CS492 Project Report

Physics Lab in Virtual Reality

Submitted in partial fulfillment of
the requirements for the award of the degree of

Bachelor of Technology
in
Computer Science and Engineering

Submitted by

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Acknowledgements

We would like to place on record our deep sense of gratitude to our project guide, Prof. Asjad Nabeel P, Department of Computer Science and Engineering, Government College of Engineering Kannur, for his generous guidance, help and useful suggestions.

We are extremely grateful to our project Co-ordinator Prof.Shine.S, for his encouragement.We express our are sincere thanks to Dr.Rafeeq. P. C, HOD of Computer Science and Engineering Department and to our college Principal Dr. V. O. Rejini, for their valuable support.

We would like to gratefully acknowledge all the students and teachers who helped in providing information to evaluate the success and usefulness of our Project.

We will be failing in duty if we do not acknowledge with grateful thanks to the authors of the references and other literature referred to in this project.

We are very much thankful to our parents and friends who guided us in every step.

Abstract

The aim of this project is to develop a virtual physics lab using immersive virtual reality technology. During Covid, the lack of physical labs have increased the gap between theoretical and practical knowledge of students. It has diminished their understanding of many essential concepts. This project is an attempt to bridge this gap by taking a small step to make the education system more interesting and effective. After creating the project which contains sections for component familiarization, experiment practice and mock tests, a qualitative evaluation of the VR application was conducted. To quantify this information we utilized a survey targeted at students and teachers. 74.2% of the students felt that the project will be a useful tool to improve their academic progress. 72.7% of the teachers responded that they would use this application as a teaching aide.

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Chapter 1

Introduction

1.1 Background Information

Covid-19 brought about many new problems in our society. Innovative minds have been solving them one at a time. We felt that students, especially school students lack access to lab. School curriculum spends more time in giving lectures which are not always effective for making the students understand the concepts. Hence students easily forget what they learn. Practical education in schools are not given much importance.Thus even before the pandemic, students had limited access to labs. Covid-19 aggravated the situation as offline classes were not available. So we decided to try and solve this issue. We believe that experiential learning is essential for understanding many concepts, especially in higher secondary classes. Our project aims to create physics lab using immersive virtual reality, which allows the students to do lab activities at their own convenience.

Virtual reality (VR) refers to a computer-generated simulation in which a person can interact within an artificial three-dimensional environment using electronic devices. It was developed to provide simulation training to US Air force pilots. By applying this technology to laboratory education we will be able to elevate it to the next level. Main advantage of using this technology in this area will be that we need not have a physical laboratory setup to practice experiments.

Physics is a core subject. It is one of the fundamental subjects on which Engineering is based. The physics lab plays an integral part in understanding many complex theoretical concepts. It also helps the student study and remember the topics more effectively. Higher secondary syllabus of physics, focuses on many foundational areas like optics, current, magnetism and forces.

Usually in physics lab, higher secondary students familiarizes with some basic instruments and does experiments to further their understanding of these topics.

So we decided to make an interactive physics lab which is accessible to home-bound plus 2 students. We want to ensure that the lab sessions are more engaging and fun. With our application, students will be able to familiarize with different lab equipment and assess their own proficiency using mock tests. They will also be able to perform an experiment.

1.2 Literature Survey

1.2.1 VRLab - A Chemistry Laboratory Platform

The work of Agbonifo et al. [3] presented a virtual reality system for the titration experiment in a chemistry laboratory. It enable students to learn the experiment in a virtual laboratory environment before proceeding to the actual chemistry lab. The virtual chemistry laboratory environment was developed using the Unity Real-Time Development Platform. The Microsoft SQL Server was used for the database to enable easy assessment of the student performance after the experiment. This virtual lab could be a useful alternative to the physical laboratory, especially where there may be a lack of some laboratory equipment or inadequate reagents to aid learning. The chemistry VRLab provides as close as possible to real-life experience for student's adaptive learning and training in chemistry titration practical procedure.

1.2.2 Physics Education In Virtual Reality

The paper by Kaufmann et al. [2] presented an immersive virtual reality (VR) application for physics education. It utilized a physics engine developed for the PC gaming market to simulate physical experiments correctly and accurately. Students are enabled to actively build their own experiments and study them. A variety of tools are provided to analyze forces, mass, paths and other properties of objects before, during and after experiments. Innovative teaching content is presented that exploits the strengths of the 3D virtual environment. Physics Playground serves as an example of how current technologies can be combined to deliver a new quality in physics education. The standard hardware setup consists of an head-mounted display (HMD), a wireless pen and a personal interaction panel (PIP).

1.2.3 Similar works

Some other projects that aid practical education through virtual platforms are Virtual lab and VR lab academy.

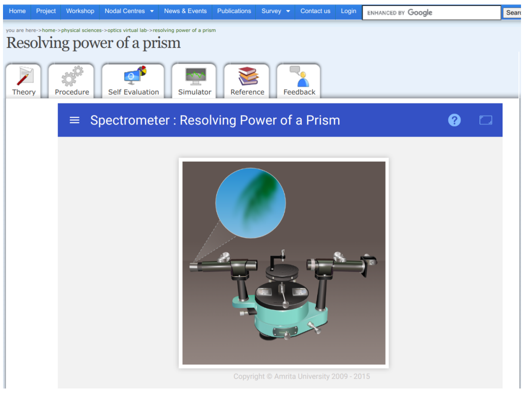

Figure 1.1: Virtual Lab

Virtual lab is a Government of India initiative which allows the undergraduate students to perform lab experiments in a 2-D environment online.

Figure 1.2: VR lab academy

VR lab academy is an online platform which allows people to do high level experiments in a VR environment. Both of these are focused on under graduate or postgraduate students. Neither of them addressed the issues of school students.

1.3 Problem Statement

To create an immersive and interactive physics lab in a 3D virtual environment which will be on-hand for students during situations like Covid-19, when real lab sessions are inaccessible.

1.4 Outline of the Report

This report describes about the project "Physics lab in Virtual Reality".

Chapter 1 starts with the background information. It explains our motivation for creating this application. As well as a short description on the novel technology we have used to create this project. It also includes a brief summary of some related papers which explores similar works and other innovative solutions which solve the problem we are attempting to solve through this project.

Chapter 2 deals with the methodology. It describes the journey we went through to complete our project. It includes our objectives and explains how we completed them. The second section of this chapter explains the architecture of our system, both hardware and software.

Chapter 3 explains the system designs through a series of diagrams. Flowchart describes the flow of actions and reactions in our system. Data flow diagram describes the flow of data and artistic diagram shows a blueprint of the physics lab.

Chapter 4 is detailed design which further explains our project through a series of UML(Unified Modelling Language) diagrams - use case diagram, class diagram, sequence diagram, activity diagram and component diagram.

Chapter 5 explains a database design using data dictionary and ER diagram.

Chapter 6 explains the evaluation and validation of this project in detail. It makes use of graphs to get a better understanding.

Chapter 7 concludes the project report and also discusses about the future scope.

Chapter 2

Methodology

2.1 About the Project work

The first step of creating a plan for this project was to collect data from the people who would use it. In order to do this we discussed the issues students faced while doing their lab practicals during the Covid-19 pandemic. We also communicated with experts about the relevance of this venture. After a lot of deliberation we decided on the features of our project. The features are:-

1. Familiarization of equipment
2. Self-Assessment
3. Simulation of an experiment

Familiarization of equipment would help the students to easily recognize the common instruments that they may come across in a physics lab. The idea is that the student will be well acquainted with all the common instruments, and thus have a much easier time navigating their physics laboratory. Every student will be able to learn about each of the equipment in detail by spending as much time as they need.

The self assessment section will have an array of questions from a variety of topics in physics domain. Using this section, the student will be able to evaluate their own proficiency. This section will also act as a mock test to prepare the students for their final examinations and viva.

The experiment section is for the students to practise the experiments they do in their own school laboratories. It will act as a study aide. It will be especially useful for students who have limited access to their laboratories. Ideally a physics lab in virtual reality should be able to accommodate a wide variety of experiments. However this is only an initial prototype, so we have set up the Ohm's law experiment as a primary venture.

After finalizing on our objectives, we consulted similar projects and other resources to explore various technologies and software which we can utilise. To create the 3D environment we had many options like Unity, Unreal engine, Amazon Lumberyard and many others. We decided on Unity as it is very beginner friendly, platform independent and had a lot of free assets. It also had a lot of free online tutorials and a vibrant online community. Although Unity has many free assets, we still had application specific assets such as the lab instruments which had to be 3D rendered separately. For this we explored different possible software and decided on Blender. Blender is a free and open-source 3D computer graphics software tool-set used for creating animated films, visual effects, art, 3D printed models, motion graphics, interactive 3D applications, virtual reality, and computer games.

Virtual reality applications can be run on two different hardware, either by using VR headset such as Oculus Rift and HTC Vive Cosmos or using Google Cardboard technology which uses a mobile phone as a screen which will be fitted on a headset. It is preferred to use the VR headset for the best experience. However, it was not feasible to purchase it for this project. Unity allows one to build the same program for different platforms. Hence choosing to create our project for a mobile VR has not compromised on the quality by any means. We can easily convert the present program to a different platform like Oculus by merely making some changes in the build settings.

Once we decided on hardware and software, we followed some tutorials and made a couple of mini projects to get accustomed to the platforms. The coding of behaviour of objects in the lab environment was done using C#.

The implementation of our project was done in 5 stages.

1. Create a physics lab in 3D environment
2. 3D render physics lab instruments
3. Set up Assessment environment
4. Simulate a lab experiment
5. Analyse project success

Creating the physics lab in 3D environment was done in Unity. Most of the assets and materials required was collected from the Unity asset store. Some of the assets like the table had to be rendered to our taste by using Blender. For making this interactive, we used gaze pointers for button-like selection.

Unity did not provide any of our lab instruments, so each of them were rendered on Blender by us. The instruments rendered were exported to Unity in FBX file format. We also collected details about the different equipment to be displayed. To make the interactions in the lab more interesting, we implemented a gaze action using a reticle pointer. The reticle pointer is a gaze based pointer that supports user to give a button input.

The main challenge for setting up the assessment environment was not just rendering the equipment, but mimicking the behaviour of an interactive quiz board. We incorporated button clicking action for the user to interact with the board. Once we overcame this difficulty, we collected some relevant questions and successfully completed the assessment section.

Setting up the experiment involved multiple steps. The first part was partially complete as we had already rendered the equipment for the familiarization section. In addition, we created a complete circuit using our 3D rendering software(Blender). Subsequently, we simulated the action of rheostat using a slider object. On receiving the selected slider values, we had to design the system to generate the values for Current and Voltage that agreed with the Ohm's Law. The next step was to generate a table with these values and then plot a graph to find out the value of resistance of the resistance wire connected across the voltmeter. Additionally we also added a door to exit the application.

We originally planned to evaluate our project by comparing the performance of students who studied using our application to others who used the 2D methods like google meet, using methods similar to the method used by Bogusevschi et.al[1]. However we had to rethink this idea as we faced difficulty to coordinate an assessment test due to lack of available headsets and the pandemic situation. Consequently we decided to conduct a qualitative assessment using questionnaire as used by Agbonifo et.al[3]. We recorded a video of the demo usage of our project and uploaded it in Youtube. Then we shared the link to our target group - students and teachers. They were asked to fill a questionnaire based on their understanding and preference to this new generation teaching tool. We summarised this response to evaluate our project.

2.2 System Architecture

The project, Physics lab in virtual reality features an immersive Virtual reality application. It requires both hardware and software components to work successfully. The hardware components are a VR headset, and a handheld controller.

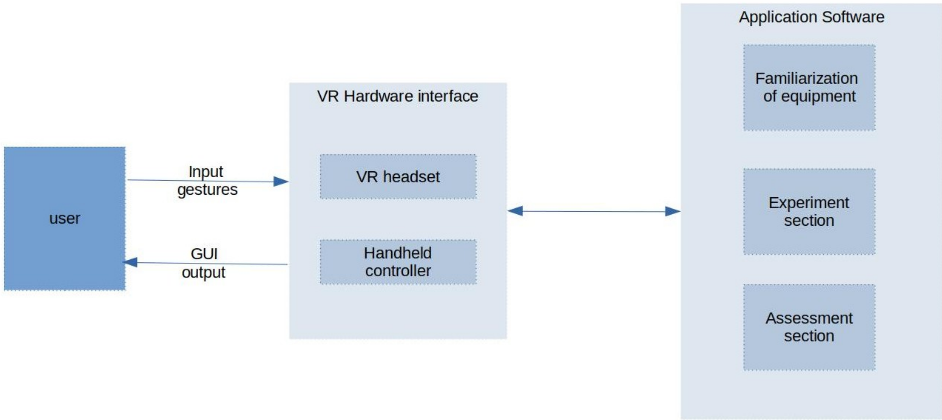

Figure 2.1: Architecture of Physics lab in VR

Figure 2.2: A headset with mobile phone screen and Bluetooth controller

A virtual reality headset is a head-mounted device that helps the wearer to see and experience the virtual world. In a sophisticated VR headset that is exclusively for VR technology such as Oculus Go, the headset will allow for 6 dimensional movement. When we use a temporary headset which uses a mobile phone with inbuilt gyroscopic technology, the movement is restricted to 3 dimensions. Both of this headsets can be paired with a handheld controller.

The user can interact with the virtual world by using the handheld controller or the VR headset itself. In case of the mobile phone, it can usually be paired with a Bluetooth controller. This controller will be able to do a default click action as well as some other customised actions. The haptic controllers which is included with a VR headset with 6 dimensional support can act as hands of a person in the virtual world. They are highly flexible and detect an array of varied movements.

The software part of the project is a VR application. The application will simulate a physics lab in 3D environment. The application will consist of three main parts - familiarization of equipment, experiment section and assessment section. Each of these sections will take input as interaction from the user via the headset and Bluetooth controller, and will change the environment or part of the environment accordingly. We developed the user using Unity Game Engine.

Chapter 3

System Design

3.1 Flowcharts

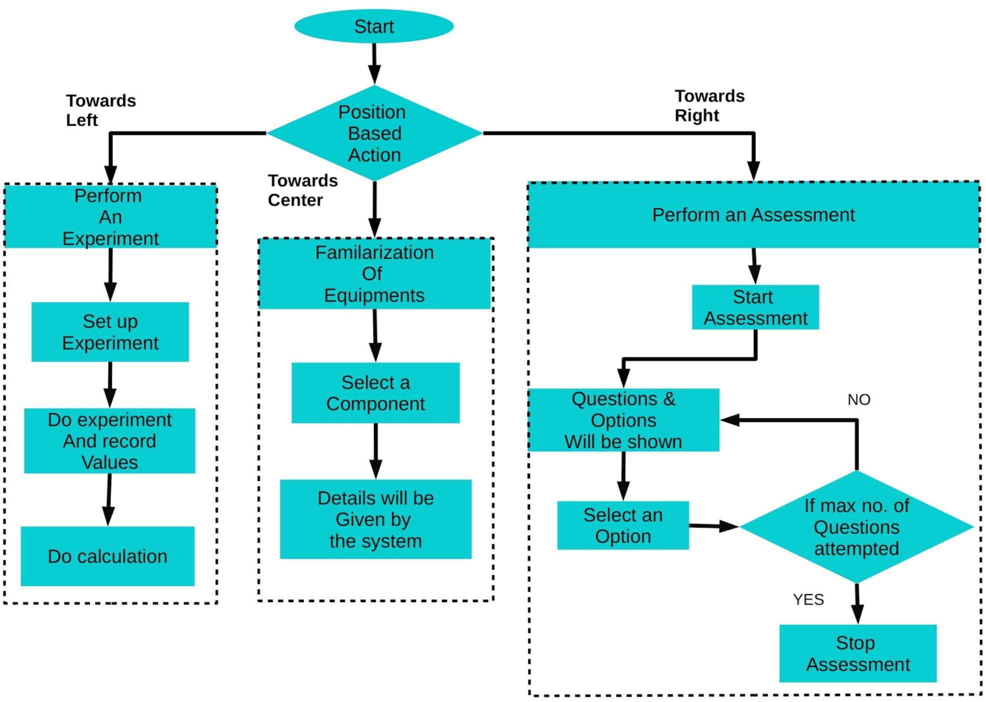

Figure 3.1: Flowchart

This flowchart shows how the VR Lab works. It has three branches and the branches are based on the direction in which the student looks. Student can take part in any of the three activities by turning towards it. Towards the left side is the experiment setup. We simulated the ohm's law experiment. All the equipment will be on the table and the student need to construct the circuit and record values. Calculation and analysis can also be done. Towards the center, we have different equipment to familiarize. These will be displayed on the table. When we pick any of the equipment, a 360 degree view of the equipment as well as its details will be shown. On the right side is the assessment window. It will be a self assessment for students.The questions will be in multiple choice quiz format. The final score will be shown at the end of the assessment.

3.2 Data Flow Diagrams

3.2.1 Level 0 Data Flow Diagrams

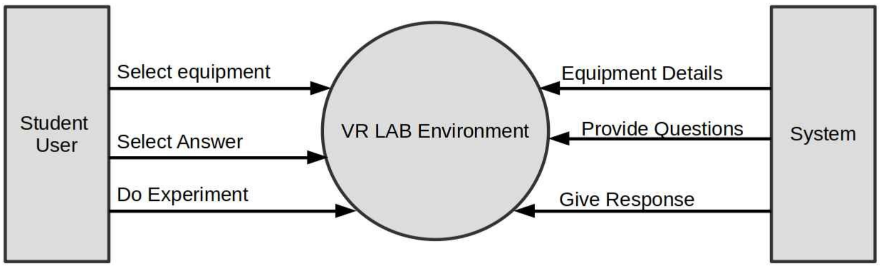

Figure 3.2: Level-0 Data Flow Diagram

This the level-0 Data flow diagram. There are three main components. The student user, VR lab environment and the System . When the student select an equipment the system will give the corresponding details. For the assessment section the system will provide the questions and options from which the student can select an option. In the experiment section, the student can perform the experiment the system will respond accordingly.

3.2.2 Level 1 Data Flow Diagrams

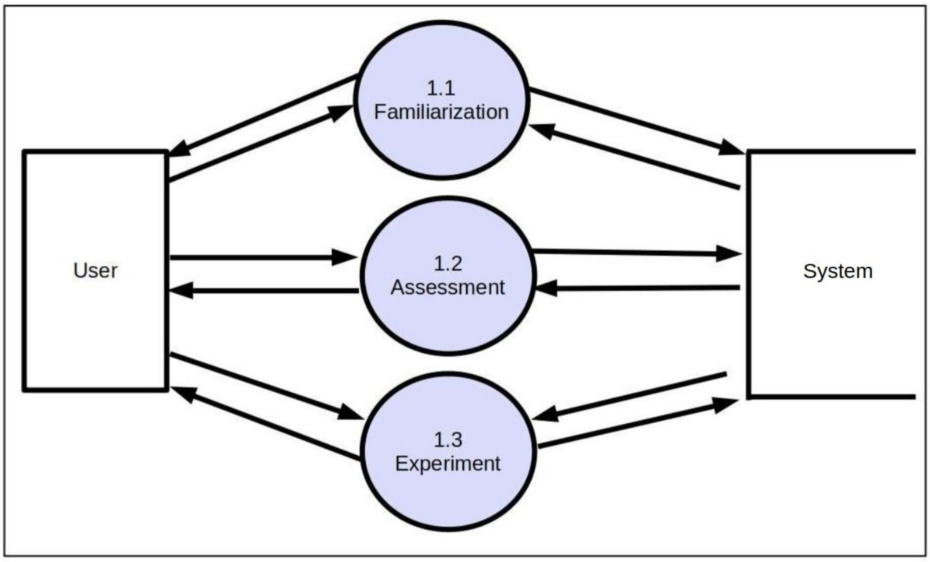

Figure 3.3: Level-1 Data Flow Diagram

This is the level 1 Data flow diagram. In the familiarisation process, the user can select an equipment and the information will be passed to the system. Details of the same will be retrieved from the system and it will be shown to the the user. In the assessment process, the question and option will be retrieved from the system and displayed to the user. The user then selects an option and the information will be passed to the system. The system will evaluate the same. In the experiment section, the system will provide the equipment and the user will do the experiment. This will then be reviewed by the system.

3.3 Artistic Diagram

Figure 3.4: Artistic Diagram

This is a visual representation of the project environment. The left side will have the experiment section, the right side shows the assessment section and the familiarization section can be seen straight at front. The front displays a table with instruments on it that can be familiarized. The right side has the assessment board that will act as an interface between user and assessment. The left side has a table with all the instruments required for performing the Ohm's Law experiment.

Chapter 4

Detailed Design

4.1 UML Diagrams

4.1.1 Use Case Diagrams

In fig.4.1, there are two actors and four use cases. The student players and the system are associated to use cases "Familiarize with Equipment", "Perform Self Assessment" and "Perform an Experiment". Use case "View Score" is included in the "Perform Self Assessment" use case as the player(student) can view score only if they perform the assessment.

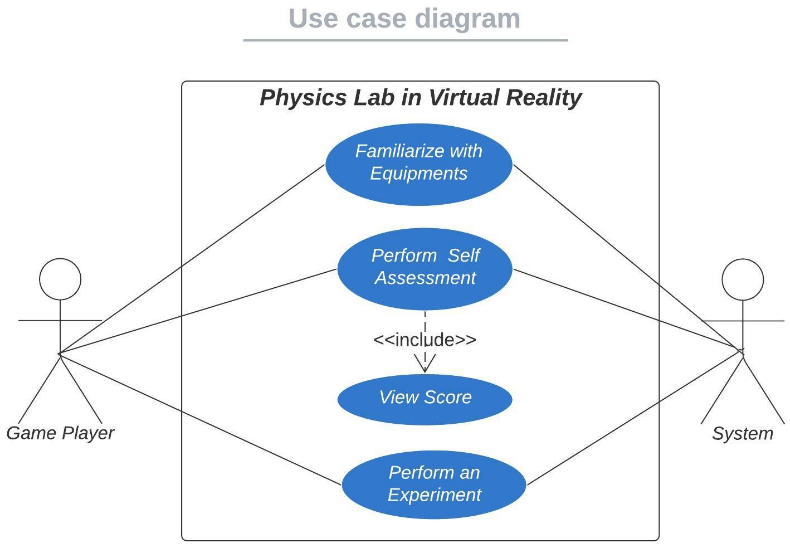

Figure 4.1: Use Case Diagram

4.1.2 Class Diagrams

Fig 4.2 depicts the class diagram of this project. This contains five classes and an interface. "Player", "Software", "Assessment Unit", "Familiarization Unit" and "Experiment Unit" are the classes and "VR Headset" is the Interface. In the "Player" class, there is only one public 'pointer' attribute that returns image. The "VR Headset" interface has three public methods, namely getDirection, displayImage and displayInfo. It is associated with the "Player" class as well as "Software" class. The "Software" class has two public attributes-GameObject and Transform. It also has a protected renderObject method and two public methods - envtCreation and dispatchScript. Both "Familiarization Unit" and "Experiment Unit" have three public attributes - name, 3DImage and description. "Familiarization Unit" have three public methods of selectInstrument,enlargeInstmt and deselectInstrument. "Experiment Unit" have showInstrument, hideInstrument, showDescription,showGraph and recordValues as public methods. "Assessment Unit" one private attribute - answer, five public attributes - question and option(1-4) , one public method- ShowQuestion and a private method-checkAnswer.

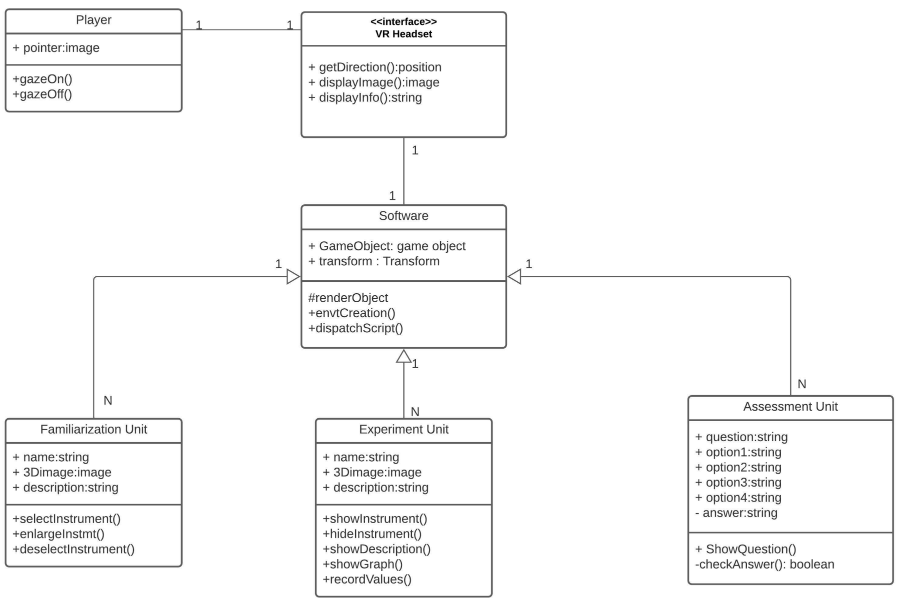

Figure 4.2: Class diagram

4.1.3 Sequence Diagrams

Figure 4.3 shows the Sequence diagram for this project. The "User" is the actor in this sequence diagram. The objects are the *VR Headset* and the *System*. On starting the application, the VR Headset will request the system for initial setup information which will be provided by the same. The sequence of events in this project depend mostly on the direction of gaze of the user in the VR Headset.

If the user focuses on any instrument that appears in the scene, then the VR headset will request and receive information about the instrument. VR headset will then display the enlarged object in the air and show the description about the same object. In order to return to normal display, the user need to focus gaze on the same object. this can be done any number of times.

If the user turns to right side, the display will be updated with an Assessment board with clickable start button. On clicking the start button, the System will display the questions along with its options. the User selects an option that will be verified by the system and the result will be displayed by the VR headset. Upon completing the given set of questions, final score will be displayed. This can also be done any number of times.

If the User turns to the left of main scene, the display will be updated. The user have to pick the instrument. The system will build the circuit. Upon gazing on any instrument on the table, system will display a short description of the instrument. The user have to adjust slider of the rheostat and record values five times. With these stored values, system will generate values of current, voltage and finally resistance. The system will then display graph with these values onto the VR Headset. The display is then updated.

If the user turns to his back, the door, then the user exits from the application.

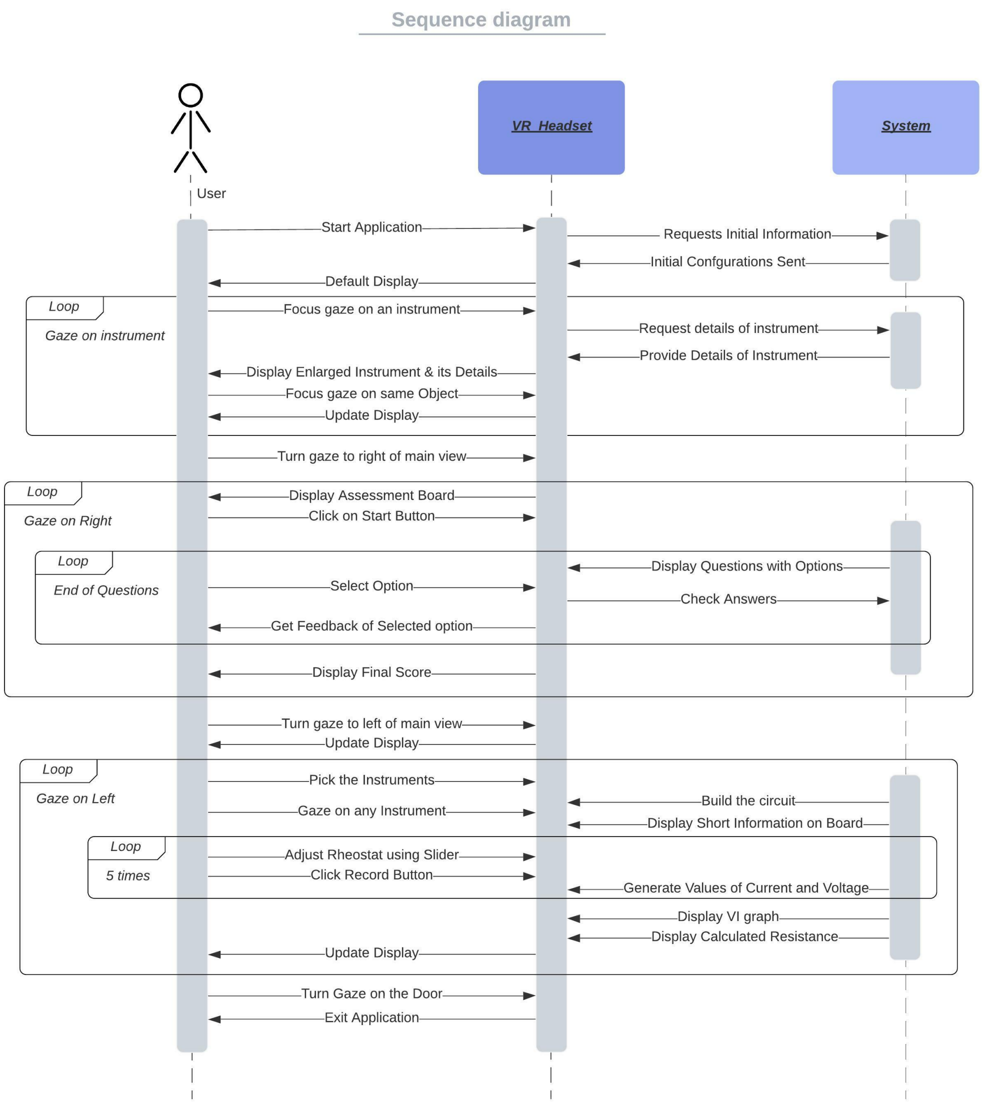

Figure 4.3: Sequence Diagram

4.1.4 Activity Diagrams

The Figure 4.4 shows the Activity Diagram of this Project. It is very similar to the sequence diagram as it represents the flow from one activity to another. In this project, the activity depends entirely on the direction in which the user gazes. If the gaze direction is to the left, it performs Experiment activity. If the gaze is in right direction, it Performs Assessment Activity. If the gaze direction is to the front, it performs Familiarization activity. And if the gaze is directed to the door in back, the activities come to an end. The steps in each activity have been thoroughly depicted in the diagram.

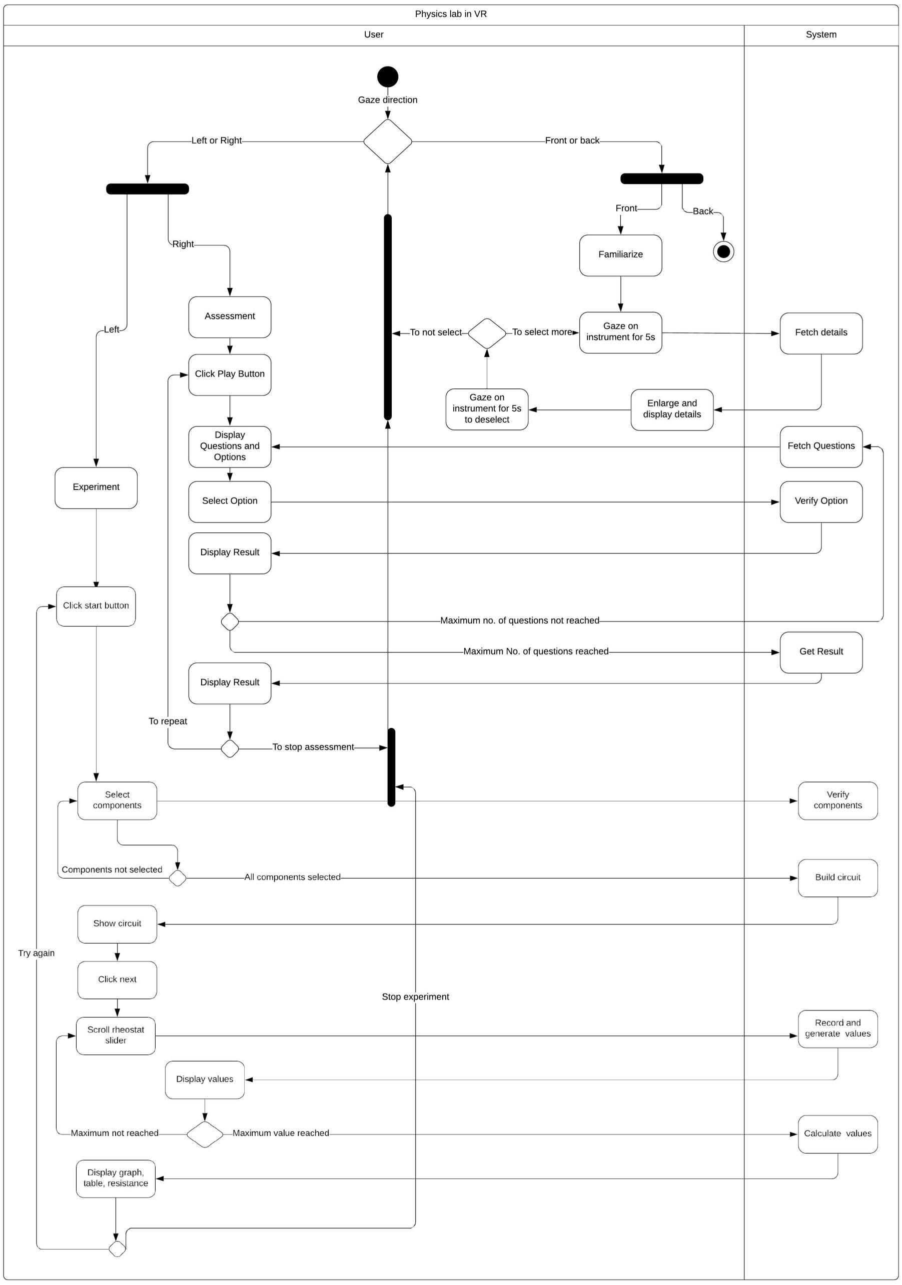

Figure 4.4: Activity Diagram

4.1.5 Component Diagrams

The Figure 4.5 shows the Component diagram of this Project. It is a type of UML diagram. In this, the user interacts with the VR application through VR Headset. In the VR application we provide three selections for familiarization, assessment and experiment and these components are associated with Unity and Blender.

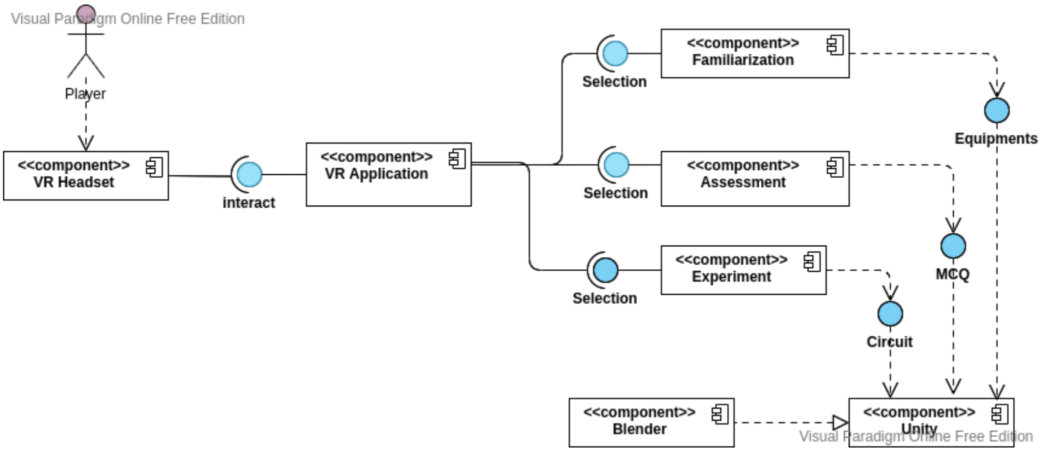

Figure 4.5: Component diagram

Chapter 5

Database Design

5.1 Data Dictionary

Figure 5.1 depicts the data dictionary of the database used in this project. There are four tables - user, questions, score and instrument. User stores the name, and user id of the students. Questions table stores each of the questions, their options and correct answers. The score table stores the scores of the user. Each row is uniquely identified by the user id and the time stamp. The instrument table stores the name and description of each instrument.

Column	Data_type	Constraints	Description
user_id	string	primary key	It is the unique id for the USER table
name	String		It is the name of the user
Question_id	int	primary key	It is the Unique id of the QUESTIONS table
Question	String		Questions for the assessment section
option1	String		Option1 of the question
option2	String		Option2 of the question
option3	String		Option3 of the question
option4	String		Option 4 of the question
correct answer	String		Correct answer of the question
User_id	String	primary key	It is the foriegn key which connects to user
time_stamp	time_stamp	primary key	Timestamp of when the student completes the assessment
Score	integer		It is the total score of the student
instrument_id	String	primary key	It is the primary key of the INSTRUMENT table
instrument_name	String		Name of the instrument
Description	String		Details about the instrument

Figure 5.1: Data dictionary of the data base used in the system; each colour depicts different entities

5.2 ER Diagrams

The Figure 5.2 depicts the ER Diagram of this project. It shows the relationships of entity sets stored in the database. The user interacts with the data sets stored in the database. In this, there is a user entity with attributes Id and Name. Here, Id is used as the primary key. The User entity is related to "Score" and "Question Set" entities on the basis of answered questions. The score entity have attributes User ID, Timestamp and score with User Id and timestamp set as primary key. The Question Set have the attributes Question, Option1, Option2, Option3, Option4, correct option and Q.No where Q.No is used as primary key. The user entity is also related to instrument details on the basis of familiarization. This entity have the attributes id, name and description with id as primary key.

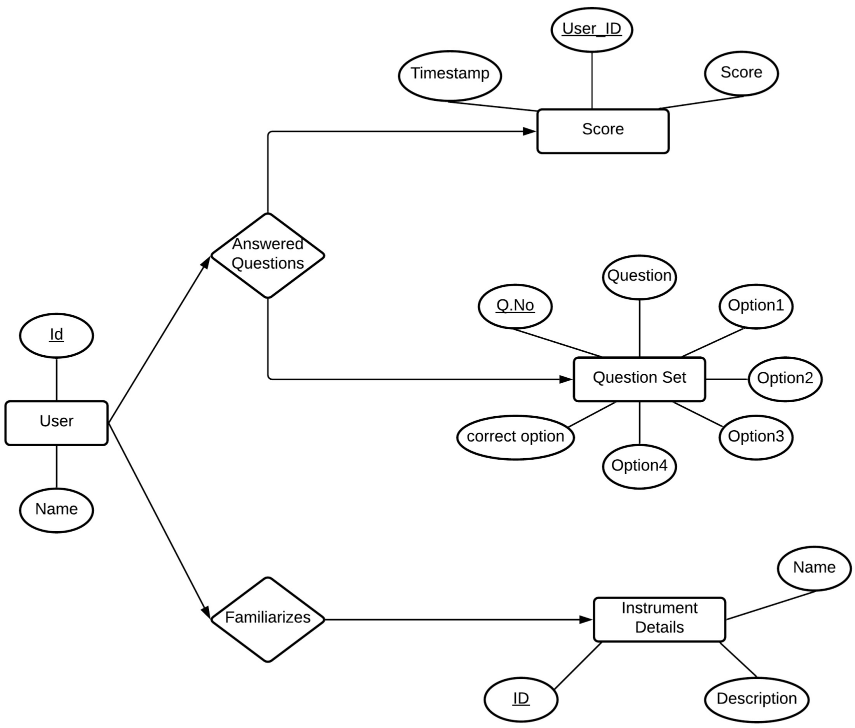

Figure 5.2: ER Diagram

Chapter 6

Experimental Results

We completed all objectives we had set at the beginning of our project. The completed application was validated by using a video demo and a questionnaire distributed to the target group. The questionnaire for students included questions about the existing system and how they think this VR lab will compare as a study aid. The questions were:

1. Practicals useful for better understanding the concepts taught in theory classes.
2. In offline labs, do you get chance to do experiments when you are in a group.
3. Do you like learning through a game?
4. The current method of learning laboratory through Google meet or Zoom is effective
5. Using a 3D medium(Virtual Reality) will be more effective than using 2D medium(Textbook) to learn lab works.
6. Familiarizing with equipment in this application will be more useful than 2D applications.
7. Do you think assessment section is useful?
8. How do you rate the user friendliness of this app?
9. How likely are you to use this app to practice lab experiments?
10. How would you rate the overall application?

We got 31 responses from students from different walks of life. 77.4% students strongly agreed that the practicals are essential for understanding the concepts in theory class. 19.4% students agreed on the same. 3% stayed neutral. 41.9% of the respondents said that they always get a chance to do experiment even when they are in a team. 12% disagreed with this and 45.2% responded that they sometimes get an opportunity to do experiments while in a group. 93.5% of the respondents said that they would like to learn through a game environment and the rest of them responded that they would like this method sometimes. 32.3% students strongly disagreed that the current method of learning through Google Meet or Zoom is effective. 35.5% disagreed on the same, 16.1% stayed neutral, 9.7% agreed and 6.5% strongly agreed that current methods are effective. 54.8% of the responses strongly agreed to the sentiment that 3D medium like virtual reality will be far more effective than 2D mediums to learn lab works. 35.5% agreed to this. 9.7% stayed neutral. 45.9% strongly agreed to the superiority of the familiarization of equipment in the VR application over more traditional 2D applications. 41.9% agreed to this opinion. 16.1% stayed neutral. 83.3% of the respondents felt that the assessment section will be useful and 16.7% responded with a maybe. 48.4% of the students gave a 5 out of 5 rating for the user friendliness of the application. 35.5% gave 4 out of 5 rating and 16.1% responded with a 3 by 5 rating. 41.9% strongly agreed that they would use the application to practise the lab experiments, 45.2% agreed to this point of view. 9.7% stayed neutral and 3.2% did not believe they would do so. 45.2% of the respondents gave a 5 out of 5 rating for the overall application, 29% gave a rating of 4 by 5. 12.9% responded with a 3 by 5, 3.2% responded with 2 by 5 rating and 9.7% responses where 1 by 5. The figure 6.1 shows a

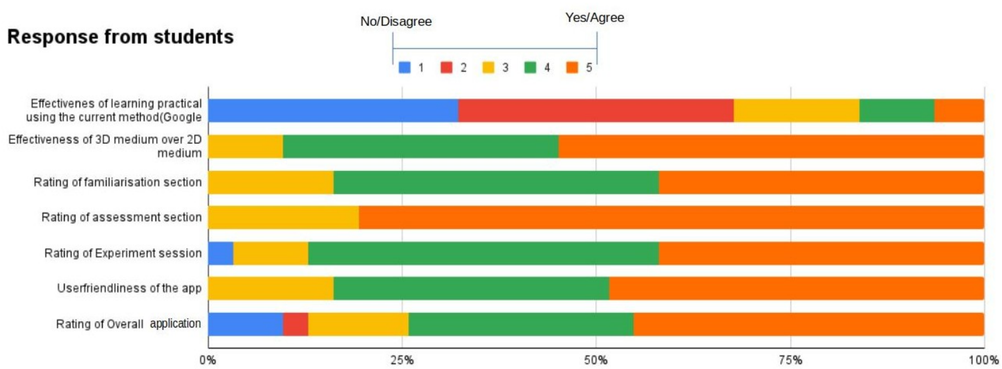

Figure 6.1: Response from students.

graphical representation of the responses of the most salient questions.

The questionnaire for teachers included questions which collected their opinion of this new technology used as a teaching aide and also collected their suggestions for future improvements.

The questionnaire for teachers:

1. The current method of performing laboratory through Google meet or Zoom is effective.

2. Using a 3D medium will be more effective than using 2D medium to learn lab works.

3. During offline lab, each student gets equal opportunity to do experiments.

4. Familiarizing with equipment in this application will be more useful than 2D applications

5. How likely are you to use such applications as an aide to teaching physics lab

6. How do you rate this overall application

11 teachers and physics experts responded to the survey. 9.1% strongly agreed and 45.5% agreed that the current method for performing the laboratory experiments through google meet or zoom is effective, 27.3% stayed neutral, 9.1% disagreed and the rest(9.1%) strongly disagreed to this opinion. 27.3% of the experts strongly agreed that using a 3D medium will be much more effective than using a 2D medium to teach lab experiments. 63.6% also agreed to this sentiment while 9.1% stayed neutral. 27.3% strongly agreed that each student gets equal opportunity while doing lab experiments. 36.4% agreed to this view, 18.2% were neutral and the remaining 18.2% disagreed. 54.5% agreed that familiarization of equipment in this application is more useful than the same in 2D media. 36.4% strongly agreed to these sentiments while 9.1% disagreed. 54.5% of the teachers strongly agreed that they are likely to use such VR applications as an aide while teaching physics lab, 18.2% agreed to this idea, another 18.2% stayed neutral and 9.1% strongly disagreed to this. 45.5% rated the overall application a 5 by 5, another 45.5% rated 4 by 5 and 9.1% rated 3 by 5. The figure 6.2 contains a graphical representation of the most important and relevant questions from the expert's questionnaire.

From the survey, we came to the conclusion that there is most definitely a need for interactive VR teaching aids for Laboratories. Students feel that they will learn more effectively with such tool, especially in the existing

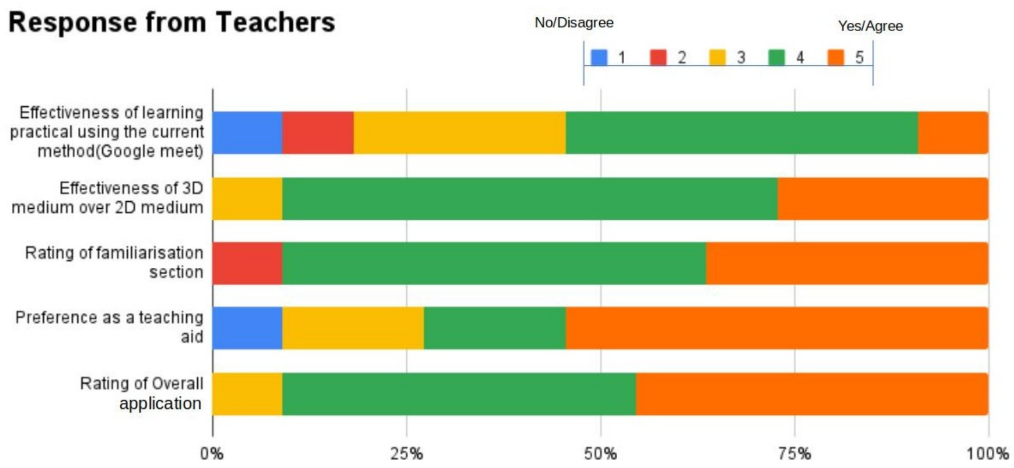

Figure 6.2: Response from teachers.

Covid pandemic situation due to lack of physical lab opportunities. Students truly believe that they are being held back from their potential in laboratory learning due to lack of proper learning tools. Teachers do not completely agree to this view but they firmly agree that such tools will be an asset to the educational system. Both students and teachers seem to be very receptive to a 3D medium as an education tool. A lot of students feel that they will be able to study more effectively using this application. Over 50% of the teachers also firmly agreed to the merits of using this application as a teaching aide. Overall there is a positive reception for this application.

Chapter 7

Conclusions and Future Work

7.1 Conclusions

Virtual Reality has a huge scope in the education sector. As we conclude our project, we have completed all our project objectives. We have successfully created a working prototype which can be considered as the first step to many laboratories in immersive virtual reality technology. We have successfully validated our application. Majority of the respondents to the survey had a positive response to this project. 74.2% of the students appreciated the project. 72.7% of the teachers responded that they would use this application as a teaching aide.

7.2 Future Work

In the future, we can increase the interactions of the student with the VR environment, especially in the experiment section. We can also add background sounds to make the VR environment more realistic and immersive. There can also be a companion web app which can be used by the teachers to add more questions to the database of the assessment section. Another suggestion is to include a tutorial for the experiment, which explains the theoretical aspects. Machine learning algorithms can be incorporated for experiment assessment. This project can be developed further to add more experiments and extend it to more subjects.

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