Work in Progress: Using Virtual Reality Technology for Remote Students and Students with Disabilities in an Electrical Engineering Lab

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***Abstract*—This Innovative Practice Work in Progress presents a step toward using virtual reality technology in the undergraduate electrical engineering classroom to offer remote students and students with disabilities access to 'hands-on' engineering labs. In this paper, we describe the VR pilot labs created for our freshman-level electronic circuits course and present initial feedback from students concerning the effectiveness of the VR environment for learning their way around a basic electronic circuits laboratory.**

Keywords—Virtual Reality, inclusive classroom

I. Introduction

The COVID-19 pandemic forced virtually all education into a state of "Emergency Remote Teaching." Faculty had to quickly come up with ways to deliver their course content in a virtual setting, which was possible for some course content (such as lecture material and computer simulations), but difficult or impossible for other course content (such as lab material that required specialized equipment). As a result, faculty were forced to come up with creative solutions to replicate lab environments at home, either by having students buy inexpensive lab equipment for themselves or having students watch video demos of someone working in a lab rather than working in a lab themselves.

In our freshman-level electronic circuits course, we asked students to purchase their own soldering kits, breadboards, digital multimeters, and electronic parts kits so that they could build circuits and test them at home. However, we were not able to give students the experience of operating benchtop digital multimeters, power supplies, function generators, and oscilloscopes - lab equipment used in standard electrical engineering laboratories. Although lower-cost options for benchtop equipment exist (e.g. Analog Discovery for $400), they are still too expensive to require each student to purchase and do not fully replicate the equipment found in common electrical engineering labs. In addition, we found it very difficult to help students troubleshoot their breadboards and printed circuit boards by looking at their circuits over streaming video. Other solutions to the same remote laboratory experience, explored by our peers, required students to perform SPICE simulations of their circuits and then watch YouTube videos of the Professor conducting the experiment in the lab. This solution too did not give students the experience of operating benchtop digital multimeters, function generators, and oscilloscopes. In general, neither of these 'virtual' options gave students the experience of being inside an electrical engineering laboratory denying them the opportunity to develop muscle memory for performing basic lab equipment operations.

Although at the time of this writing, students are back to working inside a physical laboratory, and our need for emergency remote teaching no longer exists, it is still worthwhile to consider how to offer a better introductory electrical engineering laboratory experience for those who cannot be physically present in a laboratory (such as students in an online degree program, students with some temporary or permanent disabilities, or students who missed a lab due to illness or other excusable absence). This paper contributes to the innovative practice of engineering education as it looks at using Virtual Reality (VR) technology to give remote and/or disabled students an accessible 'hands-on' virtual electrical engineering laboratory experience.

This paper is organized as follows: In Section II we describe related work of efforts to use virtual reality technology in education. In Section III, we present a description of the virtual reality labs we developed for our freshman-level electronic circuits course, highlighting 'accessible' elements we put into them to help support students with disabilities. In section IV we present initial feedback from students concerning the effectiveness of the VR environment for learning their way around a basic electronic circuits laboratory. We conclude with a discussion of future work in Section V. Although our initial testing indicated more work is needed to improve our virtual reality lab environment, the majority of the students who tried our initial labs found they could meet the same objectives as an in-person lab.

II. Related Word

Virtual Reality (VR) is an immersive experience that replaces a real-life environment with a simulated one. In a VR environment, a user typically wears a Head-Mounted Device (HMD) that provides non-contextually related environments, meaning that what is displayed in the device has no relation to the user's physical environment. The user also often wears something on their hands so they can pick up and touch objects in the virtual world. VR has most commonly been used in the gaming/entertainment industry, but has made its way into academic spaces to give students around the globe hands-on learning experiences at a comparatively minimal cost. Although many educators have been reluctant to adopt

VR in the classroom, the global COVID-19 pandemic highlighted its possible benefits. Studies showed that online courses may create a sense of isolation, especially for students [1] and environments that provide locational context and social interactions are important for student learning [2]. Thus, VR's ability to connect students and professors around the globe in a highly immersive and interactive format made educators see VR's potential.

One educational field where VR has grown is nursing. Nursing programs at Oxford use VR technology to learn how to interact with patients and make quick decisions during high-stress events. Nursing students also use VR to enhance skills training for operations such as catheter placement. The fine motor skills taught to nurses in these courses are highly common and essential procedures for any trained medical provider to know [3]. The most remarkable result from this trial and several other accounts is that the VR training had improved the student's ability to perform the operations and in some cases, the student was able to perform the procedure faster than the students in the physical setting.

Another notable application of VR in education is the Colorado School of Mine's simulated VR mine[4]. The simulated mine allows students the ability to get accustomed to identifying hazardous elements in high-stress environments, providing students the ability to think more quickly and clearly when faced with a similar situation in the physical world.

These examples clearly show that VR has a place in education. In a recent paper, Soliman et al. [5] concluded that the adoption of VR technology in Engineering Education could have many benefits, such as 1. reducing the cost that arises from investing in infrastructure and physical laboratory spaces and 2. playing a role in supporting the education of students with special needs. The same article concluded as well that institutions "that are early adopters [of VR technology] will have an edge and provide educational excellence and quality assurance to its students."

Thus our paper looks at using Virtual Reality technology in an introductory Electrical Engineering Lab to see if students can effectively learn how to build circuits and use benchtop lab equipment. An open-source platform, Short Circuit VR [6] had been developed with the intent of providing a virtual electrical engineering lab environment, but its developers discontinued its development. Thus, we developed our own virtual engineering laboratory [7] and used this environment to create a 5-week pilot lab that introduces students to building circuits on a breadboard and using common test equipment found in a beginning electric circuits laboratory course.

III. Our 5-Week Pilot Lab

We developed a 5-week pilot virtual laboratory experience for our freshman-level electronic circuits course that makes use of our homegrown virtual electric circuits laboratory (see Figure 1). In the physical classroom space, labs traditionally meet for 3 hours once a week, so we designed the virtual labs with that same time frame in mind. The overall goals of the virtual labs (like the in-person labs) are to guide students through essential electrical engineering theories such as Ohm's Law and Kirchoff's Current and Voltage Laws while introducing students to the operation of breadboards, power supplies, function generators, oscilloscopes, and bench-top multimeters through the design of simple circuits. Table 1 provides a description of each week's lab experiments.

Figure 1: Virtual Circuits Lab Environment

Table 1: Virtual Lab Weekly Experiments

LAB	**Description/Objective**
Lab 1	Student will learn how to use a multimeter to take Resistance, Voltage, and Current measurements on resistive circuits placed on a breadboard. They will then use these skills to verify Ohm's Law and Kirchhoff's Laws
Lab 2	Students will use skills obtained from the previous lab to study voltage division and loading effects with a motor and buzzer. Then, students will see these effects as they relate to a voltage follower and FET switch
Lab 3	Students will learn how to use an oscilloscope with auto and normal triggering. Additionally, students will learn basic operations for a function generator including the difference between High Z mode and 50Ω Mode
Lab 4	Students will use skills obtained from previous labs to design and simulate a circuit of their own making. Students will learn through this lab how to create a current source from an op-amp
Lab 5	Students will be introduced to an IC 4-bit DAC. In this lab, students will use the equipment in the lab to troubleshoot any problems encountered in designing the circuit

We paid particular attention to designing the VR lab environment to support remote students and students with some disabilities. The primary physical constraint we considered was to design a lab environment that could be navigated solely in a seated position. Some students may not be physically able to walk around a physical or virtual lab space and other students may just not have the physical room to walk around a large virtual environment (i.e. small dorm room). Thus the virtual lab features:

1. A laser pointer that allows students to point to and select things around the virtual space (Figure 2)
2. A teleportation feature that allows students to 'teleport' themselves and objects to different locations around the virtual lab so they do not have to physically get up and walk there

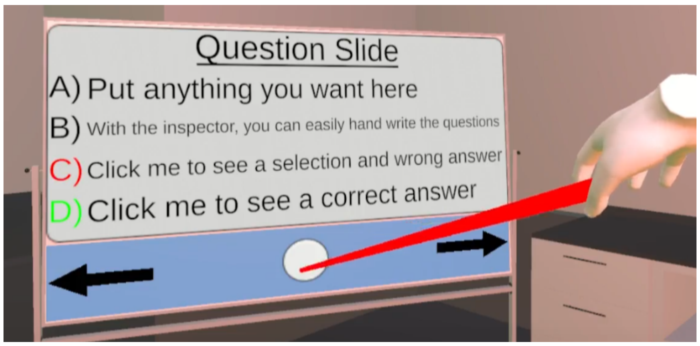

Figure 2 : Laser Pointer to Assist Student Reach

Another physical constraint we considered was fine motor skills. We designed the virtual breadboard and buttons on the benchtop lab equipment (Figure 3) to be large to allow for maneuverability around the board/equipment and precise component/button placement/selection.

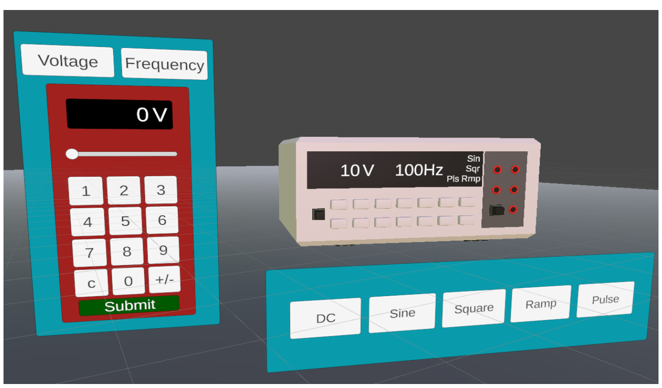

Figure 3: Function Generator Interface

To accommodate students with some mental disorders, we implemented gamified features such as interactable non-player characters (NPCs) (a raven and a wolf) and a comical warning system to alert users when they made a wiring mistake. We designed these features with the intent to increase the intrinsic motivation of the student while also lessening the severity of failure in the lab.

IV. FEEDBACK

To test our initial pilot labs, we recruited students who had already taken the in-person version of our introductory electronic circuits lab so they could comment on the virtual lab's ability to teach them the same skills as the in-person lab. Eleven electrical engineering students volunteered to participate in the pilot study. These students met once a week for five weeks to conduct the five pilot labs described in Table 1 (although the students were not able to complete the oscilloscope nor op-amp portions of the labs as these features were not completed before the pilot study). Not only were they asked to report on 'bugs' within the virtual environment, they were also asked to comment on the labs' abilities to teach them how to build resistive circuits and use standard benchtop test equipment. Below we present the list of questions we asked the students after completion of the lab:

Q1. Did you experience any motion sickness during your virtual lab sessions?

Q2. With the instructions given, were you able to complete the labs?

Q3. What were your impressions of
  a. the white board interface
  b. the bread board interface
  c. the multi-meter interface
  d. the power supply interface
  e. the function generator interface

Q4. Is there anything missing from the lab environment?

Q5. Were you able to complete the lab fully from a seated position? What did you think of the teleportation feature?

Q6. Did you enjoy the NPCs and the comical warning system?

Q7. After completing this lab do you feel like you are able to design resistive circuits on a breadboard and then take measurements with a multimeter?

Q8. After completing this lab, do you feel comfortable operating a function generator?

Q9. Did you face more, the same, or fewer hardships in the virtual lab as you did in the in-person lab?

Q10. Do you see the virtual lab as an effective alternative to the in-person lab environment given further improvements? (Yes/No)

All of the students reported they did not experience any motion sickness during any of the lab sessions (Q1) and were able to complete the labs with the instructions (Q2). They all reported favorable impressions (Q3) of the white board, digital multi-meter, power supply and function generator interfaces, but found the breadboard interface difficult to use because wires already placed on the breadboard would block the component or breadboard below those wires. In addition, due to the breadboard's large size, the user could not reach the opposite end of the breadboard without standing up. Furthermore, the breadboard incorrectly allowed for more than one component per perforation. To make the breadboard easier to use, we reduced its size, fixed the multi-component error, and replaced the solid wires inserted into the breadboard with translucent wires (Figure 4). We also implemented visual indicators to show where each end of a wire is when selected by the user.

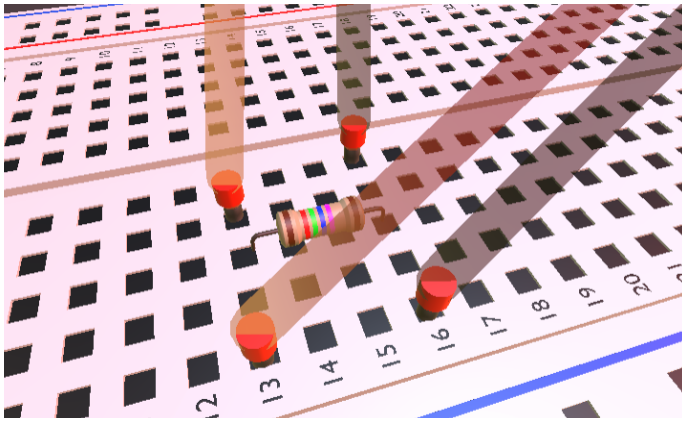

Figure 4: Translucent Wire Adjustment

The only things students reported missing from the lab environment (Q4) were the Professor and other students. In the next section, we mention that adding a multi-user capability to allow for professor-student and student-student interactions is on our list of future improvements.

Aside from the large size of the breadboard requiring students to stand up to reach the other side, all students agreed they could complete the labs from a seated position (Q5). However, some students (2) commented they did not like the teleporting feature and actually found it intrusive to their immersive experience. They had wished they could have walked to, rather than teleported to, some locations in the room. These comments helped us realize that accessibility features need to be customizable so that users can turn them on or off as desired.

All students reported appreciating the comical warning system and two students specifically mentioned they found the wolf's howl amusing (Q6).

All students reported that after completing the 5-week lab session, they felt comfortable with designing resistive circuits on breadboards and using benchtop power supplies, multi-meters and function generators (Q7, Q8).

In terms of hardships experienced by the students (Q9), 66.8% of the students experienced the same number or fewer hardships than they did in the in-person lab. Hardships were defined as any obstacles that occurred during the lab that would have prevented the student from completing the lab. Most of the hardships encountered were due to the breadboard interface as previously described, so with the interface improved, perhaps more students would find this lab to have the same or fewer obstacles to overcome compared to an in-person lab. Our goal is to ensure the virtual lab does not add additional impediments to learning over its in-person counterpart.

Most importantly, all students saw the virtual lab as an effective alternative to the in-person lab environment given further improvements (Q10). Thus our pilot study gave us confidence to continue our efforts to build a full introductory electrical engineering virtual lab experience.

V. Discussion

We recognize that there is much work to be done before we can fully launch our virtual reality electric circuit labs in lieu of our in-person labs, hence why this is a work in progress. We were encouraged by the initial outcomes of our pilot study and therefore see the potential for using this technology, especially to support our remote students and students with disabilities. Our future work involves

1. Finishing up the development of the virtual lab features (oscilloscope and op-amp)
2. Adding features to support multi-users so students can work with lab partners and their professors in the virtual lab environment
3. Adding additional features to support more assistive technologies (text to speech, font magnification, color-blind filters, etc.) and making these features customizable for the user
4. Conducting another pilot study aimed at users who identify as having disabilities and making modifications based on these users' feedback
5. Running the virtual lab with students who have not taken an in-person circuits course and then asking those students to build a circuit in the in-person lab to see how transferable the skills from the virtual environment are to the real world.

We believe virtual reality devices have a chance to change our educational landscape and provide our students with better hands-on and social experiences than previously before. For remote students and students with disabilities, VR technology has the chance to be life-changing technology affording them experiences previously impossible before by bringing the lab to their own home.

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