Remote Access Active Experiential Learning with Industrial Instruments

Kevin Kornegay
CAP Center, ECE Dept.
Morgan State University
Baltimore, MD, USA
orcid.org/0000-0002-5233-0154

Michel Kornegay
CAP Center, ECE Dept.
Morgan State University
Baltimore, MD, USA
michel.kornegay@morgan.edu

Doug Baney
Corporate Director of Education
Keysight Technologies
Santa Clara, CA, USA
doug_baney@keysight.com

Paige Harvey
CAP Center, ECE Dept.
Morgan State University
Baltimore, MD, USA
pahar9@morgan.edu

Caroline Kinyanjui
CAP Center, ECE Dept.
Morgan State University
Baltimore, MD, USA
cakin4@morgan.edu

***Abstract*—One of the grand challenges recently thrust on engineering education is providing active, experiential learning that can flex with significant global events such as pandemics and meet the needs of individual students. The COVID pandemic is a prominent driving force for change, but beyond that, meeting the needs of students with physical, economic, or temporal barriers, such as with professional learning, is critical for our education system. This is especially true for university laboratories, where hands-on nature is often more challenging to provide remote learning services to engineering students. In electrical engineering education, the immediate response to the pandemic-induced closure of university laboratories was to cancel laboratory learning, assemble hobbyist-type experimental kits, and ship the kits to students to learn fundamentals. This approach provided a flexible experimental arrangement for students but was limited due to a lack of student exposure to tools and processes used in the industry. These learnings are critical to students who want to excel in internships or their first regular employment. Here, we describe the development of a remote active, experiential training program based on industrial tools for students to learn at a distance with industrial-type laboratory equipment. A pedagogical electronic amplifier was set up in the laboratory. Instead of students attaching probe clips to various parts of the amplifier to test, electronic laboratory switches, controlled remotely by students, allowed them to probe salient parts of the amplifier and even substitute different electronic components. Based on newly available commercial software and hardware, the system will enable students access to a laboratory session, interact with other students via online chat, and conduct experiments. In this innovative practice full paper, we will review the method approach, experimental laboratory configurations, and the learning outcomes of this remote learning technique. This method is an innovative approach to remote learning. It is potentially extensible beyond electrical and electronic engineering to other engineering domains, such as photonics, mechatronics, civil, and perhaps chemical, where electronically controlled laboratory equipment is included in the student's experiential learning.**

***Index Terms*—remote measurement, active learning, linear amplifier, circuit simulation.**

I. Introduction

Active learning is an approach to teaching rather than a single, specific method. It requires active student participation in classroom activities that teachers have carefully structured. This strategy can facilitate student engagement, enhance relevance, and improve motivation by actively involving students within their classroom and experiential learning environments. Active learning consists in shifting control of the learning environment from the teacher to the learner. While there are many methods of active learning, some of which are described in this paper, they all share one crucial aspect: the learner must be actively engaged in the classroom teaching-learning process. Faculty perceptions of students' "careful listening," "paying close attention," and "being alert" do not qualify as active learning [1]. In a dynamic- learning approach, each learner must engage in the learning environment and apply constructed knowledge, skills, and attitudes. Active learning can foster students' motivation to learn beyond rote memorization, focus teaching and learning on the most critical information, and help students process and understand and retain what they have learned. Active learning engages students as partners in the teaching-learning process and allows them to take more responsibility for their learning. In a traditional lecture, passive learning predominates and typically involves one-way delivery of information and course content from teacher to learners. While it may seem efficient for transmitting large bodies of information, passive learning often requires less effort from a student, and the resulting rote memorization becomes the default "learning" outcome. Described as bulimic learning [2, 3], this teaching approach often leads to students binging on information retained in their short-term memories and subsequent purging after an examination or other evaluation. The efficacy of traditional lectures and passive learning have been challenged, notably in Bligh's book, What's the Use of Lectures [4]? On the other hand, well-designed active learning can cultivate more thorough learning wherein students relate new facts and concepts to their knowledge and skills. Understanding and applying the content of a course through active, experiential laboratory learning can extend students' learning to new situations or contexts. Active learning benefits from courses and curricula because it involves student engagement in activities, stimulating higher-order thinking, problem-solving, critical analysis, and providing teachers and students feedback about the learning process [5]. It also emphasizes student exploration of attitudes, values, and habits and can increase student motivation to learn and improve their abilities [6]. Active learning in laboratory learning, where the goals are to provide active, experiential learning of foundational theory and provide experience with the industrial tools and processes, will prepare students for the demands they'll encounter in internships and regular employment.

Typically, laboratory learning occurs face-to-face in which students have hands-on access to bench equipment to conduct experiments on circuits. The instructor is present to assist and provide instant feedback to students in the lab. However, during the COVID pandemic, university campuses worldwide were closed, and academic instruction shifted from face-to-face to virtual delivery overnight. This adjustment presented a challenge, especially for courses that required laboratory experimentation. However, with the growth of online learning, there has been increasing interest in providing a remote laboratory experience and sustaining active learning in a virtual setting. Remote laboratories that have been developed require various software and hardware tools in which face-to-face exercises are replaced with computer simulations, personalized take-home kits, or remote control of laboratory equipment. Although computer simulations can allow students to redo experiments and validate theoretical concepts, there are some shortcomings. Simulation labs do not include the use of physical hardware, and students noted that simulation labs "did not feel real" [7] and caused increased frustration [8]. Personalized take-home kits replicate traditional benchtop laboratory settings at home but require students to purchase specialized equipment at a cost. The technical equipment is used with a PC that simulates the functionality of standard industry equipment like oscilloscopes, function generators, and power supplies. Thus, students cannot gain practical hands-on experience with industry hardware tools. For students unable to afford the specialized equipment, the university department may elect to purchase the kits on the student's behalf. These recurring costs add up over time. On the other hand, laboratories that involve remote equipment control enable students to perform experiments in a remote setting. There is no cost to the student, and the one-time investment in the hardware reduces the university's overall operational cost. Remote control of laboratory equipment has been used successfully in [9-13]. Remote-controlled enabled laboratory experiments have several advantages: it is scalable, the experimental results are obtained from actual industry-like equipment [10], and students can engage in hands-on experimentation with measurement equipment. Here, we describe experiences with the new remote access laboratory learning capability set up and conducted with undergraduate students at Morgan State University.

II. Remote Measurement Configuration

A traditional laboratory arrangement for teaching electronics is shown in Fig. 1(a). Here, a BJT amplifier is studied by students in the laboratory to re-enforce theoretical skills and learn the methods and processes of testing and comparing measured performance to expectations drawn from theory. The setup consists of the amplifier under test with a transistor and supporting resistive and capacitive circuit elements, along with industrial instruments including a power supply, function generator, oscilloscope, and digital multimeter (DMM), that are used to power the circuit and provide a stimulus signal and measure the salient voltages and currents to characterize the amplifier. Probe connections are typically performed manually by the students. The parameters of amplifier circuit elements, such as resistance or capacitance values, may be changed to understand the effect of the amplifier performance compared to simulations. Direct instrument control by the students performs measurements, and data is recorded with or without a bench PC.

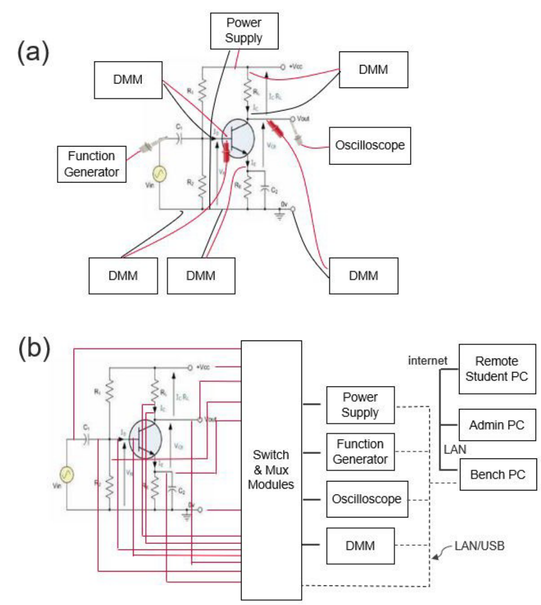


Fig. 1. Student active experiential laboratory training, (a) setup for on university premises student laboratory learning; (b) university premises laboratory setup for remote student learning.

The laboratory arrangement for the remote access active learning is shown in Fig. 1(b) and was the subject of a collaboration between Morgan State University and Keysight Technologies. The same electronic amplifier is tested. However, the connections to the amplifier are mediated by the switch and multiplexers (Keysight DAQ970A) that access the different nodes in the amplifier and connect to the electronic test instruments such as power supplies, oscilloscopes and other tools [14]. Using PathWave Lab Operations for Learning software, the lab administrator controls student access and allows remote students to make time-allotted reservations on the lab bench. Remote students collaborate in teams of up to 5 students via live chat and video, control the connections to the electronic amplifier, configure the instrument states and pull and transfer measurement data for analysis and visualization. The solution is scalable as each license supports a standard test bench setup with fifty concurrent user access and integrates with many learning management systems (LMS) solutions such as Moodle, Blackboard, and Canvas. The software uses secure single sign-on (SSO) and multi-factor authentication (MFA) security options and is built on the secure Amazon Web Services (AWS) infrastructure. Within the framework set up, guidance by the instructor is essential to ensure constant engagement with all students in the active learning process and help with challenges that the students face in conducting the remote lab exercises.

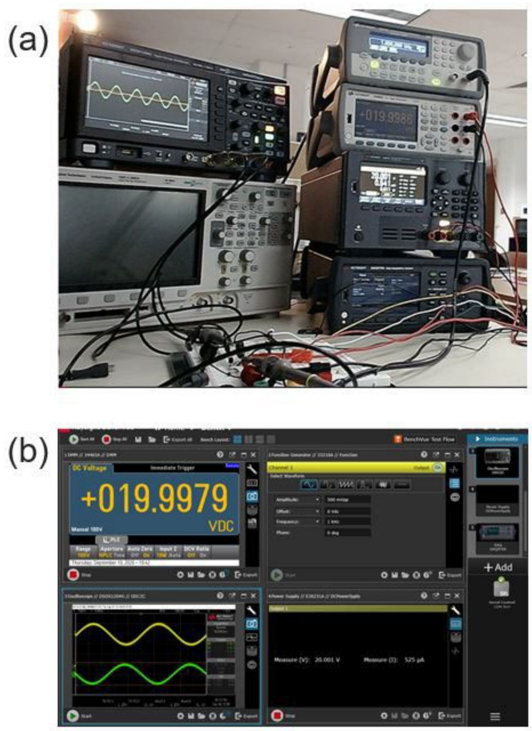


Fig. 2. Realized remote learning lab setup (a) Photo of the instruments and DAQ along with test amplifier, (b) Software interface showing data and waveform capture.

The physical build of the remote access lab with the university lab required stacking instruments, assembly on a protoboard of the circuit understudy, and wiring the circuit test points to the DAQ switch and multiplexer. Figure 2(a) shows the remote setup on the bench at Morgan State University. The test instruments are stacked next to a socketed protoboard where the BJT amplifier to be remotely studied was assembled. On the lower right side of the image in Fig. 2(a) is the DAQ with the switch matrix to connect various instruments to various nodes on the circuit under study. In Fig. 2(b), an example of the remote software interface allows remote measurement configuration of the switches to connect circuit nodes to instruments.

III. Course Details

A. Course Description

The Electrical Engineering Bachelor of Science undergraduate program at Morgan State University, MSU, incorporates an electronic circuits course in which students typically enroll during their third year of academic matriculation. This course is the third offering among a series of circuit-based classes students take before the senior capstone design. The course allows students to analyze and design electronic circuits employing diodes and active components such as bipolar junction transistors, field-effect transistors, and operational amplifiers. The system includes an applications-oriented design laboratory that reinforces concepts shared during the lecture. Before practicing with the remote laboratory exercise, students apply mathematical formulations and verify theoretical solutions with computer-aided simulation tools to solve circuit problems.

The goals of the course are to develop a deep understanding of device physics and apply Ohm's Law and Kirchhoff's voltage and current laws to circuit problems involving transistors or operational amplifiers. This includes the fundamental theories, and practices of circuit design and analysis of transistor-based linear amplifier circuits and enhancing students' circuit modeling and simulation abilities.

The course runs over fifteen weeks, during the whole semester, including laboratory learning. Two 110-minute lectures per week (this can be face-to-face or synchronous online time) with a ten-minute break within each lecture. There is also a fifty-minute recitation section once a week. The lectures are spent reviewing concepts and approaches to analyzing circuits. The recitation is a combination of problem-solving and lab introduction. Before the laboratory exercise, students must complete a pre-lab assignment to practice applying mathematical formulations and use software simulation tools to analyze device behavior in a circuit. Upon submitting the pre-lab assignment, students can do the laboratory exercise at any time.

B. Course Prerequisites

The electronic circuits course builds on the foundational concepts and principles of circuits and semiconductor devices. MSU's BSEE program's introductory circuits and device courses include electric circuits, introductory electrical laboratory, and electronic materials and devices. In these first and second-year courses, students are introduced to circuit theory, measurement equipment, and linear and nonlinear device components. Students in the introductory circuits laboratory learn to use test and measurement equipment and apply and verify analytical techniques using basic electronic instruments such as the voltmeter, ammeter, function generator, and oscilloscope. Students conduct experiments on the analysis and design of circuits employing lumped components, diodes, and transistors in the materials and devices course. All students must successfully pass introductory circuits courses before enrolling in the junior-level Electronics course.

C. Course Enrollment

The remote laboratory was implemented in the junior-level electronic circuits courses in Fall 2020 and Spring 2021. During these two semesters, all university courses were taught online at the height of the pandemic. Table 1 summarizes the student enrollment in the class for each semester. Each student must meet the prerequisite requirements noted in section B before enrolling in the electronic circuits course.

TABLE I
STUDENT ENROLLMENT NUMBERS

Academic Term	Number of Males	Number of Females	Total Number of Students
Spring 2021	11	2	13
Fall 2020	19	3	22

IV. EXAMPLE LABORATORY EXERCISE

Students examined the direct current (DC) parameters for an NPN bipolar junction transistor (BJT) in the remote access lab, using the standard emitter configuration with emitter degeneration shown in Fig. 3. Students logged into the remote access web page, reserved a time slot as seen in Fig. 4 on the test system located on university premises, and conducted experiments on the BJT amplifier. Before completing the experiment, students are given pre-lab assignments: a homework assignment and a pre-lab assignment. The pre-lab selection is typically defined within the laboratory exercise. The title page of the laboratory exercise is noted in Fig. 5. The pre-lab assignment shown in Fig. 6 allows students to use mathematical formulations to calculate the collector current, current gain, and other input and output voltages associated with a simple BJT amplifier with a voltage divider. This pre-lab activity helps students apply the theoretical concepts on a simplified circuit. An outline of the laboratory exercise provided to students is illustrated in Figure 7. The laboratory experiment comprises three parts: hand calculations, simulations using LTSpice, and measurement using remote laboratory equipment. To have an optimal user experience with the remote lab measurement, students must complete all pre-lab assignments, including hand calculations or design simulations. Students can compare the results of the hand calculations, simulated, and measured remote laboratory data on a table similar to Fig. 8. The goal is for students to obtain comparable values and reconcile differences between the hand calculations, circuit simulations, and measurements using the remote laboratory. Although students were not on- campus, with the remote laboratory, they could still have the hands-on experience of using industrial equipment to make measurements on circuits.

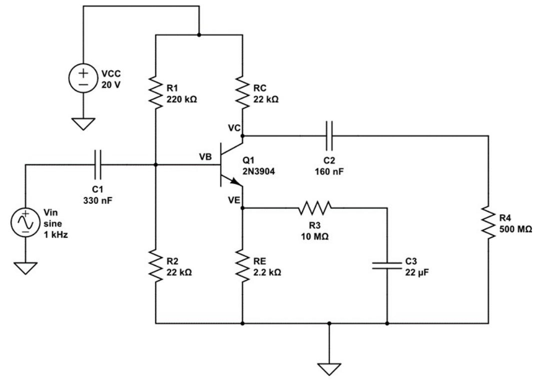


Fig. 3. Common Emitter with Emitter Degeneration Amplifier

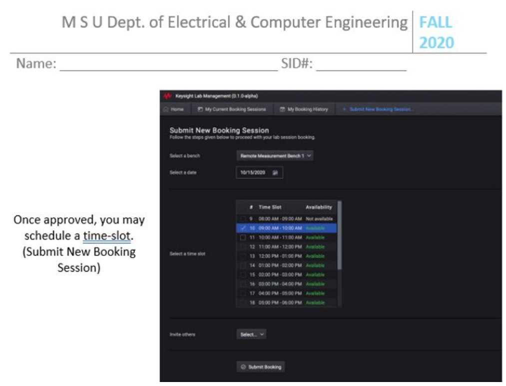


Fig. 4. Screenshot of BenchVue remote scheduling.

V. COURSE CHALLENGES AND STUDENTS' LEARNING EXPERIENCES

A. Challenges

We found that there were several challenges that the instructor and teaching assistants (TAs) had to address for the students to engage in the remote laboratory experience. The challenges noted here are summarized feedback from the teaching assistants and instructors of the course. The difficulties in student learning mentioned here are not unique but align with research that shows that for lectures delivered entirely online, the transition to remote education is challenging for students, increases student workload, and decreases students' ability to focus on school [16].

- **Remote laboratory computer and measurement equipment access:** The remote lab setup had a dedicated bench PC that enabled students to have secure access to the lab bench test equipment to conduct experiments. There were several instances when the bench PC or the measurement equipment was not available due to power failures, unknown system crashes, or students failing to log out of a registered session once completed. To solve these issues, an IP-controlled power strip for remote power control and reboot of the bench PC and any network devices was used. The web power switch by Pro Switch [17] was used in place of a conventional power strip. This enabled remote troubleshooting of any network equipment and the bench PC. Also, the TAs extended the assignment deadlines when needed.
- **Students with low motivation:** All laboratory-based courses were transitioned to an online format because of the pandemic. The TAs noted that some students had

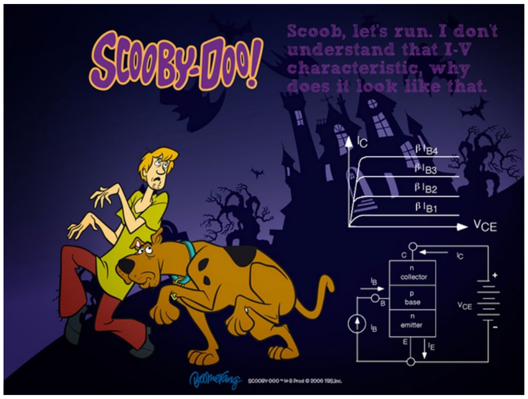
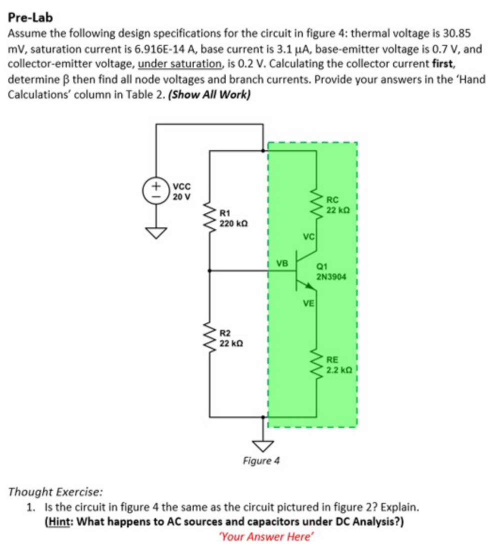


Fig. 5. BJT Lab Exercise[15].



Pre-Lab

Assume the following design specifications for the circuit in figure 4: thermal voltage is 30.85 mV, saturation current is 6.916E-14 A, base current is 3.1 μA, base-emitter voltage is 0.7 V, and collector-emitter voltage, under saturation, is 0.2 V. Calculating the collector current **first**, determine β then find all node voltages and branch currents. Provide your answers in the 'Hand Calculations' column in Table 2. ***(Show All Work)***

Figure 4

Thought Exercise:

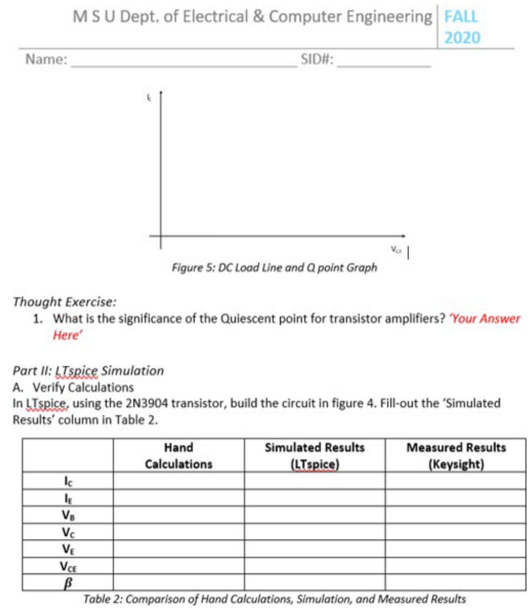
1. Is the circuit in figure 4 the same as the circuit pictured in figure 2? Explain. **(Hint: What happens to AC sources and capacitors under DC Analysis?)** *'Your Answer Here'*

Fig. 6. Pre-lab exercise.

I. Introduction
II. Lab Submission Instructions
II. Required Lab Equipment
- LTspice
- Keysight Remote Lab Instructions

III. Background
IV. Pre-Lab
V. Lab Experiment
- Part I: More Hand Calculations
- Part II: Simulation
- Part III: Measurement

Fig. 7. Laboratory exercise outline.



M S U Dept. of Electrical & Computer Engineering | FALL 2020

Name: ____________________ SID#: __________

Figure 5: DC Load Line and Q point Graph

Thought Exercise:

1. What is the significance of the Quiescent point for transistor amplifiers? *'Your Answer Here'*

Part II: LTspice Simulation

A. Verify Calculations

In LTspice, using the 2N3904 transistor, build the circuit in figure 4. Fill-out the 'Simulated Results' column in Table 2.

	Hand Calculations	Simulated Results (LTspice)	Measured Results (Keysight)
I_C			
I_E			
V_B			
V_C			
V_E			
V_{CE}			
β			

Table 2: Comparison of Hand Calculations, Simulation, and Measured Results

Fig. 8. Laboratory exercise page in which students note lab results.

difficulty adjusting to the online format. Virtual learning was a new learning style for most students. Students with low motivation often did not complete all the assignments required before the laboratory exercise. Students struggled with keeping focus during the class session. Some students were caring for loved ones, experiencing illness, or distress over losing a loved one while trying to keep up with their academic studies. To solve these challenges, the TAs would provide detailed instructions for setting up and completing the laboratory exercises, offer flexible office hours, give students constant encouragement, and the opportunity to express themselves without judgment.

- **Preparing labs to account for multiple testing scenarios:** When preparing a laboratory exercise for a remote laboratory setup, it is essential to configure the DAQ, which contains the switch and multiplexer modules as shown in Fig. 1, and the test circuit to ensure proper measurement of the output voltages and currents. Students need to remotely select different values of the resistors at specified pins to obtain an appropriate output result. The TAs set the proper configurations and verified DAQ pin output values, connections, voltages, and current measurements at all BJT amplifier nodes.
- **Inadequate student preparation:** Students who did not have a 'hands-on' introductory experience with lab tools (i.e., ammeter, voltmeter) or did not understand what each tool is supposed to do, struggled with verifying experimental results with calculated and simulated results. To solve this, before enrolling in the third-year electronics circuits course, students should successfully pass an introductory circuits laboratory course. Students must have the fundamentals of measuring the behavior of passive lumped electronic components (i.e., resistors, inductors,

capacitors), the function of measurement tools, and how to use the tools to do DC and AC analysis of electronic circuits. In addition, students were given pre-lab assignments to reinforce introductory concepts learned from pre-requisite courses, apply mathematical formulations for circuit analysis, simulate a circuit schematic, and verify mathematical and simulated results.

- **Lack of social interaction:** Each student had to complete the remote laboratory experiments individually and submit an associated laboratory report. Individual student submissions helped to ensure that each student had the opportunity to experience completing the remote laboratory exercises, utilizing the BenchVue software, and measuring the electrical behaviors of the tested circuit but it also had drawbacks. As allowed by the remote access lab capability, having students work in teams would enable them to cross-learn and share their ideas and work together. However, this would have opened the possibility that one student may dominate over the others and effectively run the entire experiment. A blend of individual and team exercises with remote access labs may be best.
- **Online format:** For many students enrolled in the course, this was the first semester in which they experienced learning online. Although students logged in for lecture sessions, at times the instructor noticed that many students were disengaged (i.e., low-class participation, provided little feedback to the instructor). However, the remote laboratory exercises provided opportunities for students to ask questions and engage with the instructor and teaching assistants. It is through the student's interaction with the remote labs that the instructor and TAs were able to gain additional insight on topics in which students grasped the concepts with success or required additional review and remediation.
- **Unstable internet connections:** Students were mandated to stay at home due to the pandemic, for some, home meant within the local region, another state, or another country. Students had to rely on home computing and internet resources. Often during lessons, students with unstable internet connections would not hear lectures or would not be able to complete laboratory exercises. As a result, the instructor recorded each lecture session so that students would have access to missed lectures at any time. In addition, because of the flexible nature of the remote laboratory, students can register for a remote session at another available time when a more stable internet connection is available.

B. Students' Learning Experience with Remote Experiential Labs

Students' learning experience with active, experiential learning using the remote laboratory is described below.

- **Vital prior preparation:** One of the critical factors that impacted students' ability to complete the remote laboratory exercises was the lack of prerequisite lab knowledge and practice. Although all students enrolled met the prerequisite course requirements, the instructor and TAs noticed that some struggled with remembering and applying foundational knowledge of analyzing circuits and using measurement equipment. To address this issue, students were required to complete pre-lab assignments. A critical aspect that was incorporated into the course was the implementation of pre-laboratory assignments that reinforced the theoretical concepts learned during the lecture session or provided a review of essential circuit measurement. The pre-laboratory assignments required students to manually analyze circuits to compute the currents and voltages and use LTSpice to simulate the circuit schematic response. Both mathematical computations and simulation responses were compared, and students used the information to help verify measurements during the remote laboratory exercise. When students did not complete the pre-laboratory exercises, they struggled with using and understanding the results from the remote lab exercise. Fig. 9 shows the class lab grade performance. As shown in Fig. 10, students who received a final course grade of 'A' or 'B' consistently submitted many pre-lab assignments and received higher pre-lab and lab grades. On the other hand, as shown in Fig. 11, students who received a final course grade of 'C' or lower consistently had a lower percent average of pre-lab assignments, pre-lab grades, and lab grades.

Academic Semester	% Average of Pre-Lab Assignments Not Submitted	% Average of Pre-Lab Assignments Submitted	% Average Prelab Grade	%Average Lab Grade
Spring 2021	26%	74%	62%	86%
Fall 2020	37%	63%	49%	59%

Fig. 9. Class Lab Performance

Academic Semester	% Average of Pre-Lab Assignments Not Submitted	% Average of Pre-Lab Assignments Submitted	% Average Prelab Grade	%Average Lab Grade
Spring 2021	8%	92%	77%	98%
Fall 2020	17%	83%	82%	82%

Fig. 10. Students with a 'A' or 'B' Grade Lab Performance

Academic Semester	% Average of Pre-Lab Assignments Not Submitted	% Average of Pre-Lab Assignments Submitted	% Average Prelab Grade	%Average Lab Grade
Spring 2021	33%	67%	55%	81%
Fall 2020	42%	58%	53%	54%

Fig. 11. Students with a 'C' Grade Lab Performance

- **TA support and interaction:** Three teaching assistants were assigned to the course. One TA focused on answering questions regarding information from lecture content and leading the recitation sessions. The other two TAs were responsible for overseeing the remote laboratory exercise development, providing laboratory instruction, and responding to student lab questions and concerns. Each TA had office hours during which students could request a Zoom conference session. Outside of the established TA office hours, students could email TAs any problems they encountered in registering for a remote lab session or questions regarding the remote laboratory exercise. This level of support and the instructor were available for every student.
- **Varied ways of learning concepts:** The remote laboratory enabled the student to apply the concepts in various ways. For example, students were able to perform DC analysis of a linear transistor amplifier, like the amplifier shown in Fig. 2(a), using the theoretical concepts to do mathematical hand computations, simulating the circuit in a computer-aided design tool such as LTSpice to verify mathematical computations, and then measuring the currents and voltages further to validate the circuit simulation and mathematical hand calculations.
- **Remote laboratory accessibility:** The remote laboratory equipment was available at any time for students to complete the laboratory exercises. Once a student is registered for a remote lab session, they gain access.

C. Lessons Learned

The authors learned the following lessons in implementing a remote laboratory experience using industrial instruments.

- **Encourage students.** Having a team of student TAs was valuable in addressing students' problems or concerns in completing the remote laboratory exercises. The TAs offered a listening ear and provided support and guidance to encourage student success. The TAs were active and accessible via Zoom, email, and recitation sessions.
- **Configure alerts when students initially request a time slot for approvals.** If sufficient time has passed and there is no conflict, the student should be able to utilize the system. This could potentially prevent over-registration during specific time periods and reduce system crashes.
- **Onboarding teaching assistants.** The TAs require an onboarding process to get them familiar with using the remote laboratory setup. There should be example experiments with the remote labs and demonstrated on the system with the students.

Other best practices include proper planning of the goals, dynamics, and the construction of the experiments, properly labeling and communicating the components being measured for the circuit, having teaching assistants to help with remote lab implementation and monitoring, and providing a process for feedback and support when students get stuck.

VI. Conclusions

The authors described this paper's successful implementation of an active, experiential learning approach. The students used remote access to industrial instruments on university premises to conduct experiments on an electrical circuit to allow them to compare with theoretical expectations. Several laboratory exercises were developed and taken by students at times convenient for them by logging into the remote access web portal where they conducted experiments on various electrical circuits. While remote-control laboratories don't offer the ability for students to perform hands-on wiring of circuits, they do provide a flexible means to learn many salient aspects of measurement and design validation. The authors note that pre-laboratory exercises that complement the remote laboratory experiment improve student outcomes and provide students with basic knowledge of the types of measurement instruments used in an electronics laboratory. The remote laboratory platform was accessible 24/7 and scalable for any user with an approach that transcends economic and geographic boundaries and allows academic participation for immuno-compromised students. It is also important to note that although many universities require students to return to classrooms, some students prefer the option of hybrid learning in which remote laboratories would greatly benefit [18].

References

[1] Linnenbrink EA, Pintrich PR. Role of affect in cognitive processing in academic contexts. In: Dai DY, Sternburg RJ, ed. Motivation, Emotion, and Cognition. Mahwah, NJ: Lawrence Erlbaum Associates; 2004:57-87.

[2] Bensley RJ, Ellsworth T. Bulimic learning: a philosophical view of teaching and learning. J Sch Health. 1992;62(8):386-387.

[3] Zorek JA, Sprague JE, Popovich NG. Bulimic learning. Am J Pharm Educ. 2010;74(8) Article 157.

[4] Bligh D. What's the Use of Lectures? 5th ed. New York, NY: John Wiley Sons; 1999.

[5] McKeachie WJ, Pintrich PR, Lin YG, Smith DA. Teaching and Learning in the College Classroom: A Review of the Literature. National Center for Research to Improve Secondary Teaching and Learning. Ann Arbor, MI: University of Michigan Press; 1987.

[6] P Prince M. Does active learning work? A review of the research. J Engineering Educ. 2004;93(3):223-231.. Arpaia, A. Baccigalupi, F. Cennamo, P. Daponte, A remote measurement laboratory for educational experiments, Measurement, Volume 21, Issue 4, 1997, Pages 157-169, ISSN 0263-2241, https://doi.org/10.1016/S0263-2241(97)00062-6.

[7] J. E. Corter, J. V. Nickerson, S. K. Esche, C. Chassapis, S. Im, and J. Ma, "Constructing reality: A study of remote, hands-on, and simulated laboratories," ACM Transactions on Computer-Human Interaction, vol. 14(2), Article 7, 2007.

[8] M. Koretsky, C. Kelly, and E. Gummer, "Student Perceptions of Learning in the Laboratory: Comparison of Industrially Situated Virtual Laboratories to Capstone Physical Laboratories," Journal of Engineering Education, vol. 100, pp. 540-573, 2011.

[9] V. J. Harward, J. A. Del Alamo, S. R. Lerman, P. H. Bailey, J. Carpenter, K. DeLong, et al. "The iLab shared architecture: A Web Services infrastructure to build communities of Internet accessible laboratories". Proceedings of the IEEE, vol. 96(6), pp. 931-950 (2008).

[10] M. Goryll, T. J. Thornton, C. Wang, S. M. Phillips and D. Allee, "Online Undergraduate Laboratories in Electrical Engineering," 2019 IEEE Frontiers in Education Conference (FIE), 2019, pp. 1-4, doi: 10.1109/FIE43999.2019.9028682.

[11] A. Khalil, M. Hasna, M. Benammar, M. Chaabane and C. B. Amar, "Development of a remote lab for electrical engineering program," 2009 3rd IEEE International Conference on E-Learning in Industrial Electronics (ICELIE), 2009, pp. 40-44, doi: 10.1109/ICELIE.2009.5413214.

[12] I. Gustavsson, ”A Remote Laboratory for Electrical Experiments”, Proceedings of the 2002 ASEE Annual Conference and Exposition, June 16-19, 2002, Montreal, Canada.
[13] K. Bangert, J. Bates, S. Beck, Z. K. Bishop, M. Di Benedetti, J. Fullwood, A. C. Funnell, et al. ” Remote practicals in the time of coronavirus, a multidisciplinary approach”, International Journal of Mechanical Engineering Education, vol. 50(2), pp. 219-239, 2022.
[14] https://www.keysight.com/us/en/assets/7120-1283/case-studies/University-of-Houston-Enhances-eLearning-with-Real-World-Labs.pdf.
[15] ”What are the switching characteristics of BJT? -quora.” [Online].Available.https://www.quora.com/What-are-the-switching-characteristics-of-BJT.
[16] Barber, Paul H et al. “Disparities in Remote Learning Faced by First-Generation and Underrepresented Minority Students during COVID-19: Insights and Opportunities from a Remote Research Experience.” Journal of microbiology biology education vol. 22,1 22.1.54. 31 Mar. 2021, doi:10.1128/jmbe.v22i1.2457.
[17] Digital Loggers, Inc. Pro Switch is available at https://dlidirect.com/products/new-pro-switch.
[18] Adrienne Lu, ’Some Colleges Are Ending Hybrid Learning. Students are Pushing Back.’ The Chronicle of Higher Education. April 11, 2022.