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APPLIED RESEARCH

Real Time Virtual Laboratory Solution Prototype and Evaluation for Online Engineering Degree Programs

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ABSTRACT One of the challenges of online engineering education is to provide students with hands-on laboratory experiences that require being in an on-campus laboratory. Virtual laboratory technical solutions have been developed over the last decade to allow learners to simulate engineering systems online or to connect to predesigned system modules within physical laboratories. However, these predesigned solutions must be acquired as software and hardware components that require a certain budget and training time before they can be used. In addition, these solutions do not concentrate on the construction portion of the systems under experimentation, but rather on testing the predesigned module using a virtual application that connects to it. In this paper, we developed a solution that enables online learners to build virtual systems, step-by-step, at their ends and connect them to real-time on-campus labs to perform remote experimentations with logic gates systems. We used a combination of technologies, such as Virtual Networking Computing (VNC) technology, Video Conferencing (VC) technology, and Object Oriented Programming (OOP). Our solution was practically proven using Python programming running on a Raspberry PI system to construct sample examples of virtual logic gates applications. This allows online students to concentrate on constructing, step-by-step, logic gate systems remotely, and to control actual physical logic gate systems within an on-campus lab with the help of a webcam. Our solution was tested by a group of learners and was proven to be a cost-effective alternative to traditional laboratory experiences.

INDEX TERMS Online education, engineering program, experiential learning, virtual laboratory, virtual systems construction, simulation, cost-effective, real-time interaction, customizable simulations.

I. INTRODUCTION

A. EXPERIENTIAL LEARNING

Experiential Learning is a powerful approach for learning, development, and change. This theory was proposed by psychologist David Kolb, who was influenced by the work of other theorists, including John Dewey, Kurt Lewin, and Jean Piaget. This emphasizes the importance of experience and its role in the learning process [1], [2]. The Institute for Experiential Learning describes it as a proactive approach to career readiness that develops students' professionalism and core competencies they need, in addition to the theoretical knowledge they gain in their degree program. Universities such as the UGA College of Engineering and Northeastern University Graduate School of Engineering have implemented experiential learning programs to give students first-hand opportunities to connect academic foundations to the world beyond the classroom [3].

Experiential Learning offers an array of benefits that can contribute to education. Some of these benefits include the following.

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1) A BETTER GRASP OF CONCEPTS

Through experiential learning, an opportunity is provided to apply ideas and data in a real-world setting, where the learner will play an active role [4].

2) CREATIVE OPPORTUNITIES

Learning through experience is one of the best ways to learn creative problem-solving [5].

3) OPPORTUNITIES TO REFLECT

Learners can reflect on their actions and how the outcome may vary from their peers [2], [4].

4) REAL-WORLD RELEVANCE

Students may tune lectures if they think that the material does not pertain to the real world. Experiential learning uses data and concepts and applies them to hands-on tasks, yielding real results [5].

B. ONLINE LEARNING ENVIRONMENT AND CHALLENGES

Online Learning Environments (OLEs) have become increasingly popular and are available to learners in all areas of education. These environments provide students with the flexibility to learn at their own pace and on their own schedule. Virtual learning can occur either in a self-paced (asynchronous) or real-time (synchronous) environment. The use of technologies, such as Virtual Networking Computing (VNC) and Video Conferencing (VC), allows for real-time interaction and collaboration between students and instructors. Online learning can also help students practice their IT skills, which are becoming increasingly important in today's digital world. Online learning can also improve students' attention and engagement when using interactive educational games. According to [6], cognitive, social, and teaching presence are significant factors in learners obtaining high-level outcomes using OLEs. The study also showed a higher student post-test success based on the noted factors. An additional study further noted the importance of online learners being just as valued as face-to-face learners from a communication frequency perspective. Instructor responsiveness is also a key factor in success [7]. Learner content interaction (LCI) and learner instructor interaction (LII) were also identified as primary factors in [8]. In recent years, OLEs have been shown to be effective in teaching student programming. Roshni and Choon observed that interaction through peer reviews in an online programming environment is beneficial for student learning. Students are better prepared to learn and apply programming in their learning and career fields [9]. However, there are challenges associated with online learning, such as the need for reliable technology and family support.

Specifically, online engineering programs can be challenging for students, particularly for those with math and science difficulties. These programs traditionally include rigorous study requirements and are content-centered, hands-on, and design-oriented [10]. The greatest challenges usually arise in the early years of a program. Some of the most common challenges that undergraduate students face during online classes include technical issues, distractions, time management, motivation, understanding course expectations, lack of in-person interaction, and adapting to unfamiliar technology [11]. Technical issues can arise when learners in various locations use devices with different operating systems or when there is limited internet access or bandwidth. Distractions and time management can be a challenge when students learn from home and must balance their studies with other responsibilities. Staying motivated can be difficult when students feel isolated and demotivated because of the lack of in-person interaction. Understanding course expectations can be challenging when students rely solely on online communication with instructors. Adapting to unfamiliar technology can also be a challenge for students who do not use online learning platforms [12].

C. RELATED WORK

Rapid developments in communications technologies during the past two decades have allowed the development of virtual laboratory technical solutions that include engineering systems online simulations, or remote access to predesigned system modules within physical laboratories. One such technology is Virtual Network Computing (VNC), which is a graphical desktop-sharing system that uses a Remote Frame Buffer (RFB) protocol to remotely control another computer [13]. It transmits keyboard and mouse input from one computer to another, relaying graphical screen updates over a network. VNC is platform-independent and supports all modern operating systems. It is commonly used for remote technical support and accessing files on one's work-computer from one's home computer or vice versa [14]. VNC was originally developed as an open-source research project, and many modern derivatives are open-source under the GNU General Public License. Virtual networking shifts networking activities to software and enables communication between multiple computers, virtual machines (VMs), virtual servers, or other devices across different offices and data center locations [15]. A software application called a virtual switch or vSwitch controls and directs communication between an existing physical network and virtual parts of the network.

An example system that can be utilized for online learning for engineering students is the Raspberry PI, which can be used to enhance students' learning as it can improve students' understanding of learning materials by putting learned concepts into practice [16]. Various Raspberry PI kits are available to learners at reasonable prices [17], [18]. A pulse-view project was developed in [19] to display pulses/signals on a device with the help of a Raspberry PI system. A beginner robot project was implemented in [20]. An oscilloscope system using a Raspberry PI was developed in [21].

Various projects utilizing these technologies and/or additional software platforms, such as LABVIEW, were used to develop solutions for online remote labs. A solution for an online platform that can be used by learners for collaboration was described in [22]. A remote network laboratory that allows remote access to real devices was discussed in [23]. In [24], a solution was proposed that involves developing lab client functionality for an available application that can result in improved latency. A remote laboratory providing a safe way to deal with hazardous substances in the industry was described in [25]. A study that involves comparing physical and remote laboratory platforms was discussed in [26]. An integration project for creating a network of remote experimental laboratories in engineering fields was described in [27].

A study in [28] concentrated on identifying how a remote lab assignment based on active learning pedagogy in higher engineering education supports student engagement. Another study [29] described remote laboratories in general and showed an example of how remote laboratories can be utilized as an integral part of engineering education.

An FPGA case study used in a remote laboratory for online engineering education was presented in [30]. A project for virtual labs and remote labs was reported in [31] and showed an example of how remote laboratories can be utilized as an integral part of engineering education. In [32], virtual reality was examined for an existing engineering education remote laboratory. An open-source remote laboratory for practical learning that uses supervisory control and a data-acquisition platform programmed with Python was reported in [33]. The work presented in [34] is related to a web-based system aimed at teaching logic design concepts and practices for computer science and engineering students that was implemented using LabVIEW. This study also used a hardware system called ELVIS. In addition, this study includes several simulations of logic systems. In [35], a cloud-based remote laboratory for electronic engineering experiments is discussed, and in [36], the VISIR circuit module of the remote laboratory platform Labsland was used together with the video conferencing platform Zoom to simulate a real electrical circuit lab environment. This research studied students' perceptions and academic performance in online lab settings in comparison to previous physical labs. This study showed that while learners can work on the lab assignments at a personal pace in their own remote environment, the software used has a high learning curve and could be more user-friendly.

Our paper is distinguished from the previous research by the fact that it concentrates on teaching the learner a step-by-step approach on how to construct a real system, using real images, that is to be experimented with. The images are selected and moved by learners to construct a full functioning system that would then be enabled to communicate with the real physical design in an on-campus laboratory. Our proposed remote lab method is simple, has a very low learning curve, and is inexpensive compared to other available systems.

The remainder of this paper is organized as follows: Section II deals with the problem hypothesis and research question. Section III concentrates on our research methods and design. In Section IV, we provide the design results. Finally, Section V presents the conclusion.

II. PROBLEM, HYPOTHESIS AND RESEARCH QUESTION

A. PROBLEM

One of the challenges of online engineering education is to provide students with hands-on laboratory experiences that are essential for their learning and career development. There are available methods that require additional hardware to be implemented and have high learning curves.

B. HYPOTHESIS STATEMENT

Providing engineering online students with a learning methodology that is characterized as being simple to learn and easy to apply virtually can result in an efficient delivery of real lab experiences to online students, while lowering the cost and initial learning curve.

C. RESEARCH QUESTION

Our main research question is how a simple learning methodology, which is easy to learn and apply remotely, can provide real experiences to online learners while maintaining a low cost and an initial learning curve.

III. METHOD AND DESIGN

In this project, we investigated the possibility of creating a generalized virtual laboratory model that can be used in online engineering courses to provide real-time experiences to online engineering students. The model uses a simple methodology of learning, which concentrates on virtually constructing the system under experimentation and verifying that the construction is performed properly. The constructed system is then capable of communicating with a real system in an on-campus laboratory. The learner will be able to remotely control the real system through a virtual software application.

Our proposed simple learning methodology consists of experiment components that are listed for the online learner, instructions that are shown to provide step-by-step information about conducting the online experiment, and the experiment space where the listed components would be moved to during the construction of the system under experimentation.

To implement our suggested simple learning methodology, we propose a generalized virtual laboratory model that consists of virtual lab components that are provided within a virtual software application. The virtual software is run over a specialized microprocessor/controller system. The controller system can be accessed and controlled via a VNC system from any desktop, laptop, or smart phone system. Any system running a VNC can communicate with other learners by using a VC tool. A remote learner can access the VC application

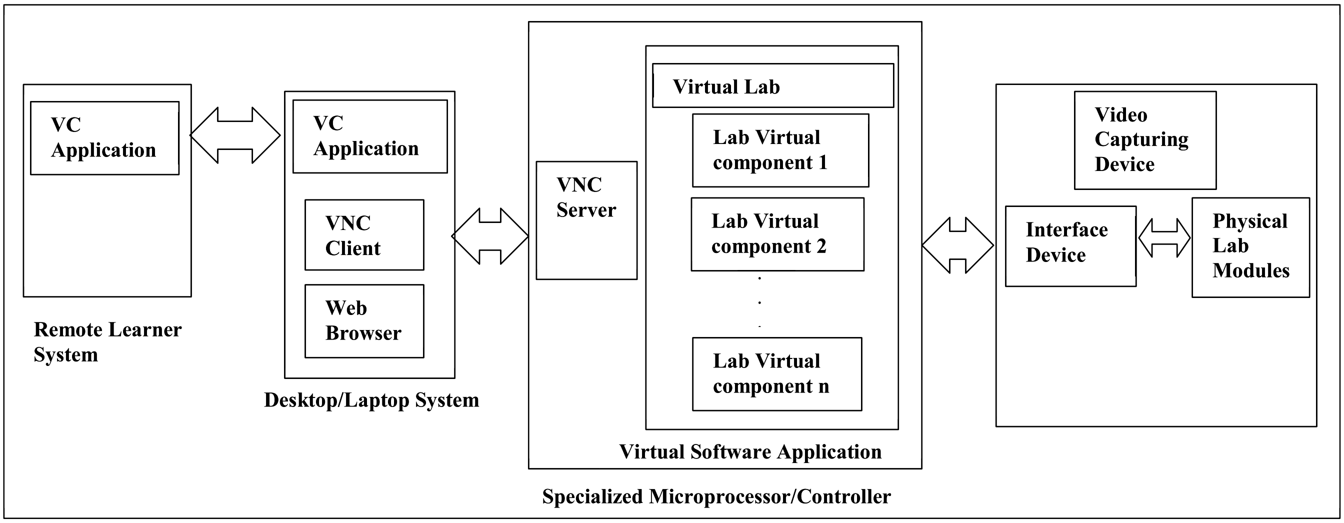

FIGURE 1. Virtual laboratory system generalized model components.

and request control of the virtual laboratory. Permission can be provided by the administrator at the lab or automatically, as specified by the administrator of the system running the VNC application.

The generalized model interacts with an actual laboratory system on the ground. Once an online learner virtually completes the required lab construction, the model sends an activation signal to the on-ground system to enable it to operate. The online student would then be able to apply input to the actual on-ground system and monitor the real-time results through proper technology. Figure 1 shows a diagram that illustrates the components of the generalized model of the virtual laboratory system.

To prove the concept of our generalized model utilizing our proposed simple method of learning, we selected a lab of logic gates design. We used a Raspberry PI kit system as our specialized microprocessor/controller system. This goal was achieved by designing two virtual labs. One lab is for the construction of an AND logic gate and the other one is for the construction of an OR logic gate. The physical component of this project was realized through an actual implemented logic design for an AND gate and an OR gate within an on-ground lab that are activated by the virtual components of the design. Our VC technology consisted of a live web camera which is connected to the Raspberry PI system kit and is used to transfer the video of the physical logic design and deliver it to an online web browser where it can be accessed and monitored.

A windows-based system is used to run a VNC client (VNCviewer) to connect to the Raspberry PI system which has an installed VNC server. The Raspberry PI is interfaced to design boards that have the physical AND, and OR logic gate systems, and to a web camera that captures the live video of the logic gates. A web browser is run on the windows-based system to display the live real time video being transferred from the lab camera. Zoom is also run to share the system with any learner who receives a Zoom link. Figure 2 shows the proposed design of the remote lab system.

The learner can access the virtual laboratory through a remote device with a VC application such as Zoom. The learner then would be constructing virtually and remotely the AND, and OR gates circuits by dragging components and placing them in their proper locations within the logic circuit design for each logic gate. When completed, the learner would be allowed to operate the corresponding circuits in an on-ground laboratory in real time while following the results of the operations through the video transferred by the lab webcam.

IV. EXPERIMENTS AND RESULTS

A. EXPERIMENT DESIGN

We developed an innovative software solution for the virtual portion of the project to realize our proposed simple learning methodology, where a student can access a Python running application for an AND logic, or an OR logic, or both and construct the required logic gates virtually.

Figure 3 shows the virtual design components for an AND, and an OR logic gate systems respectively. Those components are clickable and can be dragged by a mouse. Once learners access the virtual lab, they will be able to start the Python files for the AND, and OR logic gate systems. The student will then follow the displayed instructions for each system to correctly construct the required logic circuit.

We have ensured clarity for learners by showing them the steps that they need to follow to construct a working logic gate circuit. A learner selects the virtual components and places them in their appropriate locations in the logic design circuit. The learner can check the status of the circuit construction by using the “Test” button in the virtual software. When completed and tested by the learner, the system sends an activation signal to the corresponding physical logic gate

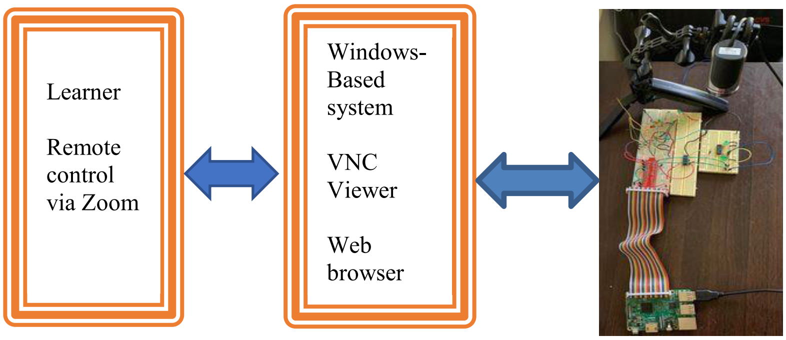

FIGURE 2. Windows-Based system connected to raspberry PI interfaced to design boards and a web camera.

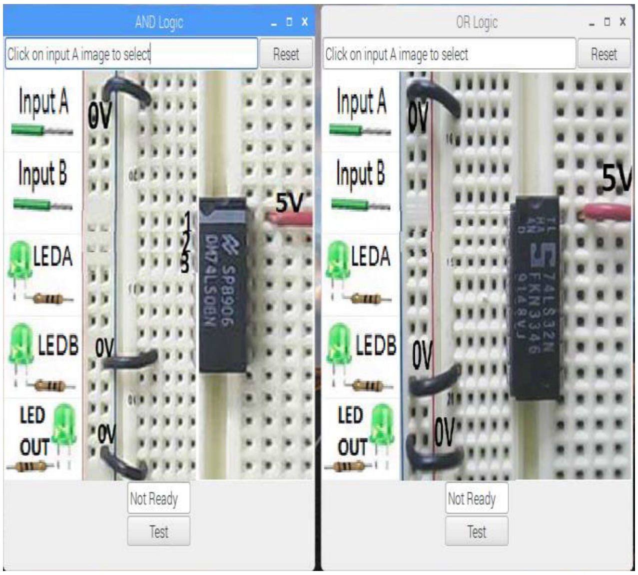

FIGURE 3. Virtual design components for an and, and an or logic gate systems.

system, allowing it to operate remotely. Inputs A and B are then enabled to pass from the Raspberry PI to each logic gate with a "ready" status.

The interfacing circuit is responsible for powering the AND, and the OR gates when the learner successfully completes the construction of the logic gate circuit virtually using the virtual application of the design.

It is also responsible for passing inputs A and B from the Raspberry PI to the logic gates circuits. Not gates are used as buffers to bring up the powering voltage to 5V.

They are also used to control Tristate switches to pass the input signals to the appropriate gates when any enable signal to power a logic gate is generated by the Raspberry PI. Figure 4 shows the interfacing circuit between the Raspberry PI kit system and the Logic Gates circuits.

Considering that the AND gate and the OR gate codes are stored in two separate Python files, and that each is used to control the same Raspberry PI and the same logic gates inputs, A and B, then the need for coordination (synchronization) between the two files arises. For example, if the AND gate code changes the A and B inputs to a certain binary combination, then the code controlling the OR gate should detect that and update its inputs to be consistent with the AND gate inputs. This is achieved by monitoring the levels of inputs A and B by the Raspberry PI and detecting any changes and making sure that the inputs of the logic gate with the non-initiating code for that change are updated as well.

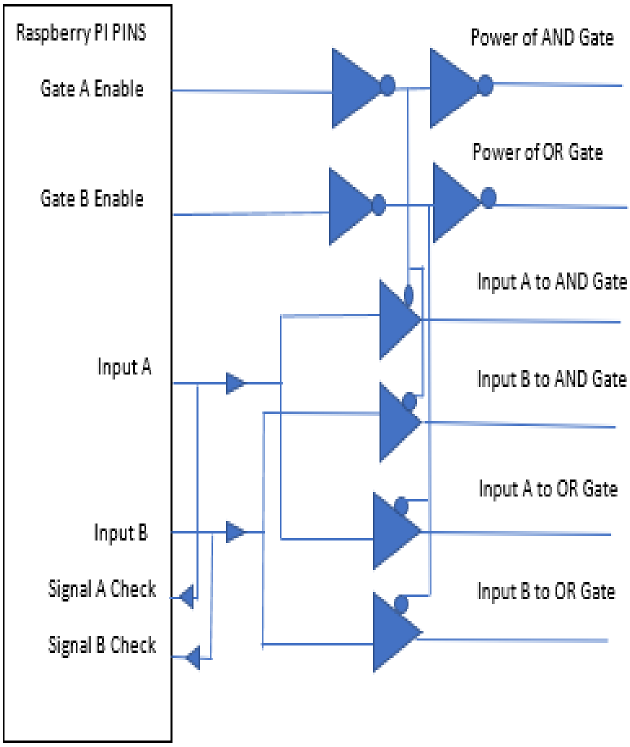

FIGURE 4. Raspberry PI pins and interface design to and, and or logic gates.

B. EXPERIMENT RESULTS

Python programming language was used to write two separate codes to simulate virtually the construction and operation of an AND, and an OR logic gate systems. The codes were run on a Raspberry PI kit system that is connected to a physical design of an AND, and an OR gate systems. A webcam was placed above the physical design to transmit real time video of the logic gates circuits. A VNC Server was installed on the Raspberry PI, and VNCviewer was installed on a windows-based system. The Raspberry PI system was accessed successfully from the windows-based system to run the two logic gate codes.

Zoom was also used to invite remote learners to participate in the learning experiment. A Zoom link was sent to 15 learners for the purpose of testing and operating the innovative design. Learners started Zoom successfully, each at a different time slot, and were able to request remote control of the host application (VNCviewer running on the windows-based system). The host was able to successfully grant permission to the learners. Learners were able to follow the step-by-step instructions provided by the virtual software to construct the logic gates remotely. The instructions were as follows:

- *Click on input A image to select*
- *Click on PIN 1 image to add input A*
- *Click on input B image to select*
- *Click on PIN 2 image to add input B*
- *Click on LED A image to select*
- *Click on PIN 1 image to add LED A*
- *Click on LED B image to select*
- *Click on PIN 2 image to add LED B*
- *Click on LED OUT image to select*
- *Click on PIN 3 image to add LED OUT*
- *Click on Test button*

Once a learner finished these steps then the status "Ready" was displayed indicating that the circuit in the on-ground laboratory is ready to be operated. The logic symbol of each logic gate was then visible, as shown in Figure 5, through the virtual design software. Learners were able to apply various patterns of binary inputs to the virtual logic gates symbols. Light emitting diodes (LEDs) in the on-campus lab were monitored by the learner (as shown in Figure 6. The image is captured by a webcam connected to the Raspberry PI and is transferred through the network to the device hosting the VNCviewer and the Zoom applications) and were compared to the status of the virtual LEDS within the virtual application. The virtual LEDs within the virtual software application operated in consistency with the physical LEDs in the lab proving the correct operation of the logic gates.

The integrated circuit used for the AND gate had the PIN numbers displayed by the virtual application. The PIN numbers for the OR gate were removed to stimulate learners to memorize where they are located. After each learner finished the experimentation, a 5-question survey was conducted to allow each learner to give feedback about his/her experience using the system. The surveys were collected and analyzed anonymously.

Each survey consisted of the following questions:

1. Are the instructions for building the logic gates clear?

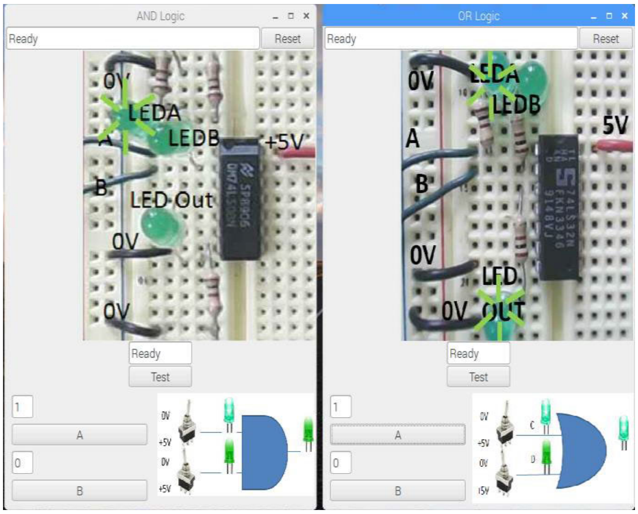

FIGURE 5. Logic gates with the status "Ready" to be operated.

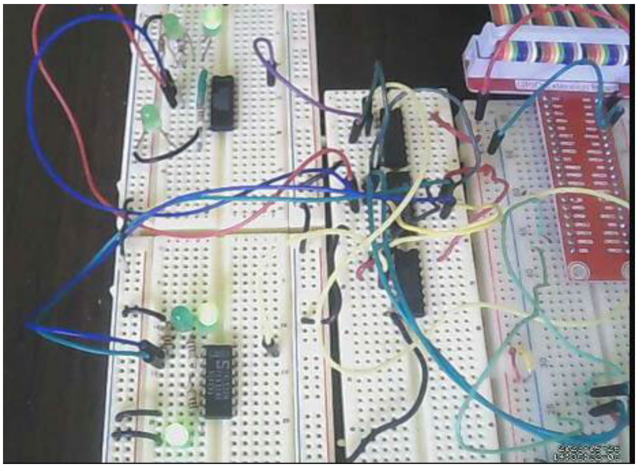

FIGURE 6. Physical lab design including raspberry PI, interfacing circuit, and logic gates.

2. Have you constructed the logic gates easily?

3. Was the time required to build each logic gate reasonable?

4. Was the operation of each logic gate easy?

5. Are you satisfied with the time needed to learn how to do the lab?

Each question has choices from 1 to 5, where 1 is very unsatisfied, 2 is unsatisfied, 3 is fair, 4 is satisfied and 5 is very satisfied.

Results show that about 93% of the learners are very satisfied related to the provided instructions for constructing the logic gates. With respect to the easiness of constructing the gates, about 86% of the learners were very satisfied, while about 14% had fair experience. When it comes to the time needed to construct the logic gates, 100% of the learners indicated that they were very satisfied. With respect to the operation of the logic gates, 80% of learners indicated that they were very satisfied, about 13% indicated that they were

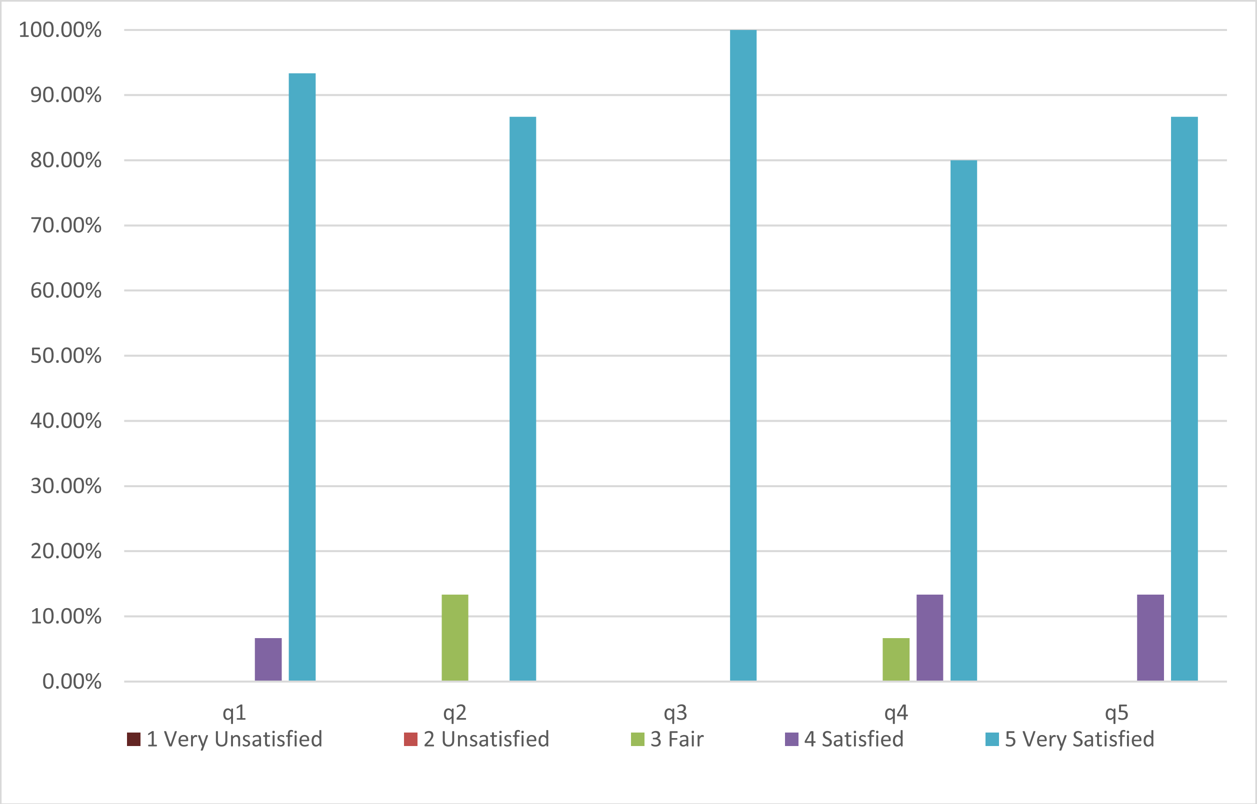

FIGURE 7. Logic gates remote lab survey results.

satisfied, while about 7% indicated they had a fair experience. Learners indicated that they were satisfied with the time needed to learn how to do the lab as about 87% indicated they were very satisfied, while 13% indicated they were satisfied. Figure 7 shows the results of the survey.

Results, in general, indicate that most of the learners had a satisfactory experience with the lab. On average it took a learner about 15 minutes to learn about how to use the lab and to construct the logic gates and operate them. This proves the low learning curve for our proposed learning methodology.

Some feedback notes were given that can explain the selection of "fair" by some learners, such as it would be easier to show PIN numbers for the OR gate integrated circuit as they were shown for the AND gate. In addition, it can be more difficult for those who tested the system using their smart phones to move the mouse to some exact locations to place selected components.

V. CONCLUSION

In this paper, we have proposed and implemented a methodology for constructing and operating a system remotely. For that purpose, we have proposed a generalized virtual laboratory model design and a prototype which provides a powerful and flexible solution for online engineering education. By utilizing Virtual Networking Computing (VNC) technology, Video Conferencing (VC) technology, and Object-Oriented programming (OOP), we proved, using a sample logic gates remote lab, that we can provide real lab experiences to learners remotely, while using a simple learning methodology to maintain a low learning curve, and achieve excellence with respect to learners' level of satisfaction.

Future research could focus on further developing and improving the virtual applications to include integrated circuits PIN numbers and to include more designs and engineering courses. In addition, research could be conducted to evaluate the effectiveness of this solution in comparison to traditional laboratory experiences, and to assess its impact on students' learning outcomes. Further research could also investigate the scalability of this solution and its potential for use in other fields of study beyond engineering education.

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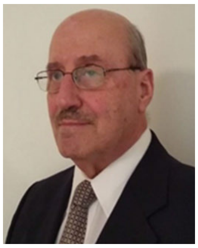

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