High School Chemistry Lab Simulation in Virtual Reality

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***Abstract*—Virtual reality (VR) has emerged as a potent tool for enriching educational experiences because of the quick development of technology. This paper presents a novel VR-based chemistry lab project designed to augment the learning environment in high school chemistry classrooms. The aim of the project is to provide students with a realistic and immersive laboratory experience, enabling them to explore chemical concepts in a safe and engaging manner.**

The VR chemistry lab incorporates a wide range of interactive simulations and experiments, closely aligned with the high school chemistry curriculum. Through the use of immersive VR headsets and interactive controllers, students can manipulate virtual apparatus, handle chemicals, and conduct experiments, all within a controlled digital environment. The incorporation of realistic physics-based interactions and accurate chemical reactions ensures an authentic laboratory experience.

This paper discusses the design considerations, development process, and pedagogical implications of integrating the VR chemistry lab into the high school chemistry curriculum. It highlights the potential of VR as a transformative tool for science education and encourages further exploration of immersive technologies in the context of chemistry education. The findings from this study contribute to the growing body of research on the application of VR in STEM education and hold promise for future advancements in educational practices.

***Index Terms*—virtual reality, chemistry education, high school, laboratory simulations, immersive learning, STEM education**

I. Introduction

This product shall aim to create a virtual environment for high school-level chemistry education to support students in learning chemistry using 3D model simulations. The system shall help students to learn in a safe environment before conducting real experiments. Students take more interest in learning by performing and observing the experiments in the chemistry laboratory which enhance and stabilize their learning capabilities. However, due to financial problems and other limitations most of the institutions cannot establish the chemistry laboratory, particularly in developing countries. The solution to these challenges is the use of Virtual Reality (VR) technologies in the educational learning process. This enables us to develop 3D virtual environments allowing users to have real-time interactions with computer-generated objects and perform the desired task while getting the illusion of reality.

II. Related Work

Due to deficient laboratories and a lack of equipment in laboratories in Turkey, Cengiz et al. developed a 2D virtual environment for chemistry education at the school level. Various experimental groups of students performed the experiments in this environment and the results were compared with habitual methods of teaching. They found that the use of a virtual laboratory had positive effects on students learning but there were no navigation techniques due to a 2D environment which is a less realistic environment.

Similarly, the Model ChemLab is also a virtual environment developed by Model Science Software Incorporation Canada. Model ChemLab not only allows users to simulate some chemical reactions but also trains them about the use of various apparatuses and chemicals. As the environment is 2D, the selection of an experiment, its apparatus and chemicals, and their required amount are made through menus and dialogue boxes which not only makes the interaction difficult but also lacks realism.

The VRAL (Virtual Reality Accidents Laboratory) is a 3D web-based virtual chemistry laboratory for undergraduate chemical engineering students. The VRAL was useful in guiding the students about the safety rules of the real laboratory. The VRAL could be used for students' training purposes in industry-level laboratories but is less relevant to the actual teaching experiments.

At Charles Sturt University a virtual chemistry laboratory has been developed. In this 3D environment, the students can work collaboratively. The students can only assemble and collect the pieces of equipment to know about the procedures of the real laboratory but there is no simulation of a chemical reaction. This 3D environment is useful only for students to train them for the real laboratory.

A 3D organic chemistry lab (VCL) for organic chemistry experiments demonstrated and explained the potential of VCL to improve student learning using advanced 3D interfaces. The VCL aimed to create a virtual 3D environment to interact with chemicals and conduct high-performance chemical experiments. High-school students evaluated VCL and found it to be beneficial for effective learning of organic chemistry [4].

Furthermore, a virtual organic chemistry lab can be used as an alternative to real chemistry labs, especially when it is impossible to establish and maintain a standard organic chemistry laboratory because of financial constraints (for example, in some schools). The nature of the virtual chemical laboratory—to try different ideas—makes the chemical practice effective and important, and it can be used to supplement and support existing schools and chemical laboratories. Therefore, science high schools are recommended to combine virtual organic chemistry laboratories with practical chemistry. For example, higher education science schools in Nigeria [5] do not have real chemical laboratories and virtual laboratories can be used to meet their needs.

In Jinkun et al. [6], a VR organic chemistry system was constructed using a wireless HMD and Leap Motion. The system used a wireless network to integrate servers and clients without additional wearables. The VR experience in organic chemistry Leap Motion training was used to detect position, and hand and finger motion data were sent to the VR server and the client. The virtual environment was shown in the user's view through the HMD. Using a smartphone with specific processing capabilities, users controlled their avatars in the virtual environment of an organic chemistry experiment by interacting with the virtual objects in real-time.

III. Methodology

A. Experimental Work

This study aims to assess the effectiveness of a virtual environment for organic chemistry experiments to support students in learning chemistry using 3D model simulations. The system helps students to learn in a safe environment before conducting real experiments. We used Unity 3D with C# programming to design and develop a chemical reaction simulation system in which users experimentally interact with 3D objects using a head-mounted display (HMD) and a hand controller.

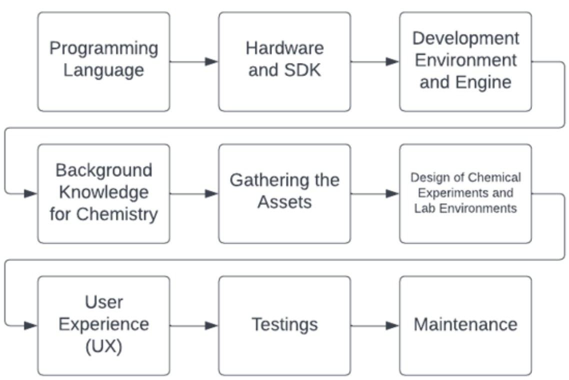

Fig. 1. Main steps of the project

1) Game Development Engine: Unity is an open source developer-friendly game development engine. Ease of use and convenience are important for Unity. So that's why the choice of game development engine for this project was decided to be Unity 3D.

2) Hardware and SDK: Most of the VR headsets in the market support OpenVR and SteamVR software kits for development and deployment. In Unity 3D, Both OpenVR and SteamVR are supported 100%. Since we wanted this project to be accessed by the audience of high school teachers and students, the choice of software will be SteamVR since it's easy to use and access.

3) Assets and Prefabs in Asset Store: This project requires chemical tools such as flasks, boilers, heaters, tubes, etc. In order to make sure that the project would work safely and securely, the assets and prefabs in asset stores were used to help create the 3D chemical laboratory environment, in addition to the objects that we designed with our own knowledge.

4) Background Knowledge for Chemistry: Since we are not chemists or chemistry teachers, we need background knowledge for certain chemical experiments that would occur in our project. We aimed to develop 2 different chemical experiments, the effect of the catalyst on the rate of reaction, and the dissolution of slump reactions. In order to develop these procedures, certain background research was conducted.

B. Development

1) VR Laboratory Scene: The figures below show an example of the interior design features displayed in the virtual chemical laboratory; figure 2 shows an exterior perspective of the virtual laboratory and figure 3 provides a first-person view of the interior setting. The scene was mainly imported from the Unity Asset Store, as well as the object that we have designed such as windows, drawers, flasks, heaters, etc, so as to simulate the real world as closely as possible. The developed system adopted a first-person camera perspective setting to deepen the users' perceptions of immersion in the virtual environment.

Fig. 2. Interior of the Lab Scene

Fig. 3. Exterior of the Lab Scene

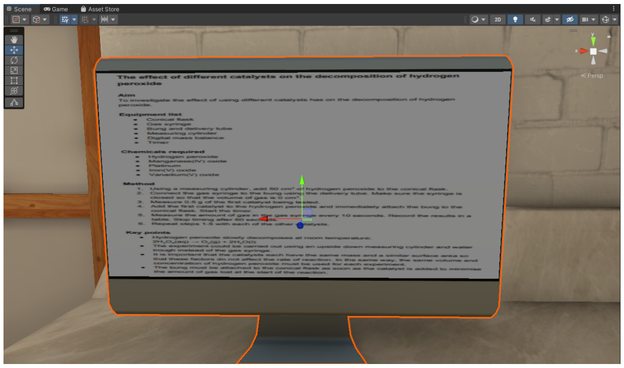

Fig. 4. Computer That Displays The Experiment's Procedures

The scene looks like a simple, real laboratory with chemistry laboratory equipment set on the table, as shown in figure 4, a computer displays the user guidelines or chemical reaction schemes that users can read before testing.

2) User Movement: In order to maintain user experience, certain scripts and plugins were necessary. Starting with the main VR plugin, SteamVR was the choice. SteamVR provides a huge library of prefab objects, built-in scripts, plugins and etc. To ensure that the user can move from one spot to another, we used built-in objects. In SteamVR, the "Teleport" function is a locomotion method that allows VR users to move around virtual environments without physically walking or using a joystick to control their movements.

When using the teleport function, a user aims a reticle or pointer at a location in the virtual world where they want to go and then clicks a button on the VR controller to instantly move to that location. The teleport function is often used in VR games and experiences to provide a smooth and comfortable way for users to navigate through the virtual environment without inducing motion sickness or discomfort.

The "Teleporting" object in SteamVR is a tool that allows developers to add teleportation functionality to their VR experiences. It provides a pre-built system for implementing the teleport locomotion method in a game or application and allows developers to customize the behavior and appearance of the teleport reticle and pointer.

The "TeleportPoint" object is a component in the SteamVR system that is used to define valid teleportation locations in a virtual environment.

When using the teleport function in SteamVR, the user can only teleport to locations that have been designated as valid teleport points. The TeleportPoint object is used to create these teleportation locations by placing the object at specific points in our virtual chemistry lab environment where the user should be able to teleport.

3) Object Interaction: The "XR Grab Interactable" script is a component in the SteamVR system that is used to make objects in a virtual environment interactable and grabbable. It allows users to pick up and manipulate objects using their VR controllers.

When an object is made interactable with the XR Grab Interactable script, it can be grabbed and released by the user using the grip button on their VR controller. The script also provides a variety of customization options to control the behavior of the object when it is being grabbed and moved around.

To ensure that chemical experiments can be done, certain objects such as flasks and tubes that contain ingredients and catalysts must be able to be grabbed or interacted with by the user.

With the help of specific scripts by C#'s UnityEngine library, physics rules can apply to the objects created in this project. Certain changes were made to the scripts such as changing the object's movement type. This change provides a smoother rotation and movement when the user moves their hand while grabbing the object. The "Rigidbody" function makes sure that the object has physics applied to it like in the real world. The "Collision Detection" method is changed to make sure that objects can collide with other objects in the environment. This script is modified for all objects that require this script.

4) Object Labeling: Object labeling in VR refers to the process of adding text or graphical labels to objects in a virtual environment. These labels are used to provide additional information about the objects, such as their name, function, or status.

Object labeling is a useful technique in VR because it can help users understand and interact with the virtual environment more easily. Labels can be used to highlight important objects, provide instructions or feedback, or indicate the location of interactive elements.

To ensure that the labels can and will only be seen when the user is interacting or looking at that object, a C# script called "ObjectLabel" has been developed. This label takes advantage of the Raycast library in C# that's specifically designed for Unity Engine.

Raycast is a technique used to detect collisions between a virtual object and other objects in the virtual environment. A Raycast is essentially a line that is projected from a point in space, in a particular direction, and which can detect if it intersects with any colliders in the scene.

A Raycast is commonly used in VR for various purposes, such as selecting and interacting with objects in the virtual environment. In our case, we used it to provide users with more information about what object they are about to interact with.

Figure 5 shows an example of a label for a flask that contains Nitrogen(II) Oxide.

5) Backend Scripts for Experiment: To ensure the physical effect of catalysts on the rate of a chemical reaction, certain scripts were developed. A catalyst is a substance that speeds up a chemical reaction by lowering the activation energy required for the reaction to take place. So, 3 different flasks with 3 different catalysts were created. To assign these catalysts different characteristics, a script called "CatalystController" was created. Each catalyst has different floating-point coefficients as an "effect" variable. Some of them have positive coefficients

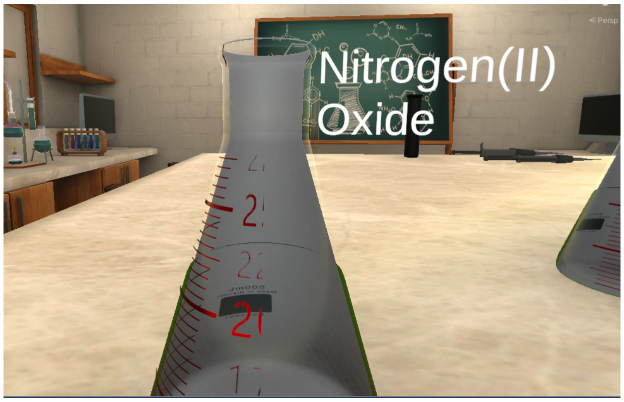

Fig. 5. An Example of Label For An Object

while some of them have negative coefficients. Therefore, catalysts with negative coefficients will slow the rate of the reaction.

For the chemical ingredients that will be in the chemical reaction beaker, a script called "IngredientController" has been developed. This script assigns each ingredient a base temperature value. These base temp values will be affected by the catalysts when catalysts enter the reaction scheme via using Collider provided by Unity.

For the heater, a script called "HeaterController" has been developed. This script class has 3 different member functions, the first one updates the heater temperature, the second one deals with the process of catalysts entering or exiting the reaction, and the third function deals with the process of ending the heating.

IV. Conclusion

The creation and inclusion of a virtual reality (VR) chemistry lab within the high school chemistry curriculum has proved to have significant promise for improving student learning. Students can participate in interactive simulations and experiments in the VR lab, which provides a realistic and immersive setting that helps them better comprehend chemical principles.

Through the use of VR headsets and interactive controllers, students are able to manipulate virtual apparatus, handle chemicals, and conduct experiments with accurate physics-based interactions and realistic chemical reactions. This not only provides a safe learning environment but also offers students the opportunity to repeat experiments, explore different scenarios, and visualize abstract concepts that are otherwise challenging to grasp in traditional laboratory settings.

The advantages of the VR chemistry lab extend beyond safety and accessibility. It addresses the limitations of physical labs, such as limited resources and time constraints, by providing a virtually unlimited supply of chemicals and apparatus. The immersive quality of the VR environment also increases student enthusiasm and engagement, which improves knowledge retention and conceptual understanding.

The VR chemistry lab initiative has produced positive results, according to preliminary reviews, with pupils expressing higher levels of interest and enthusiasm in chemistry. The evidence suggests that the VR lab experience improves students' problem-solving, critical thinking, and practical skills.

The design concerns, development procedure, and pedagogical effects of integrating a VR chemistry lab into the high school curriculum have been covered in this study. It emphasizes how VR technology has the power to revolutionize science education, especially in the study of chemistry. The good findings of this study stimulate future investigation and implementation of immersive technology in educational practices with the goal of delivering engaging and successful learning experiences to students.

The VR chemistry lab could be improved and expanded in future research, adding more experiments and features to cover a larger spectrum of chemistry topics. To gain a fuller knowledge of the advantages and constraints of virtual reality in high school chemistry instruction, further research into long-term effects and comparisons of the learning outcomes between VR-based laboratories and conventional hands-on labs are also necessary.

Overall, the incorporation of a VR chemistry lab is a novel strategy for educating and engaging high school students, allowing them to build a strong foundation in the topic and cultivating a lifelong interest in it. We can improve the inclusiveness, accessibility, and effectiveness of the learning environment for the scientists and problem solvers of tomorrow by utilizing the promise of immersive technologies.

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