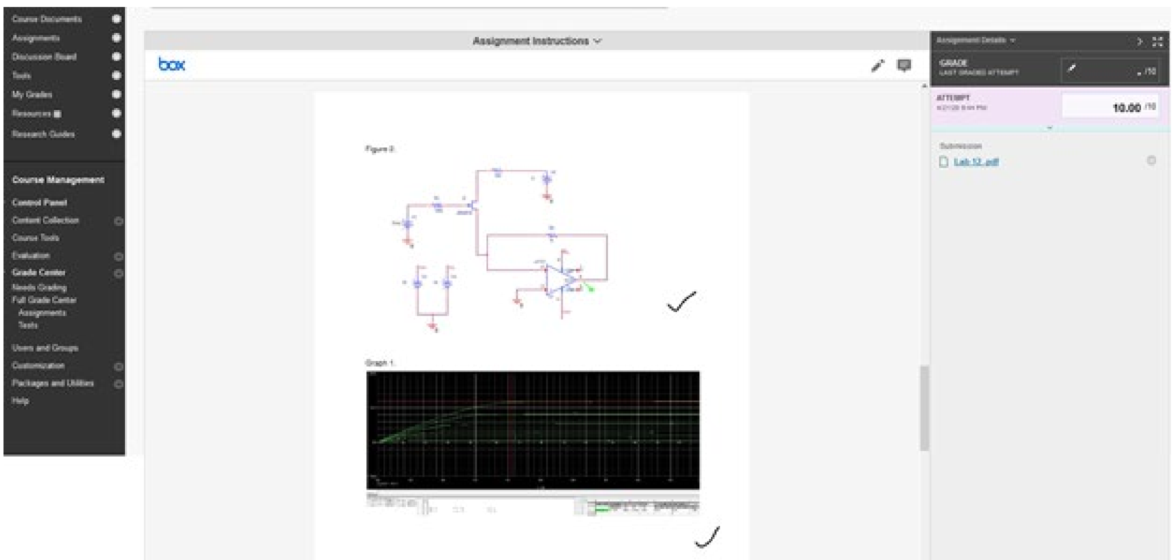


Fig. 2 An image of grading the student's lab report on Blackboard

Table 3 shows the score comparison of lab experiment averages of the whole lab course in 2019 (28 students) and 2020 (21 students).

The highest score for each lab experiment is 10.05. From the table below, it seems that lab going virtual is fine since the students achieved about the same scores or even higher in the experiments. In the table, the experiments going virtual were presented as cells in green color of 2020 Experiments 8 through 13.

Table 3 The lab experiment score comparison of 2019 lab (traditional) and 2020 (later half virtual)

	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Exp9	Exp10	Exp11	Exp12	Exp13
2019	10.00	9.48	9.75	10.05	9.76	10.34	10.00	9.77	9.85	9.48	9.89	9.96	9.96
2020	9.95	9.64	9.57	9.76	9.86	9.45	10.00	9.91	9.76	9.81	9.95	10.00	10.00

2.4.2 Course training quality

Microelectronics circuits lab gives students hand-on experience with faculty members and helped them obtain written and oral communication, collaboration, and time management skills. The course quality is high since students are able to apply engineering design to produce solutions that meet specified needs and are able to communicate effectively with lab-mates. Our students were highly engaged and very motivated. They reacted and participated in the lab preparation well.

3. ECE 4303L Computer network lab

A computer network lab course, which is a core course of computer engineering curriculum as presented here lets the students practice the networking concept that they learned from the computer network lecture course, from the ground up.

3.1. Lab overview

3.1.1 List of experiments

This semester version of computer network lab consist of 13 networking experiments as shown below:

Table 4 List of experiments for this lab course, where highlighted experiments from experiment 8 through 13 went virtual in spring 2020 from March till May

Exp	Category	Explanation	Description
1	software	Basics	Client / Server Communications
2	software	Basics	Display host name, IP address & MAC programmatically.
3	software	email SW	sending emails
4	software	email SW	reading emails
5	software	email SW	CC, BCC, forward, reply
6	software	email SW	attachment using MIME
7	software	email SW	input folder, send folder, and delete folder.
8	Micro & RF	2 Micros	**Connecting two microcontrollers (wirelessly or wired)**
9	Micro & RF	3 Micros	**Communication with 2 and 3 microcontrollers**
10	Micro & RF	Micros NW	Network of 5 microcontrollers
11	IoT	IoT network	An Arduino controller with sensor data for computer
12	IoT	IoT network	IoT Project that students can freely choose / design

13	IoT	IoT network	Ibid.

3.1.2 Peer communications between two devices

All the experiments in the computer network lab course have one common feature that is different from the other engineering courses: two or more computers / devices are needed / used. The following three figures show two computer programs (called server and client) looking for each other and get connected (the two programs can run in the same computer like shown here for testing, but should run in two different computers in general)

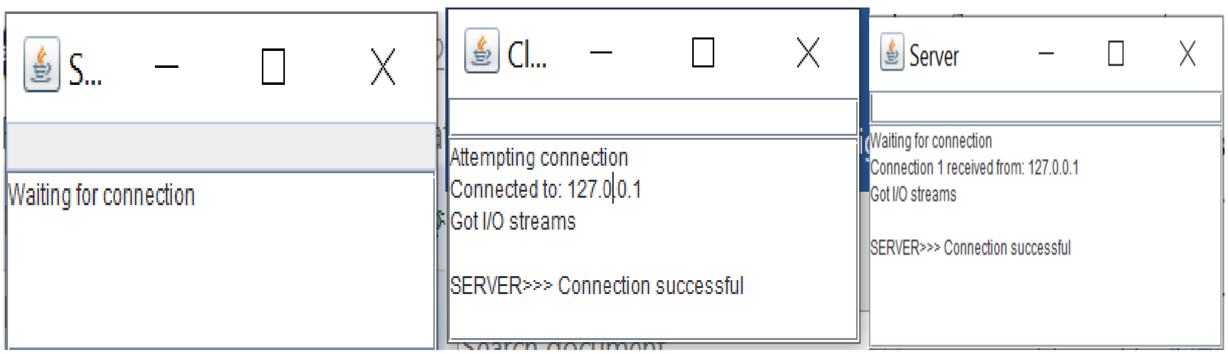


Fig. 3-1 Server waiting **Fig. 3-2** Client connecting **Fig. 3-3** Server connected

The explanations are as below:

- First the server starts, waiting for the client to come up any time (which could be say 5 seconds later, 5 minutes later, or maybe never) as shown in Figure 3.1.2-1
- Then the client starts, looking for the server and if found, connects to server, as shown in Figure 3.1.2-2. (or if not found, then the two processes server and client are both waiting indefinitely to connect)
- After client starts and connects to the server, the server's status changes from "Waiting for connection" to "Connected", as shown in Figure 3.1.2-3. Now server and client both can send data and message to each other.

3.2 Converting Computer Network Lab course from traditional to virtual

3.2.1 Traditional computer network lab

A traditional computer network lab is conducted in the physical facility of campus laboratories. Students are grouped into benches working and presenting together with bench size of 2 usually (but can be more than two as needed).

Bench Set Up: The bench comes with school provided oscilloscopes, function / signal generator, and voltage measuring multimeter for the experiments of ECE (Electrical and Computer Engineering) students. It comes with a desktop computer.

Students Prepared Materials and Equipment: ECE students need to prepare a tool box with breadboards, BNC cables, some electrical parts like resistors, wires, etc. For the computer network lab, they need to either bring their own laptop(s) to facilitate the experiments that need two computers or two benches need to demo together.

Lab course conduct: Each experiment consists of the pre-lab instructions helping the students to get ready, the lab day with instructions and students demo, and the post-lab report due usually one week later.

3.2.2 Transitioning to Virtual

Several steps are needed to make a lab meeting face-to-face virtual or online.

Step 1: online instruction tools: this means Zoom and Blackboard now.

- Zoom: Instructors need to install Zoom client with account (school account). Need to know how to use Zoom effectively. There is still some learning curve, though not steep (such as knowing how to use Sharing screen, setting Passcode etc.). Students need to know coming to the Zoom meeting instead of classrooms, need to communicate with the instructor using microphone and chat in Zoom plus emails.
- Blackboard: instructors learn to post some class materials on Blackboard for students' study, post assignments and exams on Blackboard so that the students can submit / turn in reports, assignments etc. for grading.

Step 2: evaluate each individual experiment and decide how to convert that virtually.

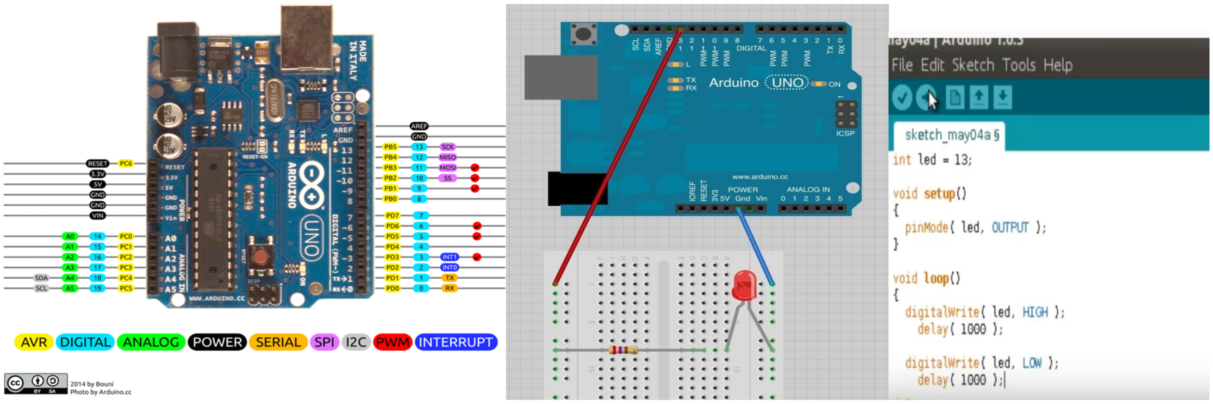
- If the experiment uses school provided equipment then these need to be replaced by simulating software.
- If the experiment uses student provided equipment, the students can demo the experiment live from their home with camera, they can prerecord and play a video file, an animated GIF file, etc. or they can negotiate with the instructor of doing this by software simulation.
- If the experiment is purely software based, the students can use share screen to show how the software runs on their computer.

3.3 Outcomes

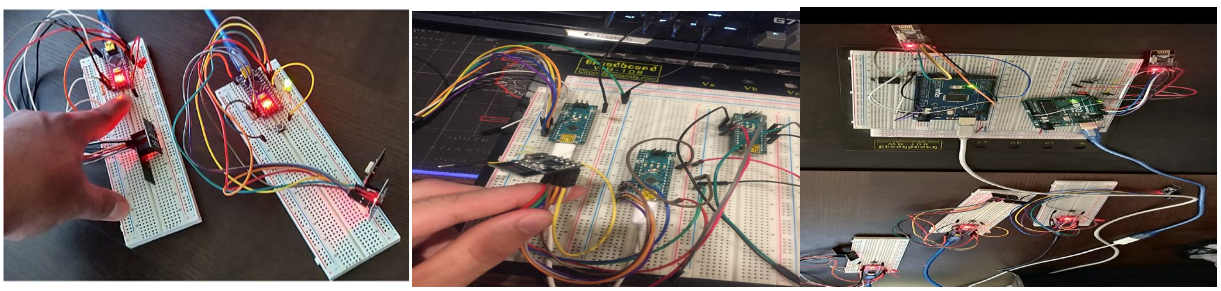
None of the first seven software experiments were conducted virtually due to the timing. The last six experiments on connecting two or more microcontrollers or IoT (Internet of Things) were conducted. They were purely hardware with equipment provided by the students.

3.3.1 Pictures of experiments 8 through 10 using Arduino, Raspberry Pi etc.

In experiments 8 through 13, students used couple or more Arduino, Raspberry Pi, ESP8266 and other microcontrollers. Computer languages include Arduino code, Python etc.



1) Arduino pin diagram 2) Blinking LED 3)Arduino code



4) Two Arduinos 5) Three Arudinos 6) Five Arduinos

Fig 4. Experiments 8 through 10 using Arduino, Raspberry Pi etc.

3.3.2 Comparison of the lab scores of 2019 (traditional) and 2020 (half virtual)

To find if virtual lab is viable for both the students and the instructor, I tabulate here the score comparison of lab experiment averages of the whole lab course in 2019 (31 students) and 2020 (45 students).

The highest score for each lab experiment is 6.5 grade points. From the table and also the Excel chart below, it seems that lab going virtual is fine since the students achieved about the same scores or even higher in the experiments. In the table, the experiments going virtual were presented as cells in green color of 2020 Experiments 8 through 13.

Table 5 The lab experiment score comparison of 2019 lab (traditional) and 2020 (later half virtual)

	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Exp9	Exp10	Exp11	Exp12	Exp13
2019	5.68	5	5.69	5.21	5.71	5.64	5.64	5.58	4.57	4.62	4.43	3.59	2.54
2020	5.47	5.22	5.99	5.79	5.49	5.71	5.25	5.52	4.67	4.3	5.12	5.55	5.454

4. ECE 3300L Digital circuit design lab

4.1 Lab Overview

The purpose of the Digital Circuit Design lab is two-folded. First, the students are expected to learn the Hardware Description Language (HDL) named “Verilog.” This HDL language allows engineers to develop digital circuits in a “programmable” way. Once a circuit is synthesized by using the provided IDE (integrated Development Environment), the circuit can be downloaded onto the hardware device called FPGA (Field Programmable Gate Array). The second objective of this lab is then to have the students experiencing the design, develop, simulate and test procedures.

Each student in the lab is equipped with a FPGA board and a laptop or PC, where the IDE (Integrated Development Environment) is installed. Hence the necessary hardware and software are available for each student. It is thus convenient for this lab course to be transitioned to the virtual mode. Each lab assignment is done individually and demonstrated remotely. Lab demonstrations are recorded by students and the videos are posted through some video-sharing platform such as YouTube. For each lab, the instructor conducts the teaching in real time using video conference application Zoom. Since the explanation is done synchronously, students can ask questions in real time.

4.2 Challenges and Approaches

4.2.1 A Building Block Approach

The biggest challenge in remote teaching is students’ engagement. An essential strategy to attack this challenge is to make the labs interesting. The approach we took is to design the labs incrementally. That is, beginning with a simple exercise which ensures the success for all students, then incrementally adding components to build more complex circuits. This way, students observe that the knowledge they accumulate can actually help them building something really useful and interesting.

A “building block” approach can relate labs together. For example, a counter is constructed in one lab, followed by building a digital clock using the counter. Another lab that teaches students to develop a “sound generation” circuit using a speaker can be followed by the lab to build an alarm clock. Explaining the growth of the system with this building-block approach, at the beginning of the semester, can encourage students to pursue further and stay engaged.

In particular, the sequence of the lab is listed below:

Table 6 The sequence of the lab

Using Vivado (Vivado is the IDE for developing Verilog codes and download the synthesized circuits onto FPGA boards)
Verilog tutorial & Simulation
FPGA Implementation

Use Single 7-Segment Display as output device
Adders
Counters
Digital Clock
Sound generation
Alarm Clock
Rising Edge Detector and Debouncing Circuit
Data Transmission & Parity bit generation
Turing Machine Design and Development
Final Project Design and Development

As shown above, the lab starts from learning how to use the IDE, followed by a tutorial of the language Verilog. After students are familiar with the basic building blocks, they will be asked to build more complex and interesting circuits such as digital clocks and alarm clocks.

4.2.2 Providing Detailed Instructions

Another approach is to provide detailed instructions for each lab. This is because students are easily get distracted during the virtual sessions. Hence the challenge is to bring their attention back to the class. Providing detailed guidelines and instructions can help students to come back and ensure them to successfully complete the labs. Detailed instructions are critical especially at the beginning of the semester; if students cannot successfully conduct the simple labs, for sure they cannot perform the more comprehensive ones.

4.2.3 Platforms to Support Demonstrations

Encouraging students to share their outcomes is essential to the success of the lab class. For this purpose, students are asked to record the demonstrations of their finished products. Various platforms are supported so that they can upload their videos to YouTube, or simply submit the video to BlackBoard.

It was learned quickly that students love to demonstrate their products through videos. Some videos were really professional. Instructor was impressed by their performance that decided to share some videos during the class sessions, which triggered more students to produce good videos. Demonstrations sharing really has a positive impact on their learning, as they want to do a good project in order to "show off".

An example can be seen here

https://www.youtube.com/watch?v=BwPeGdc-L0c&feature=youtu.be.

4.3 Outcomes

The most important outcome of this lab class is that students had fun learning. It is believed that having fun can make the learning lasts longer.

Grade assessment of this lab is based on the following factors: Quizzes (30%), Lab Demonstration (50%), Reports (10%) and Final project (10%). As shown in the following figure, most students are doing well (toward the left end).

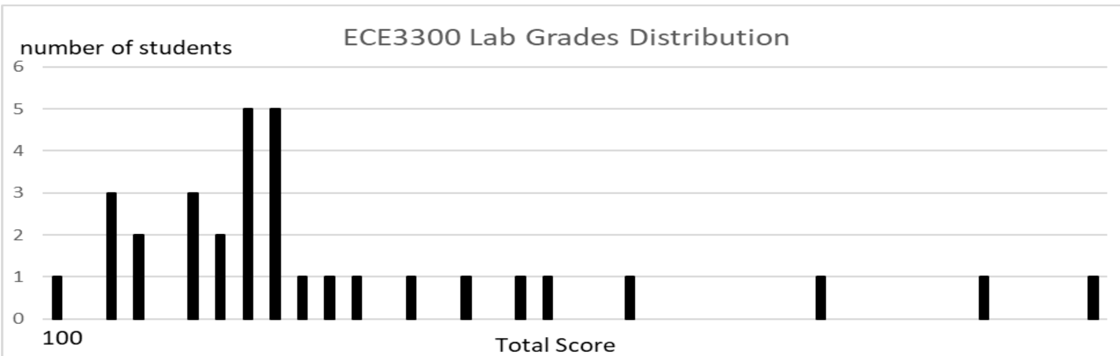


Fig. 6 Grade assessment of this lab

Conclusion

The three lab courses ECE 2200L, ECE 4303L, and ECE 3300L all went from the traditional way to virtually in spring 2020 uneventfully. The students seemed to learn what they should learn from the traditional way as we discussed in the Outcomes sections of the three courses (sections 2.4, 3.3 and 4.3). Table 7 summarized key results for all three courses.

Table 7 Summarizing key results for all three courses

#	Course key results	Student scores compares to in-person courses
ECE 2200L	Used PSpice simulation for the microelectronics circuits design and analyzed the data	same
ECE 4303L	Used multiple Arduino, Raspberry Pi, or some other microcontrollers with radio frequency (RF) wireless capabilities	same
ECE 3300L	Used Xilinx FPGA board and also Verilog hardware design language and software like Xilinx or Cadence	same

The virtual lab course effectively trained the students in design, construct and characterize experiments. The students were delivered clear instructions and performed labs without a teacher being present. The students gained the ability to build trust, be respectful, show empathy and compassion.

They also obtained writing and analytical skills through explaining how the data be measured, and the theoretical analysis.

The lab offers students active, hands on learning experiences in and out classroom, thus following the learn-by-doing paradigm. The lessons learned from the virtual lab are: it not only provides resources more approachable for prospective students to learn during the COVID19 Pandemic Transition, but also for future course applications where current on-campus laboratories are not available due to over-crowding or other constraints such as lab maintenance or equipment shut-down.

Going virtual was originally the only option, and it could be also an option or a viable option in the future even if the face-to-face mode or hybrid mode of instructions may be resumed in the future. One obvious advantage of virtual mode is the flexibility for both the students and the instructor.

The possible drawback of virtual lab is: less or very few communications between the students and the instructor. Another possible drawback is the uneven workload among the students in the same bench; it seems that in many benches, one student did most of the demos.

To benefit more students and people, enhancing virtual labs to a lab courseware is some possible alternative to consider.

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