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From Online to In-person Electrical Circuits Laboratories sessions: Benefits, limitations, and challenges

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Abstract

Before the shutdown due to COVID-19, all courses and laboratories from the Electrical and Computer Engineering Department (ECE) at The University of Texas at El Paso (UTEP) were conducted in person at the university facilities. Many of the laboratories required students to work in groups due to the limited equipment availability. Most universities were forced to adopt distance learning as a primary teaching modality when the pandemic started. Previously, the Learning Management Systems (LMS) were used mainly for support course functions, where students could review the content and grades in their own time, submit assignments, or download materials. During the pandemic time, students attended virtual sessions via video conference, reviewed materials independently, or had restricted interactions. This modality limited the ability to conduct lab experiments. The adopted lab methodologies were to offer online circuits laboratories implemented via portable equipment, designed for work at home, and acquired for the students; or by providing remote access to some university equipment. The ECE department had additional challenges because most of our students live in the border region between USA and México, and many had limited technological resources to access virtual or remote laboratories.

UTEP started resuming face-to-face courses and events on campus after the pandemic acute phase period. For the fall 2021 semester, the school initiated activities under enhanced safety precautions for in-person classes. Currently, the circuits laboratory returned to face-to-face delivery mode using bench industrial-grade equipment with higher resolution and accuracy than personal devices, offering students a more comprehensive range of experiments to improve their abilities and knowledge in the technical field. However, some characteristics of the virtual model were kept, such as working at home in the preliminary laboratory phase using portable equipment and then allowing students to work individually at the university workstation, using time more efficiently, and keeping the improved LMS content.

This paper compares online and in-person circuits laboratory sessions, exploring the differences, limitations, benefits, and challenges for the students and the response due to geographic restrictions**.**

Keywords: Online Education, Face to face education, Learning Management System, laboratory online.

Introduction

There are multiple modalities of teaching used in education, and sometimes, the naming convention can be ambiguous. We will use the framework proposed in a previous study (Magana et al, 2018) [1],[2], with the following methods, Passive Learning, Active Learning, Constructive Learning, and Interactive Learning. Passive Learning is the traditional lecture method where the student just receives information in one direction but is not expected to react in any way. Active Learning requires the student to have some type of reaction to the process, and the effect is observable. Constructive Learning requires the student to generate a product beyond the information received, such as analysis or synthesis. Interactive Learning adds the dimension of working with other students. We can associate Passive Learning with the first layer of Bloom's Cognitive Taxonomy (Knowledge) [3]. Active Learning will typically address the lower three layers (Knowledge, Comprehension, and Application), while Constructive Learning will reach the upper layers (Analysis, Synthesis, and Evaluation). The Interactive Learning modality adds the collaboration dimension to the process and might apply to all Bloom's levels.

Since the Electrical and Computer Engineering (ECE) Department was established in 1947, courses and laboratories have been offered in a face-to-face modality (known as teacher-centered) where professors determine the classroom dynamics according to the course content providing a sense of direction to the students. The instructor used passive, active, constructive, or interactive methods according to their teaching style. However, in March 2020, educational institutions were forced to shut down due to the COVID-19 crisis, and The University of Texas at El Paso (UTEP) was not the exception. Traditional education was changed to virtual education using Learning management systems (LMS such as Blackboard or Moodle), video-conference tools, virtual tutoring, and learning software for delivering the course content. Online instruction is a student-centered modality; however, active Learning usually is not perceived as being associated with it [4] because the timing of the interactions might not be immediately observable. Online instruction can be offered in a synchronous mode or asynchronous (self-paced), determining the possible types of engagement between the instructor and students.

Several advantages and disadvantages are associated with in-person and virtual instruction modalities. Traditional classroom teaching provides high student engagement with professors and course content and promotes competitiveness among students. Also, the conventional education environment improves the interaction among students and provides the atmosphere to learn from each other. There is an excellent opportunity to provide formative assessment in this setting [5]. Some disadvantages of this modality are the commuting cost, students having less time to learn and understand because of the schedule assigned, loss of individualization in a large group, and limited learning methods used by students.

In online education, synchronous and asynchronous modes can be used. Asynchronous mode provides handouts, articles, Powerpoint presentations, and audio and video lectures for the students. Course material is available anywhere and anytime. In this mode, students need to develop the abilities of self-study and self-learning strategies because of the limited tutoring time. On the other hand, synchronous e-learning involves Learning and teaching simultaneously via LMS systems, in real-time, increasing the active learning strategies interaction. Table 1 shows the advantages and disadvantages of both modalities [6]-[11]. Most educative institutions were forced to move to online mode during the COVID-19 pandemic, involving many challenges due to the sudden transition [12], [13].

After the COVID-19 main crisis, UTEP resumed the activities and courses at the campus facilities allowing instructors to keep using some of the online tools used during the virtual instruction phase. This paper focuses on analyzing the circuit's laboratory on the new "hybrid modality".

Table 1. Advantages and Disadvantages for Traditional and Virtual Education [6]-[11]

<table>
<tr><th>Traditional Education</th><th colspan="2">Virtual Education</th></tr>
<tr><th colspan="3">Advantages</th></tr>
<tr><td rowspan="3">- Engagement with professors and course content
- Social connection
- Ability to work in groups
- Provides direction and a solid plan for students.
- A few distractions in the classroom
- Active learning strategies</td><th>Synchronous</th><th>Asynchronous</th></tr>
<tr><td>- Active learning strategies.
- Provides direction and a solid plan for students.</td><td>- Student attendance
- Course available anywhere, anytime</td></tr>
<tr><td colspan="2">- Course content is available via LMS systems
- Several learning methods
- Affordability
- Flexibility and accessibility</td></tr>
<tr><th colspan="3">Disadvantages</th></tr>
<tr><td>- Commuting cost
- Less time to learn and understand topics
- Limited learning methods
Loss of individualization in large groups</td><td colspan="2">- Technical problems
- Computer failures
- Internet connectivity
- Need compromise, self-discipline
- Self-motivation
- More distractions
- Limited social connection</td></tr>
</table>

Case of study: Circuits laboratory for Electrical Engineering

The main objectives of this course are to provide the students with a clear understanding of how to analyze electrical networks using a workstation at the lab (oscilloscope, function generator, power supply, and multimeter) and find circuits troubles and solutions to improve the circuit implementation time. This course involves ten laboratories covering topics from pure resistive circuits to RLC circuits analysis and applications. The Electric Circuits theory is offered in a sequence of two lectures, and the Circuits Lab is a single-semester course taken in parallel with the second circuits course.

Due to the pandemic period for COVID-19, all courses at UTEP were migrated to virtual format using both synchronous and asynchronous modalities depending on the lab activities.

Each lab is divided into four activities:

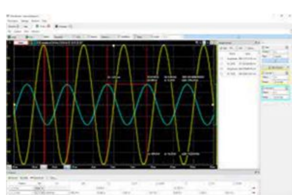
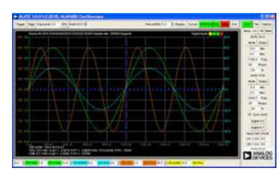
1- Prelab: This section includes all the mathematical calculations required to obtain the appropriate circuit result. Students are expected to be able to solve this section on their own. The student needs to read and understand the lab topic from the textbook or academic literature in this step. The lab theory topics were explained in the separate lectures.
2- Simulation: In this stage, students simulate the circuits using Multisim® (from National Instruments) and compare their calculations with the simulation results. Prelab and simulation activities were delivered in asynchronous mode. (Constructive learning mode)

3- Implementation: In this section, students implement the circuits in the breadboard and compare their results with the previous simulations. These lab sessions were taught in a synchronous modality where students were provided with supplemental methodologies related to the current laboratory. During the synchronous session, the instructor created "virtual teams" through breakout rooms where students and the professor interacted virtually with questions and specific activities according to the lab topic, motivating the active and interactive learning strategies. (Active and Interactive Learning modes)

4- Lab report: The last activity for each lab is the final report, where each student writes their readings, analysis of the results, conclusions, and additional thoughts collected during the lab session. This section was given in asynchronous modality (Constructive learning modality).

The most critical challenge in this laboratory during the COVID-19 crisis was getting specialized portable equipment (for use at home) to take measurements from the circuits implemented for the students and provide the electrical signal for the correct circuit function. Some available instruments used for the laboratory were Analog Discovery (from Digilent) and ADALM2000/1000 (from Analog Devices). Table 2 presents the three options used for the circuits Lab [11].

Table 2. Portable Equipment options for Circuits Lab [11],[14],[15]

Manufacturer	**Digilent**	**Analog Devices**	
Equipment	 Analog Discovery [14]	 Adalm2000 [15]	 Adalm1000 [15]
Software	 Waveforms [14]	 Scopy [15]	 Alice/Pixel pulse [15]

The LMS platform used for delivering the circuits laboratory was Blackboard Ultra®, where course content, activities, and support material were provided at the beginning of each semester, and grades were supplied on time. Also, students could attend the laboratory sessions in synchronous mode according to the schedule provided by the university. Students worked individually from home, built the circuits on the breadboard following the handout provided on Blackboard, took the measurements, and compared them with the calculations and simulation created on Multisim®. This approach is like the method described by (Berry, 2015) [16], with different components and instruments.

According to these observations, the ECE Department decided to include some of these virtual characteristics in the face-to-face course session. Since Fall 2021, the circuits lab content has been delivered on the Blackboard platform, including grades, assignment submissions, students' announcements, and notifications. Also, the course dynamics changed as follows. Students work at home on the calculations, simulation, and implementation of the circuits. Then, they bring their circuits (already tested with the portable equipment) to the lab session, connect the standalone equipment from the physical laboratory to the circuits, take the measurements, and compare the readings with the previous work.

Using this method, the students spent less time in the laboratory, applying constructive learning activities to understand the course topics. Such as developing the abilities to wire circuits, troubleshooting circuit issues, and improving their circuit analysis skills by comparing the theoretical section with the practice section themselves. Also, they can compare the equipment responses between portable equipment and bench instruments. Table 3 shows the circuits lab process comparison for the Face-to-face and virtual sessions during the COVID-19 pandemic, the post-pandemic, against the pre-pandemic modality.

Discussion

Because of the worldwide pandemic, universities moved the traditional teaching delivery mode entirely online. In the ECE department at UTEP, theoretical courses and laboratories changed to an online method. The teaching team from the circuits' laboratory created a teaching methodology to help the students understand the circuits' analysis and behavior. After this period, UTEP determined to move the virtual mode to an in-person modality applying the lesson learned on the COVID-19 crisis increasing the students' knowledge and the course quality. The topics covered during the lab sessions are:

Lab 1: Wheatstone bridge

Lab 2: Sources transformation and Delta to WYE conversion

Lab 3: Introduction to Oscilloscope and function generators

Lab 4: Operational amplifiers

Lab 5: RLC circuits – Sinusoidal steady-state analysis

Lab 6: RL circuits – Steady-state power analysis

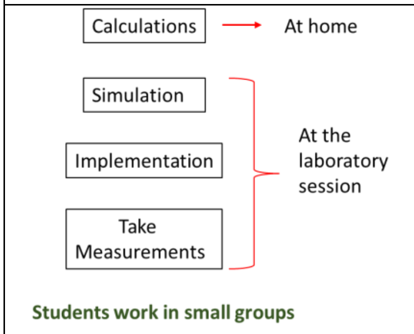
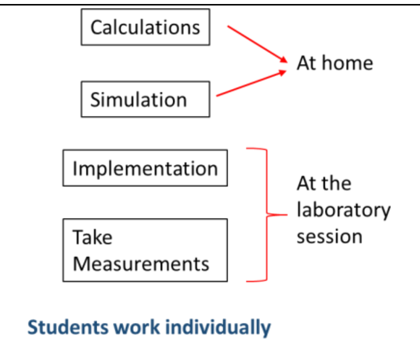
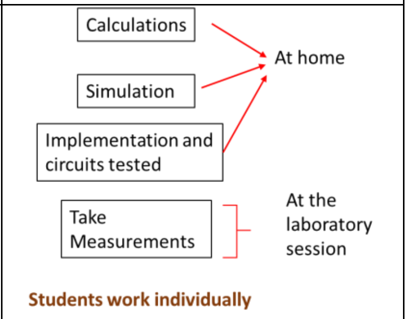
Lab 7: RL and RC circuits – Natural response

Lab 8: RLC circuits – Second order

Lab 9: Frequency response and filters

Lab 10: Final project.

Table 3. Circuits Lab process comparison pre-pandemic, post-pandemic, and during the pandemic.

Face-to-face sessions before COVID-19 crisis	**Virtual sessions during COVID-19 crisis**	**Face-to-face session after COVID-19 crisis**
		
Notes: -Course content was delivered via email or print on paper. -Grades were posted in the middle and at the end of the semester. -Tutoring hours were fixed and in-person mode only. -Course work was submitted on paper at the beginning of the lab session.	**Notes:** -Course content was delivered via Blackboard. -Grades were posted at the end of each lab session on Blackboard. -Tutoring hours were fixed or by appointment via Blackboard (virtually). -Course work was submitted online.	**Notes**: -Course content was delivered via Blackboard. -Grades were posted at the end of each lab session on Blackboard. -Tutoring hours were fixed or by appointment via Blackboard (virtually) or in person. -Course work was submitted online

In-Person Lab sessions before the COVID-19 outbreak

Students worked at home on the lab calculations in the face-to-face lab modality before COVID-19. Then they came to the lab session, where the instructor divided the class into small teams (2 or 3 people per group). Students worked on the assigned handout, simulation programming, and circuit implementation. In these sessions, instructors observed that only a few students understood the course topics and developed the ability to wire circuits and troubleshoot the problems. In contrast, the remaining students just collected the measurement results for the lab report. That typically means one student per group worked on the demonstration part while the others waited until the circuit was ready to take the measurements. Many students needed the instructor's help throughout all the sessions to check and fix the components and devices' connections, and they did not develop troubleshooting skills or wiring abilities. Almost 80% of the students required help in resolving their circuits. We estimate the average time spent by the students at the lab was approximately three hours, and the passing rate average was 91% based on the group work and not on the individual performance at the lab.

Virtual Lab Sessions during the COVID-19 crisis

Students worked individually in the virtual lab sessions at home on the calculations, simulation, implementation, and final report. They learned by themselves (with instruction tutoring) how to use and wire the electronic components and devices, get the measurements from the circuits, and analyze the circuit's behavior while developing their troubleshooting methods. These skills were developed in sessions 1 to 4 and made the lab work more efficient and more manageable, decreasing the implementation time by 30% for the remaining sessions (we estimate average 60-minute savings). The demonstration part took a maximum of two hours, and the approval rate was 88%. This data was collected via Blackboard. This LMS system generates assistance reports for each lab and tutoring session.

Because of the structure of online delivery, approximately 40% of the students needed instructor support to find problems and fix the circuit implementation. The instructor observed and reported the interaction, estimating that 60% of the students became self-sufficient in executing the lab tasks independently, compared to only 20% before.

Face to face lab sessions after the COVID-19 crisis

In Fall 2021, UTEP decided to return the virtual course's sessions to in-person sessions, and the circuits lab was not the exception. Due to the experience gained with virtual sessions, the instructors decided to incorporate some activities and methods developed during the pandemic time into the face-to-face circuits' lab sessions, such as:

- Course content and grades are delivered on Blackboard
- Students work individually in their own circuits and designs.
- Students work on calculations, simulations, and implementation parts at home and come to the lab session for circuit demonstration.
- Students keep working with portable equipment at home to check the operation of the circuits (portable equipment is available to borrow at the university facilities).
- Tutoring is available virtually and in person.
- Calculations and final reports are submitted via Blackboard.

Each student is assigned to an individual workstation at the physical lab, where circuits can be connected to the power supply, oscilloscope, multimeter, and wave generator to demonstrate the circuit function. Students developed the ability to connect components and devices in labs 1, 2, and 3. In lab 4, they acquired the ability to troubleshoot the circuits' failures. The Constructive Learning approach prepared the students to be more self-sufficient for the subsequent labs. In general, students' engagement now is higher than during the virtual mode, as they prefer handling more physical equipment and having closer interaction with their classmates. They also became more interested in how they could apply the topics learned in the theoretical course. The passing rate increased with this method, according to fig.1, and the estimated time spent at the lab was reduced by 33% (1-hour average) because students tested and fixed the circuits at home using portable equipment. Less than 20% of the students needed instructor assistance finding circuit failures. Fig. 1 presents the approval and failure rate (lab modules throughout the semester) for virtual sessions during the pandemic and in-person sessions for post-pandemic time. The 10th session is the final project, and the challenge level combined with the available time affected the performance. Fig. 2 shows the time spent at the physical lab and fig. 3 represents the percentage of students who required support from the instructor to fix the circuits. The data was collected by observation, and instructor reports, from the in-person sessions, before and after COVID-19. That includes the average time spent at the lab and the interaction between instructor and students.

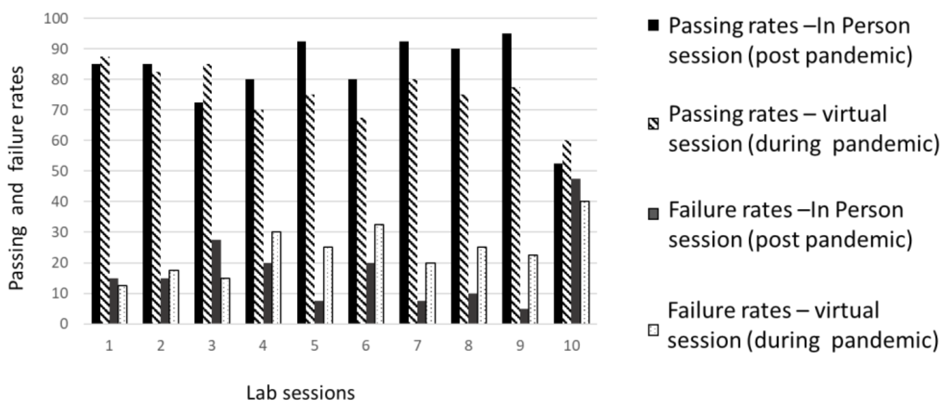


Figure 1. Passing and failure rates for Virtual sessions (during the pandemic) and in-person sessions after the COVID-19 outbreak.

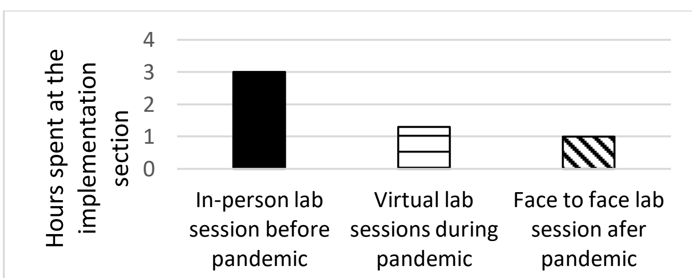


Figure 2. Hours at the implementation section for virtual sessions (during the pandemic) and in-person sessions before and after the COVID-19 outbreak.

A survey was conducted to obtain students' perceptions of the delivery modes in virtual mode labs during the pandemic and in-person sessions after the pandemic. This survey was applied to the current circuits' students. They compared the current circuits lab with another lab delivered online (such as Introduction to Electrical Engineering and Digital Systems Design). Table 4 shows the results. Columns 2 and 3 (Online Session and In-person sessions) represent the percentage of the student's agreement with the statement.

According to table 4, students prefer face-to-face lab sessions over virtual mode. The reasons are the lack of interaction and feedback between students and professors and the inability to ask and answer questions immediately related to the topic. Also, activities were not clearly explained in the online sessions generating confusion. On the other hand, face-to-face sessions are clear to understand, tutor engagement and feedback are immediate, and instructions are explicit in the classroom. Students agree with the benefits of Blackboard course structure and grade feedback because course notes, content, and announcements are more organized and understandable.

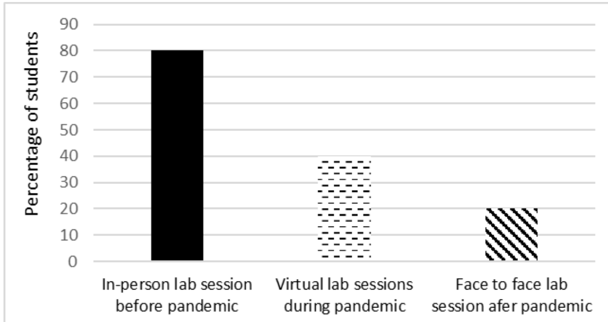


Figure 3. The percentage of students demanded support during the implementation section for virtual sessions (during the pandemic) and in-person sessions before and after the COVID-19 outbreak.

Table 4. Survey results for circuits lab

Statement	**Online Sessions**	**In-Person Sessions**
Lab sessions preference	20%	80%
Course structure in Blackboard is easy to understand either in-person or virtual mode	100%	100%
Tutor* engagement	60%	100%
Tutor* Feedback	50%	100%
Activities clearly explained	53%	100%

*Tutor is the Teaching Assistant

Conclusions

To summarize, LMS platforms such as Blackboard, as an essential part of the laboratory, provide a strong course structure because the course content is available anywhere, anytime. The use of assignments such as prelab, simulation, implementation, and lab reports allows work standardization. It provides guidance and transparency to complete the lab tasks in form and on time. Also, students can submit their lab work on the platform avoiding extra-cost for printing documents and losing time in the process.

The individual work methodology created during the COVID-19 outbreak, and migrated into the in-person lab sessions, helps the students to increase their learning level conducting experiments, enabling future participation in other classes and research projects. In addition, this mode makes the instructor operate as a moderator rather than as a lecturer, improving the collaborative work between students. In other words, students share their lab experiences and troubleshooting experiences with their peers, increasing their knowledge of circuit topics. Using the portable equipment at home helps the students understand the circuits' operations, failures, and expected responses. According to Fig 2 and 3, students spent less time at the physical lab at the university facilities because they are focused on connecting and interpreting the results obtained from the standalone equipment instead of figuring out how to troubleshoot the circuits. In addition, students prefer in-person sessions because of the tutor (TA) engagement and feedback, as stated in Table 4.

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