Tomorrow's Classroom: Virtual Reality Chemistry Lab

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ABSTRACT
In the context of immersive technologies, the introduction of Virtual Reality (VR) in education opens up new perspectives for learning and teaching, allowing students to explore and interact with intuitively teaching materials and providing innovative ways to experience and understand complex concepts such as chemical reactions, the anatomy of the human body, the evolution of biological species, outer space, geological processes or historical events. This application shows how advanced technologies like VR can revolutionize the way students discover and understand information, allowing them to explore theoretical concepts visually and interactively. Through VR, theoretical notions become tangible and applicable, facilitating experiential learning that stimulates students' curiosity and active engagement. By creating a virtual laboratory, participants can directly experience the effects and dynamics of various chemical reactions without the risks associated with handling real substances. This approach not only increases student engagement and curiosity but also improves information retention and a deep understanding of chemical processes. Also, our solution shows how, by incorporating Artificial Intelligence algorithms in virtual environments, we can take the field of eLearning to a higher level.

Author Keywords
Virtual Reality; User experience; eLearning; Game Development; Natural Language Processing; Artificial Intelligence; guidance

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces. H.3.2. Information Storage and Retrieval: Information Storage.

General Terms
Human Factors; Design; Measurement.
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INTRODUCTION
VR has made remarkable progress in multiple fields, revolutionizing the education [1], medical [2], gaming [3] [4] and entertainment [5] sectors. By using VR, chemistry becomes more immersive, allowing students to conduct chemical experiments in a safe, controlled, isolated and harmless environment. Introducing elements such as educational games or incorporating voice-controlled chatbots into eLearning VR applications adds a new level of digital interaction, improving personalization and accessibility. These innovations make learning more engaging and effective, facilitating a deeper understanding and application of chemical concepts for diverse user groups. The use of VR in chemistry teaching enables interactive exploration and real-time visualization of complex chemical reactions, thus providing a deeper and more intuitive understanding of abstract concepts that are difficult to illustrate by traditional methods.

This application proposes a laboratory where users can carry out chemical experiments, being guided by a robot through both written and verbal instructions, this functionality can be found within the application under the name of *Learn to make reactions*, this being one of the three main functionalities of the application. Also, our solution aims to incorporate advanced speech recognition and natural language processing (NLP) technologies, by incorporating a chatbot, this functionality being called *Lab Assistant*. One last functionality that must be mentioned here is the evaluation one, *Test your knowledge*, where users can test their acquired knowledge: both theoretical notions (from the robot's explanations and from what they can see during the reactions), as well as practical ones, here being able to test if they have understood the stages of making the reactions. Our approach not only improves personalization over traditional VR applications, but also leverages the immersive environment of VR to facilitate deeper and more meaningful user engagement in the learning process. Our contribution includes the creation of a VR application incorporating a realistic and immersive chemistry laboratory and an advanced conversational agent, demonstrating their ability to effectively optimize the delivery of educational content and respond to users' curiosities and concerns, whether related to theoretical notions, either by the context of the application. Preliminary feedback confirms the effectiveness of our system in meeting diverse user requirements, laying the foundations for a more integrated and accessible digital future. The paper will detail the development of the system, its innovative architecture and key findings from preliminary user interaction.

EXISTING APPLICATIONS

VR Chemistry Lab
VR Chemistry Lab[1] is an application that supports a wide range

[1]https://sidequestvr.com/app/11063/the-vr-chemistry-lab

of chemical reactions, which can be used not only by pupils or beginners in this field but also by students or people with experience in chemistry who want to observe certain characteristics of some reactions. This application features a variety of tools, substances, and pH indicators. The application has a very high level of immersion, being very close to reality, through the natural course of reactions and offering specialized and complex equipment.

Unreal Chemist - Chemistry Lab

Unreal Chemist - Chemistry Lab[2] is a mobile application that allows you to perform chemical reactions with some remarkable visual effects. The main menu of the application offers two options: (1) choosing a reaction in which we combine two or more substances and (2) choosing a reaction that takes place in the presence of fire - most often, a decomposition reaction.

Chemistry Lab

Chemistry Lab[3] is also a mobile application, where the user can combine substances in a Berzelius beaker and see the equations of the chemical reactions displayed at the top of the screen. The user is permitted to subject the substance or substances in the Berzelius beaker to heating by exposure to a flame, likely equivalent to that produced by a Bunsen burner. The present application provides a variety of liquid, solid and gaseous substances. A weak point observed in this application is the lack of sounds and high-quality graphics and animations, which could have provided a more engaging and interactive experience for users.

BEAKER - Mix Chemicals

BEAKER - Mix Chemicals[4] is a mobile application similar to the previously mentioned, Chemistry Lab, but with a captivating and intriguing concept. Here there are no glasses, test tubes or containers, but the application places the user from the start inside such a glass. The first impact with the application is a black screen, but with two easily identifiable white graphics at the top of the screen. These elements represent navigation buttons: one for selecting a physical component (the square with three horizontal lines in the middle, resembling a shelf) and one for selecting chemical elements. The first leads to a screen where a lid (to prevent the loss of gases and the flow of substances) or an incandescent wire (symbolizing a heat source) can be selected in the free version. For a fee, utensils such as matches, AirMix, a Meter, a filter, a separator, a cooler, and a blender can be unlocked. This category also includes access to another application, in which much more diverse and complex reactions can be performed. Acting on the second element leads to the archive of available substances arranged alphabetically, all available for free. A new element is the fact that the current application can detect the physical orientation of the device in space and act accordingly.

[2]https://play.google.com/store/apps/details?id=com.PixelMiller.UnrealChemist
[3]https://play.google.com/store/apps/details?id=com.VNS.ChemistryLab
[4]https://thix.co/beaker
[5]https://chemcollective.org/

In other words, if we turn the phone upside down in the main interface, the substances will flow out of the glass or be stopped by the lid.

ChemCollective

ChemCollective[5] is a web application used to teach and learn chemistry. It contains a collection of virtual labs, scenario-based learning activities, tutorials, and tests. Teachers can use the content of this application as an alternative to textbook assignments and for individual or team classroom activities. Students can review and learn chemistry concepts using the provided virtual labs, simulations, and tutorials. In these labs, users are asked to solve a problem in a practical way (for example, determining the concentration of a silver nitrate solution or examining the solubility of a salt) using the materials and utensils available. The application offers a wide range of types of reactions that can be performed. In other words, the user can perform a reaction in the fields of stoichiometry, thermochemistry, kinetics, chemical equilibrium, reactions between bases and acids, oxidation/reduction reactions and electrochemistry, analytical chemistry and laboratory techniques, physical chemistry, and properties of solutions.

The analysis of similar applications provided valuable insights into best practices and innovations needed to create an effective and engaging learning experience. In this context, the architecture of our application has been carefully designed to integrate new elements and to specifically address the needs and challenges encountered in learning chemistry through Virtual Reality.

ARCHITECTURE

The application consists of three main functionalities:

1. The "*Learn to make reactions*" part, in which the user will be guided in learning by a robot through written and verbal instructions that will explain step by step what the stages of making the reactions are. In this part, the user can learn to perform reactions such as combination, decomposition, simple substitution, or neutralization reactions. The experiment you want to perform can be chosen from the book that is initially on the desk next to the work table. To choose the experiment, the user can navigate through the content of the book until he reaches the desired chemical reaction, represented here in the form of the chemical reaction equation. From the moment the user presses the "Play" button, the necessary substances and utensils will appear on the table and the robot will start giving the appropriate instructions. In Fig. 1 you can see the book and the work table with the chemical substances needed to carry out the chemical reaction with natrium and water. The users will receive constant feedback, and this is represented by the animations that can be visualized in the different stages of the realization of the experiment - the change of colors, the

release of different gaseous substances, the boiling effect or the explosive effect, but also by the interventions of the robot, written and verbal, through which are confirmed to us the achieved stages and the next stages are explained to us. An important thing to mention is that users cannot make mistakes in performing reactions; even if they spend more time pouring a substance, the application will automatically adjust the amount to the correct one.

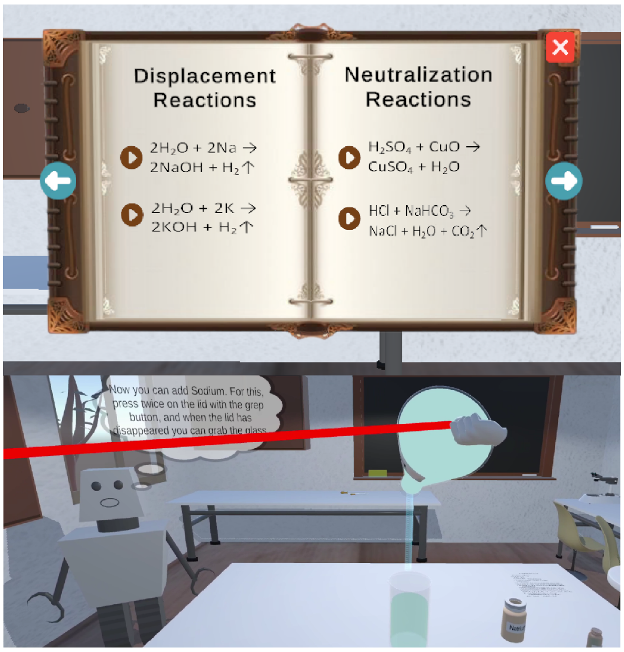

Figure 1. ***Learn to make reactions*** **part.**

2. The "*Test your knowledge*" part, where the user can test how well he understood and memorized the concepts presented in the previous part. From the main scene, the user can select which types of tasks he can receive (theoretical or practical, or both), and when he enters the evaluation part, he will have 60 seconds to complete the task. Fig. 2 shows what a theoretical task looks like and what a practical one looks like. If, in a theoretical task, the user ticks the wrong answer, then the selected answer will be red, and if he ticks the correct answer, the answer will be green. In the case of both types of tasks, if the user will not perform the task in the allotted time, then it will skip to the next task. For both types of tasks, if the user does not know how to solve the task, then it will be up to him to return to the "*Learn to make reactions*" part for fixing the concepts.

Figure 2. ***Test your knowledge*** **part.**

3. The "*Lab Assistant*" part, where the user can talk to a virtual assistant on topics related to chemistry: he can ask questions about the application, about the stages of a chemical reaction or about other theoretical notions in chemistry. The virtual assistant will provide both written and verbal answers. It was made using the tool from Inworld.AI[6]. Inworld.AI relies on advanced NLP techniques such as semantic analysis, natural language processing through neural networks (including transformation models like BERT), entity recognition and sentiment analysis to provide accurate and tailored suggestions to the specific context of the text. These techniques enable the identification of linguistic nuances and text structure, thereby optimizing content for clarity and impact.

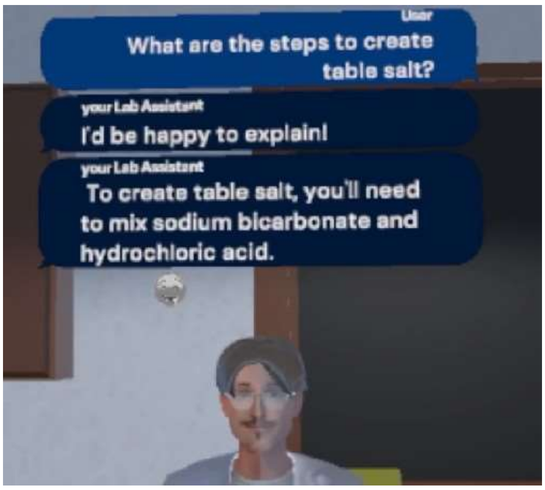

Figure 3. ***Lab Assistant*** **part.**

[6]https://inworld.ai/

TECHNOLOGIES USED

1. Unity[9] game engine was mainly used in the development of this application. Unity is the most popular game engine in the world for reasons such as its powerful tools, its excellent learning curve its ability to develop games for many platforms, like desktop (Windows, Mac, Linux Standalone), mobile (iOS, Android), console, Oculus, PlayStation VR, and other AR/VR devices. Unity supports 2D and 3D graphics, AR/VR/XR visualizations, and scripting in three languages, including C#, JavaScript, and Boo. Among the used Unity packages, you can also count the XR Plugin Management, XR Interaction Toolkit, OpenXR Plugin, Inworld.AI, or Shader Graph.
2. Blender[10] is a free and open-source 3D creation suite used for creating animations, visual effects, art, 3D-printed models, motion graphics, interactive 3D applications, virtual reality, and, formerly, video games.
3. Meta Quest[11] 2, also known as Oculus Quest 2 before Facebook rebranded the company as Meta, is a standalone VR headset that works independently without requiring a connection to a computer or game console. Launched in October 2020, it is one of the most popular VR devices on the market due to its combination of high performance, portability, and affordability.

USABILITY TESTS

In order to evaluate how intuitive, efficient and easy to use application is for users, usability tests were conducted involving people with a wide range of technical skills and minimal knowledge of chemistry.

The evaluation was organized in two distinct phases to ensure a comprehensive analysis. Participants first completed a pre-questionnaire in which they were asked to provide demographic information and previous experience with technologies relevant to the study and were then introduced to the application's capabilities through detailed accelerator sessions supplemented by video tutorials designed to provide a solid understanding of how to interact with the chemistry laboratory and virtual assistant in the VR environment. These individuals were then invited to interact directly with the virtual assistant and the lab, both training and knowledge testing, using the Meta Quest 2 headset to navigate the virtual environment and experience its features. Their experiences and impressions were then captured through post-questionnaire, allowing us to effectively assess application usability and overall user experience.

The usability tests were structured to cover three distinct modules: the experience with Learn to make reactions, the experience with Test your knowledge, and the interaction and conversation with the Lab Assistant.

This approach allowed the comprehensive evaluation of every aspect of the application. By dividing the usability tests into these three modules, we ensured a thorough evaluation of the application's main functionalities, capturing detailed feedback about the users' experience and their interaction with the virtual environment of the laboratory.

Our evaluation methodology for the VR laboratory involved a simplified four-part process:

- collecting demographic and experience information to better understand who the participants are,
- introducing participants into the system,
- engaging them in VR using Meta Quest 2,
- collecting feedback through a post-test questionnaire.

To understand the user experience at different skill levels, participants were divided into technical and non-technical groups, allowing a focused analysis of the use and dynamics of interaction with the application. Two groups were involved: 5 people with technical knowledge (including VR knowledge), and 5 non-technical people. Their feedback is presented in the Table 1.

Opinions	Technical	Non-Technical
Found the application to be an engaging way to learn and receive information in the chemical field	X	X
Believe that the system can be easily updated with new information and features	X	
Exploring the VR environment felt challenging initially		X
The system user-friendly and intuitive	X	X
Performed the chemical reactions with difficulty		X

Table 1. Opinions of Technical and Non-Technical Participants.

In the following, use cases, methodology, completed tasks, and remarks for each module will be presented.

Learn to make reactions

Use-case: The first interaction of users with the application is with the *Main Menu Scene*. Here he will interact with the main menu, which will lead the user to a scene where he can start exploring the virtual world of the chemistry laboratory. Thus, by pressing the *Learn to make reactions* button and entering the appropriate scene, the use-case is:

[9] https://unity.com/
[10] https://www.blender.org
[11] https://www.meta.com/quest/products/quest-2/

- Open the book → Navigate through book → Select the desired reaction → Perform the reaction according to the robot's instructions → Repeat.

Methodology: The evaluation methodology used for the Learn to make reactions module involved a three-part process: (1) explaining the interactions and how the instruction will unfold, (2) engaging users in VR using the Meta Quest 2 to explore the chemistry laboratory environment with VR controllers, and (3) gathering feedback through a post-questionnaire.

Performed tasks: In the tasks performed, the participants paid attention to the instructions provided by the robot and interacted with the chemistry book and the substances. In some situations, they were also asked to test the pH of the resulting solution.

Remarks: Both groups expressed their satisfaction and enthusiasm in interacting with the *Learn to make reactions* part. The technical group found the controls easily, while the non-technical participants had some difficulty. Also, some non-technical participants realized the reactions with a little more difficulty compared to the technical participants. Some participants reported dizziness, a common problem with VR systems, while others reported headaches, eye pain, or even motion sickness. Feedback from these sessions is critical to ongoing development efforts, ensuring that the proposed solution not only meets current standards in education but also anticipates future needs and trends.

Results: To the question "*How hard was it for you to do the chemical reactions*?" 10% of the answers were neutral, 20% of the participants made the reactions easily, and 70% very easily, and to the question "*How would you describe your experience with Learn to make reactions part*?" all the answers fall into the "Very good" category. Also, all respondents stated at the end of the test that they were able to learn at least one chemical reaction among those performed and that they could more easily identify the substances they saw and used while using the application.

Test your knowledge

Use-case: By pressing the button Test your knowledge from the Main Menu and entering the appropriate scene, the use- cases are:

1. Receive a new task
2. For a practical task, perform it within time. If the task is completed successfully, the user will receive a score.
3. For a theoretical task, select the answer within time. If the answer is correct, receive a score.
4. Move to the next task.

Methodology: The evaluation methodology used for the *Test your knowledge* module involved a three-part process: (1) explaining how tasks will be received and how they are intended to be completed, as well as mentioning that can select theoretical, practical, or both types of tasks, (2) engaging users in VR using Meta Quest 2 to explore the chemistry laboratory test environment with VR controllers, and (3) collect feedback through a post-questionnaire.

Performed tasks: the participants received both practical and theoretical tasks, having to remember the stages of making reactions as they learned in the *Learn to make reactions* part, but also to remember the theoretical notions from the explanations provided by the robot or from what they visualized during the experiments.

Remarks: Both groups expressed their satisfaction and enthusiasm in interacting with the *Test your knowledge* part. The technical group managed to complete the reactions in the available time several times, while the non- technical group did not manage to finish all the reactions given as a task. On the other hand, all the participants managed to answer the theoretical questions, many of them even managing to give the correct answers, thus memorizing the information that was delivered to them in the *Learn to make reactions* part.

Results: To the question "*How would you describe your experience with Test your knowledge part*?" all the answers fall into the "Very good" category.

Lab Assistant

Use-case:By pressing the button *Lab Assistant* from the Main Menu and entering the appropriate scene, the use- cases are:

- Open the book → Navigate through book → Select the desired reaction → Perform the reaction according to the robot's instructions → Repeat

Methodology: The evaluation methodology used for the Learn to make reactions module involved a three-part process: (1) explaining the interactions and how the instruction will unfold, (2) engaging users in VR using the Meta Quest 2 to explore the chemistry laboratory environment with VR controllers, and (3) gathering feedback through a post-questionnaire.

Performed tasks: In the tasks performed, the participants paid attention to the instructions provided by the robot and interacted with the chemistry book and the substances. In some situations, they were also asked to test the pH of the resulting solution.

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CONCLUSION

The development of this application started from the identification of some problems in the teaching and learning of chemistry in schools, among which are the lack of attractiveness of the field among students, the small number of practical chemistry hours, the risk caused by the handling of dangerous substances and the dependence on the existence of a laboratory or a suitable environment. As new elements, the application proposes the integration of a chatbot to answer users' questions, as well as the guidance part that facilitates the learning process of a chemical reaction or the evaluation part.

FUTURE IMPROVEMENTS

We have proposed to continue the development of this application by implementing an interactive Periodic Table. It involves displaying more information related to the selected chemical element, including a 3D model containing the nucleus formed by protons and neutrons, as well as the electronic shell made up of the orbitals specific to each element. Other displayed information could be represented by a short history of the element, serial number and atomic mass, its radioactivity and so on.

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