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Development of a virtual laboratory system for kirchoff's current and voltage laws

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Abstract
The contextual use of technology in engineering education has improved distance learning and collaborative learning with virtual labs and simulations. In the past, only students on campus could access laboratory equipment in traditional courses, but now online courses have it too. Implementing modelling and simulation can be a powerful tool for offering virtual laboratories to distance learners. This research work attempts to design a virtual lab system capable of carrying out experiments on Kirchoff's Voltage Law (KVL) and Kirchoff's Current Law (KCL). The power supply unit provided appropriate voltage levels (12 volts, 5 volts, 4.3 volts) that electricity could flow among components, using an embedded system coordinated with a measuring unit that is also connected to internet connectivity via the SIM900 Module. Measurement modules are linked to Microcontroller's ADC and send data collected by the module into the server on the GSM module that provides internet connectivity. Results from these sources are being compared and evaluated to validate obtained results generated by the developed system.

Keywords: Current, IoT, kirchoff, virtual laboratory and voltage

1. Introduction

The relentless increase in human knowledge and steady technological advancement call for continuous improvements of higher educational provisions, especially in engineering, to make the best use of the resources available and keep the student up to date academically. Modern online technologies provide rapid and inexpensive access to various novel, useful learning resources like vendor technical documentation and application notes, topical tutorials, forum discussions, educational videos and even massive open online courses (MOOC). E-learning uses recent technological developments to reduce educational costs and widen participation.

Distance education dates back to the end of the 19th century, and its evolution comes along with more meaningful advancements in technological development.

Virtual laboratories are computer-simulated laboratories that look like, operate, and produce results similar to real ones. A virtual laboratory is characterised by its versatility and flexibility because it is software based. Like traditional laboratories, virtual laboratories have several advantages and disadvantages. Overall, in many situations, the advantages of a virtual laboratory can outweigh the disadvantages, thus making it a feasible option. The lack of physical contact means there is little opportunity to discuss ideas or concepts that fall outside the simulation's range. In many cases, it seems as if the ideal solution, where possible, is to combine a virtual laboratory with traditional ones.

Virtual lab accommodates practical education with all limitations, like tools and materials of practical equipment in schools that are not in line with the current technology. Although virtual laboratories have been realised as a supporting tool in the learning process, their applications in vocational education have not been extensively explored. The learning characteristics of the vocational are a fairly large proportion of practical compared to theoretical activities. Several types of research have revealed that the latest developments of virtual labs are to gain insight into the various virtual laboratories that may be relevant to vocational education. This study employs a systematic literature review of selected research findings based on relevant keywords of the virtual lab in vocational education. Insights gained from the findings made and reviewed were subsequently developed to elaborate on using a virtual lab in vocational education. Practical learning in vocational education with a virtual lab becomes more flexible without limited space and time. In terms of financing, the development of a virtual lab does not require much investment compared to actual laboratory development.

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For a long implementation period, a basic learning process must be added. The user must first get experience-based learning that emphasises the role of active experience and student involvement.

The term Virtual Laboratory (VL) can be used in different ways. While some VLs perform computational simulations, others allow the conduction and the remote control of real experiments by the internet. This is the case in this research study. With the increasing number of things on the internet, providing integrated services resulting from communication amongst heterogeneous networks is gaining momentum. In the last half-century, electronics and communication technology advancements have enabled scientists to connect machinery with a computer system that can remotely operate over the internet. With the increasing internet users around the globe, many people work from home instead of going to office premises since it tends to save time and cost for both employer and employee. These technologies are also beneficial for students to perform experiments remotely instead of going into laboratories. In this way, students must not wait for the equipment time slot but must register for an online experiment slot according to their convenience. By registering, the system allocates a time slot to each user for experimenting.

Problem Statement
Due to physical contact restrictions occasioned by the outbreak of COVID-19, many institutions in developing countries have decided to introduce a virtual learning system. However, this does not include a practical class for most engineering students because some circuit components need to be physically connected. Hence, the need for this research work.

Aim & Objectives
This research work aims to design and implement a virtual laboratory system to experiment on Kirchoff's Voltage Law (KVL) and Kirchoff's Current Law (KCL). The specific objectives of the work are;
1. To design and implement a virtually enabled circuitry for both KVL and KCL
2. To design and implement a mobile-based application to enable the circuitry

Scope of study
The experimental part of this study is conducted at the department of Electrical and Electronics Engineering of Osun State University, Osogbo, Nigeria.

2. Virtual Laboratories
Virtual labs are simulated versions of conventional laboratories that adopt a learner-centred approach in which the student is given virtual representations of real-world things used in traditional laboratories. Virtual labs may help with teaching and learning by allowing students to learn by doing, presenting them with engaging and fun activities that encourage them to explore, and ensuring active classroom participation via discussions and debates (Lkhagva, Ulambayar, & Enkhtsetseg, 2012) [17]. By speeding up or slowing down time, virtual labs may allow students to study circumstances that are impossible to test in real-time (Aldrich, 2005) [3]. Advanced ideas like relativity and experimentation, which would not be researched or implemented in typical laboratory settings, also benefit from

them (Aldrich, 2005; Reese, 2013; Scheckler, 2003) [3, 24, 26]. Virtual labs give a visual context for various abstract subjects, impressive visualisation, and graphical analytic capabilities (Wieman & Perkins, 2005) [33].

Advantages of virtual labs
Virtual labs offer a solution to the limitations of traditional practical classes in STEM education by offering environments for students to interact with each other and use virtual objects and apparatus through a software interface connected to hardware in one centralised place. Since elementary education reforms have emphasised inquiry-based learning, virtual labs allow students to develop their reasoning, critical thinking, and innovative and creative skills without limited time, resources and space. They also enable inquiry-based learning while assisting in acquiring deep conceptual domain knowledge and inquiry skills.

Challenges faced by virtual labs
Virtual labs have the potential to revolutionise the teaching of STEM subjects, but gaps in their recognised potential and the actual applications still exist. Virtual labs have become under criticism for lack of real-life feel and for not teaching about health and safety to students. With augmented reality, sensorial devices, live videos, interactive videos and serious games, students can immerse into an incredibly life-like lab experience while maintaining all the benefits of a virtual lab. Avatars have also given virtual labs a new level of personalisation, allowing students to feel more comfortable interacting with other users and carrying out experiments themselves.

The virtual lab architecture
An analogy between the virtual design studios and virtual electrical engineering lab is based on the view that similar to the studios in the design field, electrical engineering laboratories, now equipped with extensive computing facilities, are a place where engineering professionals and students interact and discuss projects, conduct laboratory experiments, organise and structure the project data, transfer and share various representations, develop and publish project documentation. In all of these activities, information and communication can be handled electronically. Recent developments in virtual instrumentation and corresponding applications have shown that conventional experiments and engineering projects can be presented as active digital media, which includes custom-written virtual instrumentation.

The arrangement of the virtual lab comprises the following key issues
- Metaphor(s) and models for communication and collaboration in the environment; for representation and embodiment of human and software agents that assist the completion of the engineering tasks; for embodiment and representation of the virtual instruments in the collaborative environment.
- An agreement about the instrumentation support, information archiving and documentation sharing, including a central location for accessing the latest documentation of the experiments or project; a set of file formats for exchanging documents within the lab; a set of tools that model, draw, analyse, document the

circuits under investigation and simulation, using approved formats.

3. Methodology

This chapter discusses the techniques adopted to achieve the stated aim and objectives of the study. It explains step-by-step methods employed in the hardware and software interconnection to achieve the stated aim and objectives. The system design comprises the hardware and software, further discussed below.

Hardware Design

The hardware has three parts: the power supply, the embedded system, and the IoT unit. In order to complete the project, the power supply unit provided the appropriate voltage levels (12 volts, 5volts, and 4.3 volts). The core of this system is a control unit that comprises an embedded system and a measuring unit. As discussed in the previous chapter, Internet connectivity for the IoT gadget is provided via the SIM900 Module.

Measurement and Control unit

A microcontroller (ATMEGA 328P), a transistor array IC (ULN2003A), a hex inverter (74HC14), as discussed in chapter two, and discrete components make up this system. Measurement modules are linked to Microcontroller's ADC. The controller calculates and sends the measured value to the server using a GSM module, which enables internet connectivity.

The switches control unit consists of a 12V relay employed in the selection based on the required value of resistor and microcontroller I/O pins for corresponding pin selection. The microcontroller (ATMEGA 328P) is the heart of this project as it determines the necessary action based on the code. GSM Module provides internet support to the system. The system is powered by a 12V battery with battery management and charging system units. The microcontroller is powered with 5V from regulated power supply units. Relays are used to make connections in the resistor network and switch circuit shown in figure 1 below. The complete circuit diagram of the system is shown in figure 2 below.
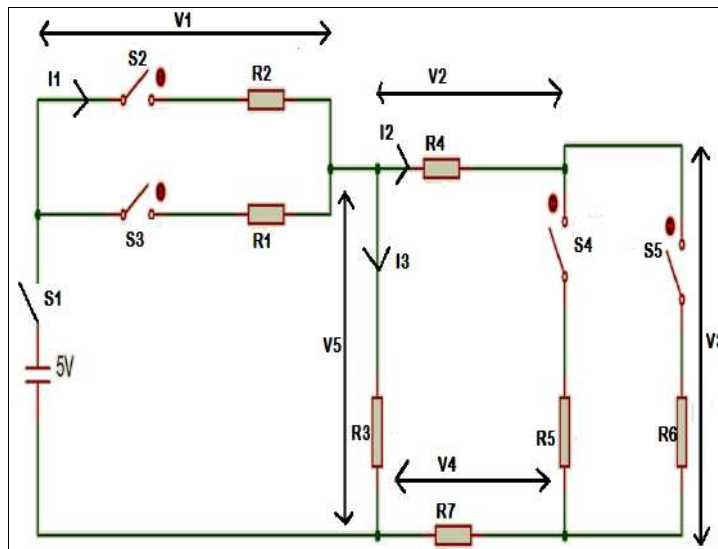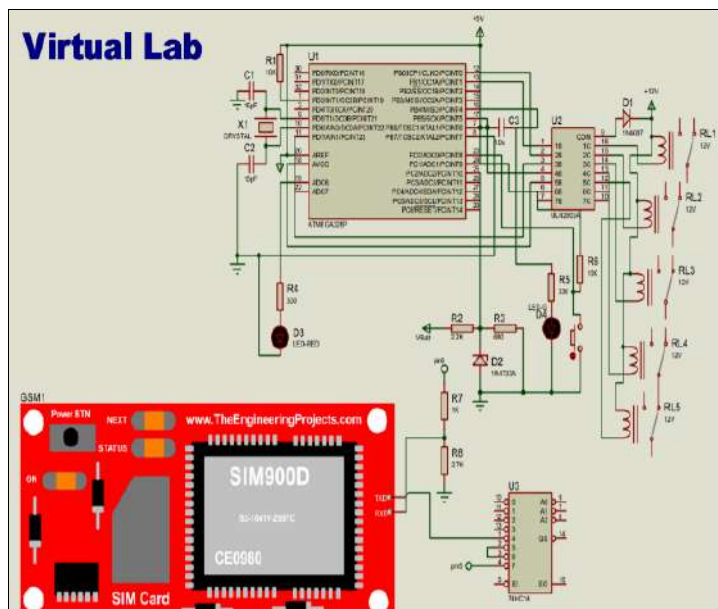

Fig 1: Resistor network and switch

Fig 2: Complete Circuit Diagram

System Architecture

The complete block diagram of the system architecture, as shown in figure 3.3 below, describes the architecture of the Virtual Laboratory experiment. Resistor network circuit/switch blocks are the resistors used for KVL and KCL circuit experiments. Current and Voltage measurement units are used to measure the instantaneous value of Current and Voltage from the experimental circuit board. The switches control unit consists of a 12v relay which is used to select the desired value of resistor and Microcontroller I/O pins for the experiment. The microcontroller serves as the heart of this project. It determines the necessary action to take place. GSM Module provides internet support to the system. The whole system is powered with a 12v Batter which includes a battery management unit and charging system. The microcontroller is powered with 5v from regulated power supply units.
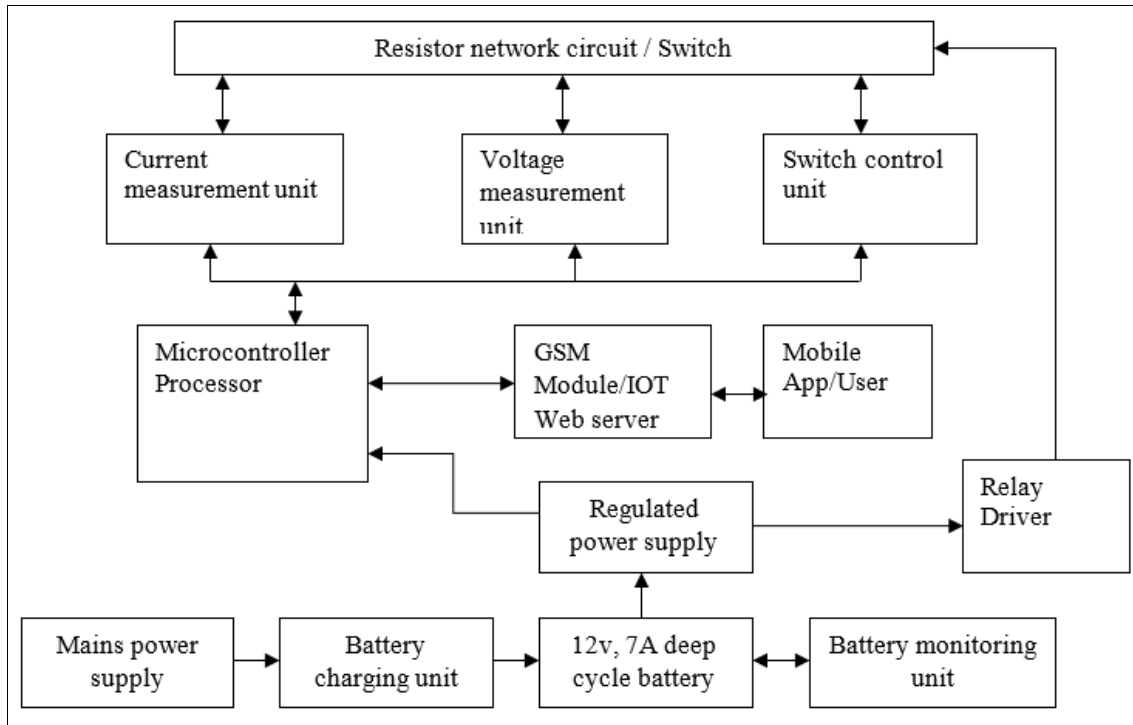

Fig 3: Block diagram of the system architecture

Possible circuit combination

The resistor network and switch circuit, as discussed in the previous section, has sixteen (16) possible combinations, as shown in table 1a; out of these combinations, only ten (10) possible combinations were considered, and this is shown in table 1b below.

Different switches can be combined to perform various operations on a circuit. Table 1a shows the various possible switch combinations. Also, among these combinations, some switches depend on others to work effectively while others can work independently; as a result, table 1b shows the possible switch combinations considered for this study.

Table 1a: Switch truth table.

S/N	S2	S3	S4	S5	Case	S2	S3	S4	S5
1	0	0	0	0	A	0	1	0	1
2	0	0	0	1	B	0	1	1	0
3	0	0	1	0	C	0	1	1	1
4	0	0	1	1	D	1	0	0	1
5	0	1	0	0	E	1	0	1	0
6	0	1	0	1	F	1	0	1	1
7	0	1	1	0	G	1	0	0	0
8	0	1	1	1	H	1	1	1	1
9	1	0	0	0	I	1	1	0	0
10	1	0	0	1	J	1	1	0	1
11	1	0	1	0					
12	1	0	1	1					
13	1	1	0	0					
14	1	1	0	1					
15	1	1	1	0					
16	1	1	1	1					

Table 1b: Possible Switch Combination

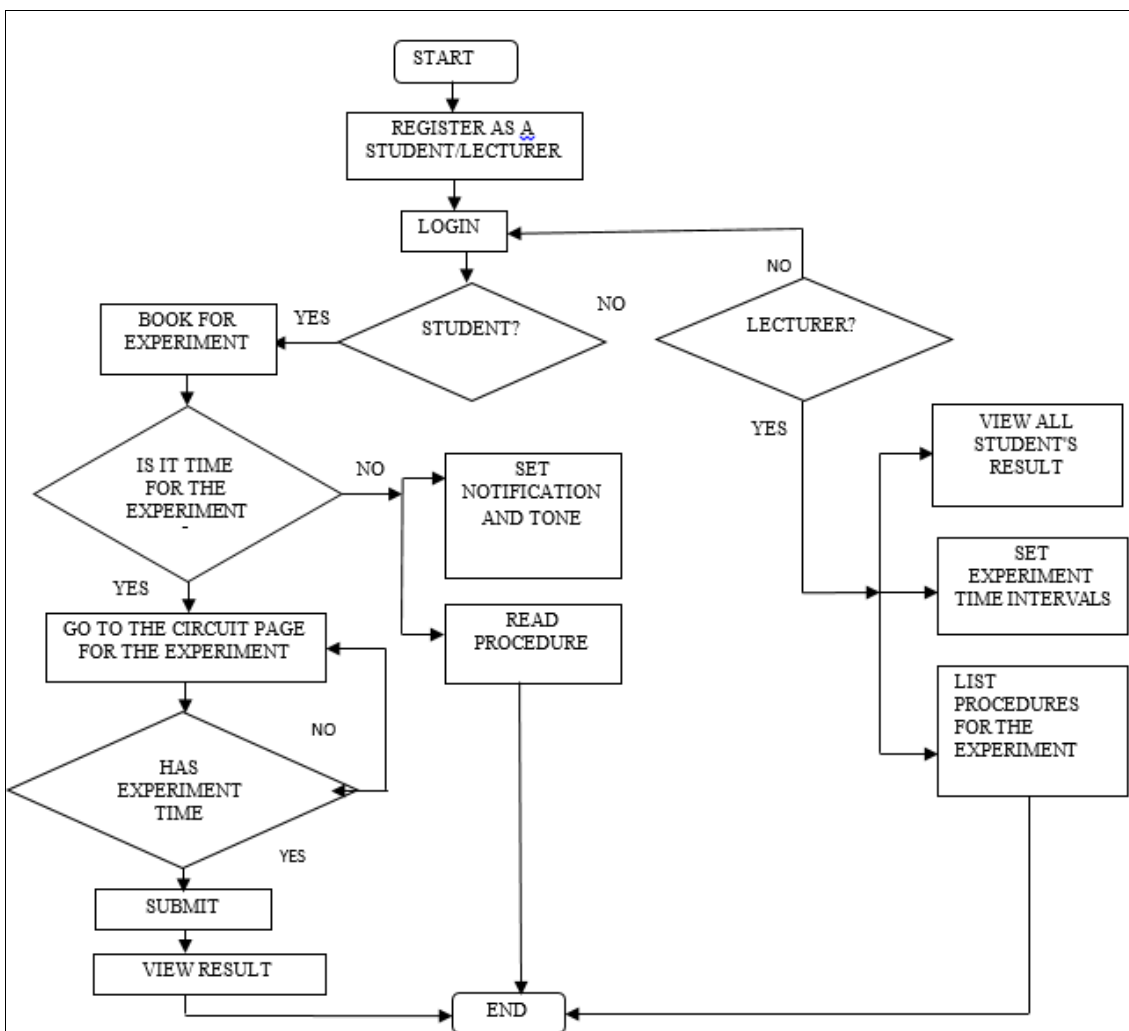| Case	S2	S3	S4	S5
A	0	1	0	1
B	0	1	1	0
C	0	1	1	1
D	1	0	0	1
E	1	0	1	0
F	1	0	1	1
G	1	0	0	0
H	1	1	1	1
I	1	1	0	0
J	1	1	0	1

Fig 4: Flowchart diagram of the system architecture

The flowchart above illustrates the flow of working processes of the developed mobile application, which allows students and instructors to apply for registration. Afterwards, registered users can log in to their profile as a student or an instructor.

Log in as a student would allow you to schedule and book an experiment time, read the instructions before heading to the circuit page, and view experimental results.

While login in as an instructor would allow for the ability to establish experiment time intervals, alter protocol, examine all the data in the experiment and view all student's experimental results.

4. Result and Discussion

This chapter discusses the outcome of the experimental procedure. The results obtained from different sources during the virtual, physical experiments and hand calculations are being compared and evaluated to validate obtained results for the developed system.

Some interface of Developed App

Figure 5 shows the login interface using the android application. The interface consists of email and passport; users can register through the mobile App.

Fig 5: User Login page

This page allows unregistered users to register and also allows registered ones to log in.

Figure 6 is the dashboard page. After successful login, the dashboard shows the experiment booking and the no experiment tab. It also shows the finished experiment by each student and the result.

Fig 6: Dashboard page (Student's and lecturer's dashboard)

Once a person has successfully signed in, the first page is typically shown.

This page provides information about the user, such as the results of the user's previous experiments, the time the user expects to spend in the laboratory, and the time the user intends to leave the laboratory. In addition, it allows the user to know whether the laboratory is open for use at the moment, has been booked/allocated to another user, or if it permits the user to advance for further experimentation.

Figure 7 shows the time Interval and procedure setting page. The procedures for each experiment were well analysed and explained. It also shows the start time and ends the time for the students. Furthermore, the student can make changes to each experiment
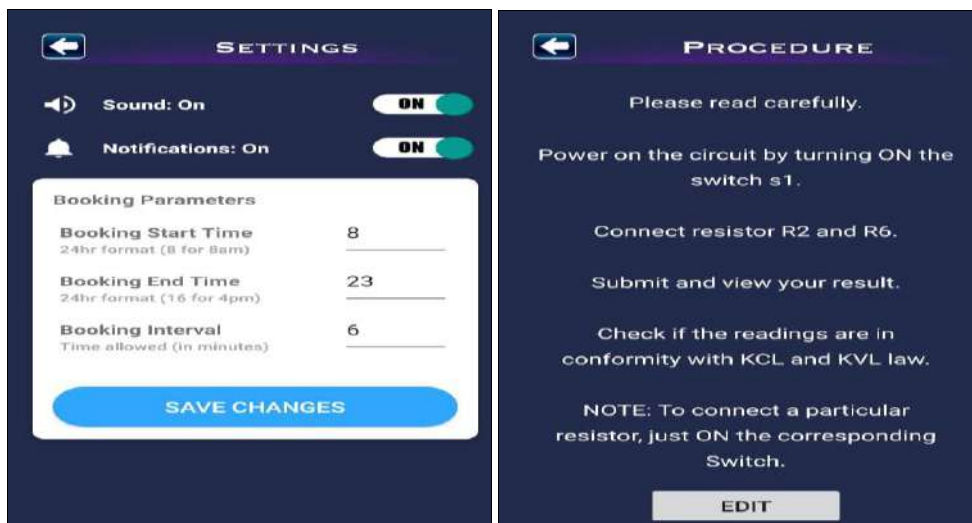
.

Fig 7: Time Interval and procedure setting page

This page lets the lecturer specify a time and list the actions needed to complete a practical. Figure 8 shows the time Selection and Go to Circuit page. It also shows the experimental time for each task.

Fig 8: Time Selection and Go to Circuit page

The time selection page allows users to select and book a practical session within the available time.

Figure 9 shows the circuit on the App for selected experimental combinations. The circuit mimics real-life circuit behaviour when the switches are triggered or deactivated by switching them on or off. When a successful connection is created, the labels change to green. This is also a way for the user to have feedback on whether the switch is ON in the real circuit. The S1 must be ON for this to occur.
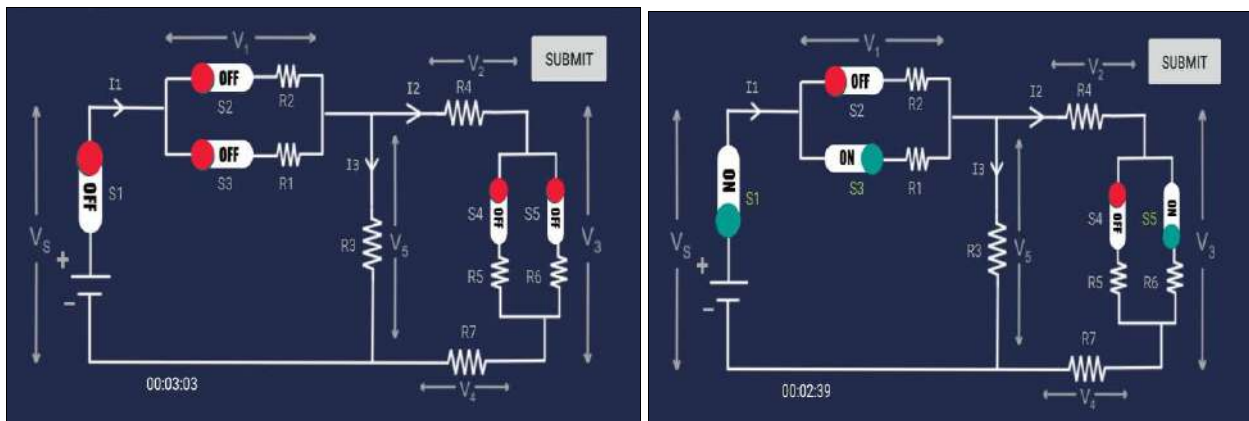

Fig 9: Circuit on the App for selected experimental combinations

Figure 10 shows the page displaying the results of two different experiments made. The dashboard shows the result of two different experiments carried out by the student.

Fig 10: Some Experimental results

Comparison on Results

Table 2: Virtual, Physical and Hand calculation results

Case	Experiment type	V_s (V)	V_1(V)	V_2(V)	V_3(V)	V_4(V)	V_5(V)	$V_x = (V_2+V_3+V_4)$	I_1(A)	I_2(A)	I_3(A)	$I_x = (I_2+I_3)$
A	Virtual	5.1	2.5	0.61	0.61	1.3	2.52	2.52	0.012	0.006	0.006	0.012
	Physical	5.1	2.53	0.61	0.61	1.34	2.59	2.56	0.011	0.006	0.006	0.0117
	Hand Calculation	5.1	2.64	0.61	0.61	1.34	2.68	2.562	0.012	0.006	0.006	0.0118
B	Virtual	5.1	2.25	0.43	1.42	0.93	2.78	2.78	0.01	0.004	0.006	0.01
	Physical	5.1	2.27	0.43	1.44	0.95	2.84	2.82	0.01	0.004	0.006	0.0104
	Hand Calculation	5.1	2.27	0.43	1.419	0.95	2.82	2.795	0.01	0.004	0.006	0.0103
C	Virtual	5.1	2.54	0.632	0.488	1.36	2.48	2.48	0.012	0.006	0.006	0.012
	Physical	5.1	2.57	0.64	0.49	1.4	2.55	2.53	0.012	0.006	0.005	0.0118
	Hand Calculation	5.1	2.57	0.63	0.485	1.39	2.54	2.501	0.117	0.006	0.005	0.0117
D	Virtual	5.1	3.41	0.384	0.392	0.84	1.62	1.616	0.008	0.004	0.004	0.008
	Physical	5.1	3.46	0.39	0.39	0.86	1.67	1.64	0.008	0.004	0.004	0.0074
	Hand Calculation	5.1	3.48	0.39	0.39	0.86	1.65	1.638	0.007	0.004	0.004	0.0074
E	Virtual	5.1	3.14	0.288	0.944	0.62	1.86	1.856	0.007	0.003	0.004	0.007
	Physical	5.1	3.22	0.29	0.98	0.63	1.9	1.9	0.007	0.003	0.004	0.0069
	Hand Calculation	5.1	3.23	0.289	0.954	0.64	1.87	1.8785	0.007	0.003	0.004	0.0069
F	Virtual	5.1	3.42	0.4	0.312	0.87	1.58	1.584	0.008	0.004	0.004	0.008
	Physical	5.1	3.5	0.41	0.31	0.89	1.63	1.61	0.008	0.004	0.004	0.0075
	Hand Calculation	5.1	3.48	0.4	0.308	0.88	1.6	1.588	0.007	0.004	0.003	0.0074
G	Virtual	5.1	2.5	0	0	0	2.52	0	0.006	0	0.006	0.006
	Physical	5.1	2.57	0	0	0	2.57	0	0.006	0	0.006	0.0055
	Hand Calculation	5.1	2.54	0	0	0	2.54	0	0.005	0	0.005	0.0054
H	Virtual	5.1	2.06	0.744	0.592	1.62	2.95	2.952	0.014	0.007	0.007	0.014
	Physical	5.1	2.1	0.76	0.59	1.67	3.03	3.02	0.014	0.008	0.007	0.0141
	Hand Calculation	5.1	2.1	0.76	0.585	1.67	3.01	3.017	0.014	0.008	0.006	0.014

This illustrates the analysis and comparison of the outcome of different cases (i.e. different combinations of voltage (V) and current (I) outputs) gotten from the Virtual, physical and hand calculation experimentation where V_x is the summation of V_2, V_3 and V_4. At the same time, I_x is the summation of I_2 and I_3.

The essence of this is to validate the results of virtual experimentation to ensure they are reliable.

Graphical representation of Comparison of Results
The graphs below illustrate the result from the combinations of virtual, physical and by-hand calculation experiments. It shows how closely the results are and validates the results from the developed system.

The plot of Case A
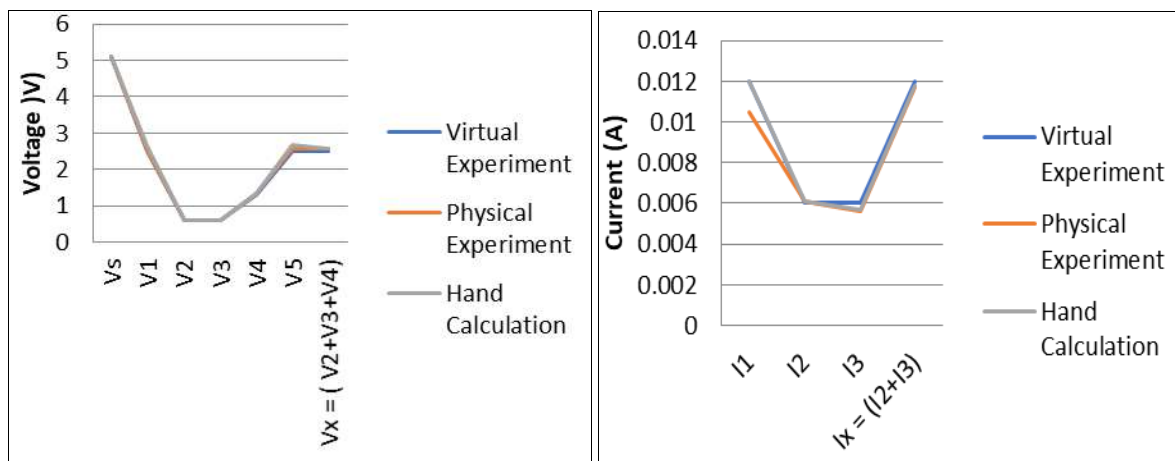Figure 11a shows the voltage plot, and figure 11b shows the current plot.

Fig 11a: Graph showing Voltage plot

Fig 11b: Graph showing the Current plot

5. Feedback Analysis
Out of ten students selected to carry out the virtual experiment, nine of nine responded on the google form created for satisfactory response; their responses are shown in the chart below.
Figure 12a shows the general rating result, (b) shows the

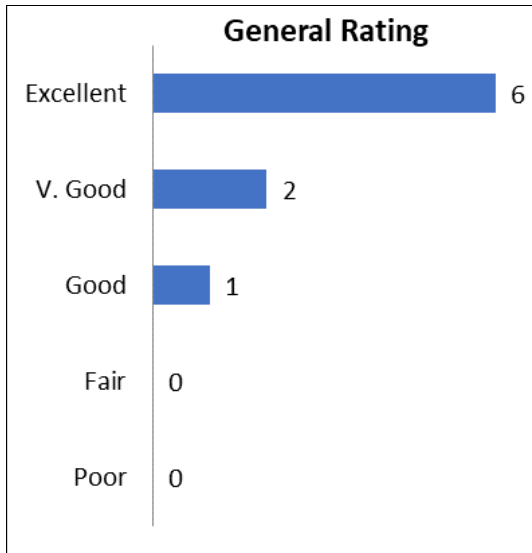conformity level and (c) shows the speed of returning results.
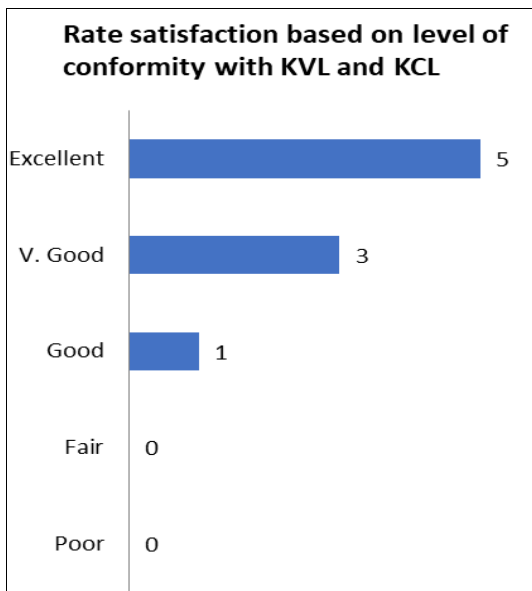
Fig 12a: General Rating
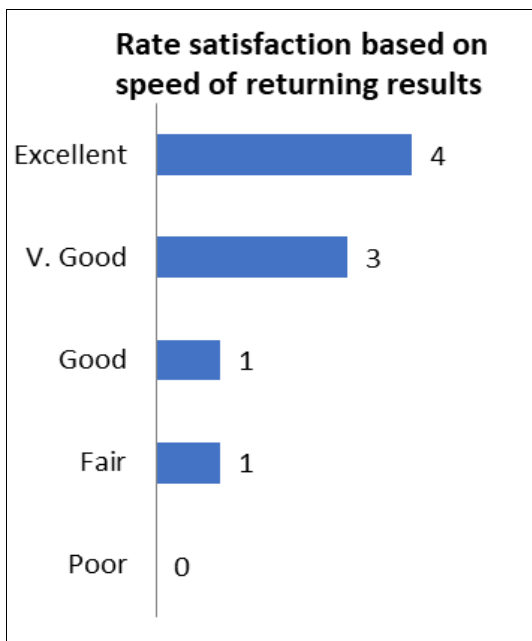

Fig 12b: Conformity level

Fig 12c: Speed of returning Results

Figure 12a shows the user-friendly rating, (b) is the time allocation, (c) is the network generation and (d) is the service provider.

Summary of Result
The result obtained from the virtual laboratory is comparable to the results from physical and calculated experiments, as seen by the near match between the three plots. Hence the result of the virtual experiment is reliable. These studies have demonstrated that virtual laboratories may be used as practice labs. Hence, it is critical to include a virtual laboratory in the lesson plan while teaching. With the help of this research, the student can do practicals at their convenient time, even from home, using the mobile application.

6. Conclusion and recommendation
Conclusion
The virtual laboratory has been designed, constructed and tested okay. Students in experimental disciplines, such as electrical and electronic engineering, are adversely affected by the most recent social distance limits. With this research, it is possible to use virtual labs in higher education for undergraduates and postgraduates. Students may carry out important experiments online from the comfort of their homes, enabling them to continue their education without interruption.

7. Recommendation
Virtual laboratories impact research during a pandemic, and it has been recommended that more hands be played in virtual laboratories for engineering students. This kind of research should be given more attention to avoid the study gap for engineering students whenever there is a pandemic. It is also recommended that students should be subjected to the virtual laboratory to increase their understanding of it before any form of a pandemic outbreak.

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