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Exploring the Effects of Game-based Learning

Anowar Hussain Mondal[1] and Ranjan Maity[2]
[1,2]Department of CSE, CIT Kokrajhar, BTR, Assam, 783370
[1]p22cse1004@cit.ac.in
[2]r.maity@cit.ac.in

Abstract : Advancements in technologies are helping the education system to improve and explore a new dimension of learning. Learning beyond class hours is an important issue. Traditional textbooks and learning materials (online as well as offline) may help to overcome this challenge for theory-based papers. On contrary, experimenting in a lab beyond the class hour is challenging, more specifically in schools. The effect of the COVID pandemic also forced the researchers to explore new ways of learning, particularly in lab work. In this work, an interactive virtual Lab was developed for school students. They can virtually perform Ohm's Law experiments using a mobile phone or computer. The proposed lab was designed using Unity Engine with C#. In order to check the acceptance of the proposed applications, we conducted a usability evaluation. It was observed that students learned more effectively using our proposed application.

Keywords : Simulation, 3D Model, Virtual Reality, Usability Testing.

Anowar Hussain Mondal
Department of CSE, CIT Kokrajhar, BTR, Assam, 783370
p22cse1004@cit.ac.in

1. Introduction

Our education system has evolved from the ages of Pandulipi to modern ICT (information and communication technology) based learning systems in many countries -including India. To date, textbooks are considered the main media of learning. Besides this, different learning materials in the world of the web are also used to improve modern education. This includes online lecture notes and video lectures. NPTEL (nptel.ac.in), and MIT OpenCourseWare (ocw.mit.edu) are examples of such platforms where a student in any part of the world can gain knowledge using video lectures. Besides this, many learning applications are available for kids learning in different schools. It has been observed that many of them are costly. As a result, it becomes difficult to afford for the parents of an average and low-income family. These applications often need a persistent internet connection. Therefore, they may not be suitable for those areas where good network connectivity is an issue.

The above-mentioned challenges are true for theory-based subjects. The problem becomes more severe for conducting laboratory work beyond the class hour. During the pandemic, COVID-19 outbreak, educational institutions were shut down to curb the spread of COVID-19. However, the online platforms were used to conduct theory classes but the conduction of laboratory experiments was difficult as the equipment is not available at home. Students were not able to do the experiments as in the case of regular laboratories at their respective institutes.

Technology's evolution may help overcome this scenario to a certain extent. Virtual reality (VR) (Burdea & Coiffet, 2003; Zhang et al. 2016) may be very effective in this context. VR is defined as the technology that provides almost real and/or believable experiences synthetically or virtually, while Augmented Reality enhances the real world by superimposing computer-generated information on top of it (Shen & Shirmohammadi 2008).

Virtual simulation can provide the necessary technology to overcome this situation. Students can use such virtual laboratories to perform an experiment and learn. The role of virtual reality in modern education was reported long back in 1992 by Sandra Helsel (Helsel, 1992). A systematic review of virtual reality in the modern education system was reported (Kavanagh et al, 2017). It was reported that teachers may use VR in specialized cases of education where realistic simulations are required for better learning. Many works (Hu-Au and Lee 2017; Choi et al. 2016; Nˇemec et al. 2017) over the last ten years were proposed in this direction. It has been observed that most VR-based applications (Nˇemec et al.2017; Concannon et al. 2019) often use HMD (Head Mounted Display). These HMD devices have six degrees of freedom - X, Y, Z, Roll, Pitch, and Yaw (Alhalabi, 2016). Although HMD devices can provide complete immersive experiences, they are generally costly in nature and require special maintenance care. Efforts have been made to develop low-cost-based HMD as reported by (Zhang et al., 2016; Bun et al., 2017 Brito and Mitchell, 2019; Takano et al., 2021). It has been observed that these low-cost devices often face severe technical glitches and are also beyond the budget of middle-class and poor families.

Contrary to the costly HMD, mobile devices are commonly used by all most all groups of people. It was reported (Sun, 2022) that percentage of the mobile users in India is currently 66% and will reach almost 90% by 2040. Virtual Labs (https://www.vlab.co.in/) is a project maintained by the Ministry of Education, Govt. of India, under the National Mission on Education through Information and Communication Technology. This is a web-based approach where there are web pages for each experiment. The simulations are 2Ds in nature and mostly static in nature. In other words, students may not get the feeling of a real lab as they can not customize lab apparatus according to their need Therefore, the development of VR-based applications suitable for mobile devices can be considered the need of the hour. In this work, a VR-based Ohm's law experiment was developed for mobile devices without persistent internet connectivity. The proposed application was developed by Unity Game Engine. In order to test the suitability of the application, usability testing was conducted using seventeen students. Statistical testing on the empirical results shows the potentiality of the proposed application.

2. Methodology

To develop the application, Ohm's law of electricity was selected, which is generally conducted in Physics and Electrical labs. The law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperatures remain constant. In the following equation, Ohm's law, where V is the Voltage and I, R denotes Current and Resistance, respectively.

$$V=I\times R \qquad (1)$$

- In order to carry out the Ohm's law experiment, the following apparatus are required in a lab.

- Ammeter: An ammeter is an electrical instrument used to measure the current flowing through a circuit in Amperes. It is connected in a series connection with the circuit.

- Voltmeter: A voltmeter is an electrical instrument used to measure the voltage across two points. It is connected in parallel connection with the circuit.

- Battery Eliminator: A battery Eliminator is an electronic device that converts AC Source to DC voltage. It is connected to equipment that requires DC voltage. It can work as a battery with an AC power source and provide the variable Voltage required for the experiment. In a simple Battery Eliminator, there is two terminal to be connected to the circuit, a screen to display the output voltage, the main switch, an indicator, and buttons or knob to adjust the voltage.

- Key: In an electrical circuit, a Key is used to close or open the circuit. The Key is the main switch for the experiment circuit to work.

- Rheostat: A rheostat is an electrical instrument used in an electrical experiment that requires varying resistance or current. Wires can be connected to two different combinations depending on the requirement. The first is for full resistance of the rheostat wires connected to terminals A and B in Figure 1. The second is for variable resistance Terminals C and B. The slider is moved to change the resistance.

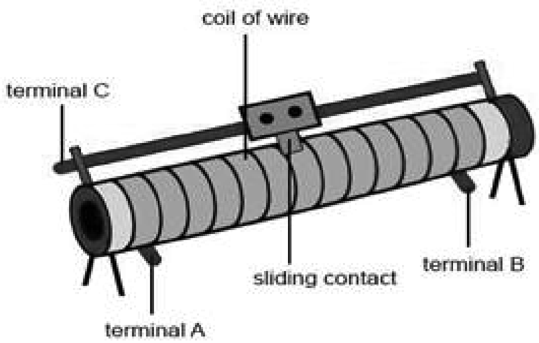


Fig 1: Diagram of Rheostat

To add all these elements to the proposed applications the 3D models of each component were developed and are discussed below.

2.1 Development of 3D Models

The 3D models of the Ammeter, Voltmeter, Battery Eliminator, Key, and Rheostat were developed using Maya which is very popular among designers for 3D model development. Maya is a computer graphics tool that is used to make 3D computer graphics models. Maya was used for making 3D models of the equipment and environment objects such as chairs, tables, etc. Individual models were made separately and texture was created by adding colors and materials. In Figure 2, the developed 3D models are shown. It may be noted that the rheostat, ammeter and voltmeter, and battery are shown in Figures 2a, 2b, and 2c, respectively.

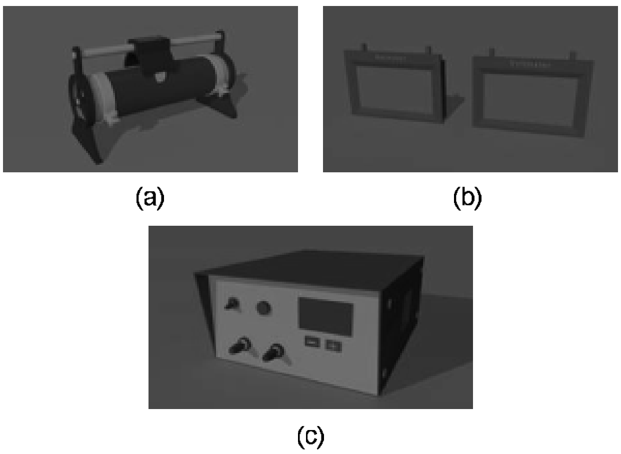


Fig 2: 3D Models of used apparatus (a)Rheostat (b) Ammeter and Voltmeter and (c) Battery Eliminator.

Except for the above-mentioned instruments, there was a need to develop a 3D model for the lab. For this purpose also, Maya was used. The environment is developed in such a way that users feel they are inside a laboratory. It includes common objects that are found in a laboratory. Object Collider was added to the floor for objects to fall on. Some objects were made interactable, such as stools, and boxes. A 3D virtual laptop showing the tutorial of Ohm's law inside 3D the environment was added. In Figure 3, a 3D model of the proposed lab is presented.

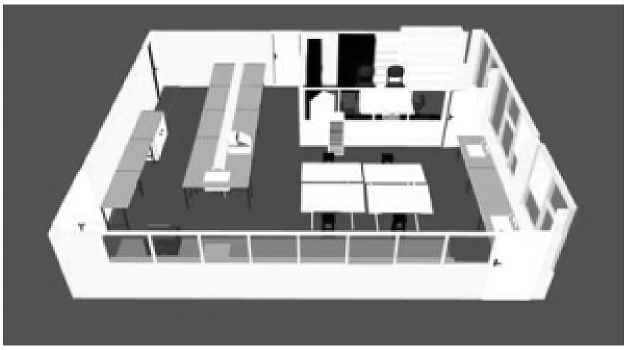


Fig 3: 3D model of our proposed Lab.

2.2 Application Development

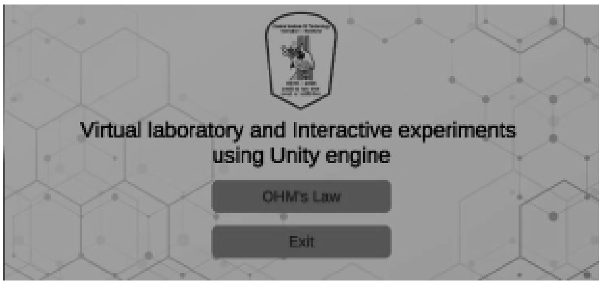
After the development of the 3D models, it was exported in fbx format and used to exchange the 3D models. Then they were imported into Unity for scripting. The scripting was done in such a way that users may move around in all directions inside the virtual lab. The applications were developed for both desktop/laptop (suitable for Windows OS) and mobile devices (suitable for Android OS). Interactions and controls for the proposed application are mentioned below.

In Windows OS users can move around with WASD and Arrow Keys. Right-click and hold to rotate the camera and left-click to interact with the equipment. In Android OS Joys sticks are placed on the screen which can be used to move around and rotate the camera. Users can interact with equipment with touch input. Users can interact with the rheostat like a real rheostat by moving the slider to change the resistance. Ammeter and Voltmeter show the reading in real time on their display in VR and on-screen in easy mode. Battery eliminator can be operated by touching the button to turn it on and other buttons to change its values. These interactions are designed just like real-life equipment.

In the proposed application, theory, procedure, and control buttons for learning the theory of the experiment, how to experiment, and how to control the experiments using navigation were added. In Figure 4 screenshots of different pages are shown. Figure 5a shows the controls of the simulated experiment. This is a static page showing where the controls are present. Figure 5b shows the Screenshot of the tutorial video. The tutorial video goes through all the controls of the application. A pause button was added that is accessible during the experiment to go to other scenes or exit the main menu.

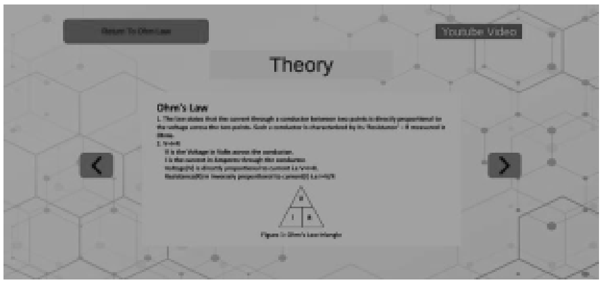
Using the Experiment button of UI as shown in Figure 4b a user can carry out the Ohm's Law experiment. Figure 6 shows the screenshot of the main simulation in Windows OS with easy UI enabled.

After the development of the proposed application, there is a necessity to check its acceptability of it. Consequently, the usability test of the application was carried out, as discussed in the following section.

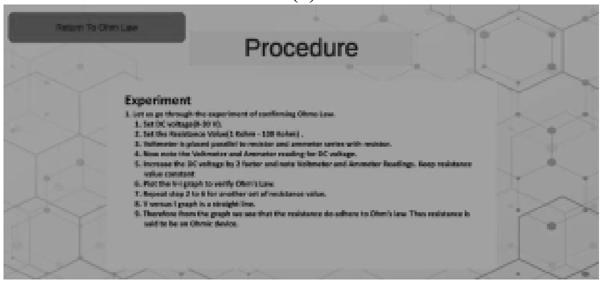


(a)

(b)

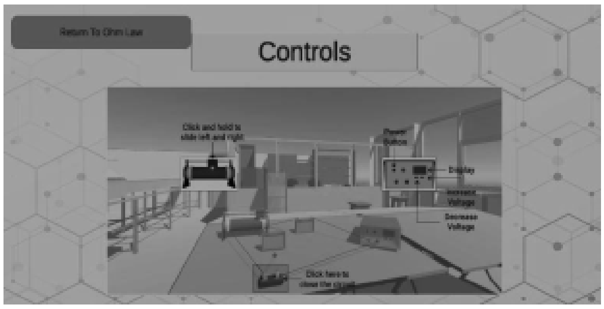


(c)

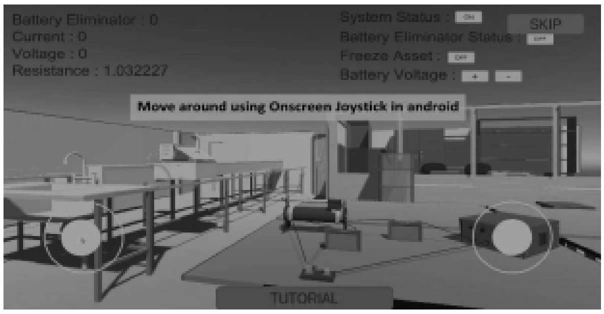


(d)

Fig 4: Screenshots of the proposed application.



(a)



(b)

Fig 5: Screenshots of (a) control and (b)tutorial button action.

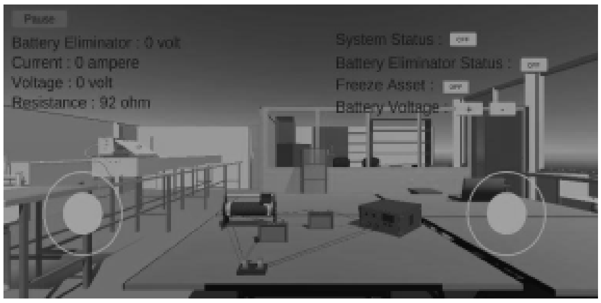


Fig 6: Simulation with easy UI in Windows OS.

3. Usability Testing

In order to carry out the testing, first, participants are needed to be identified. It was mentioned (Nielsen, 1993) that seven participants are good enough for carrying out usability studies. Accordingly, it was planned to test the usability of the application by considering seven participants from an engineering institute. Out of these seven participants, there were four girls and the rest were boys. All the participants were normal vision without color blindness (self-reported). The theory of Ohm's Law and its' working principle were mentioned. Then they were asked to experiment in a traditional lab. After this, the participants were asked to answer fifteen MCQ (Multiple Choice Questions). We reported these questions along with their choices in Appendix A. In Table 1, the participants' results are shown. It may be noted that the average score of the participants is 7.71.

Table 1: Survey Results Of 15 Mcqs

Approach	Avg.	Median	Low	Max
Traditional	7.71	7	1	11
Our Approach	9.86	10	7	12
Improvement	2.15	3	5	1

Followed by the first phase of the survey, participants were asked to use the developed application for 45 minutes. Again, they were asked to answer the same fifteen MCQs used in the previous survey. It was observed that the average score of the participants was 9.86 as reported in Table 1. It may be noted that the average score increased by 2.15 out of 15 marks. The median and low scores were increased to three and six marks respectively. The max score was also improved by one mark. Therefore, it can be claimed that by using the proposed application participants improved their learning.

After the effectiveness of the proposed application, we were also interested to measure its reliability of it. In order to measure it, Keller's Instructional Materials Motivation Survey (IMMS)(Keller, 2010) was used. It tests the motivational characteristics of instructional materials or courses in terms of the Attention, Relevance, Confidence, and Satisfaction (ARCS) model of motivation. Altogether, thirty-six questions are used in this survey. Out of them, twelve are in the attention category, nine in the confidence category, nine in the Relevance category, and six questions in the satisfaction category. A five-point Likert scale is used for the collection of empirical data, where five stands for very true and one is used for not true at all. Assessing the motivation of participants gives the measure of how reliable the material is as students tend to learn more if they are motivated. To carry out this survey, seven of the earlier participants and ten new participants were selected. These ten new participants were aware of the Ohm's Law experiment and performed it several times in the lab (self-reported). The main objective is to add this group of participants to check the reliability of the application to new as well as experienced users. Altogether seventeen students (avg. age = 17) were asked to fill up the IMMS survey form. Cronbach's Alpha was used to find out the internal consistency of the survey. In Equation 2, we reported the formula to compute Cronbach Alpha. In the following equation, N denotes the number of items,c represents the average covariance between item pairs, and V signifies average variance.

$$\alpha = (N \times c)/(V + (n-1) \times c) \;......(2)$$

In Table 2 the calculated Cronbach alpha values for attention, confidence, relevance, and satisfaction are reported.

Table 2:Calculated Cronbach Alphas of IMMS Survey

Sl. No	Item	Cronbach Alpha
1.	Attention	0.8354
2.	Confidence	0.7797
3.	Relevance	0.7814
4.	Satisfaction	0.8740

Cronbach alpha is greater than 0.77 across all IMMS categories. Confidence and Relevance are above 0.7 which is acceptable on the Cronbach scale. Attention and Satisfaction scored above 0.8 which is Good on the Cronbach scale. Good scores in Cronbach alpha observed for the four different parameters signify the reliability of the proposed application.

4. Conclusion

With the emergence of VR technology, the trend of using interactive 3D applications and virtual/mixed reality applications in a virtual classroom, meeting, etc. has increased. This simulation can be helpful to students as it can provide the feel of being in the Physics Lab and they will be able to perform a virtual experiment. Also, our application will make Laboratory more accessible to students from remote places where there is limited access to a laboratory. This project will also enhance student productivity, as it allows the students to conduct various experiments without any constraints on place or time. The use of virtual equipment will also reduce the cost of performing such experiments in a laboratory. Also, there is no risk of breaking any equipment. In the future, we plan to enhance our application with the following -

- User experience can be improved with better UI and more options to use the simulation such as an on-screen button as well as a button on the 3D model.
- Immersion can be improved by improving the simulation and more user interactions.
- Other features such as note-taking, state saving, etc can be added.
- More experiments can be added.

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Appendix A: Mcqs Used In Our Study

ŸQ1. What are the necessary conditions for current flow through the conductor?

- There must be a closed circuit.
- There must be a source of electrical energy
- None of the Above
- Both of the Above

Q2. Choose the correct statement.

- The resistance of a material is independent of the current passing through it.
- All of them are true
- Resistance of a material is the measure of how much it opposes the passage of free electrons.
- Every material has resistance.

Q3. Which of the following represents ohm's law?

- Current = Resistance / Potential difference
- Current = Resistance × potential difference
- None of these
- Potential difference / current = Resistance

Q4 What does the current through a wire depend on?

- The potential difference applied.
- Both resistance and potential difference.
- The resistance of the wire
- The thickness of the wire.

Q5. What is the potential difference required to pass a current of 5A through a metallic rod of resistance 10Ω?

- 0.5V
- 50V
- 5V
- 0.05V

Q6. Ohm's law is true for?

- Metallic conductors at low temperature
- Metallic conductors at high temperature
- For electrolytes, when current passes through them
- For diode when current flows

Q7. An EMF source of 8.0 V is connected to a purely resistive electrical appliance. An electric current of 2.0 A flows through it. What is the resistance offered by the electrical appliances?

- 4 ohm
- 6 ohm
- 2 ohm
- 3 ohm

Q8. If the conductor resistance is 50 ohm and the current passing through it is 5 A. What is the value of potential difference?

- 150 V
- 250 V
- 50 V
- 15 V

Q9. The current passing through a resistor in a circuit is 1 A when the voltage across the same resistor is 10 V. What is the value of current when the voltage across the resistor is 8 V?

- 0.8 A
- 8 A
- 80 A
- 18 A

Q10. How is the ammeter connected in a circuit?

- Connected in Series
- Connected in parallel
- None of the Above
- Both of the Above

Q11. Identify the Image. [Image of Ammeter]

- Ammeter
- Voltmeter
- Multimeter
- None of these

Q12. Identify the Image. [Image of Voltmeter]

- Ammeter
- Voltmeter
- Multimeter
- None of these

Q13. Identify the Image. [Image of Battery Eliminator]

- Battery Eliminator
- Bread Board
- Rheostat
- Galvanometer

Q14. Identify the Image. [Image of Voltmeter]

- Ammeter
- Voltmeter
- Multimeter
- None of these

Q15. Which one of these is Battery Eliminator?

- Image of Battery Eliminator
- Image of Leclanche Cell
- Image of Oscilloscope
- Image of Multimeter