Pandemic-Induced Challenges and Creative Instructor Solutions to Convert University Engineering Laboratory Courses to Online Format

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***Abstract*—*Contribution*: This paper is a case study of how our electrical engineering department's laboratory courses have been adapted in response to the COVID-19 pandemic.**

***Background:* Engineering laboratory education has been significantly impacted by the COVID-19 pandemic; yet, in spite of the disruption there have been improvements to educational processes instigated by the pandemic. Research Questions: How can engineering laboratory courses be adapted to the quarantine restrictions brought on by the pandemic in a manner that preserves the quality of instruction for the students while keeping them engaged?**

***Intended Outcomes:* To be able to quickly find a way to convert in person engineering lab courses to online courses due to the COVID-19 global pandemic.**

***Application Design:* The engineering department opted to invest in the purchase of and then to loan to the laboratory students, small remote laboratory kits that they could use at home. The kits are for lab projects involving building and programming Arduino based robot kits and making and testing digital networking and analog circuits using the National Instruments MyDAQ.**

***Findings:* This paper addresses the aspects of our university's effort to make engineering lab courses transition to online courses in response to the pandemic in order to maximize the quality of professional skills that can be taught to the students to help them each pursue a successful career. The student response to the laboratory changes were favorable.**

Index Terms—Online learning, distance learning, blended learning, flipped classroom, COVID-19 electrical engineering course conversion instructor experiences.

I. INTRODUCTION

Engineering laboratory education has been significantly impacted by the COVID-19 pandemic [1-5]; yet, in spite of the disruption there have been improvements to educational processes instigated by the pandemic. It caused a discussion on the need to modernize teaching methods with new technologies and tools [1]. It was in the summer of 2020 that the electrical engineering (EE) department of California State University, Long Beach (CSULB) set out to convert most of the classes to online starting in the Fall of 2020 because of the global COVID19 pandemic. Of the many EE laboratory classes that were converted, in this paper we discuss a junior level robotics and mechatronics programming class, a senior level computer network technology class, and a senior level analog electronics class. Figure 1 shows the assembled robot kit in the robotics class. Figure 2 depicts the computer networking technology kit in the computer network technology class. Instead of resorting to the use of simulations for lab courses, the EE department decided to record hardware lab experiments for 17 courses and to provide lab kits for students to borrow from the university in order to conduct the hardware experiments at home or in the garage. The students were instructed to mimic the hardware lab experiments after watching videos at home.

II. ACQUIRING MOBILE LABORATORIES (KITS)

Internal studies had concluded that students learn more effectively when engaged in hands-on laboratories compared to simulated laboratories [6]. The acquisition of the kits came through a grant provided by the Corona Virus Aid, Relief and Economic Security (CARES) Act and Higher Education Emergency Relief Fund (HEERF). The EE department already had Arduino based complete robotics kits with sensors and wires that students could check out, so the large purchase consisted of several hundred data acquisition MyDAQ devices from National Instruments (NI) and a few other components for a computer network class. Figure 3 shows the NI's MyDAQ employed in circuits, analog electronics I and II, and control classes. These NI units were chosen for their quality and compatibility with various operating systems. For the network technology and analog electronics courses a parts kit was put together by the instructor and parts were purchased by the students.

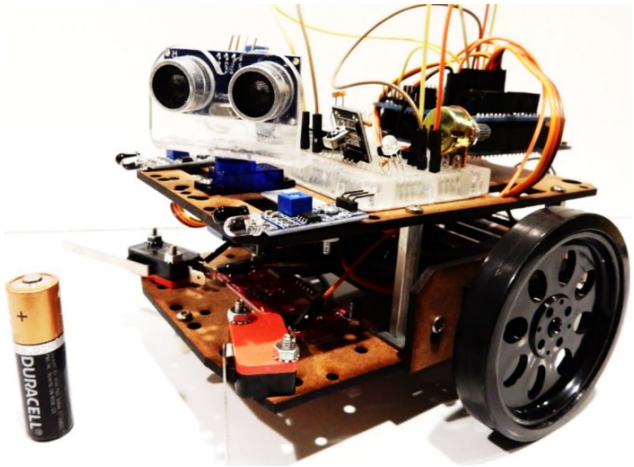

Fig. 1. This is an Arduino Robot Kit, assembled.

III. KIT DISTRIBUTION LOGISTICS

One challenge was how these new educational technology tools were going to be distributed to the students. It was decided that the university bookstore was already equipped to do the collection, distribution and record keeping of these materials. Students could go to a single location that met the State of California disinfection and cleaning rules to pick up their kit at a well-known convenient location during working hours. Students who lived too far from the campus had the option of having the kits and components shipped to them, this was the case for the robotics kits. Material was to be returned at the end of the semester to the bookstore or the instructor. When components were missing or broken the instructor would meet the student on the campus and provide these components. We found some students were lacking essential tools such as multimeters or soldering irons to troubleshoot or repair so the student would have to come and temporarily use the campus tool. This was also difficult because instructors would have to get permission for the time to be physically on campus. It was also found that some students unfortunately lacked the monetary funds to purchase these basic tools.

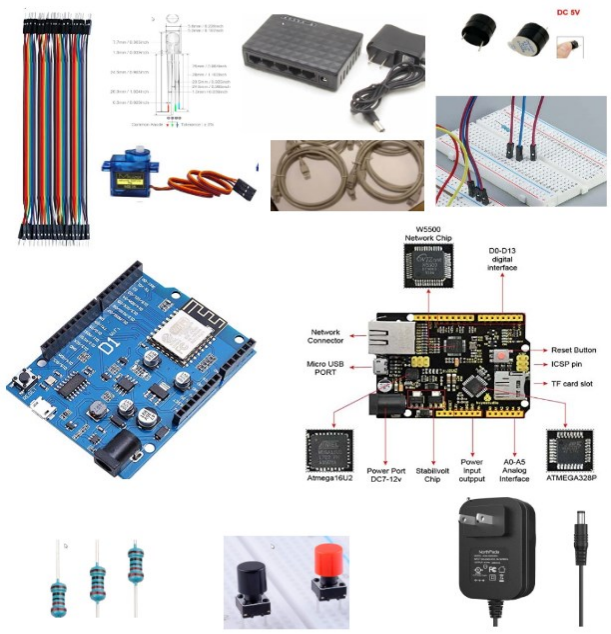

Fig. 2. Computer Networking Technology Kit.

CSULB has a very diverse and large group of students. Diverse Issues in Higher Education also ranked the College third for awarding engineering degrees to minority students. Approximately 52% of the CSULB students are underrepresented minorities, as defined by NSF, including 59.2% female, 46.9% Hispanic, 4.5% African American and 1% Native American. As a result, CSULB is recognized as a minority serving institution: namely Hispanic, Asian American, Native American and Pacific-Islander serving institutions. More than half of our students are low-income or first-generation college students. The CSULB College of Engineering has more than 120 faculty and 5000 students undergraduate and graduate and offers 11 engineering programs [7]. Some of the students lack funding and support to a point where they do not have their own computer or Internet access at home. A recent survey showed that access to high-speed internet was a challenge for many college students [8]. Fortunately, the grant funds were also used to purchase a large number of laptops and Internet access points that students who lacked these tools could borrow for the semester along with the kits. Our central information technology department managed the laptop and hotspot distribution.

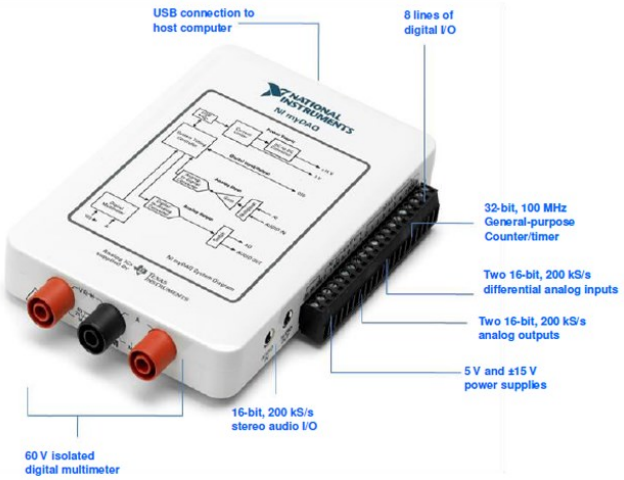

Fig. 3. National Instruments MyDAQ.

On rare occasions when the student broke a part or the kit had failed or missing components, the instructor would meet the student in an open area on campus where they could swap components. All other troubleshooting was done online via Zoom including office hours. Lots of other tools were combined such as higher resolution web cameras by the instructor to demonstrate close-ups of wiring or phones used by the students to take photos of their lab wiring to show the instructor where they were having problems. Drawing tablets were offered by the department and were used also by the instructor to pinpoint details and do markups on a photo or presentation. This was another tool that instructors had learned how to use. The university also created a few open air areas where students could come (meeting social distance requirements by the State) and plug their equipment with WiFi coverage and access to all of the campus online resources. This worked for some thanks to the great California weather.

IV. WE HAVE THE MOBILE LABORATORIES, NOW WHAT?

During the summer before the fall 2020 semester another challenge was to train other instructors on using these mobile laboratories. The college of engineering used part of the grant to fund stipends for several instructors to record videos on how to use these tools. The recordings included videos of the entire lab assignments with instructions and demonstrations. It turned out that our department received approval to record more remote instructional videos than any other department at our university, suggesting that our department might have made more of a unique effort to prepare during the summer of 2020 for the coming pandemic-mode remote teaching scenario than other departments. This actually proved beneficial to

both the instructors and students. Any instructors using these mobile laboratories could quickly get up to speed on how to use the tools. The university provided classes via Zoom and Microsoft Teams managed by a learning customized learning management software (LMS) dubbed BeachBoard with which instructors could learn how to convert an in person course to online by using tools such as Camtasia or Snagit to record videos. Online tutorial classes were provided on how to use Zoom with tools such as breakout rooms to provide the ability for students to work in virtual groups as they would in regular in person classes. One requirement by the university was to have accurate closed captioning (CC). Tools used for these included BeachBoard's built in software and YouTube. We found that online learning is benefitted by the use of multiple platform tools such as what we used [9], but making sure the closed captions were correct took many hours or reviewing and editing for the instructor.

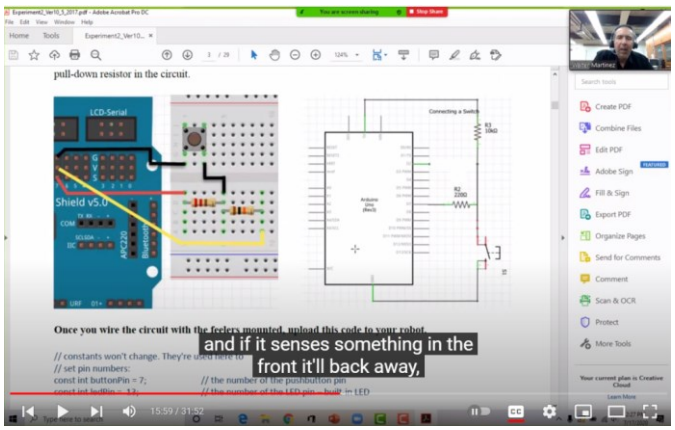

Fig. 4. Screenshot of pre-recorded lab requirements to the students in a Zoom picture-in-picture style showing the instructor on the top right-hand corner of the screen to make it more personal for the students. The videos were recorded in the labs on campus to give the student a better impression.

V. Methods

The courses are managed under the BeachBoard online course learning management system. In that system courses can be organized with content tabs such as Lectures, Labs, Test and Quiz Study Guides, Reference Material, Extra Credit and Syllabus. The instructor stores all contents here and students can download it to their computers. Students can also submit laboratory reports, tests and homework in this system. Feedback and scores can be recorded in this system. These online methodologies integrate and extend the traditional on-campus education [10]. In the online Robotics course grades improved from the traditional in-person classes because students had a lot more time to complete the laboratory work on their own time at home. This demonstrates that online methodologies can improve grades and even retention [6][11].

a. Pedagogical Approach of Courses

For the classes we combined synchronous and asynchronous approaches where the lectures started all online and students interacted live while online and the labs were mostly done at home on the student's own time while they received most of the laboratory instruction and demonstrations via pre-recorded videos and guides.

b. Working in Groups

A great benefit of in person classes is having the students work in groups. In the online world Zoom provided the ability to do breakout rooms that allowed the students to work in virtual groups. This worked out great because when projects required students to work in groups the students would work on the projects as a virtual group and the instructor would jump from virtual group to virtual group to make sure they were doing their work. Students also had the ability to raise their hands virtually and the instructor could jump into that group. The instructor could easily also chat and share files and links with the students in real-time. The instructor's Zoom account would allow for a lot more Zoom meeting time so the instructor would open up the session and leave it open for students to meet for longer periods of time after the lecture ended to discuss group lab questions amongst themselves. In a sense this gave students an easy to use platform for collaboration that got them even more engaged. The use of cameras on the student's part was not required unless they had to present a project, but they had the option to pre-record it anywhere they wanted to and present it later.

c. Submitting Lab Reports, Assignments, Tests and Correcting Papers

Students have a standard template they can use to write a lab report explaining what they did, code, problems encountered and findings. In the case of the robotics class lab report students were required to in addition to a written report also provide a video clip demo of their robot working. Students used their mobile phones for these videos and uploaded them to OneDrive, BeachBoard's DropBox or YouTube. It was interesting to see the student's creativity as they had to demo a rolling autonomous robot avoiding obstacles inside their homes. This also meant the instructor would have to spend more time checking different places and be familiar with all of these online platforms to provide the student credit. One of the most difficult parts was correcting exams as the existing tests for the robotics course were in PDF format. The students would print it at home, write their answers and then take photos with their mobile devices used as scanners and submit individual pages to the Dropbox folder in BeachBoard with their answers. Others found ways to write directly on the PDF, scan and submit. The department also recommended and provided funds for instructors to purchase some inexpensive writing tablets that could be connected via USB to the computer and most of the software would recognize it as a pen. With this pen you can do corrections and markups while on BeachBoard or during lectures to provide the student instant feedback. In some cases it was difficult to determine if there was cheating on the take home exams although there are tools built into the BeachBoard software that checks for plagiarism, the multiple formats of tests submission made it difficult to do auto plagiarism checking. Requiring the students to all submit using the same format would better support the auto plagiarism system.

VI. Student Experiences, Benefits and Conclusion

The positive student feedback shows that the effort put in by the instructors was worth it as it helped the students gain a new mode and quality of educational experience. We were able to bring down the misconception that online education is solitary, non-instructor led, self-paced only [10]. One of the students was traveling to the Middle East and was stuck there because all flights were cancelled due to COVID-19 restrictions, yet he was able to complete the course since it was all online. The student did have to make the effort of being present during the Zoom classes while it was very late in his local time zone though. In the case of the robotics course students competed against other students where a task was assigned for the robot to do and whatever robot completed the fastest won, thereby awarding the builder extra credit. This was all shown either live from their homes using the camera on their phones or laptops or they prerecorded the completed laboratory and presented the video during class. This gamification of the online lab also worked great and it motivated the students to do better and we noticed that students put the extra effort to do their best.

An improvement that the MyDAQ brings to the analog electronic student laboratory experience is that it includes a Bode Analyzer utility that automates the measurement and plotting of frequency response sweeps. It saves the student significant time in measuring amplifier, filter, and control system circuits that otherwise would have to be done by manually taking measurements at tens of frequencies for each circuit and collecting hand-written data that might not be transcribed correctly. Thereby the MyDAQ Bode Analyzer utility improves the quality of the student measurement data by avoiding hand transcription data errors.

One of the largest benefits observed was that since online students have a lot more time allocated to completing a lab from their homes and have videos that they can refer to on demand, the quality of the lab demonstration improved tremendously, and successful completion rate has also increased. Instructors have to spend significantly less time explaining the labs plus it ensures that what you are trying to convey is clear and consistent. The use of mostly open source software in the case of the Arduino robot kits also made the distribution of files and documentation a lot easier. Another benefit that came from this effort is that the following semester the new students taking the classes also had the advantage of viewing the recorded class lectures from the previous semester thus converting the class automatically into a flipped classroom model. A unique benefit of this flipped mode of remote laboratory classroom, especially in the context of pandemic remote teaching, is that any Internet outage or problem experienced by a student or the instructor during the scheduled remote laboratory class session does not detract from the instructional component of the class. The instructional component is supposed to be studied by the students by watching the pre-recorded online tutorial videos prior to the scheduled class time. To deal with Internet outages during scheduled class time we've found that it's beneficial for the instructor to simultaneously host a non-VOIP telephone conference line along with the Zoom class session so that any student who loses Internet connection during the class session can continue participating with the class on the audio conference line. Even the entire class could immediately switch from Zoom to the audio conference in case the instructor experiences a loss of Internet service during the class. There have been several instances for which a student did not completely lose Internet service but degraded enough to make that student's Zoom audio useless: In each case those students were able to immediately continue participating in the class session using the dial-in conference audio. During the first remote class session of the semester all the students are directed to temporarily step away from the Zoom session and dial into the audio conference as a sort of drill and training for the possibility of an Internet outage.

Fun online courses like the ones described in this paper provide student retention, engineering specific course interest and opportunity by providing access to richer and broader sets of learning experiences [10]. Adding multimedia material to education is beneficial and specially in blended learning where students cannot regularly attend classes [11]. While this approach cannot be done with all engineering courses as they might require hands-on experiments with high power equipment, we received positive evaluations and instructors were able to provide students with a new quality of education experience with loaned mobile lab equipment that can be reused in subsequent semesters by other lab students. Figures 5a and 5b present a Student Perception of Teaching (SPOT) survey during the pandemic done by the students to rate the teacher and effectiveness of an Introduction to Robotics course that was converted to online. This shows the overall student satisfaction was high. Figure 5c presents a similar SPOT survey also during the pandemic from senior-level analog electronic courses also converted to online format.

Overall, what we've discussed in this paper were aspects of our university's effort to make additional effort in response to the pandemic in order to maximize the quality of professional skills that can be taught to the students to help them each pursue a successful career.

Academic Term	Course No.	No. of Students Enrolled	No. of Students Respond	Mean	Standard Dev.*	Dept. Mean	Dept. SD	School Mean	School SD*	Class GPA	Dept. GPA at Same Level (LD, UD,GR)
Fall 2019	ET 387-01	22	16	5.88	0.34	5.46	1.05	5.17	1.28	3.57	3.19
Fall 2020	ET 387-01	14	10	5.60	.52	5.38	1.15	4.99	1.44	3.86	3.49
Fall 2021	ET 387-01	14	11	5.45	1.51	5.20	1.28	4.94	1.50	3.79	3.37

Fig. 5a. Summary of SPOT survey including departmental GPA.

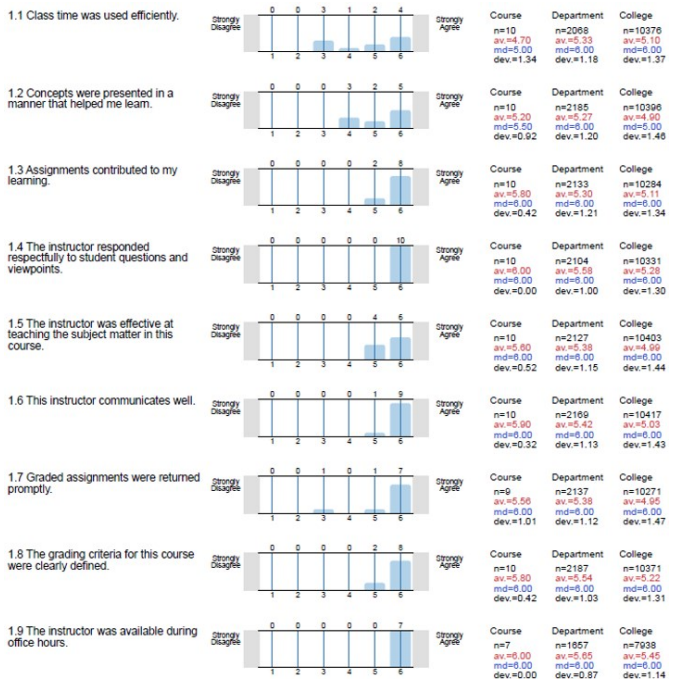

Fig. 5b. SPOT student survey for junior level intro to robotics course, Fall 2020, conducted online during the pandemic.

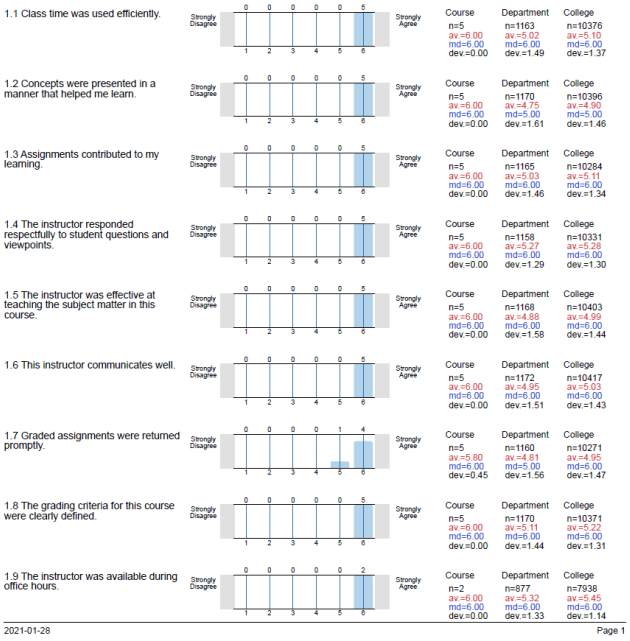

Fig. 5c. SPOT student survey of a senior level analog electronics laboratory, Fall 2020, conducted online during the pandemic.

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