"ALEXANDRU IOAN CUZA" UNIVERSITY OF IASI

FACULTY OF COMPUTER SCIENCE IASI

BACHELOR'S THESIS

Experimenting with Chemical Reactions in Virtual Reality

by

Alina Duca

Session: July, 2024

Advisor

Prof. Dr. Adrian Iftene

Colab. George-Gabriel Constantinescu

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Contents

Motivation

I chose this topic for my bachelor's thesis because of my particular interest in this subject, namely chemistry. Ever since middle school I have been fascinated and captivated by how substances can interact, giving rise to other substances with completely different properties. The central question that guided the development of this application is: *"How can I make learning chemistry an engaging experience for students?"*. Thus, the development process of this application was guided by creating an interactive and educational experience that would stimulate curiosity and facilitate understanding of the complexity of chemistry.

This application provides a perfect visual interface and framework for conducting chemical experiments in a safe, protected, isolated, and harmless way for both the environment and the experimenters furthermore allows experiments to be carried out anywhere without being restricted by working in a laboratory, with specific equipment. Furthermore, I chose an E-Learning theme because I desired to provide an interactive, enjoyable, and easy-to-use way to facilitate the learning of this vast and captivating field, this application particularly stands out because the concepts learned can be repeated by the user for fixation and reinforcement, that users can get used to the experiments before they are faced with the need to perform them themselves, that in the first phase, users will be guided step by step to learn the stages of carrying out a reaction, or they will be able to receive answers to any concerns or curiosities.

The application consists of three parts, each of which is located in the chemistry laboratory:

- The *Learn to make reactions* part, in which the user will be guided in learning and will be explained step by step what are the stages of making the reactions.
- The *Test your knowledge* part, structured in the form of a game, in which the user will be able to test his accumulated knowledge, to see how well he has assimilated the notions and stages of making certain reactions, and based on this he will

be given a score. The score will be given depending on how quickly the tasks are completed. If the time allotted for the task ends, then the user will receive 0 points for that task and will move on to the next stage. Based on the points obtained in this part, the user will be able to unlock new reactions from the learning stage.

- The *Lab Assistant* part, where the user will be able to ask questions in the field of chemistry or related to the context of the application and where he will receive the answers from a character using AI.

In summary, I believe that learning chemistry can be fascinating, and full of remarkable and interesting discoveries, but sometimes it is difficult for students to discover this side because of the uneven balance between theoretical and practical aspects. Thus, the present application constitutes a chemistry laboratory where the user can learn to perform chemical reactions and experiments. It also offers the possibility to visualize the consequences of these reactions, such as color changes when a chemical base interacts with phenolphthalein, or the violent and exothermic reaction of alkali metals with water, accompanied by the release of H_2.

Introduction

1. Existing Work

The history of Virtual Reality (VR) dates back to the 1960s, and the platform originally built was used for both VR and AR. This incorporated a transparent head-mounted optical display that could be mechanically or ultrasonically monitored. While Augmented Reality (AR) involves a dynamic, three-dimensional interaction, a computer-generated world over views of the real world, Virtual Reality (VR) presents an autonomous computer environment, a completely computer-generated world. [4]

The two technologies are booming with huge potential to revolutionize learning in many fields, according to source [1]. A trend of introducing AR/VR technologies into the educational process has been noticed in recent years, coming as a complement to the theoretical notions taught in the classroom. In this section, the existing work will be reviewed and some conclusions will be drawn on the impact that the technologies under discussion have in eLearning, by discussing some applications.

By eLearning is understood the totality of educational situations in which the means of information and communication technology are significantly used.[1]

In the article [6], a study was carried out whose purpose was to explore the perceptions, experiences, and behaviors of 62 middle school students in the state of Colorado about the use of VR technology in the process of learning chemistry. The first question from which this research started is: "What are the perceptions of middle school students towards the use of VR technology as a learning tool in chemistry?". The results and findings indicated that the use of VR as a tool for learning chemistry was positively perceived by middle school students, with no gender differences.

Thus, the 21st century has witnessed an enormous transformation in the way education is delivered. The association of education and technology has proven to

[1] https://www.elearning.ro/elearning-repere-conceptuale

produce excellent results across the globe. VR technology has gained attention as an educational and training tool to provide learners with a safe, enjoyable, and flexible learner-centered environment. The integration of digital skills into educational systems has become a necessity for students, representing some essential skills to survive in the future market, society, and the world in general.

Virtual Reality has 3 main features that provide opportunities for constructive, student-centered learning:

- immersion
- interaction
- imagination

VR eLearning applications provide an innovative way to acquire new knowledge in scientific fields. Thus, within an educational process of teaching a subject such as chemistry, advanced technologies can be effectively used to provide additional information or even to reinforce experiences and information of a practical nature. A favorable aspect of these technologies is that they provide a student-oriented space in terms of the educational field.

According to source [1], "From the age of 14, children have chemistry classes, and the concepts often seem difficult to understand. In this context, AR/VR applications come to the aid of students, relying on visual elements that help to understand concepts and aim to improve the learning process." This article presents the ARChemistry Learning application, in which the user can learn information about substances by positioning the smartphone camera on the name of a chemical element. The application has four main functionalities: (1) Learn with the manual, (2) Learn with the cards, (3) Test your knowledge, and (4) Add a substance.

As mentioned in source [2], in eLearning, the combination of classical and virtual content (the latter coming with 3D models, animations, images, and sounds) can help the teacher to better explain the content of the courses. The need to introduce advanced technologies in education has been noted by texts such as Morton Heiling's patent for Sensorama, in which it is described as a solution for teaching, training, and educating people in various fields, or the pioneering work of Caudell and Mizel.

Source [2] presents four AR applications, among which are two games and two eLearning applications in biology and geography. The games presented here are meant to develop communication and teamwork skills while eLearning applications come to offer an attractive and interactive way of teaching. The reason for creating these types of apps is to make classes more engaging and to allow students to process and accumulate new information more easily. Also, the source in question emphasizes that it is not desired to completely replace the current educational means, but only to improve them by adding some helpful elements, given that the pedagogical past is a rich resource for the future. AR technologies have huge potential to provide a useful context for education, enabling learning and discovery experiences connected to real-world information, and facilitating learning away from traditional classroom spaces, so that physical presence is not required for the educational act.

From another perspective, as highlighted in article [4], chemistry is a difficult subject to learn, given the fact that it consists of a series of formulas that must be memorized. Moreover, there is a lack of practical implementation in the teaching of chemistry in schools, and in the context where chemical reactions are difficult to understand only by reading the textbook, the study of chemistry becomes a challenging one.

The invention of augmented reality has revolutionized the way we live, work, and play, and thus, the solution that the article [4] comes up with to this problem lies in AR/VR technologies, as it helps to obtain a 3D view of chemistry concepts, the way through that students can learn difficult concepts easily and improve their knowledge, which can help strengthen their understanding of chemistry concepts. Digitized graphics components such as audio or other digitally transmitted sensory stimulation create an augmented rendering of the real physical world, which facilitates the educational process.

In the same article, an AR application for interactive learning of chemistry from school textbooks is described, helping to learn concepts by visualizing patterns and reactions rather than simply reading from traditional textbooks. By using augmented reality to render models, the educational process is simplified and students are encouraged to understand abstract concepts. The application described here is made with the Vuforia library, Blender for 2D and 3D graphics, and Unity, with the System Development Life Cycle technique, and is designed on the Android platform for a mobile AR system (smartphone or tablet). It is based on high school chemistry textbooks and uses registered markers. To simplify the educational process and help students understand complex concepts, visualization of difficult topics has been resorted to by incorporating videos and other multimedia materials. Notions that can be visualized are molecular models, bonds between atoms, or atomic structures. The application was tested on 110 people, of whom 74.5% strongly believe that the introduction of AR technologies as a chemical study tool is effective, 13.6% agree, and the remaining 11.8% were neutral.

In source [5] a very strong emphasis is placed on pedagogical principles and theoretical foundations that support effective education. Interactive and immersive environments can effectively teach fundamental chemistry concepts such as chemical bonds and formulas, making these otherwise abstract and intangible ideas more accessible and understandable.

While online platforms have gained popularity, they are limited by 2D displays. This limitation decreases the level of engagement and immersion for students who want to understand complex concepts. To address these challenges, researchers have turned their attention to Virtual Reality.

Chemistry is very often considered one of the most difficult and least popular subjects among students, and thus, the present study came up with the solution of a virtual chemistry classroom to facilitate the learning of chemical bonds and formulas for middle school students. In other words, a chemistry classroom based on virtual reality was proposed to facilitate the educational process through a game-based learning approach. The application called **Virtual chemistry classroom for chemical bonding for remote education** (VC3B), includes two different games to learn chemical bonds and formulas. The first game, *Molecule construction*, asks students to reconstruct the structure of molecules by rearranging atoms, and in the second game, *Chemical formula*, students compose the chemical formula of a chemical compound to memorize the chemical formula. These games are designed to facilitate learning about chemical bonds and formulas respectively. As proposed games, our approach to integrating gamification elements such as scores, leaderboards, feedback, rewards, and progress tracking improves student engagement, motivation, and active participation by providing immediate feedback and enabling an individualized learning path.

The app incorporates pedagogical principles of constructivism, critical thinking, reflection, feedback, active engagement, differentiation, assessment, and problem-solving, thus providing a pedagogically sound learning experience. The TPACK model, which intersects technological, pedagogical, and content knowledge, played an essential role in the design process.

The system in question was created with Blender and Unity, was designed on the Oculus Quest 2, and has 10 chemical elements incorporated, each on a different level.

The testing took place on 90 middle school students and it was observed that the participants were motivated to learn and improve their knowledge. VC3B has been observed to have the ability to significantly improve students' thinking and problem-solving skills, thereby effectively contributing to the overall effectiveness of game-based learning.

A comprehensive understanding of abstract chemical notions is crucial for learning chemistry, considering its fundamental role in fields such as medicine, the pharmaceutical industry, or the food industry, so many VR-based applications have been developed to facilitate learning chemistry in an environment interactive and immersive. AR and VR technologies provide a dynamic and immersive learning environment that not only educates but also inspires and empowers students in their educational journey.

2. Paper Structure

The present thesis is structured in seven chapters, within which the evolution of the application over time is captured, as well as a detailed description of the component elements.

Chapter I: Similar applications contains a detailed analysis of applications similar to the one developed and presented in the present work, as well as outstanding elements observed within each or elements that could be improved.

Chapter II: Headset alternatives contains a list of headset alternatives used for the development of the present project, as well as their description.

Chapter III: Technologies used includes a description of the technologies used in the development of the application.

Chapter IV: Application architecture and implementation outlines the structure of the application and how it is implemented, while also providing details on the scenes incorporated within the project.

Chapter V: Usability tests presents the usage scenarios of the application and the reviews provided by various users to evaluate and improve the application.

Chapter VI: Immersiveness and methods used for a better user experience explores the strategies and methods employed to enhance user engagement and improve overall experience.

Chapter VII: Future directions outlines potential advancements and paths for further development.

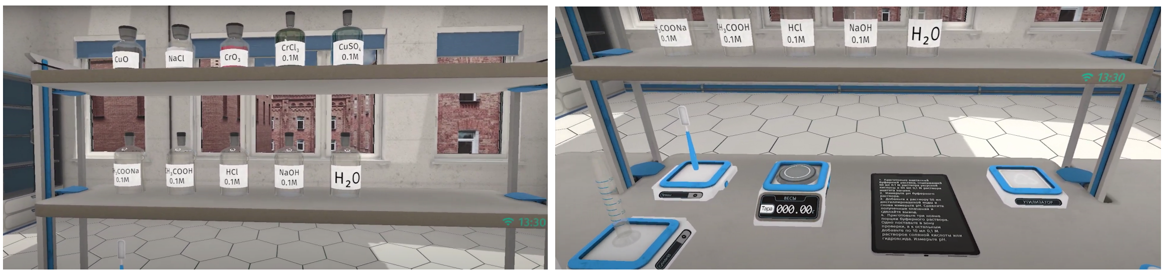
Chapter 1

Similar applications

This chapter analyzes several applications similar to the present one, highlighting how this application brings a series of additional, interactive, and fun elements. As the application was developed with the desire to provide users with a new way to learn chemistry concepts and interact with reactants and reaction products, we will finally explore how this new approach can improve understanding and to stimulate interest in the subject under discussion, thus contributing to a more effective and engaging educational experience.

1.1 VR Chemistry Lab

VR Chemistry Lab[1] is an application that supports a wide range 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 the field of chemistry who want to observe certain characteristics of some reactions. This application features a variety of tools, substances, and pH indicators.



[1]https://vrchemlab.ru/

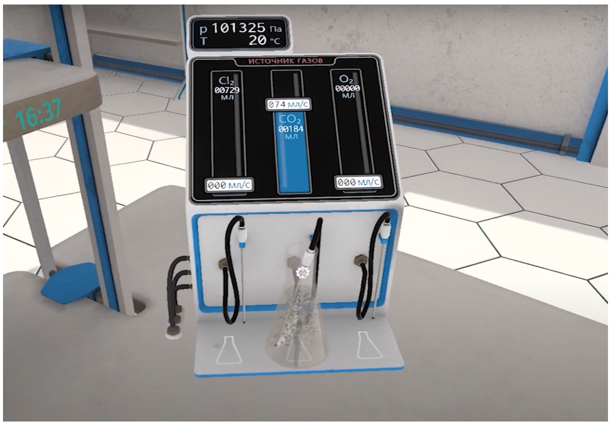


Figure 1.1: Images from the VR Chemistry Lab app

As can be seen in Figure 1.1, 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.

Figure 1.2: Working with liquids in the VR Chemistry Lab

However, some aspects are missing in the presented application, such as sounds and animations to reproduce the flow of liquids, as illustrated in Figure 1.2.

The present application is available only in the paid version and is used predominantly in educational institutions in the Russian area.

1.2 The VR Chemistry Lab

The VR Chemistry Lab[2] is a VR application released on 16 November 2021 and is still a work in progress. It is being used in research but has potential for student use as a hands-on science lab experience at home or school. It also contains experiences where players can explore substance creation in an immersive environment as well as play a game of catalyzing a chemical reaction.

[2]https://www.meta.com/experiences/the-vr-chemistry-lab/3919613214752680/

As new elements, the user is offered a sheet with all the materials listed and the description of the experiment and a blackboard on which he can write down the observations for each step on the side of the experiments carried out (see Figure 1.3). Also, a plus of this application is that the graphics and material content are well-finished.

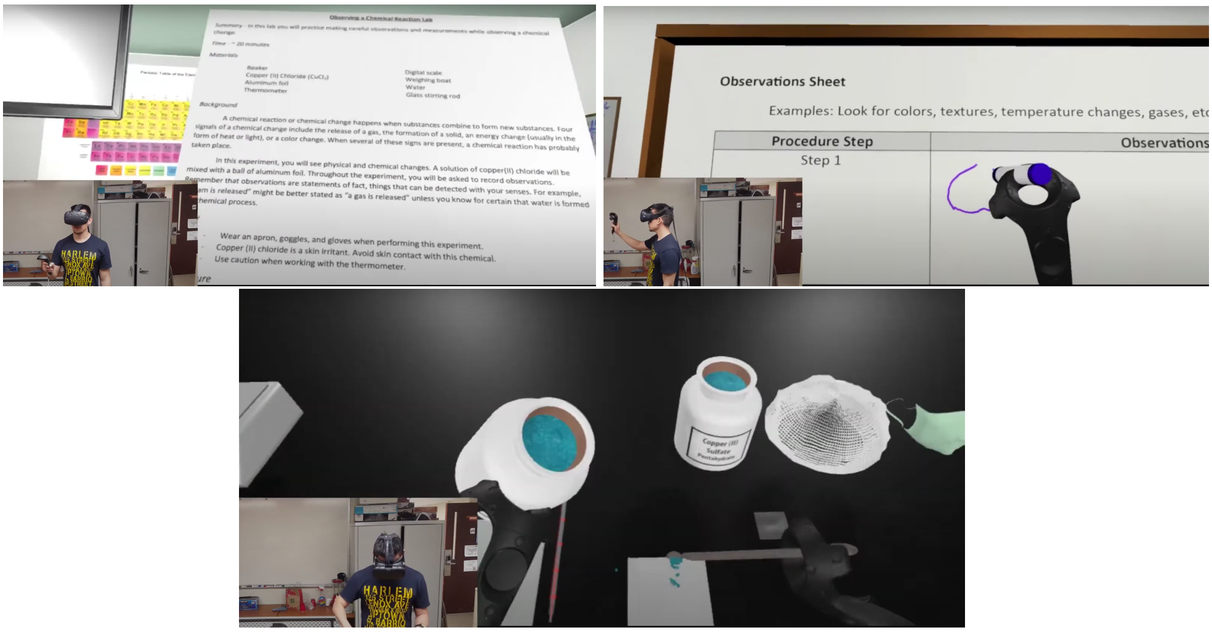


Figure 1.3: Images from The VR Chemistry Lab application

The weak points that the application presents are found in the area of measuring spoons and controllers. More specifically, the application only uses touch controllers, while using the hands would help more, and measuring spoons does not allow taking an exact amount of the substance, as specified in the sheet. Also, working with all the objects on the table is inconvenient. The application can be purchased at the price of $2.99 on Meta Quest apps and games[3].

1.3 Unreal Chemist - Chemistry Lab

Unreal Chemist - Chemistry Lab[4] is a mobile application that allows you to perform chemical reactions with some remarkable visual effects. The main menu of the application can lead us in two directions: choosing a reaction in which we combine two or more substances and choosing a reaction that takes place in the presence of fire - most often, in this case, it is the decomposition reaction.

[3]https://www.meta.com/experiences/

[4]https://play.google.com/store/apps/details?id=com.PixelMiller.UnrealChemist

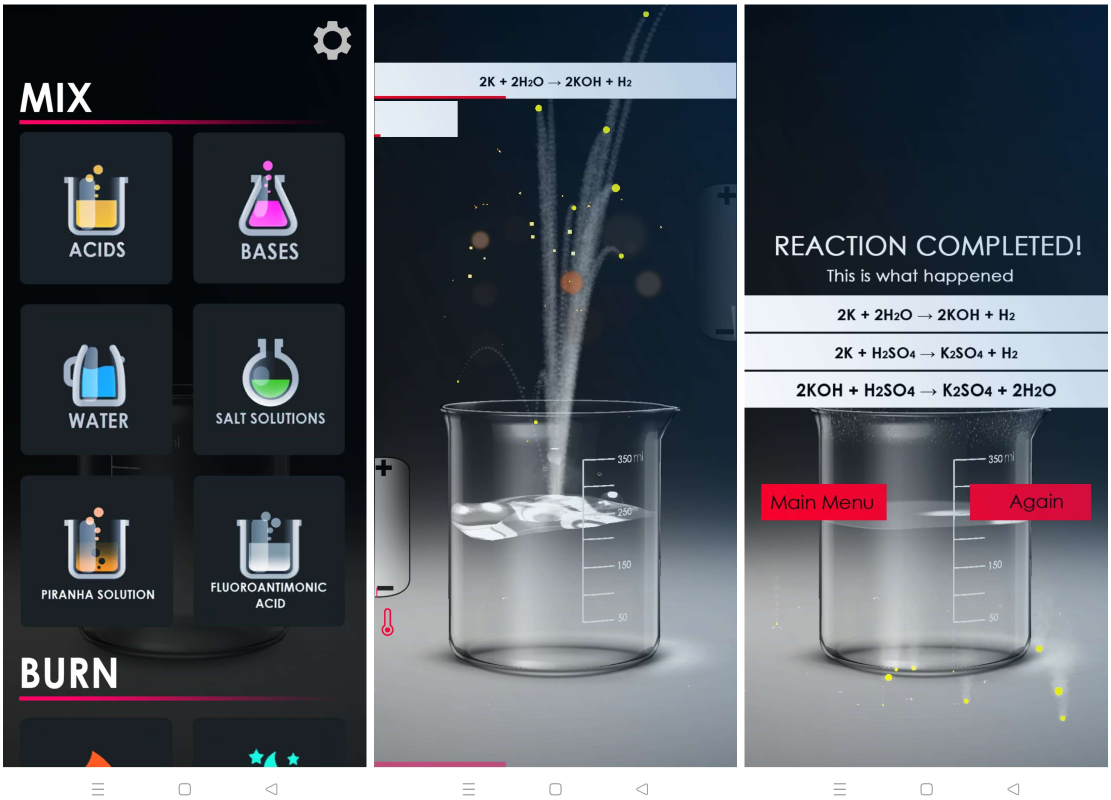


Figure 1.4: Images from the Unreal Chemist - Chemistry Lab application

In the case of the first type of reaction, as can be seen in Figure 1.4, the user can choose substitution, double substitution, combination (in the case of the first four variants), or decomposition (in the case of the last two) reactions. Within them, different procedures can be used, such as bubbling a gaseous substance into a liquid, identifying the pH of some reaction products with the help of indicators, weighing the substances to be mixed, etc. Within the last two types of reactions mentioned, the decomposition reaction of some organic or inorganic substances into superacids is reproduced in detail, truthfully. In other words, users can choose substances such as a piece of chocolate, a coffee bean, or a sugar cube, which they can then combine with piranha solution or fluoroantimonic acid. These two are considered superacids because they are much more acidic than 100% pure sulfuric acid, which on the Hammet acidity scale has a value of H_2O = -12. Even more specifically, fluoroantimonic acid is an acid formed by combining hydrofluoric acid (HF) with stanium pentafluoride (SbF_5), while piranha acid is a mixture of concentrated hydrogen peroxide and concentrated sulfuric acid, the name coming from its ability to corrode a wide range of organic and inorganic substances. In the case of the second type of reaction, the user can set fire to salts or metals, the visual result being downright spectacular, as can be seen in Figure 1.5.

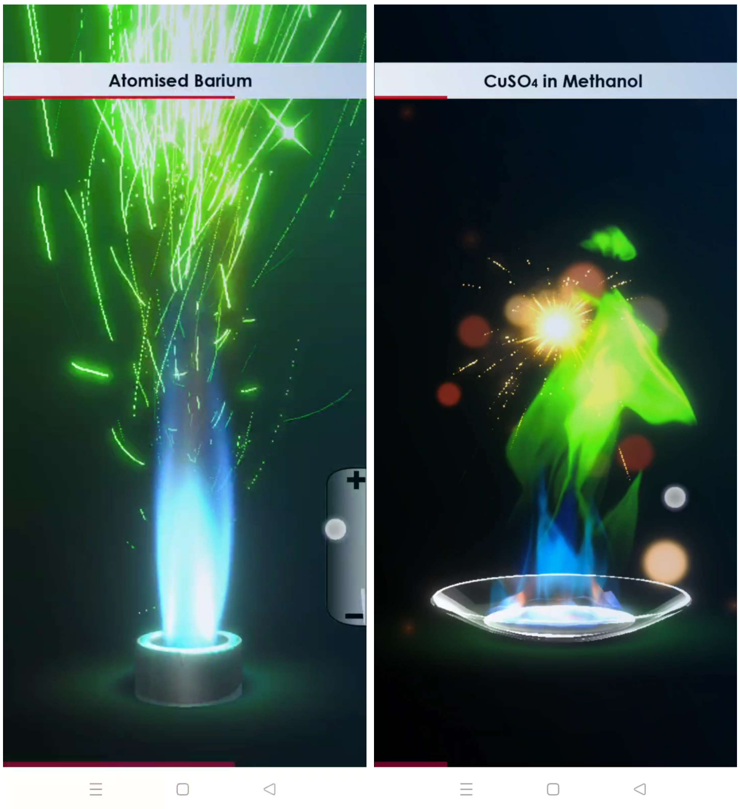


Figure 1.5: Images from the Unreal Chemist application - Burns

Last but not least, the present application allows us to increase the speed at which a chemical reaction takes place, by swiping to the right (action that causes the speed to increase) or to the left (action that causes the speed to decrease). It displays information about substances, such as density, acidity, or molar mass, and after any reaction performed, a panel with the equations of the chemical reactions that took place is displayed.

A final detail related to this application that caught my attention and which I think should be mentioned is the fact that when highly reactive substances are mixed in inappropriate amounts, the Berzelius beaker in which the reaction took place breaks, highlighting thus the strong effects of these reactions and the care we must take in choosing the quantities. An example here would be mixing 225 ml of water with 2.7 g of Potassium (K), the result of this reaction being visible in Figure 1.6. Water reacts strongly and violently with alkaline metals such as Potassium, Natrium, Lithium, or Cesium, and it has a similar effect in the reaction with alkaline earth metals, such as Magnesium or Calcium.

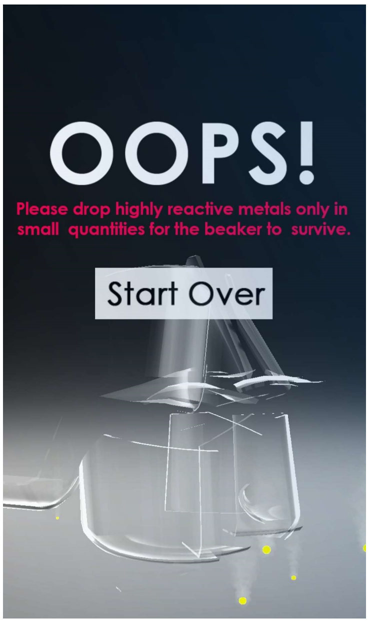


Figure 1.6: Screenshots from Unreal Chemist - High Reactivity Reactions

A weak point of the present application, comparing it to the other analyzed applications, consists in the fact that the user cannot mix any substances within the current reaction, but is required to follow a sequence of steps.

I think that this application excels with its graphics, animations, and sound effects, offering a unique and captivating experience to users.

1.4 Chemistry Lab

Chemistry Lab[5] is also a mobile application, where the user can combine substances in a Berzelius beaker at will and see the equations of the chemical reactions that have taken place in the upper area of the screen, as can be seen in Figure 1.7. The user is permitted to subject the substance or substances in the Berzelius beaker to heating by exposure to a heat source in the form of a flame, in reality, this is probably the equivalent of the flame produced by a Bunsen bulb.

The present application provides a variety of liquid, solid, and gaseous substances, and offers users the option to unlock even more substances for a fee.

[5] https://play.google.com/store/apps/details?id=com.VNS.ChemistryLab

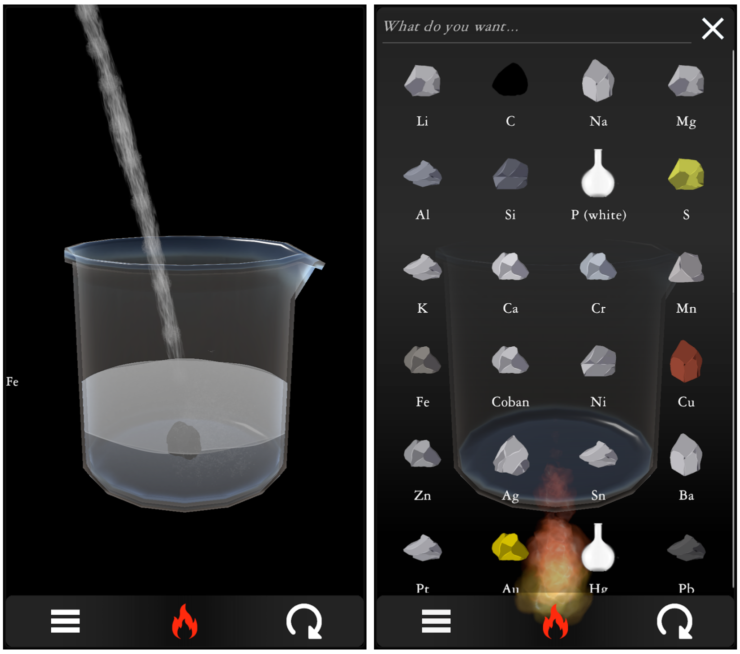


Figure 1.7: Images from the Chemistry Lab app

A weak point observed in the case of the present application is both the lack of sounds and the lack of outstanding graphics and animations, which could have provided a more engaging and interactive experience to users.

1.5 BEAKER - Mix Chemicals

BEAKER - Mix Chemicals[6] is a mobile application similar to the previously featured app, Chemistry Lab, but captivating and intriguing with an interesting 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 of the application is a black screen but with two graphics at the top of the screen, which are white and easy to identify. These elements represent some navigation buttons, one for selecting a physical component specific to the optimal development of reactions (the square with three horizontal lines in the middle, resembling a shelf), and one for selecting chemical elements.

[6]https://beaker-mix-chemicals.en.softonic.com/android

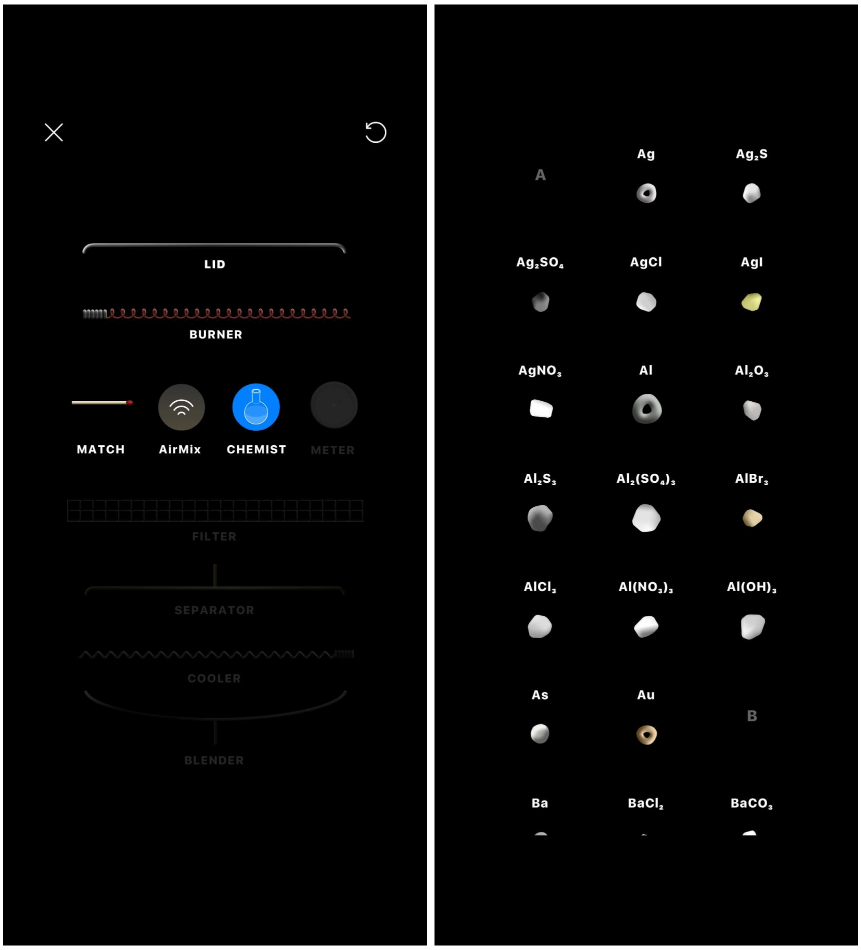


Figure 1.8: BEAKER - Mix Chemicals

The first of them leads to the screen in the first image of Figure 1.8, from where a lid (prevents the loss of gases and the flow of liquid and gaseous substances) or an incandescent wire, symbol of a source of fire, for heating substances, 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 of which are made available for free. A representation of this section can be seen in the second image in Figure 1.8.

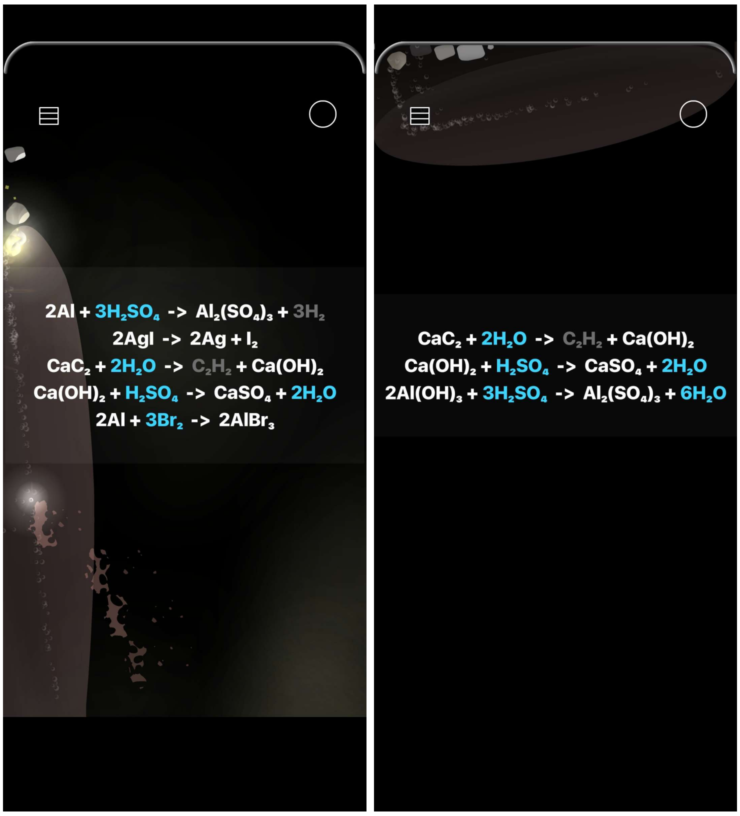


Figure 1.9: BEAKER - Mix Chemicals

Among the reactions can be noted a very good animation for liquids, as well as other visual and sound effects. Following the combination of some reactive substances, the equation of the chemical reaction that took place is written on the screen, as can be seen in Figure 1.9.

A new element is the fact that the current application can detect the physical orientation of the device in space and act accordingly. In other words, if the user turns the phone upside down while in the main interface, then the substances will flow out of the glass or be stopped by the lid.

1.6 ChemCollective

ChemCollective[7] 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 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.

[7]https://chemcollective.org/

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.

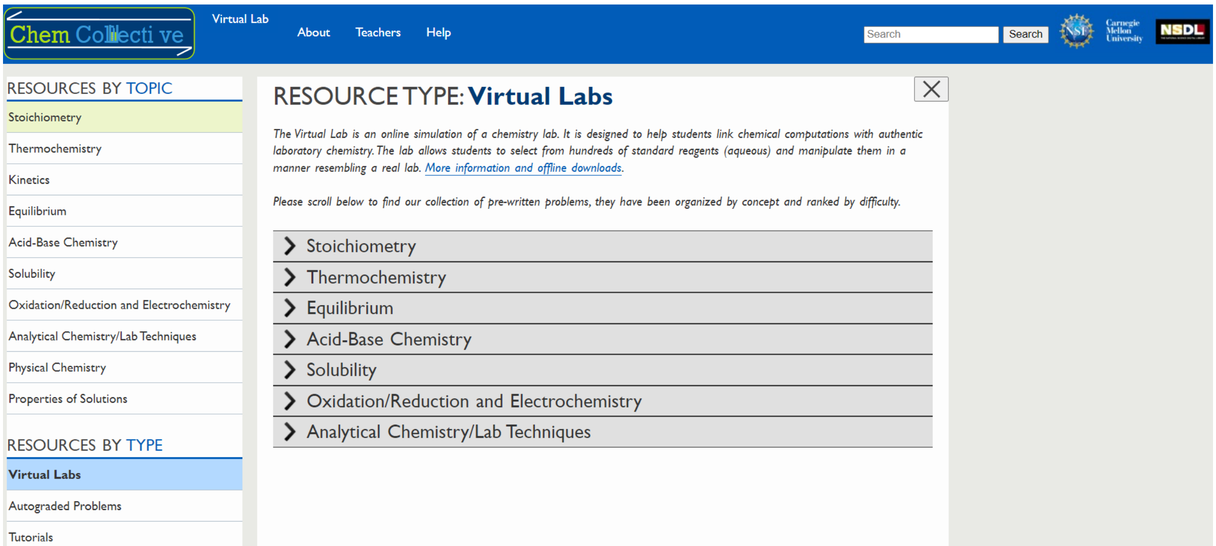


Figure 1.10: ChemCollective application home page

As can be seen in Figure 1.10, 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.

As can be noted in Figure 1.11, each practical problem proposed within the application comes with a virtual laboratory to which specific substances and utensils are associated, necessary to solve that problem, each substance being associated with a series of properties, such as temperature, density, molarity or volume. Following the practical laboratory activity, the user will have to determine certain numerical values, representing quantities, densities, molar masses, solubilities or pH, or even the names of initially unknown substances, based on atomic number or other properties, and then send them to verify that the experiment was successful and that the required notions were correctly determined. Following submission, the user will receive instant feedback. After three wrong submissions, the user will be given the correct answer.

Although it offers a purely 2D experience, this application is an exceptional educational resource for pupils and students who want to deepen their study of chemistry through practical applications, also provides a series of courses, tutorials, and theory

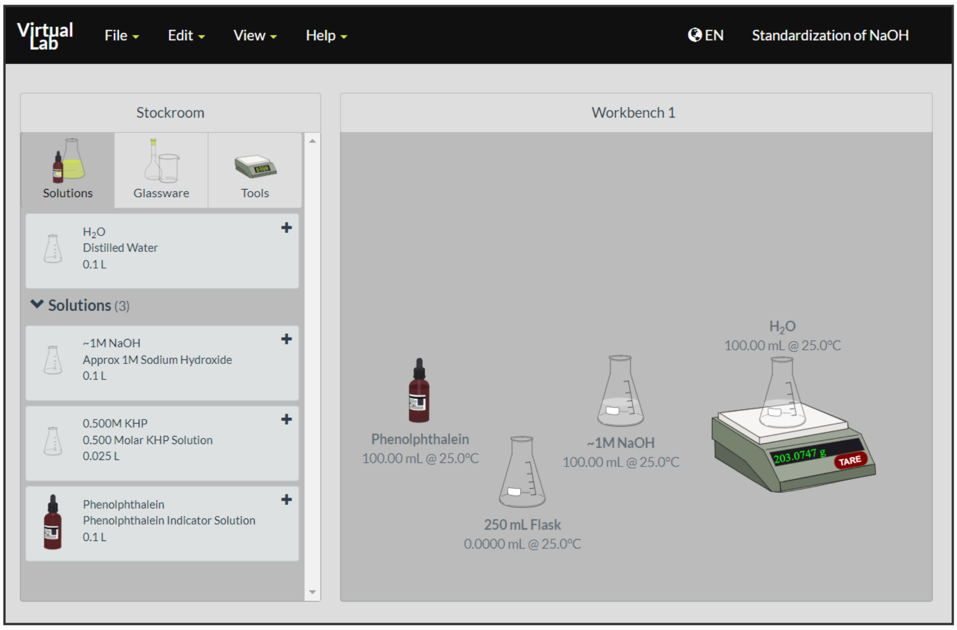


Figure 1.11: Virtual lab within the ChemCollective app

tests, the courses covering chemistry general I and II. Instructors and teachers are provided with information about student performance that they can use to adjust their teaching and instructional methods at the classroom level.

1.7 Conclusions

In this chapter, we have analyzed various applications similar to the one made and highlighted the outstanding aspects of each of them. Each application has unique features and more or less different approaches, providing a broad perspective on how the current application could be improved.

Following the research stage of applications that aim to take the study of chemistry to a higher level, by providing users with elements necessary to carry out experiments, a new factor can be extracted that could improve the user experience and understanding of the concepts, specifically, providing a virtual assistant who can answer users' questions.

On the other hand, considering the set of elements within the presented applications, we have identified several common components with the present application, among which is the possibility to observe the consequences of a reaction, the possibility to choose from a wide range of substances or the provision of specific utensils.

Chapter 2

Headset alternatives

This chapter presents the headset alternatives used in the development of the project. In this application was used Meta Quest 2, and in the following, we will detail the features of similar headsets.

2.1 HTC Vive Focus 3

HTC Vive Focus 3[1] is a standalone virtual reality headset for professionals. It has a bridge distance with seamless remote collaboration, very high efficiency, very good graphics, ergonomic comfort, and a wide range of applications (see Figure 2.7).

Figure 2.1: HTC Vive Focus 3

An important feature of this headset is high-fidelity hand tracking, providing a

[1]https://www.vive.com/us/product/vive-focus3/overview/

more intuitive metaverse experience. We can put the controllers down at any time to activate 26-point hand tracking, allowing for a new level of precision as we interact with our virtual surroundings. Built-in hand gesture recognition unlocks customized actions in VR applications, including menu navigation with a simple pinch of the fingers.

2.2 Google Cardboard

Google Cardboard[2] is an affordable alternative offered by Google for headsets, making experiencing virtual reality simple and fun.

Figure 2.2: Google Cardboard

As can be seen in Figure 2.2, Google Cardboard headsets are built out of simple, low-cost components, like a piece of cardboard folded in a specific way and two lenses. The use of Google Cardboard is accompanied by a phone running the Google Cardboard app available on Android and iOS (see Figure 2.3[3]).

Figure 2.3: Google Cardboard app

[2] https://arvr.google.com/cardboard/

[3] https://play.google.com/store/apps/details?id=com.google.samples.apps.cardboarddemo&pcampaignid=web_share

2.3 Sony PlayStation VR

Sony PlayStation VR[4] is a virtual reality system developed by Sony Interactive Entertainment, designed specifically for use with the PlayStation 4 and PlayStation 5 consoles. It was released in October 2016 and is known for providing immersive video game experiences through the use of virtual reality (see Figure 2.4).

Figure 2.4: Sony PlayStation VR

This headset offers a smooth field of view with stunning visuals such as a custom OLED screen and smooth visuals at 120 fps. The sound is based on 3D audio technology that allows us to precisely locate the direction and distance of the sounds around us. It also has a built-in microphone and precise tracking, thanks to the fact that the Camera follows nine LEDs positioned in front, behind, and on the sides of the PS VR headset, ensuring very high accuracy in the game world, wherever we are in the room.

To have full control over the virtual world, we can connect with several types of controllers, including DUALSHOCK 4 Wireless Controller, PlayStation Move Motion Controller or PS VR Target Controller (see Figure 2.5).

Sony PlayStation VR has a range of exclusive games, some of which can be played as a team, by projecting PS VR experiences directly onto the TV screen with Mirror mode, giving friends and family the ability to see what we're seeing through an open window to your virtual world. We can also share the adventures with friends and have them in the game as the second player, using a second controller that can be played on the TV screen.

[4]https://www.playstation.com/en-us/ps-vr/

Figure 2.5: Sony PlayStation Controllers

2.4 Pico Neo 3 Pro

Pico Neo 3[5] is a standalone VR headset, requiring no connection to a PC or a console to operate, having all the necessary components integrated directly into the device. It is produced by Pico Interactive, a company that focuses on creating VR solutions for both consumer commercial and business applications (see Figure 2.6).

Figure 2.6: Pico Neo 3 Pro

It has a self-developed next-generation 6DoF positioning and tracking algorithm, equipped with multiple optical sensors and millimeter precision in spatial positioning and ultra-low tracking delay.

It allows easy switching to PC VR mode with a 5m PICO DP cable. It also provides business-level comfort through the special ergonomic design, being manufactured with improved ergonomics to balance weight distribution and improve the user experience for wearing it for a long period, resulting in less motion sickness as well.

[5]https://www.picoxr.com/global/products/neo3-pro-eye

Pico Neo 3 Pro also comes with eye-tracking technology, which provides deep insights about the user with gaze interaction, eye movement analysis, and other capabilities. Additionally, it provides a variety of solutions and practices for businesses to increase development efficiency, reduce costs and implementation barriers, and address technical challenges, thereby helping to achieve greater success in business endeavors.

2.5 Valve Index

Valve Index[6] is an advanced VR headset developed by Valve Corporation, known for its involvement in games and gaming technologies, including the popular distribution platform Steam. Launched in June 2019, Valve Index is aimed at VR users looking for a high-quality experience, offering some of the best specs and features available on the consumer market (see Figure 2.7).

Figure 2.7: Valve Index

The Valve Index is notable for its high-resolution LCD screens, each with 1440x1600 pixels. The system supports variable refresh rates, including 80 Hz, 90 Hz, 120 Hz, and an experimental 144 Hz mode, which contributes to smooth and detailed viewing. The wide field of view, which can reach up to 130 degrees, improves immersion and visual comfort. SteamVR Tracking 2.0 advanced tracking technology requires base stations to track precise head and controller movements, allowing for extended freedom of movement in virtual space.

Index controllers are distinguished by the ability to detect individual movements of each finger, providing a deep and intuitive interaction with the VR environment. They also include pressure sensors that assess the force with which the user grasps

[6]https://www.valvesoftware.com/ro/index

virtual objects. The ergonomic design and adjustability of the headset ensure comfort for long periods of use, with the possibility of adjusting the distance of the lenses from the eyes. The audio system uses near-ear speakers, creating a natural sound without completely isolating the user from external sounds, which is ideal for extended gaming sessions or virtual exploration (see Figure 2.8).

Figure 2.8: Valve Index Controllers

2.6 HP Reverb G2

HP Reverb G2[7] is a VR headset developed by HP in collaboration with Valve and Microsoft, released in late 2020. It is mainly intended for VR users interested in games, simulations and professional applications, offering high image quality and improved comfort compared to many other VR devices available in the market (see Figure 2.9).

Figure 2.9: HP Reverb G2

The HP Reverb G2 is distinguished by its LCD screens, each with a resolution of 2160 x 2160 pixels, which provide very sharp images, ideal for use in precise simulations and complex visual applications. It has an ergonomic design with an adjustable

[7] https://www.hp.com/gb-en/vr/reverb-g2-vr-headset.html

headband and foam cushion, which allows the weight of the device to be evenly distributed and reduces discomfort during extended sessions of use.

Its tracking system uses four integrated cameras to precisely monitor the position and movements of the head and controllers, eliminating the need for external sensors. The controllers are optimized for increased comfort and functionality, facilitating natural and intuitive interaction in virtual reality. HP Reverb G2 also integrates off-ear speakers, developed in collaboration with Valve, which produce high-quality spatial sound, completing the immersive experience without isolating the user from the environment. Extensive support for Windows Mixed Reality and SteamVR ensures access to a wide range of VR content, from games to educational applications.

2.7 Conclusions

In summary, exploring Meta Quest 2 headset alternatives such as the HTC Vive Focus 3, Google Cardboard, Sony PlayStation VR Pico Neo 3 Pro, Valve Index and HP Reverb G2 highlights the diversity and complexity of options available in the virtual reality market. Each of these devices brings unique features that make them suitable for different types of users, from those looking for stand-alone and easy-to-use solutions to enthusiasts who want the highest fidelity and performance in games and simulations. Regardless of specific needs in terms of resolution, comfort, compatibility, or tracking capability, today's market offers robust solutions that can enrich the virtual reality experience for consumers, professionals, businesses, and developers alike.

Chapter 3

Technologies used

In this chapter, we will present and analyze the main software and hardware tools that were essential in the development and implementation of the present license project. The choice of technologies was dictated by the specific needs of the project, their efficiency in achieving the proposed objectives and the compatibility between the various software and hardware components.

The first part of this chapter will focus on the software technologies used. Here, we will detail the programming languages, libraries, frameworks, and other software tools that were essential in the development of the project. We will discuss the reasons for the selection of each technology and how they contributed to the achievement of the project's objectives.

In the second part, we will focus on the hardware components involved. We will describe the specific hardware used, including how it interacts with the software. This part will also include a discussion of the problems encountered during implementation and the solutions adopted to overcome them.

Finally, we will evaluate the effectiveness of the combination of technologies used in the context of our project, providing insight into how they facilitated the achievement of the objectives and influenced the final results of the project.

3.1 Unity

The Unity game engine and the Blender modeling program were mainly used in the development of this application. Unity[1] is the most popular game engine in the

[1]https://unity.com/

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. In the process of creating the present application, was used Unity version LTS 2021.3.31f1, and the scripts were written in the C# programming language, in the Visual Studio 2022 editor, which we will talk about in the following.

First was creating the Unity project, using Unity Hub. This is a standalone application for accessing the Unity ecosystem. This is used for things like managing your Unity projects, installing editor versions, and add-on components, or for licensing. The version that was used is Unity Hub 3.5.2 (see Figure 3.1).

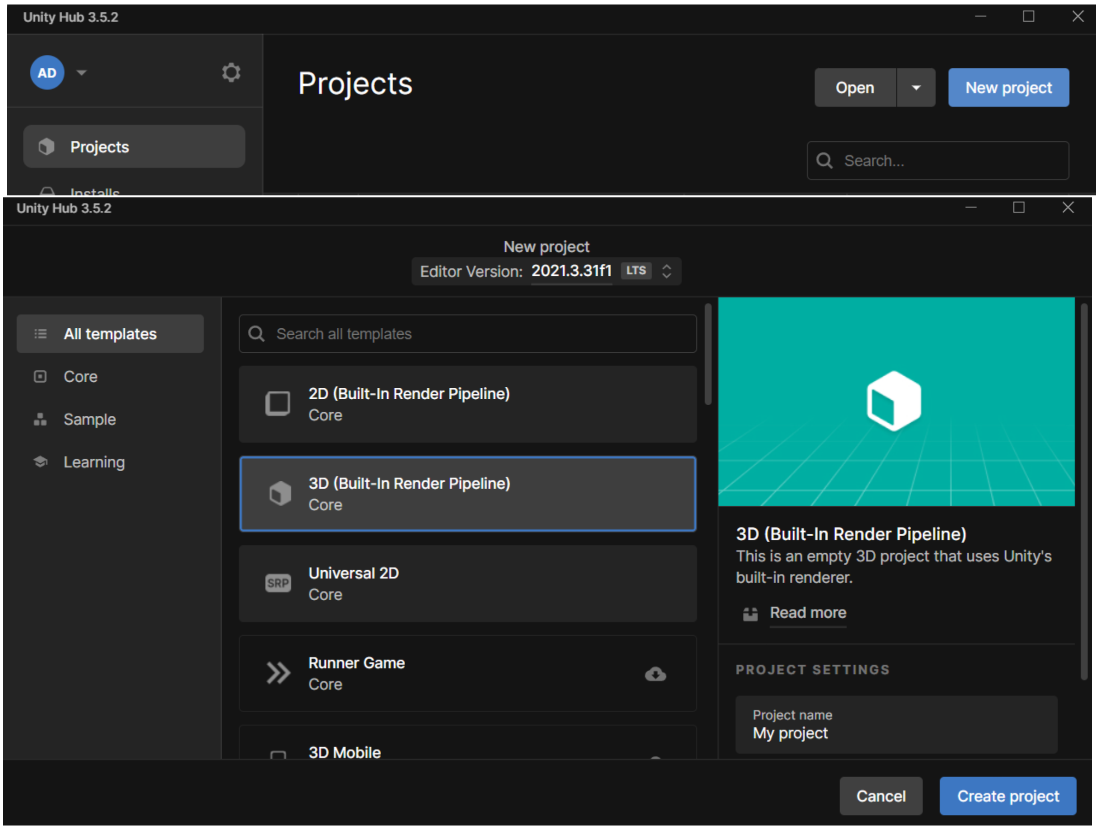


Figure 3.1: Images from the Unity Hub application

Next, came the installation of XR Plugin Management version 4.4.0 and XR Interaction Toolkit, experimental version 0.10.0-preview.7. Another package installed was MockHMD XR Plugin, experimental version 1.3.1-preview.1, to test the project without a VR headset. This package was used intensively in the first part of the development of the project, to facilitate the testing process of the new elements added. Afterward, the

Oculus XR Plugin, OpenXR Plugin, Inworld.AI, Post Processing, Visual Effect Graph, and Shader Graph packages were installed. The last of them has been used intensely for the physics of liquids. Among them, there can be found some pre-installed packages, such as Test Framework, Text Mesh Pro, Timeline, Unity UI, Version Control, Visual Scripting, or Visual Studio Editor.

3.1.1 XR Plugin Management

XR Plugin Management[2] is a software component that facilitates the integration and management of various XR plugins within a development environment, ensuring compatibility and execution efficiency.

3.1.2 XR Interaction Toolkit

The XR Interaction Toolkit[3] is a toolkit that provides developers with a set of pre-made tools and components to simplify the creation of user-friendly interactions in augmented and virtual reality applications.

3.1.3 MockHMD XR Plugin

The MockHMD XR Plugin[4] allows developers to simulate a virtual reality headset in test environments, facilitating the development of VR applications without the need for physical hardware.

3.1.4 Oculus XR Plugin

The Oculus XR Plugin[5] is a specific plugin that enables the integration and compatibility of VR applications with Oculus devices, ensuring optimal performance and access to Oculus-specific features.

[2] https://docs.unity3d.com/Manual/com.unity.xr.management.html

[3] https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@3.0/manual/index.html

[4] https://docs.unity3d.com/Packages/com.unity.xr.mock-hmd@1.0/manual/index.html

[5] https://docs.unity3d.com/Manual/com.unity.xr.oculus.html

3.1.5 OpenXR Plugin

OpenXR Plugin[6] supports the OpenXR standard, which is an open-source initiative to create a unified standard for augmented and virtual reality applications, thereby promoting interoperability between various devices and platforms.

3.1.6 Inworld.AI

Inworld.AI[7] is a tool that allows developers to embed AI agents within applications. The Inworld Engine drives real-time gameplay mechanics that adapt to players' every decision. This unlocks new levels of depth and immersion, integrating AI NPCs with advanced cognition, perception, and behavior.

3.1.7 Post Processing

The Post Processing[8] package is used to apply visual effects to the final image after the scene has been rendered. These effects are used to improve the visual quality of games or apps created in Unity, providing a more polished and professional look.

3.1.8 Visual Effect Graph

The Visual Effect Graph[9] package is used to create complex and custom real-time visual effects such as fire, smoke, explosions, magic, water effects and more. This is a powerful tool that allows artists and developers to create visual effects without writing code, using a node-based visual interface.

3.1.9 Shader Graph

Shader Graph[10] is a visual tool that allows developers to create and customize shaders more intuitively and visually without writing shader code by hand, optimizing the graphic design process in games and interactive applications.

[6] https://docs.unity3d.com/Packages/com.unity.xr.openxr@1.11/manual/index.html
[7] https://inworld.ai/
[8] https://docs.unity3d.com/Packages/com.unity.postprocessing@3.2/manual/Installation.html
[9] https://docs.unity3d.com/Packages/com.unity.visualeffectgraph@12.0/manual/index.html
[10] https://docs.unity3d.com/Manual/shader-graph.html

3.1.10 Test Framework

The Test Framework[11] package is used to create and run automated tests in Unity projects, helping developers ensure the quality and stability of their code. It provides a set of tools to write unit tests and integration tests, making it easier to detect and solve problems in the early stages of development.

3.1.11 Text Mesh Pro

The Text Mesh Pro[12] package is used to create and manipulate high-quality text in games and applications. It offers a wide range of advanced functionality for handling text, going beyond the limitations of Unity's standard text components.

3.1.12 Timeline

The Timeline[13] package is used to create and control cinematics, animations, and other temporal events in games and applications. It provides a visual interface based on a timeline, allowing developers and designers to orchestrate complex events without writing additional code.

3.1.13 Unity UI

The Unity UI[14] (User Interface) package is used to create and manage graphical user interface elements in games and applications developed with Unity. It offers a full range of tools and functionality to design intuitive and attractive user interfaces.

3.1.14 Version Control

The Version Control[15] package is used to integrate and manage version control directly from the Unity editor. It facilitates collaboration between development team members, ensuring that changes to the project are tracked, managed, and synchronized effectively.

[11] https://docs.unity3d.com/Packages/com.unity.test-framework@1.1/manual/index.html
[12] https://docs.unity3d.com/Packages/com.unity.textmeshpro@2.2/manual/index.html
[13] https://docs.unity3d.com/Packages/com.unity.timeline@1.1/manual/index.html
[14] https://docs.unity3d.com/Packages/com.unity.ugui@1.0/manual/index.html
[15] https://unity.com/how-to/redeem/version-control

3.1.15 Visual Scripting

The Visual Scripting[16] package is used to create game and application logic without writing traditional code, using a node-based visual interface. This is especially useful for designers, artists, and developers who want to quickly create and iterate on gameplay and other functionality without the need for advanced programming knowledge. Although it is very useful and easy to use, it was used minimally in the present project.

3.1.16 Visual Studio Editor

The Visual Studio Editor[17] package is used to integrate Visual Studio, an integrated development environment (IDE), with Unity. This integration makes it easy to write, debug, and manage C# code for Unity projects.

3.2 Visual Studio

Visual Studio[18], developed by Microsoft[19], is a software development tool used to create web applications, websites, mobile applications, and Windows programs. The development kit consists of an IDE and other testing tools.

In this application, the IDE was used for writing C# code, where the entire application logic was defined. The usage of the IDE involved the following steps: creating a GameObject in the Unity scene, creating a script within the object, naming the script (see Figure 3.2), double-clicking on it to open the Visual Studio IDE, making the necessary code modifications, and saving the changes with "Save" or "Ctrl+S". After these steps, the Unity project was ready for testing.

When a new script is created in Unity, it contains two predefined methods: Start and Update. These methods are part of the lifecycle of a Unity script. The Start method is called once, immediately after the component is activated for the first time. It is used to initialize variables, set initial states, and perform other operations that need to occur once at the beginning of a GameObject's lifecycle. The Update method is called once per frame and is used to implement logic that needs to be evaluated continuously

[16]https://docs.unity3d.com/Packages/com.unity.visualscripting@1.8/manual/index.html
[17]https://docs.unity3d.com/Manual/com.unity.ide.visualstudio.html
[18]https://visualstudio.microsoft.com/
[19]https://www.microsoft.com/

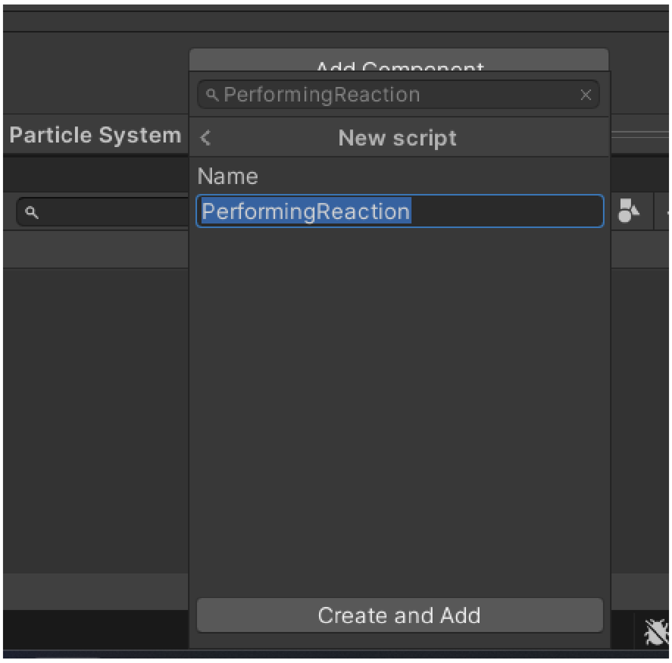


Figure 3.2: Creating a new script in Unity

throughout a GameObject's lifecycle. It is where most of the game logic that requires constant updating is placed, such as detecting user input, moving objects, setting flags or global variables, and other repetitive operations (see Figure 3.3).

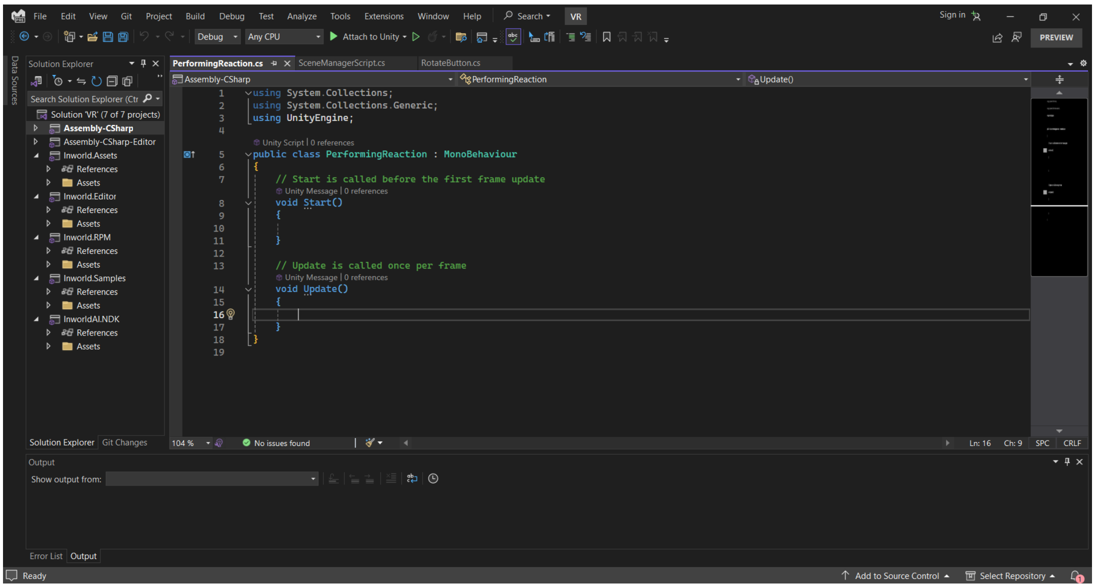


Figure 3.3: Visual Studio interface

3.3 Blender

Blender[20] 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. Blender is primarily used for 3D modeling, which involves creating and manipulating digital objects in a 3D environment. It was launched in early 1994 by Ton Roosendaal[21].

The default starting object is a cube, therefore, the first interaction with this tool is by modifying the cube, using the tools on the right in Object Mode or Edit Mode (see Figure 3.4).

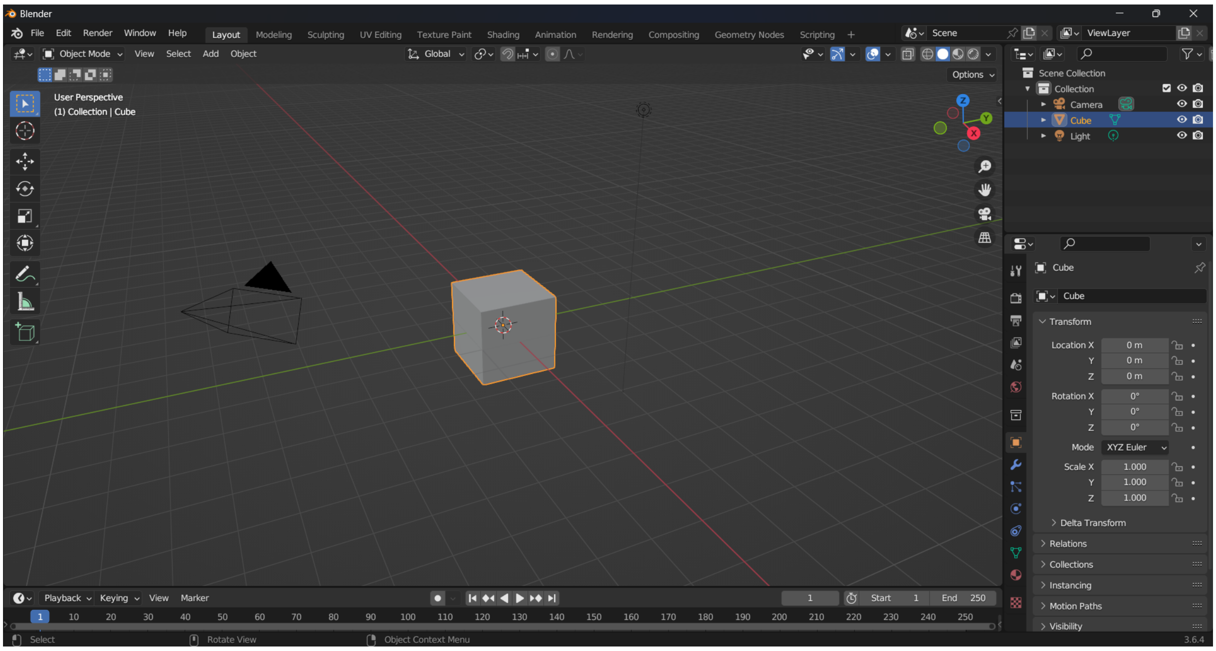


Figure 3.4: The main interface of the Blender software

Blender offers the possibility to edit objects by vertices, by edges or by planes (see Figure 3.5).

While Blender is extremely popular due to its affordability and vast capabilities, there are other 3D modeling software that can be considered as alternatives, each with specific features. Autodesk Maya[22] is one of the most well-known alternatives, offering a rich set of tools for animation, modeling, and rendering, and is highly regarded in the

[20] https://www.blender.org/
[21] https://www.blender.org/about/history/
[22] https://www.autodesk.com/products/maya

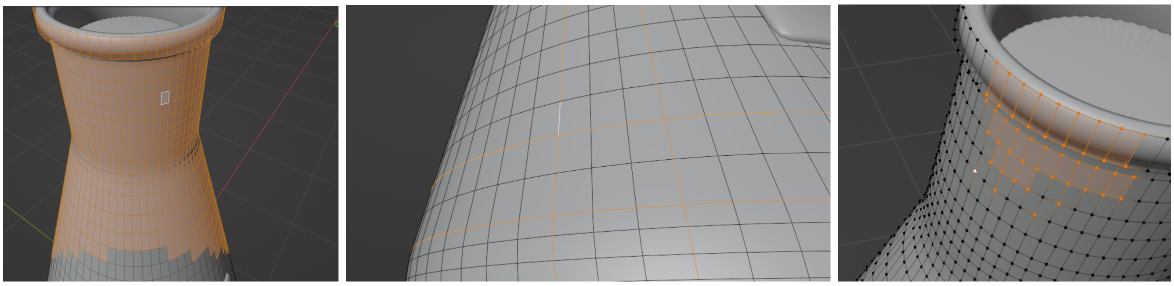


Figure 3.5: Editing modes in Blender

film and video game industries for its advanced animation capabilities. 3ds Max[23], also from Autodesk, is popular with game developers and architectural visualization designers, offering powerful tools for polygon modeling and rendering. Cinema 4D[24] is recognized for its intuitive interface and ability to quickly produce high-quality renderings and is preferred in motion graphics and visual design. Finally, for those interested in an open-source alternative to Blender, SketchUp[25] software can be a valuable option, known for its ease of use in conceptual and architectural 3D modeling. In choosing the Blender software, the ease of working and manipulating objects was taken into account. Also, it has a lot of functionalities: 3D modeling, sculpting, rigging, animating, rendering, unwrapping meshes, and many more.

3.4 Meta Quest 2

Meta Quest 2[26], 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 (see Figure 3.6).

Equipped with the Qualcomm Snapdragon XR2[27] processor, Oculus Quest 2 offers an enhanced virtual reality experience with high graphics performance and the ability to run complex games and applications independently. The headset has a display with a resolution of 1832 x 1920 pixels per eye, ensuring clear and detailed images

[23]https://www.autodesk.com/ca-en/products/3ds-max
[24]https://www.maxon.net/en/cinema-4d
[25]https://www.sketchup.com
[26]https://www.meta.com/quest/products/quest-2/
[27]https://www.qualcomm.com/products/mobile/snapdragon/xr-vr-ar/snapdragon-xr2-5g-platform

Figure 3.6: Valve Index Controllers

for a deep immersion in the virtual environment. The inside-out tracking system uses cameras integrated directly into the device to track the user's movements, thus eliminating the need for external sensors and facilitating a quick and easy installation.

Oculus Touch controllers, improved over the previous version, provide precise interaction with the virtual environment, allowing users to manipulate virtual objects with improved accuracy. Oculus Quest 2 is compatible with Oculus Link, a feature that allows the headset to be connected to a PC to access a wider range of VR games and applications from the SteamVR platform and other sources. It also supports an extensive library of content available through the Oculus Store, giving users access to a variety of games, applications, and educational and social experiences.

3.5 Conclusions

In this chapter, we explored three essential tools in the creation and development of interactive applications and immersive experiences: Blender, Unity, and Meta Quest 2. Each of these technologies contributes uniquely to the digital world, providing developers and content creators with powerful and flexible tools. for realizing their artistic and technical visions.

Chapter 4

Architecture and Main Scenes

This chapter will present what each component consists of and how it was implemented. In Figure 4.1[1], you can see the three main functionalities: *Learn to make reactions*, *Test your knowledge* and *Lab Assistant*. We will detail the three components of the project further.

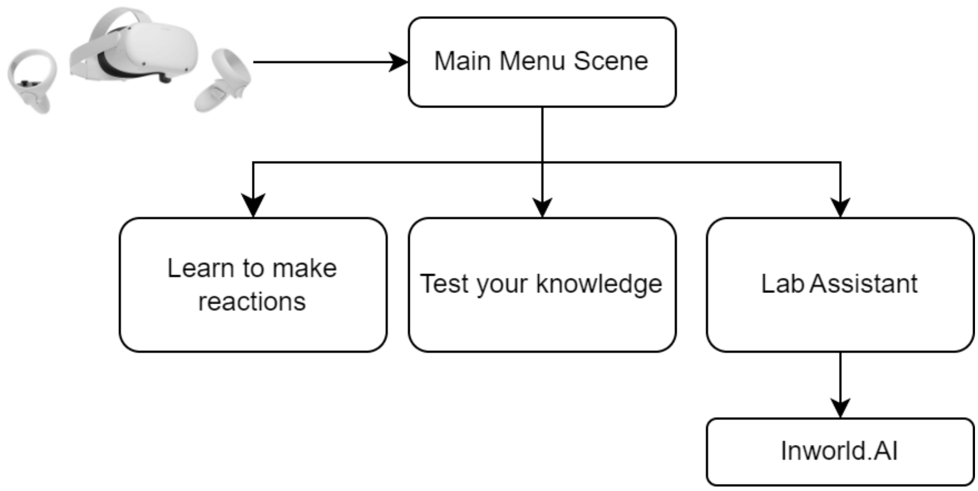


Figure 4.1: General application architecture

4.1 Architecture

Being developed on Meta Quest 2, certain interactions with elements in the virtual environment were set on both controllers. In Figure 4.2, the trigger and grab buttons can be noticed. The Trigger button (L2 and R2) is used within the application to

[1]https://draw.io/

initiate events, interacting with the UI buttons that can be found within UI Canvases. Among the actions that can be initiated are changing the scenes, browsing through the book with reaction substances, selecting a reaction to perform or selecting an answer in the *Test your knowledge* part, for the theoretical tasks.

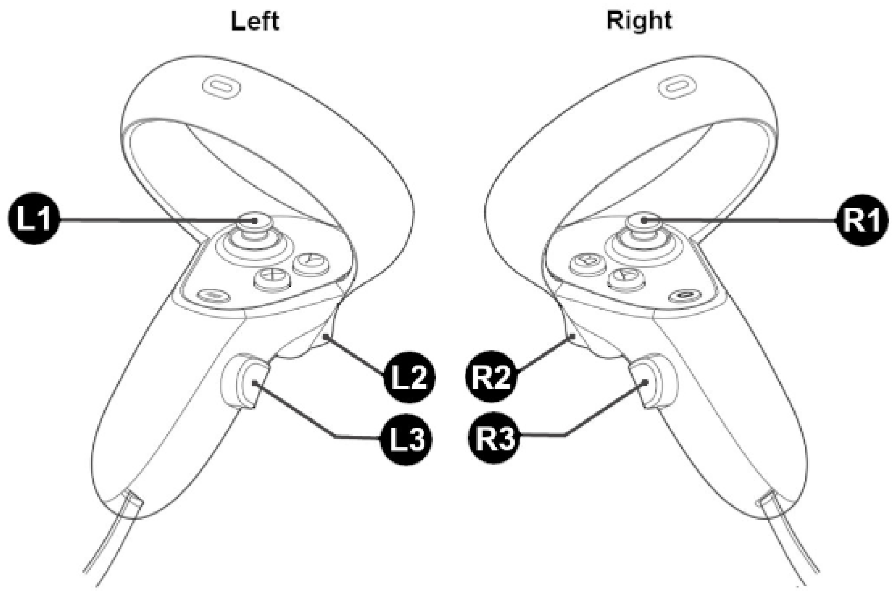


Figure 4.2: Meta Quest 2 controllers

The Grab button (L3 and R3) is used within the application both to grab objects and to initiate actions by interacting with GameObjects, such as the book or the sink button. For GameObjects to behave like some UI Buttons, it was necessary to insert the XR Simple Interactable component on the GameObject. One last thing that can be done with the Grab button is to start the lid opening application on the substance containers: to start the animation and remove the lid, it takes two presses of the Grab button on the lid.

Thumbsticks were also configured for movement and positioning. To move in the chemistry laboratory, we can use the free locomotive or we can use the thumbstick available on the left-hand controller (L1). To change the perspective, we can change the position of our body or head, but we can also use the thumbstick available on the right-hand controller (R1).

It is also necessary to mention the use of static data to transfer information from one scene to another. More concretely, to transfer the information of the inclusion of a type of task from the *Main Menu* Scene in the *Test your knowledge* Scene, I created the StaticData class which includes the static variable in which the options selected for the

Test your knowledge section are properly stored from the main menu, thus providing continuity and coherence.

On the other hand, to always be aware of the current state of chemical reactions, I set flags that will be checked later and display the corresponding information: the start of an animation, the coloring of a substance, the sound effect of the reaction, etc. In this way, the progress and results of each experiment carried out by the users can be precisely tracked within the application.

4.2 Main Scenes

As can be seen from Figure 4.1, the application has three main parts and four Unity scenes: *Main Menu*, *Learn to make reactions*, *Test your knowledge*, and *Lab Assistant*. In the following, details will be provided for each of these.

4.2.1 Main Menu Scene

The first scene, the first interaction with the application, places the user within the *Main Menu* Scene, where he can choose which part of the application he will interact with next. This will also be the scene that the user will return to whenever they want to change the scene to interact with another application functionality or when they want to exit the application.

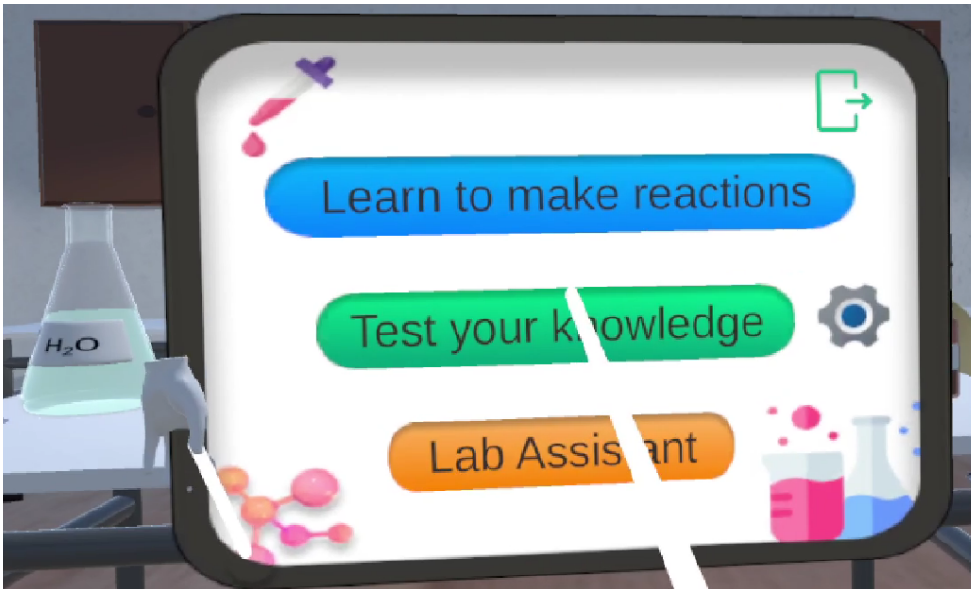


Figure 4.3: Main Menu Scene

As can be seen in Figure 4.3, the Main Menu Scene places the user in the chemistry lab. Despite this, the user will not be able to perform chemical reactions and will not be able to interact with the objects in the scene, to be able to do so having to select one of the three options available. To ensure that the user will select one of the three scenes, the menu has been placed as a child of the Main Camera component, as can be seen in Figure 4.4, so the menu will move according by the user's movements, always being in front of him.

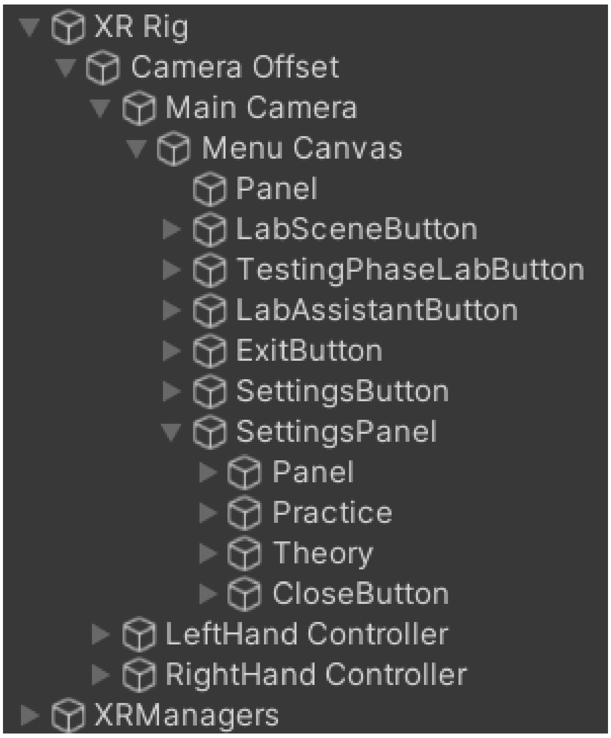


Figure 4.4: Menu Canvas as a child of Main Camera

Returning to Figure 4.3, we can see the sign for **Exit**, upon which action the user will exit the application, as well as the setting button next to the *Test your knowledge* button, upon whose action the settings menu opens, from which we can select what kind of tasks (theoretical or practical) will be included in the test, as can be seen in Figure 4.5. By default, the inclusion of practical tasks is set. It is also not allowed to uncheck both types of tasks at the same time.

Menus are made with Canvases: the panel on which the menu background made in Figma[2] was placed and four buttons whose design was also made in Figma, including three on the action to which the user will be placed in a new scene, the fourth one which leads to exiting the application, and the fifth one which opens the second menu,

[2]https://www.figma.com/

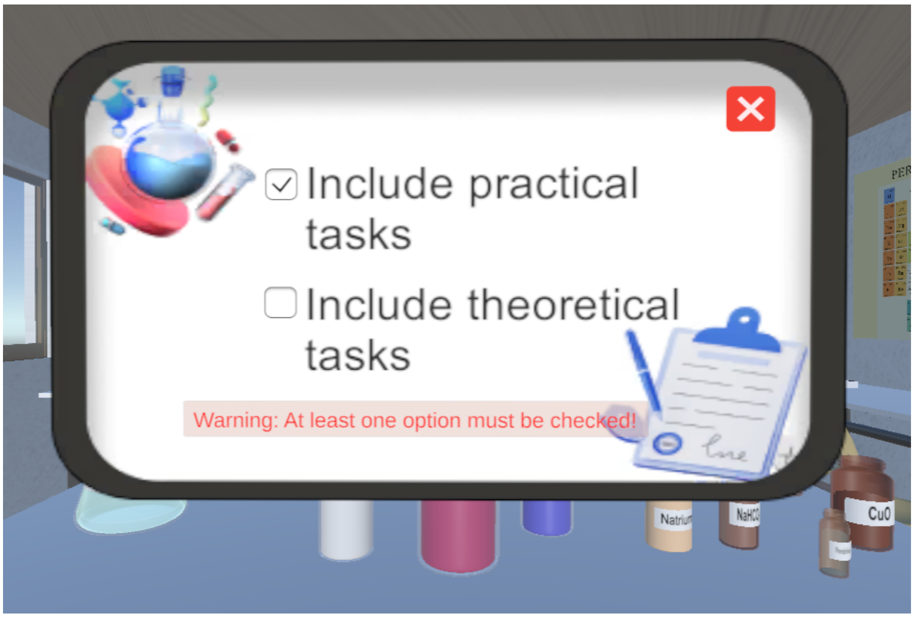


Figure 4.5: Settings Menu

this one being made similarly, but using toggles instead of buttons, and a close button.

4.2.2 Learn to make reactions

Upon entering this scene, the user is positioned in front of the laboratory table where the chemical reactions will take place, which is initially empty. To the left of the table he will see the RoboChem robot that will give him instructions during the reactions, and to the right he will notice a desk with a book, as can be seen in Figure 4.6.

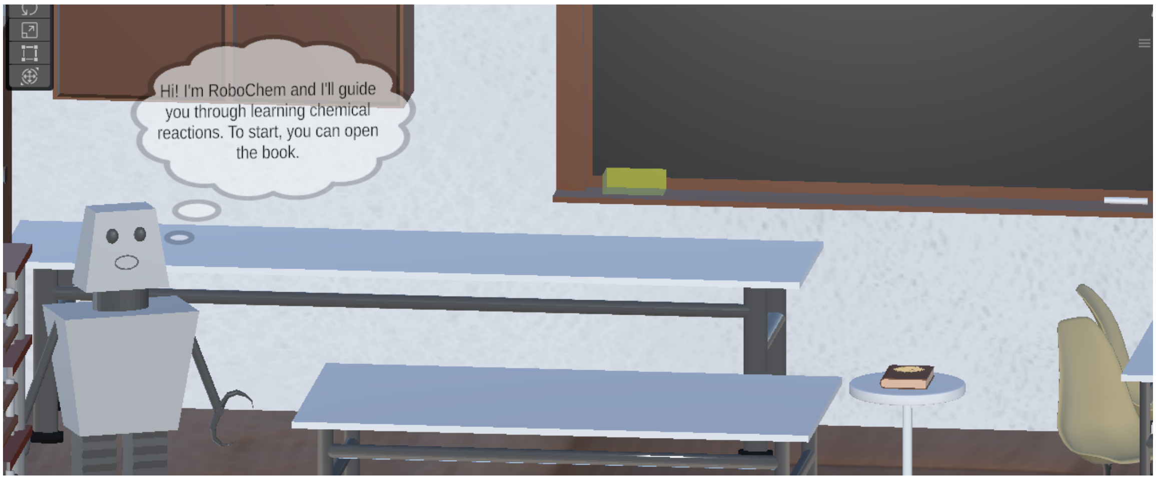


Figure 4.6: Learn to make reactions Scene

The user will be able to choose which reaction they want to learn by selecting the reaction from the book on the round desk next to the table. Once the user selects the book, a canvas with the book's content will appear on the screen, as shown in Figure 4.7.

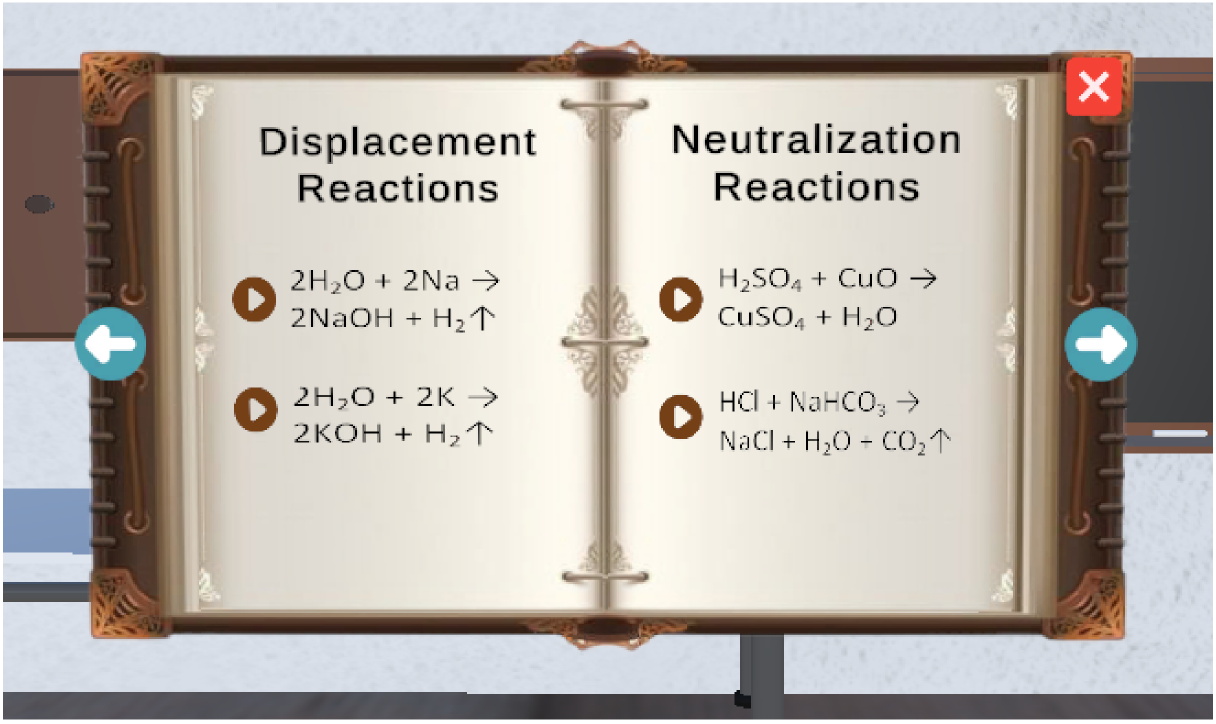


Figure 4.7: The book's content

As can be seen in Figure 4.7, the book contains the experiments classified according to their type, and several types of reactions can be performed within the application, such as combination, decomposition, substitution reactions, etc. The user can navigate through the content of the book until he finds the experiment he wants to do, and once the user has chosen the desired experiment, the necessary substances will appear on the table and he will be given instructions on the steps of experimenting, as shown in the Figure 4.8.

During the guidance, the robot will provide both written indications and audio guidance, the audio part being generated with the Text to Speech[3] tool. Here, the voice of Adam, an American narrator, was selected. Thus, for each reaction and for each stage of its realization, there is an audio sequence that will start to provide the necessary information, the same information can be found and written on the canvas above the robot, in the form of speech bubbles (see Figure 4.8).

[3]https://elevenlabs.io/text-to-speech

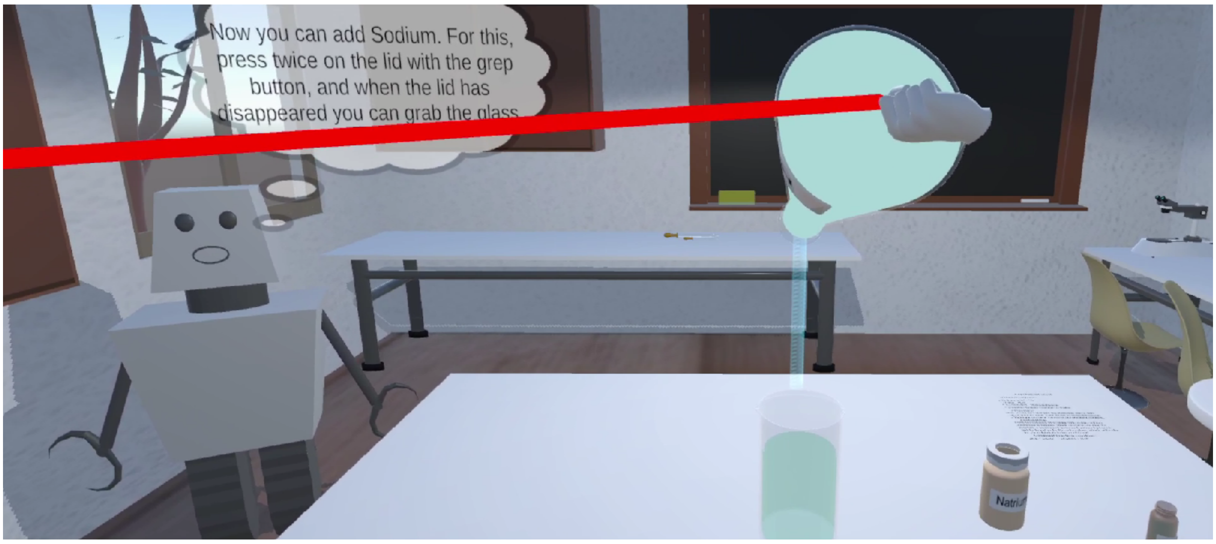


Figure 4.8: The book's content

When the user finishes performing a reaction, he will be recommended to learn a new reaction, by searching through the book again.

This scene has the same exit as the *Test your knowledge* and *Lab Assistant* scenes, namely the **Exit** button above the door, as can be seen in Figure 4.9.

Figure 4.9: Exit button

4.2.3 Test your knowledge

In this part, the user will be given tasks to be completed within a certain time, more precisely, within one minute. Depending on the options he selects from the settings menu in the Main Menu Scene, he will have to complete theoretical tasks or practical tasks. Depending on how quickly they perform the respective task, the user will receive a score, the maximum being 100 points. However, if he fails to perform the chemical reaction before the time runs out, he will not be penalized but will be assessed 0 points and move on to the next task.

Scoring is done as follows:

- if the user manages to finish the task in less than 30 seconds, 100 points will be awarded;
- if the user manages to finish the task in less than 35 seconds, 50 points will be awarded;
- if the user manages to finish the task in less than 40 seconds, 40 points will be awarded;
- if the user manages to finish the task in less than 45 seconds, 30 points will be awarded;
- if the user manages to finish the task in less than 50 seconds, 20 points will be awarded;
- if the user manages to finish the task in less than 55 seconds, 10 points will be awarded;
- if the user manages to finish the task in less than 60 seconds, 5 points will be awarded;
- and if 60 seconds pass without the user completing the task, then 0 points will be awarded.

If the user has to perform a theoretical exercise, then a canvas containing a question and three possible answers will appear on the screen, as can be seen in Figure 4.10. After selecting an answer, if he gave the correct answer, he will receive the score, and if he gave a wrong answer, he will be shown the correct answer and move on to the next task. Regardless of whether he chooses the right or wrong answer, he will not be allowed to select another answer and will not be able to receive points for that question.

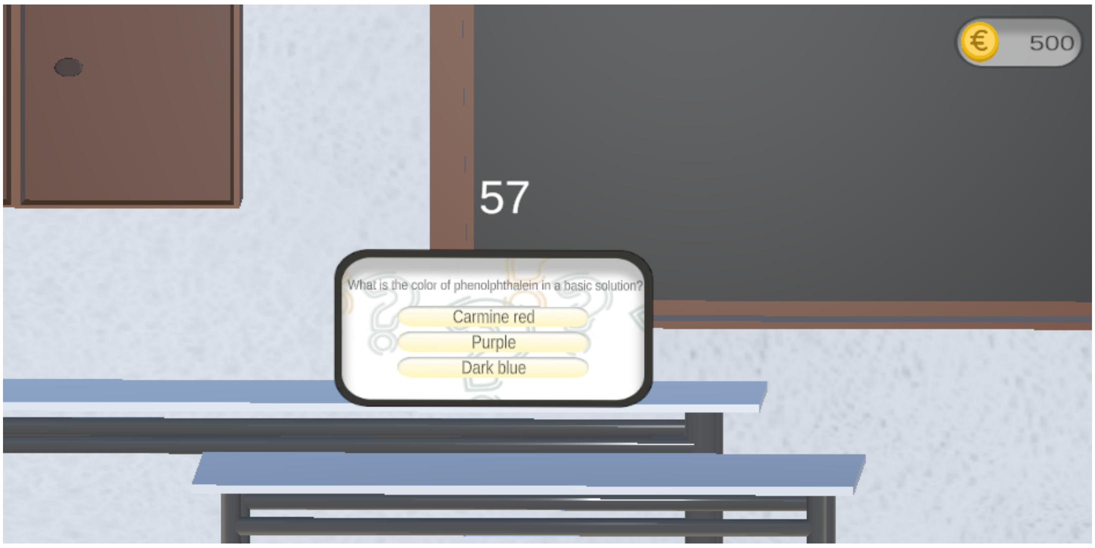


Figure 4.10: Test your knowledge Scene - Theoretical Task

If the user has to perform a practical exercise, then the necessary containers, substances, and utensils will appear on the table, as can be seen in Figure 4.11, he must perform the indicated chemical reaction as he was guided in the *Learn to make reactions* part. The task will not specify concretely which chemical reaction must be carried out, but only which chemical compound is to be obtained, the choice of the substances that must react being the responsibility of the user.

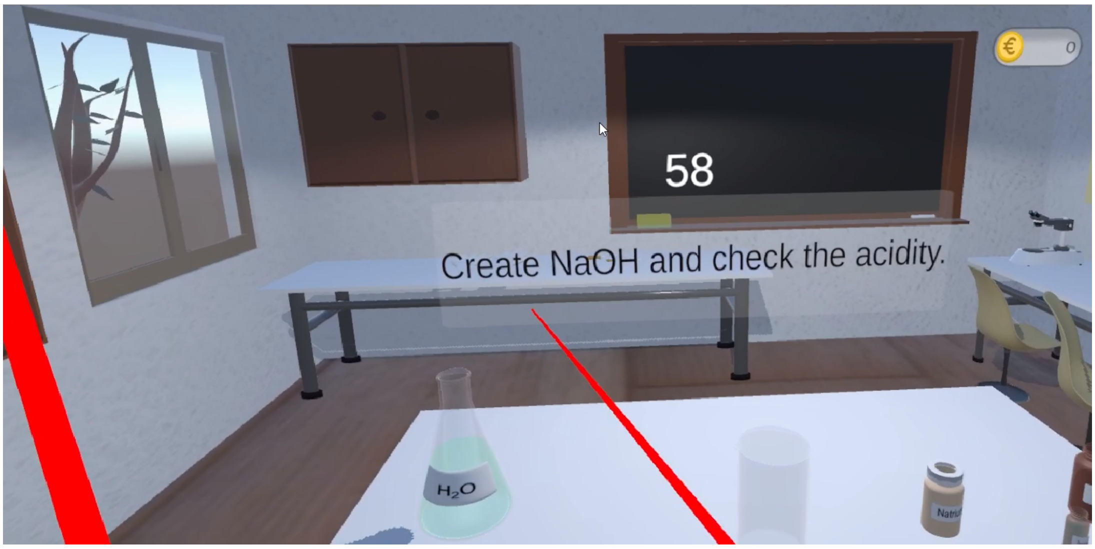


Figure 4.11: Test your knowledge Scene - Practical Task

The order of reactions is completely random, after a theoretical task another theoretical task may appear, and after a practical task, another practical task may appear, depending on the options chosen by the user. If both types of tasks are not selected to be included, then the user will only receive tasks of the selected type. If the user does not enter the respective menu and does not select the types of tasks he wants to test, the default is set for only practical tasks.

After completing all the tasks, a canvas with a specific message will appear to the user, as can be seen in Figure 4.12.

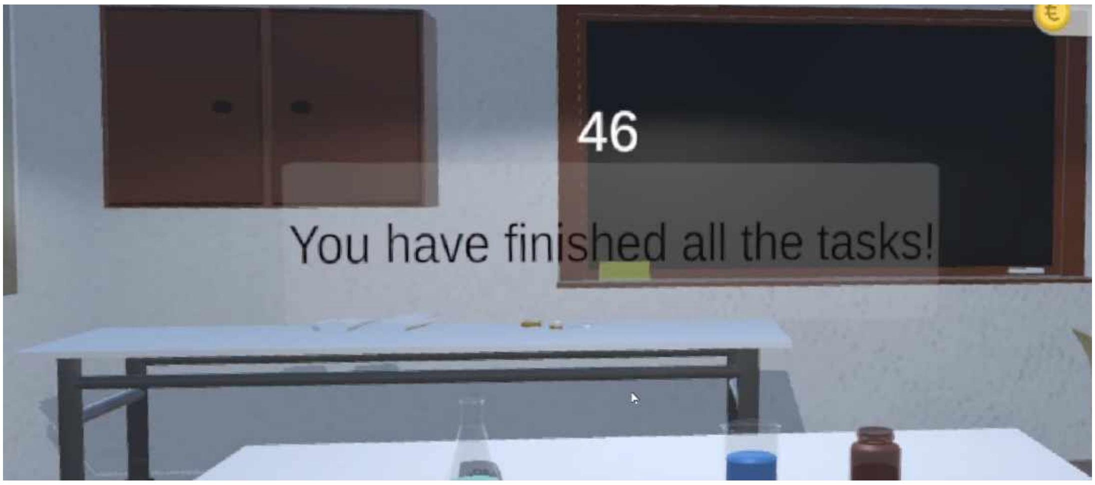


Figure 4.12: Completion Message Canvas

4.2.4 Lab Assistant

In this part, the user will be able to interact with a chatbot through voice commands. The virtual assistant is made with the tool from Inworld.AI[4], which we talked about in Section 3.1.6. Visually, as can be seen in Figure 4.13, he is properly equipped for working in a chemical laboratory, wearing a white coat, safety glasses, and protective gloves.

A new character was created on the Inworld.AI website and customized by giving it a specific description and setting various properties. In the description provided, the personality of the character was outlined and I gave the context of the application, specifying the main functionalities, the types of reactions that can be carried out within the application, but also examples of such reactions. Also, for the personality outline, I sketched him out as a chemistry major who is always willing to help with any chemistry-related problem, is friendly, and has some of the wisdom of Albert Ein-

[4]https://inworld.ai/

Figure 4.13: Lab Assistant

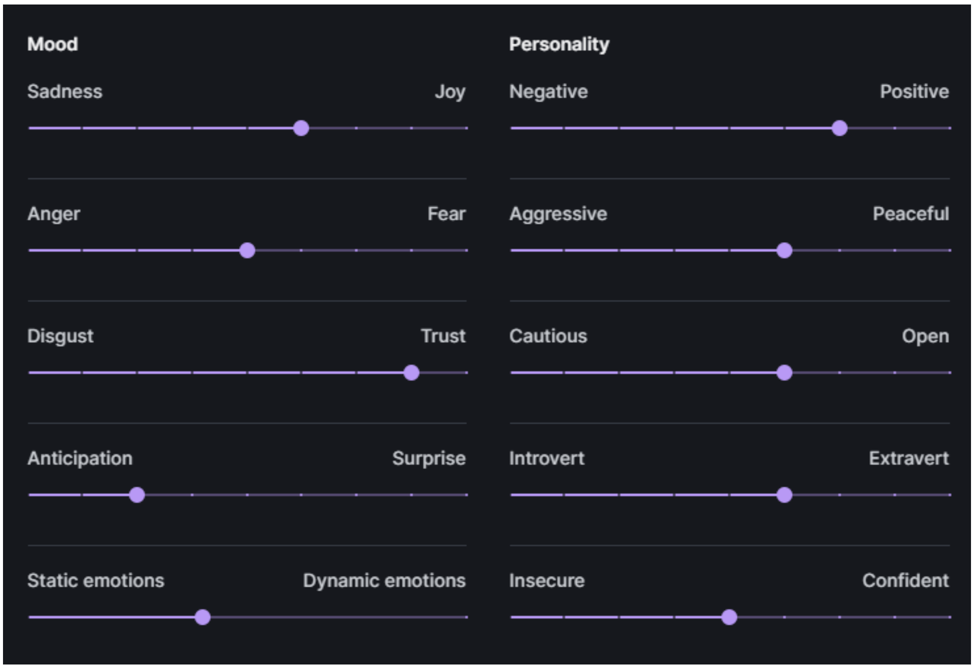
stein or Dmitri Mendeleev. The Lab Assistant is passionate about experimenting and discovering new things. He enjoys sharing his knowledge with others and helping them understand the wonders of chemistry and always encourages his students to ask questions and explore the world of chemistry.

An example of the answer that the laboratory assistant can give to his users is: *"I can explain to you the steps to perform this reaction, to begin with, you have to add the sulfuric acid, and over it, you have to pour the copper oxide. The resulting solution is blue and represents copper sulfate"*. Through this sample answer, we wanted to outline the way to provide information to the user, step by step, also providing information about the final product of the reaction, such as its resulting color.

In the *"motivation"* field, *"The lab assistant wants to inspire others to follow their passion for chemistry and make learning fun and engaging"* was written. Other settings include:

- *name*: your Lab Assistant
- *alternative name*: Chemist Master
- *role*: Chemist
- *pronouns*: he/his/him
- *stage of life*: middle adulthood
- *hobbies and interests*: chemistry

- *dialogue style*: present
- *voice*: William (calm, professional)
- *pitch*: 0
- *talking speed*: 1.25
- *personality*:



In this part the user will not have access to substances, no more tasks to complete, and no experiments, as this part is only intended to clarify some misunderstandings, answer questions, discuss various topics related to chemistry, provide detailed steps for to make a reaction, provide information related to the application or fix some theoretical notions.

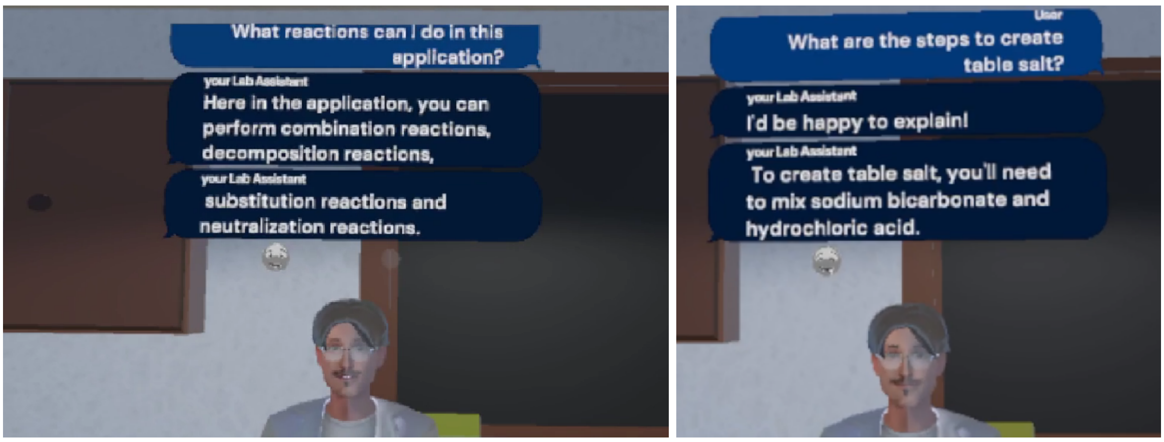


Figure 4.14: Lab Assistant Talking

4.3 Creating 3D models

Within this application, most of the 3D elements were made from scratch using the Blender platform, mentioned in Section 3.3. Thus, objects such as the laboratory, table, Erlenmeyer beakers, Berzelius beakers, shelves, cabinets, microscope, the robot, chairs, test tubes or pipettes were made:

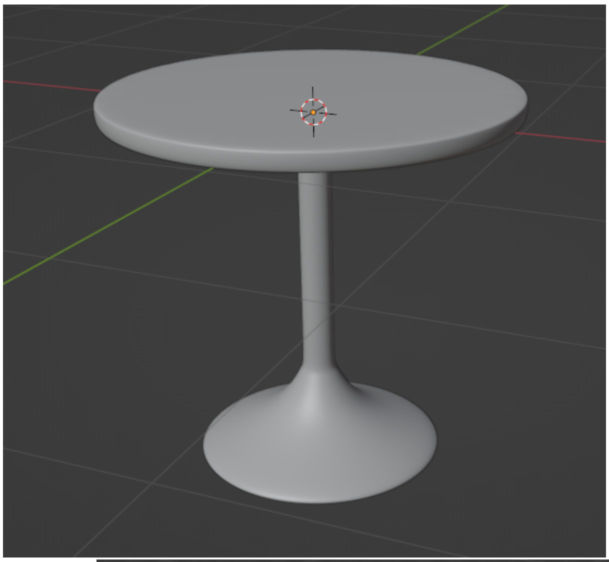
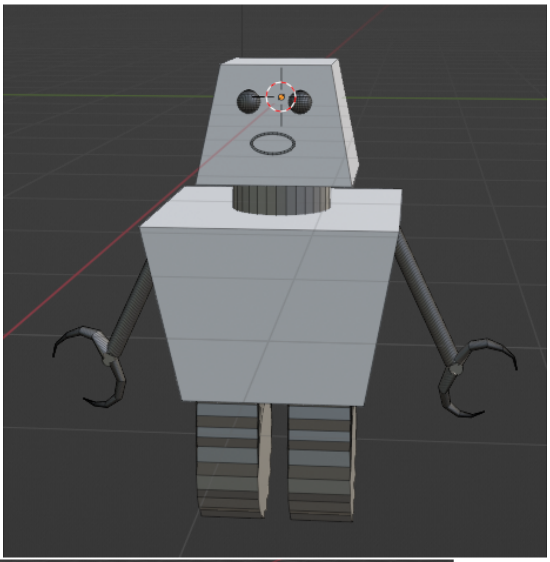
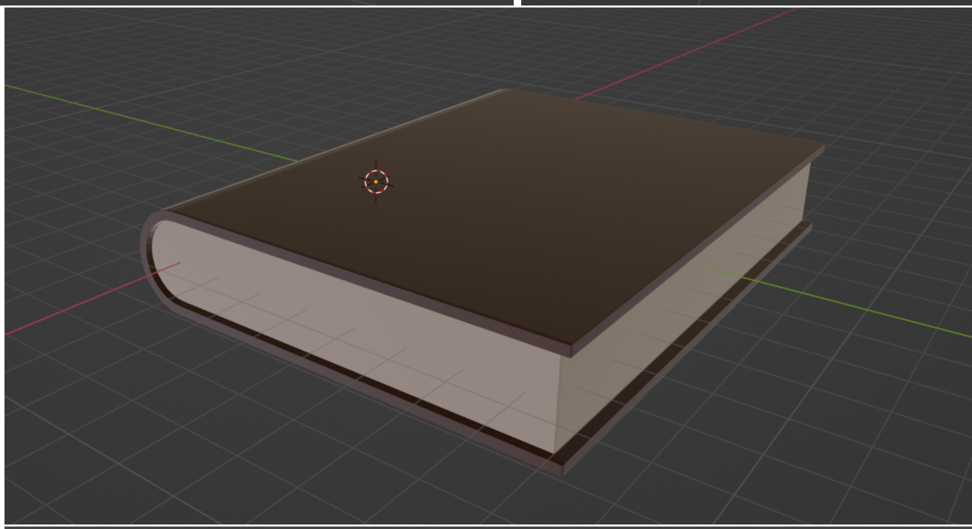
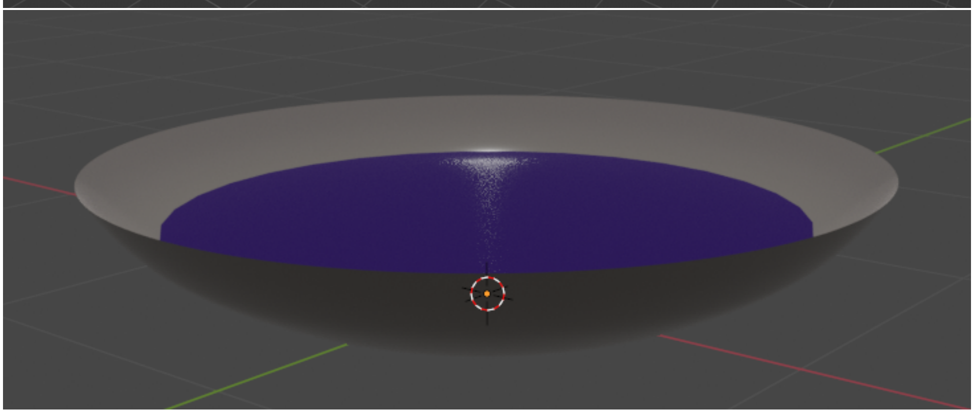





Figure 4.15: 3D models made in Blender

The simpler models, such as the exercise sheet or the periodic table, were made directly in Unity, with Planes over which textures were applied.

4.4 Creating textures

Most of the textures created were for the labels on the Berzelius and Erlenmeyer beakers: each substance has a label, and each label is made with a texture (originally an image taken from the Internet or made in Paint[5] or Figma[6]. Other textures are those from the experiment sheet, there is one for each reaction, those from the label and the contents of the book, the panels, the buttons, those from the Periodic Table of the Elements, or from substances that flow (a drop of water, a piece of metal, etc.).

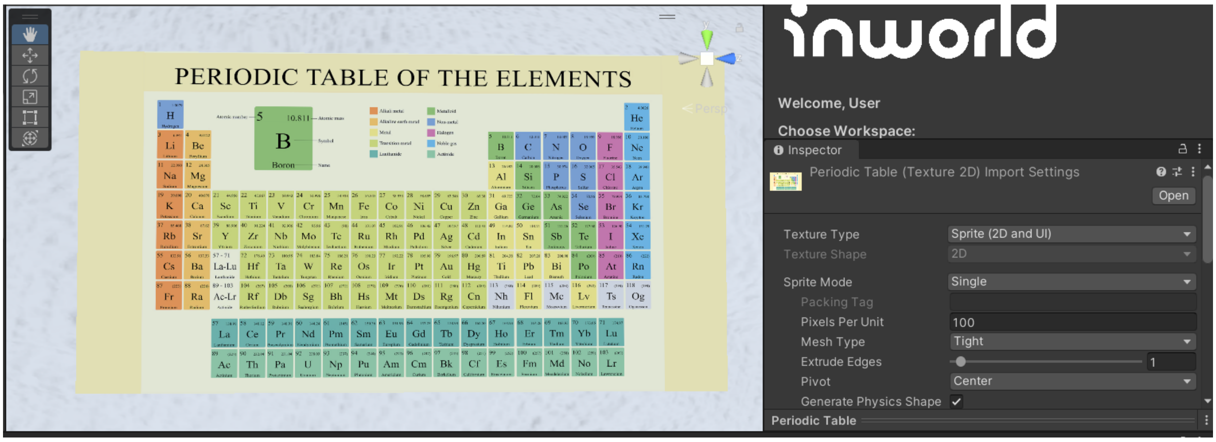


Figure 4.16: Texture example: Periodic Table of Elements

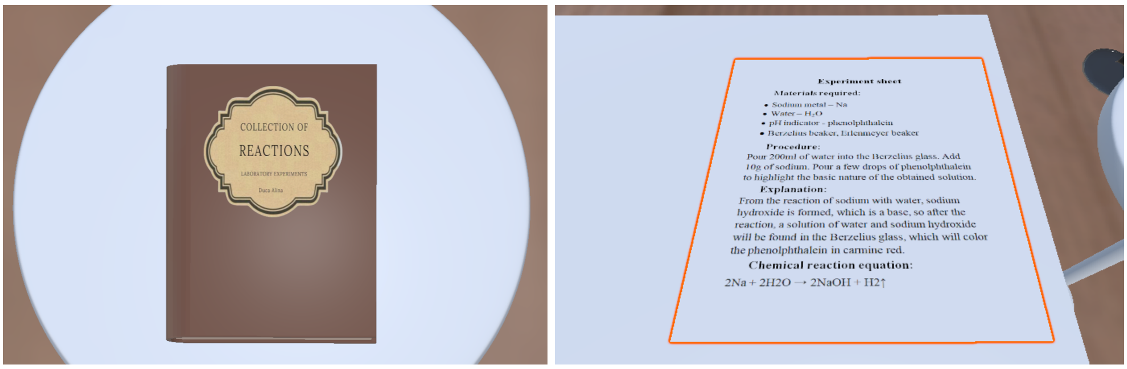


Figure 4.17: Texture examples: Experiment Sheet and Book's Label

[5]https://www.microsoft.com/ro-ro/windows/paint#imagecreator
[6]https://www.figma.com/

4.5 Creating shaders

Shaders have been used a lot for liquids. A Shader Graph applied to a GameObject makes it behave similarly to liquid substances, making its surface parallel to the horizontal plane of the virtual world.

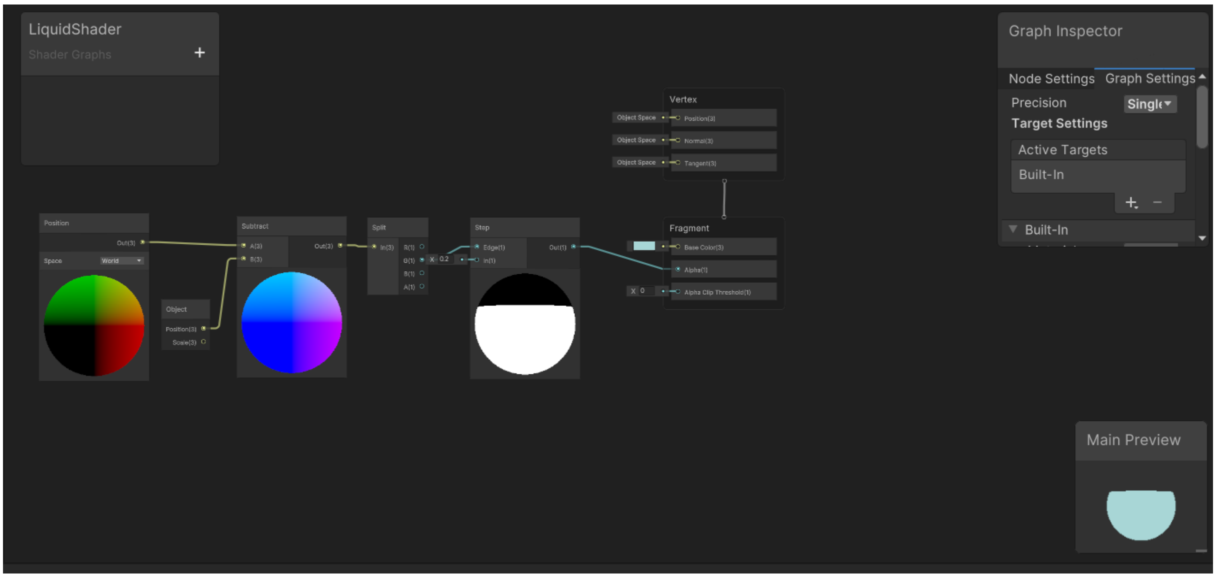


Figure 4.18: Creating a Liquid Shader Graph in the Graph Inspector

4.6 Creating materials

Materials were used in the project to put colors or images on GameObjects. Since Blender materials such as glass or other transparent materials are not preserved on export, new materials were created within the Unity platform. Whether simple colors, shaders or textures, materials have been used predominantly. As concrete examples of places where materials were used in Unity, glasses (glass material), liquid substances (materials with Shader Graphs), laboratory walls, the book, tables, etc can be listed. Materials are created by right-clicking in Assets, followed by Create and Material (see Figure 4.19).

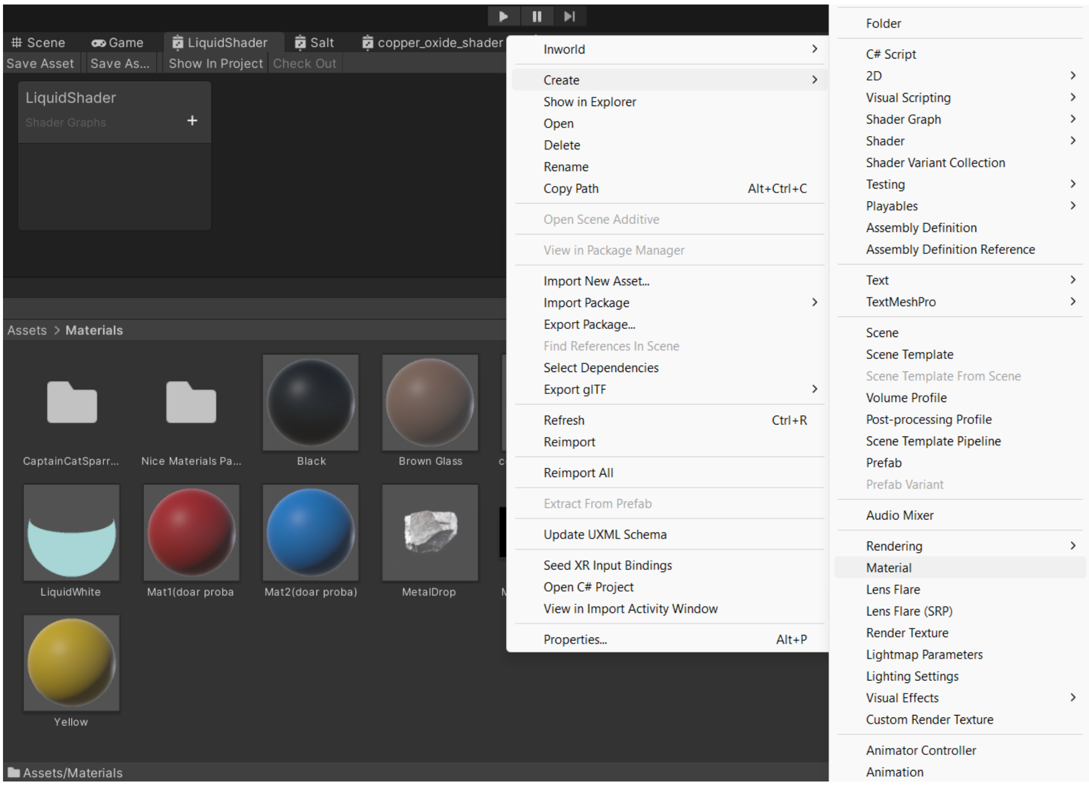


Figure 4.19: Creating a new material in Unity

4.7 Creating canvases for interfaces

Canvases were used within the application for several purposes: to create menus, such as the main menu or the settings menu, to display messages related to reaction steps, such as directions from *Learn to make reactions* or tasks from *Test your knowledge*, and to display the content of the book, as can be seen in Figure 4.7. Most often, they contain a panel with a background and a TextMeshPro, buttons, or toggles.

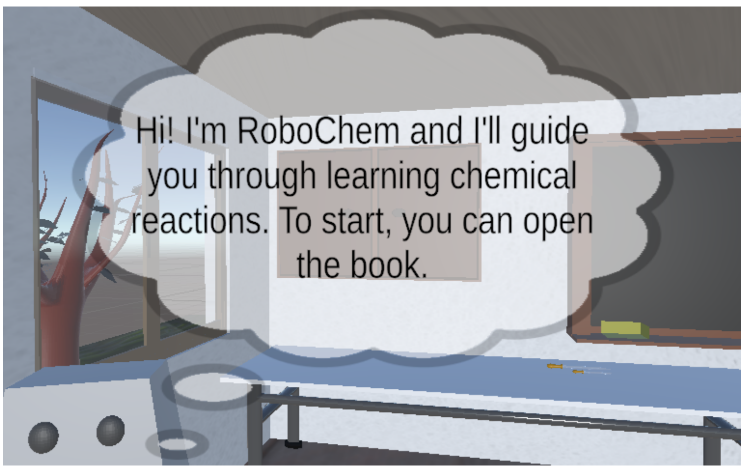


Figure 4.20: Canvas example: Speech bubble

4.8 Creating Animations and Particle System effects

Within the application, Particle System effects were used for the animations of pouring liquids or substances in powder form, but also of explosions, such as the explosion resulting from the reaction between water and alkali metals. A Particle System is created by right-clicking in the hierarchy, followed by Effects and Particle System. Then, from the Inspector, edit this Particle System until the desired result is reached. Among the settings that can be made here are duration, looping, start delay, start lifetime, start speed, start size, start rotation, simulation speed, play on awake, max particles, emissions (rate over time and rate over distance), shape, and so on.

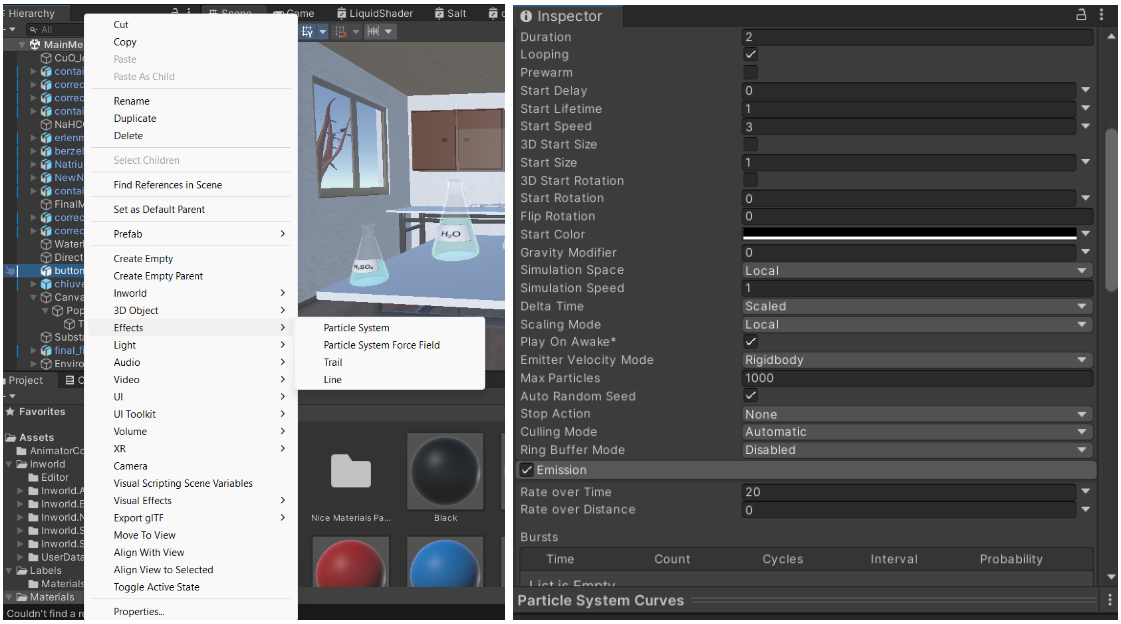


Figure 4.21: Creating a Particle System

The use of Particle System effects within the application helps to increase immersion and a more realistic experience in the virtual world. On the other hand, animations were also used in this application, such as the one that appears when opening the lid of the substance container.

4.9 Conclusions

In this chapter, we have delved into the main functionalities of our VR chemistry application developed for the Meta Quest 2. The discussion encompassed the overall architecture of the application, detailing the roles and interactions of its three primary scenes: *Learn to Make Reactions*, *Test Your Knowledge*, and *Lab Assistant*. Each scene is designed to provide a unique aspect of the educational experience, enhancing the user's understanding and engagement through different methods.

Additionally, we touched upon the various elements used in developing the application, including creating 3D models, textures, shaders, materials, and canvases for interfaces. These components work together to create a realistic and engaging virtual environment, ensuring users receive a comprehensive and immersive educational experience.

Chapter 5

Usability tests

In order to evaluate how intuitive, efficient and easy to use the **Experimenting with chemical reactions in Virtual Reality** 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 Google Forms[1] 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 **Experimenting with chemical reactions in Virtual Reality** application. By dividing the usability tests into these three modules, we ensured a thorough evaluation of the application's main functionalities, capturing

[1]https://www.google.com/forms/about/

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:

1. collecting demographic and experience information to better understand who the participants are,

2. introducing participants into the system,

3. engaging them in VR using Meta Quest 2,

4. 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.

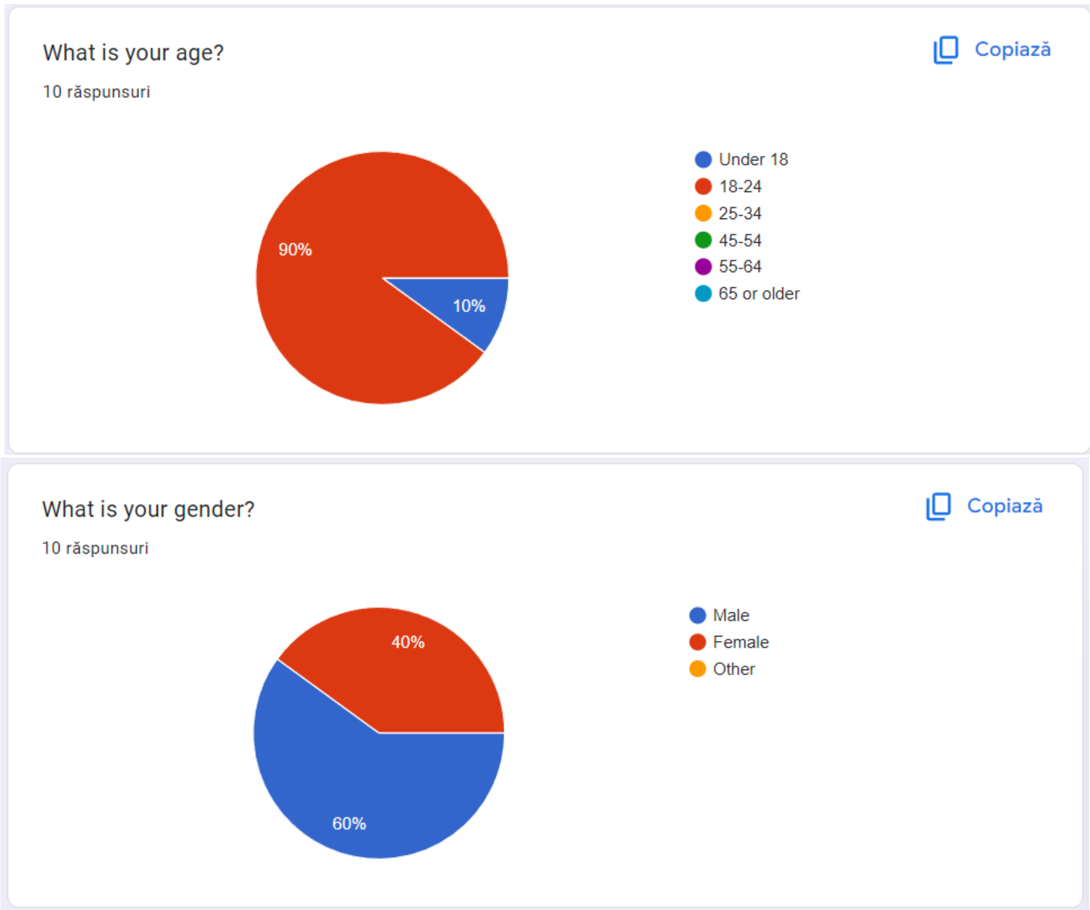


Figure 5.1: Percentage of participants' ages and genres

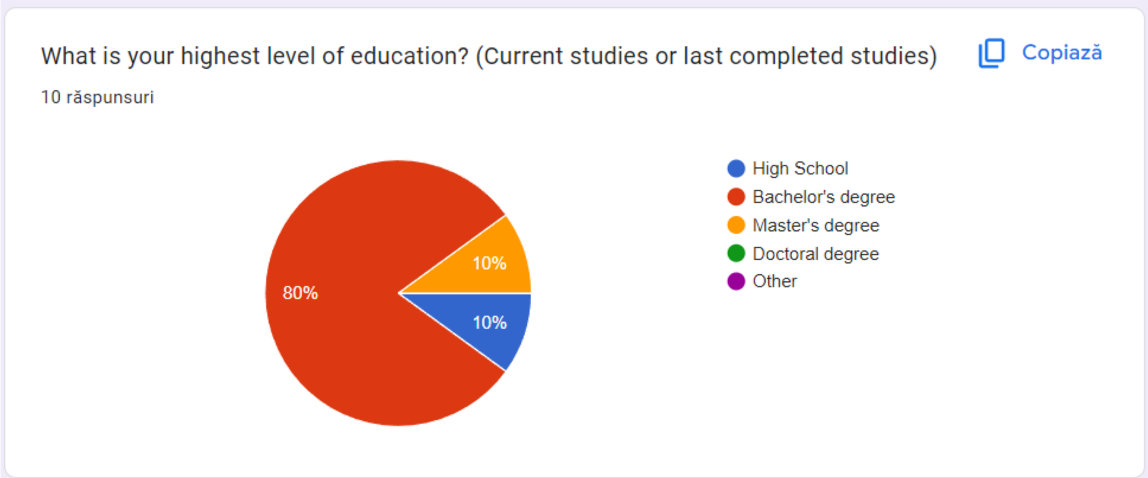


Figure 5.2: Percentage of participants' education levels

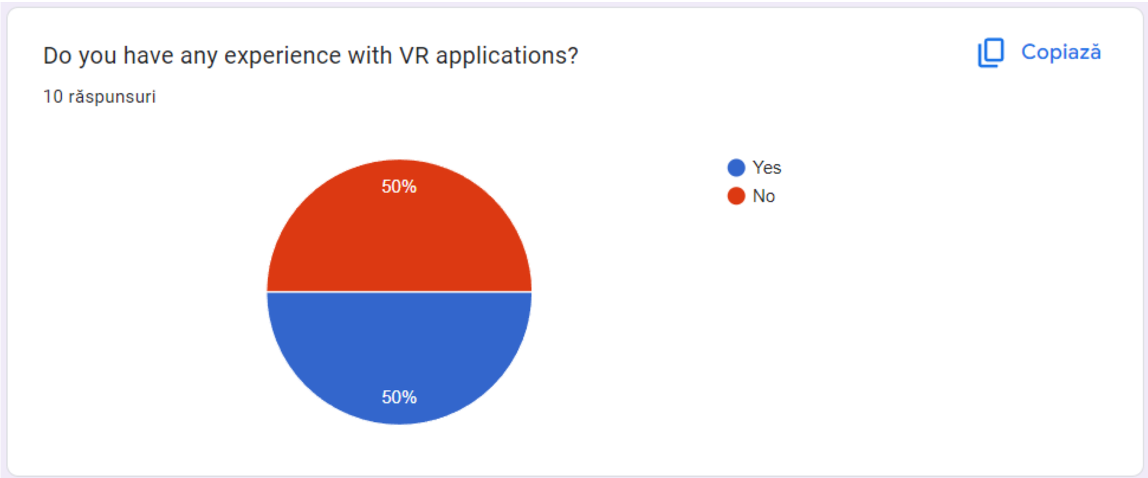


Figure 5.3: Percentage of participants experienced with VR

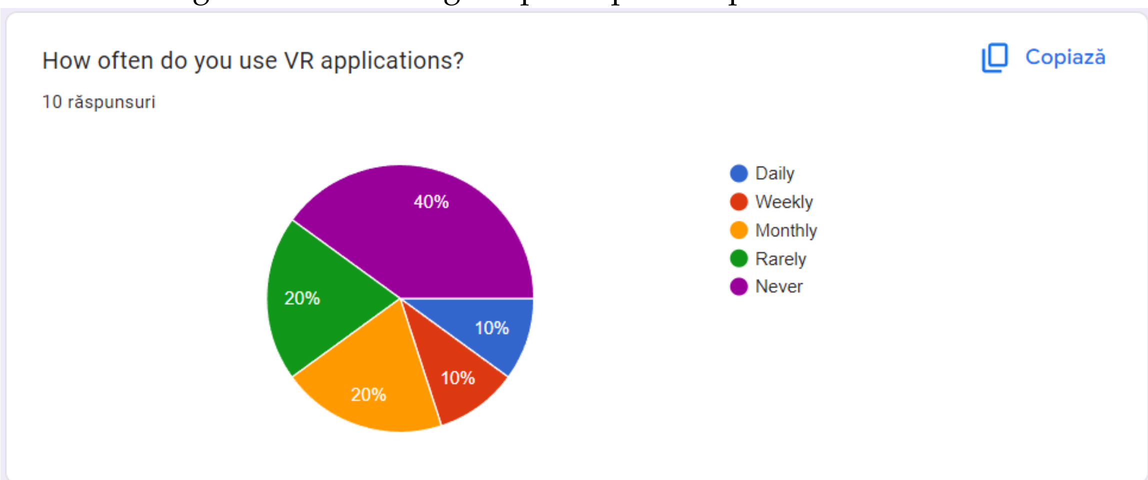


Figure 5.4: Frequency of VR application usage among participants

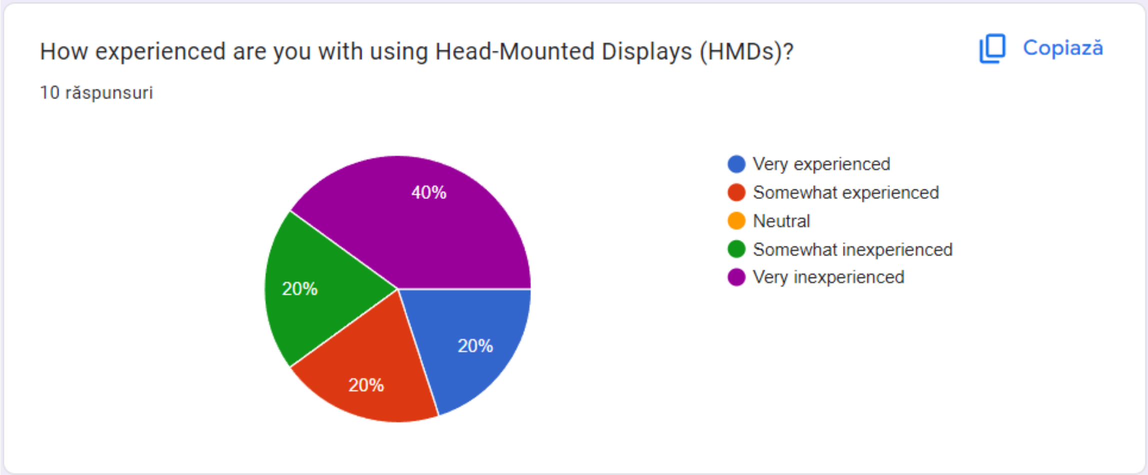


Figure 5.5: Percentage of participants experienced with HMD

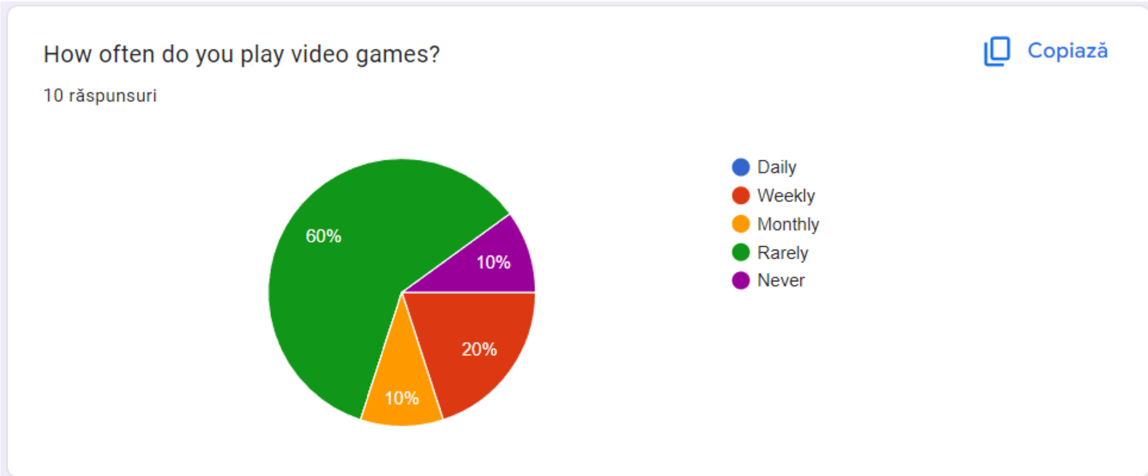


Figure 5.6: Frequency of video game play among participants

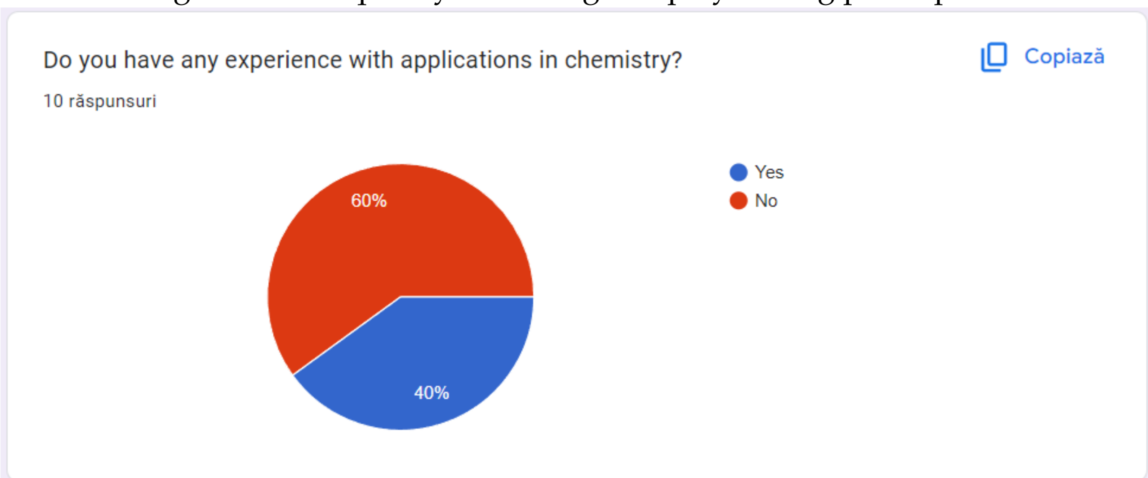


Figure 5.7: Percentage of participants with experience in Chemistry Applications

As previously mentioned, the usability tests involved 5 people with VR knowledge (technical participants), and 5 people without VR experience (non-technical participants). Their feedback is presented in **Table 5.1**.

Table 5.1: Opinions of Technical and Non-Technical Participants

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

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

5.1 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. In this sense, the use-case diagram[2] can be viewed in Figure 5.8.

[2]https://draw.io/

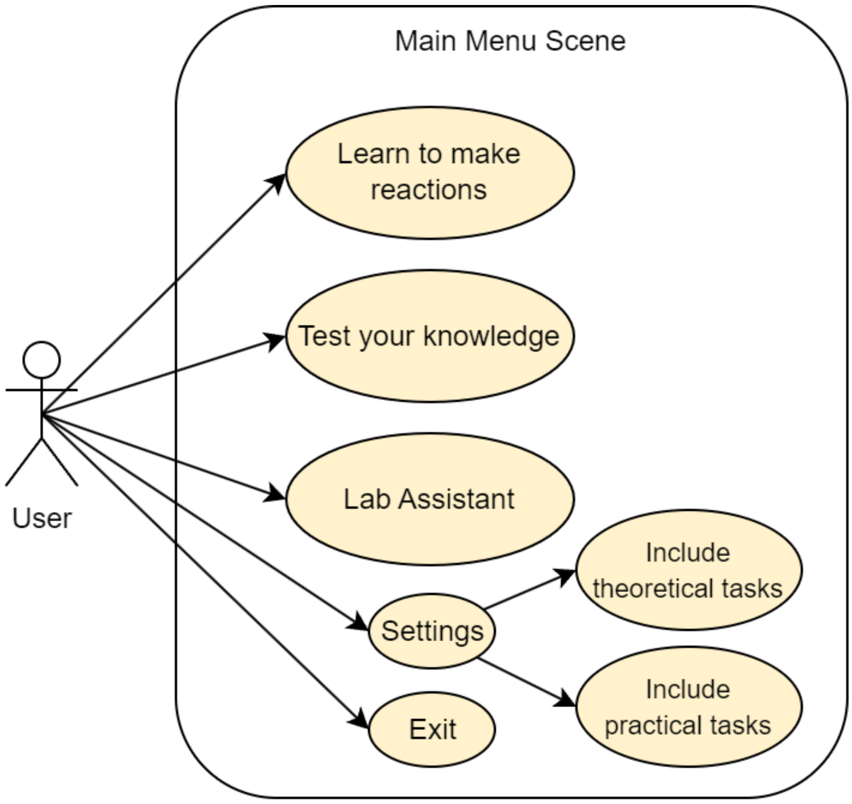


Figure 5.8: Use-case diagram for Main Menu Scene

Thus, by pressing the **Learn to make reactions** button and entering the appropriate scene, the use-cases are those presented in the diagram in Figure 5.9.

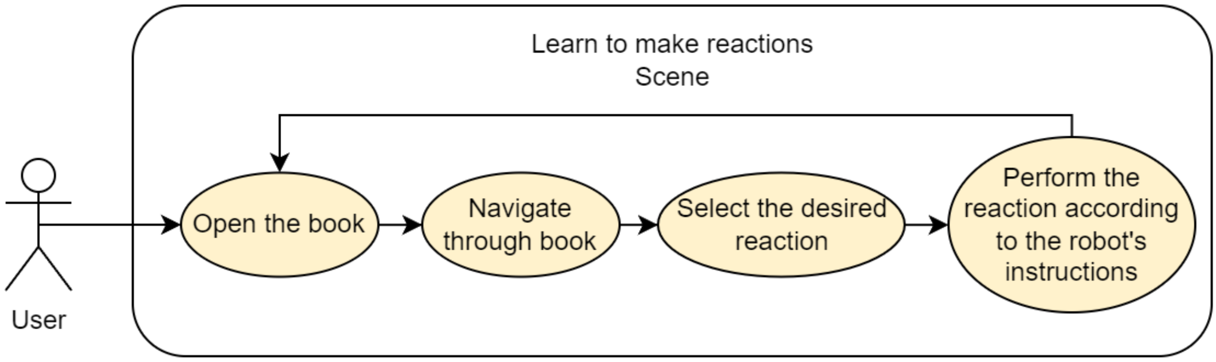


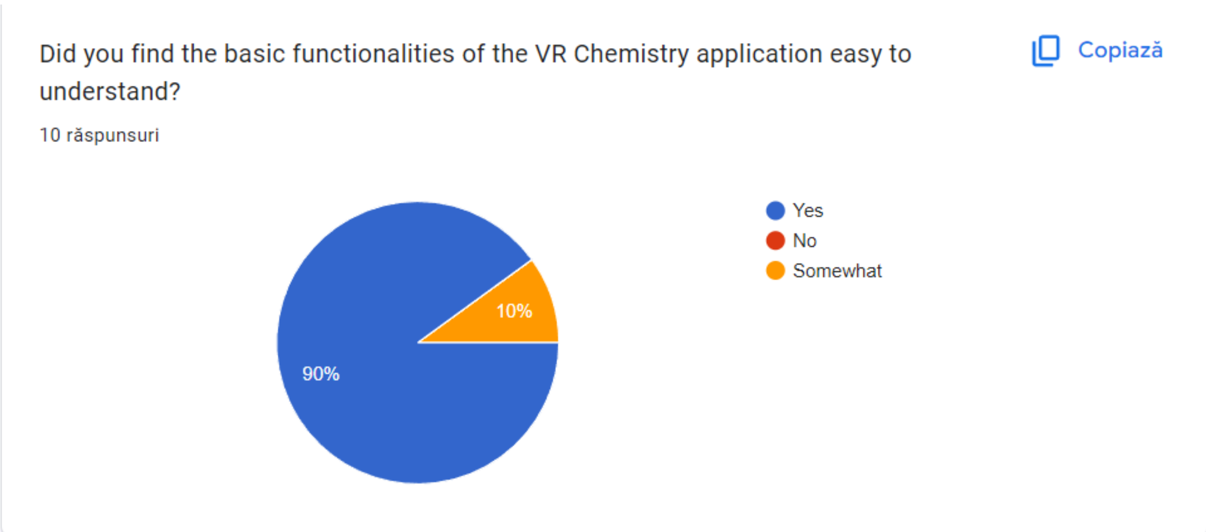
Figure 5.9: Use-case diagram for Learn to make reactions Scene

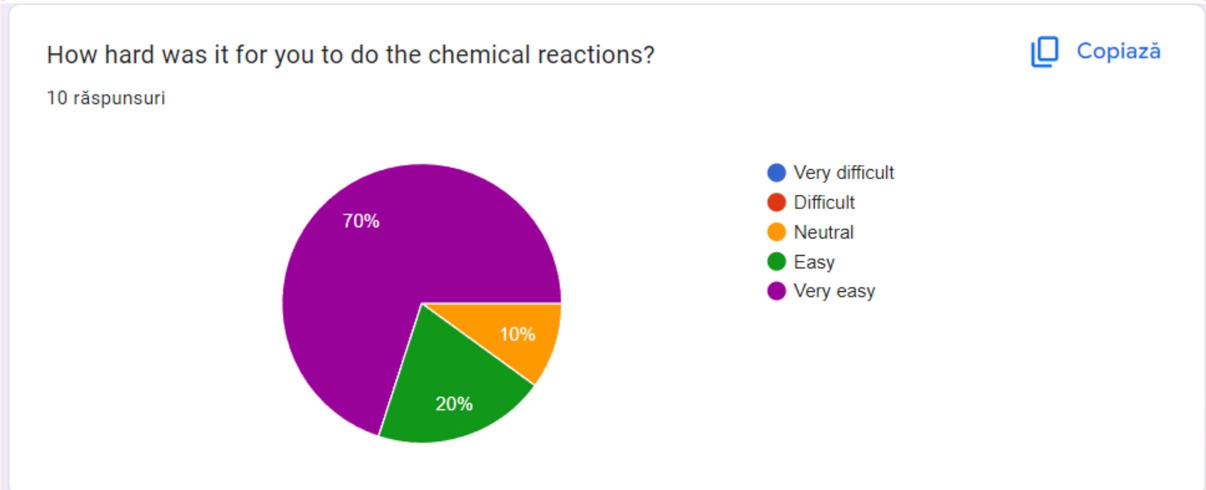
Methodology: The evaluation methodology used for the *Learn to make reactions* Module involved a three-part process: (1) explaining the interactions and how the instruction will unfold, (2) engaging users in VR using the Meta Quest 2 to explore the chemistry laboratory environment with VR controllers,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





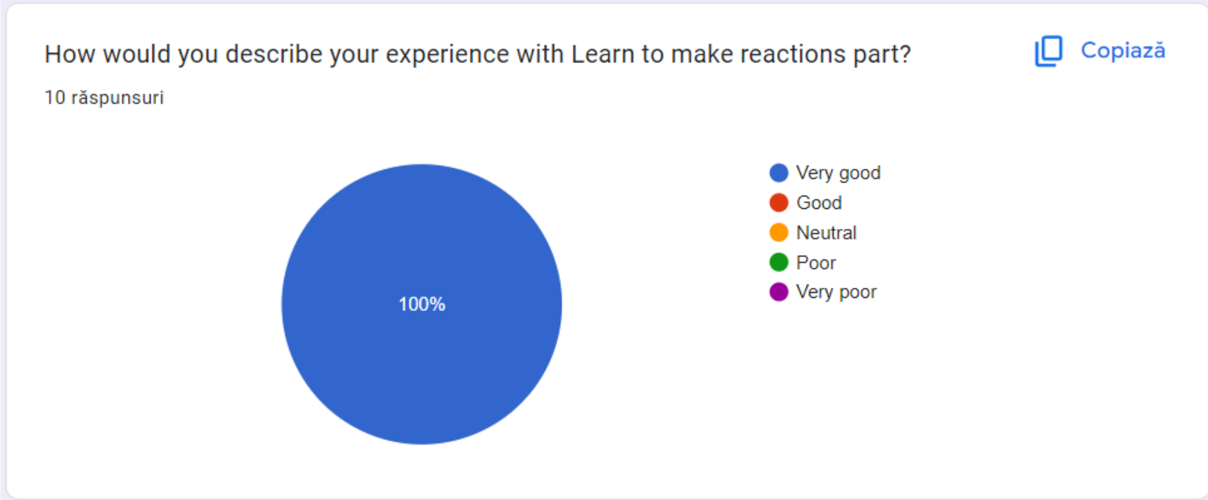


Figure 5.10: Learn to make reaction Post-Questionnaire

5.2 Test your knowledge

Use-case: By pressing the button *Test your knowledge* from the main menu, as shown in Figure 5.8, and entering the appropriate scene, the use-cases are those shown in the diagram in Figure 5.11.

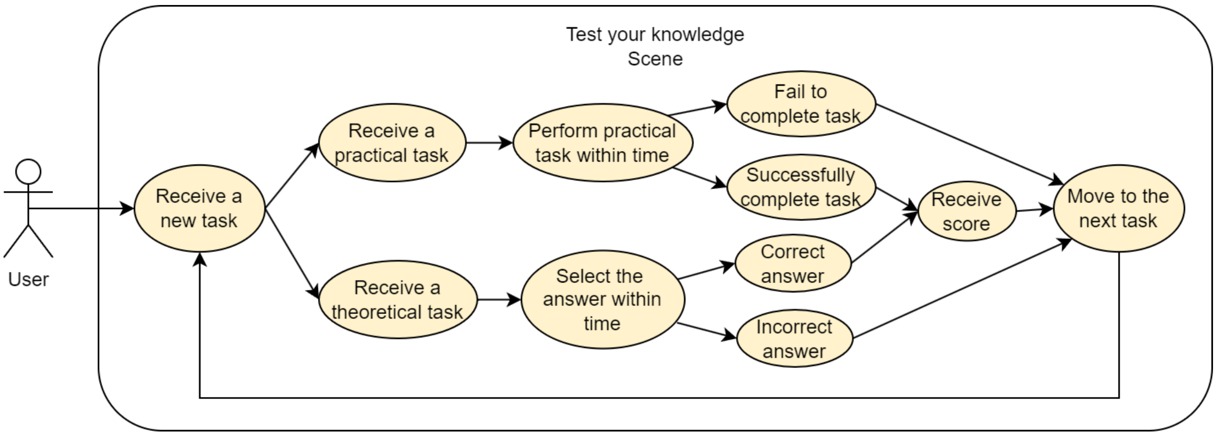


Figure 5.11: Use-case diagram for Learn to make reactions Scene

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:

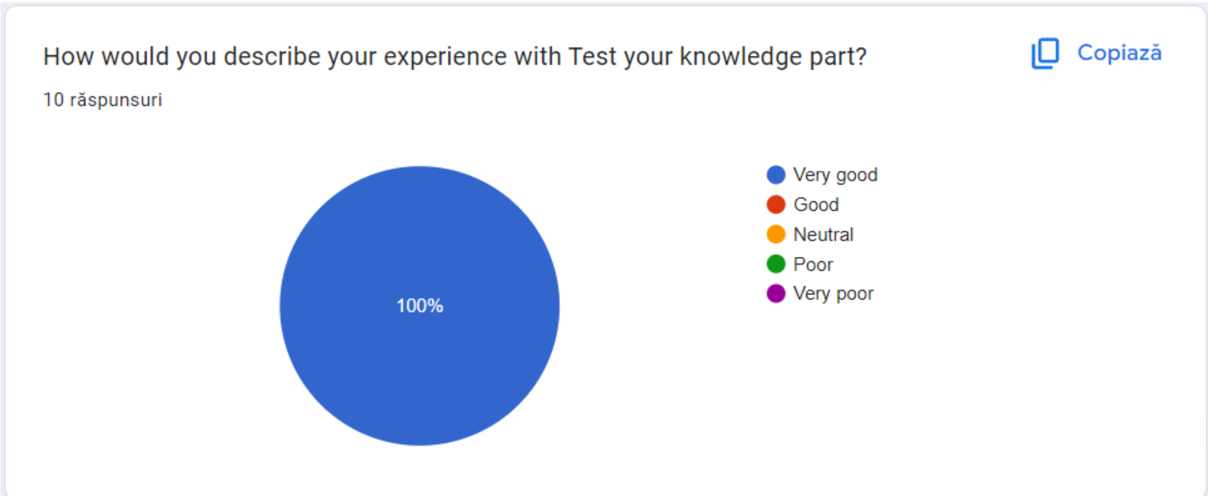


Figure 5.12: Test your knowledge Post-Questionnaire

5.3 Lab Assistant

Use-case: By pressing the button *Lab Assistant* from the main menu, as shown in Figure 5.8, and entering the appropriate scene, the use-cases are those shown in the diagram in Figure 5.13.

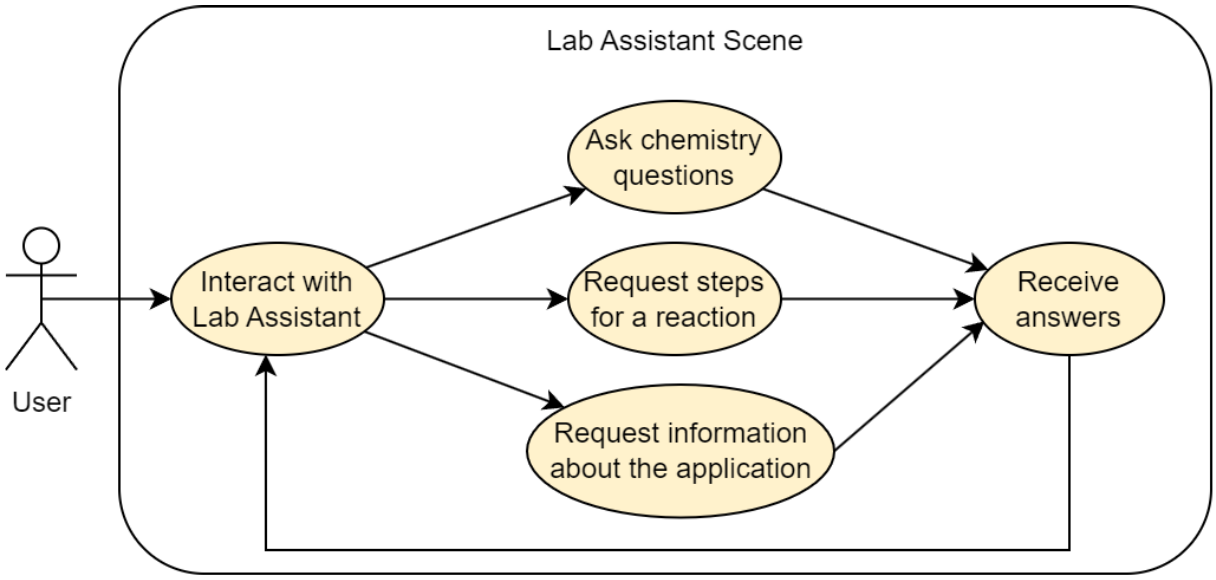


Figure 5.13: Use-case diagram for Lab Assistant Scene

Methodology: The evaluation methodology used for the *Lab Assistant* module involved a three-part process: (1) explaining how to interact with the virtual assistant, including the use of voice commands, and informing users that they can ask the assistant for clarifications, details on the stages of performing a reaction, or information about the experiments that can be conducted within the application, (2) involving users in VR using Meta Quest 2 to explore the environment, and (3) collecting feedback through a post-questionnaire.

Performed tasks: In the tasks performed, the participants interacted with the virtual assistant, being able to clarify their curiosities and concerns accumulated following the experience of the two modules mentioned previously. The virtual assistant provided information about the pH of some substances, the color of the chemical product resulting from a combination, existing acidity indicators, where some substances are found in nature or in what form, the stages of making a chemical compound or what reactions can be made within the application, showing its ability to engage in the learning process and to respond to the user's ambiguities.

Remarks: Both groups expressed their satisfaction and enthusiasm in interacting with the *Lab Assistant* part, though some participants from the non-technical group considered that the assistant was too verbose or that it could not be interrupted after providing a partial answer.

Results:

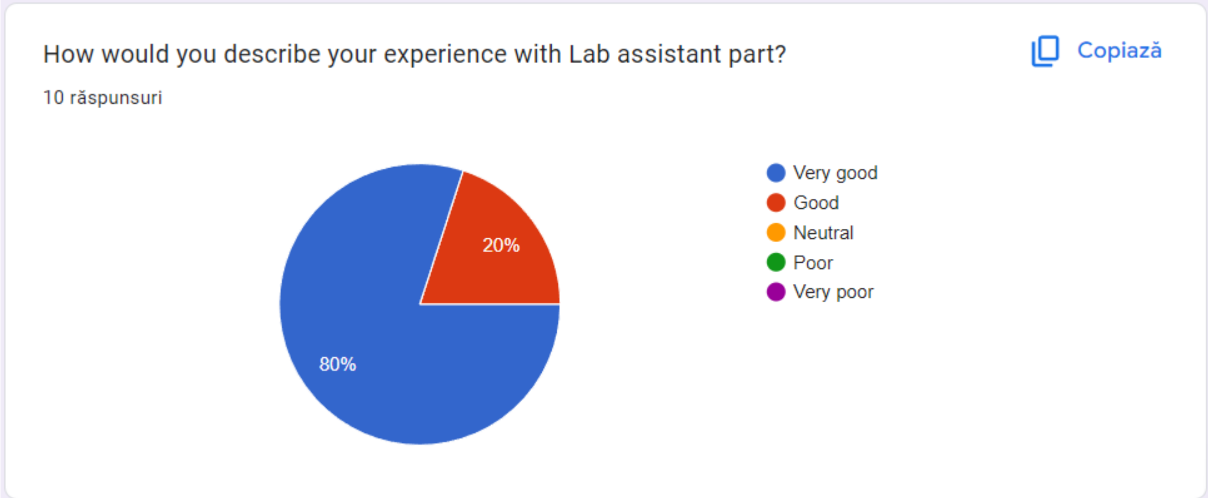


Figure 5.14: Lab Assistant Post-Questionnaire

While the usability tests highlighted certain constraints, such as a limited group of participants and the scope of the experiment, the overwhelmingly positive response underscores the appeal of the VR chemistry laboratory. Users appreciated the new way to interact with substances and chemistry, signaling a strong interest in the wider application of VR applications for education. This enthusiasm is a testament to the significant potential of VR applications to revolutionize the way information about the study of chemistry is accessed and delivered.

5.4 Additions and Later Implementations

Following the feedback of the participants in the usability tests, both those received in the post-questionnaire and those expressed verbally during the VR world experience, new functionalities were added to the application. Among them are:

- The robot's voice guide in the *Learn to make reaction"* part, using the Text to Speech[3] tool.
- Including the experiment sheet in the *Learn to make reactions* part,
- Limiting the movement space inside the laboratory,
- Changing the angle at which a container must be tilted to cause the substance to flow.

[3]https://elevenlabs.io/text-to-speech

5.5 Conclusion

Following the usability tests conducted, it was observed that most of the participants gave positive feedback on the idea, concept and the application itself. The application has been described as both useful and innovative. This was liked by users both due to the integration of Virtual Reality aspects, as well as due to the introduction of gamification elements. These features have significantly contributed to the application's appeal.

The VR component provided an immersive experience that enhanced user engagement, making the application more engaging and interactive. Gamification elements such as rewards, tasks, and progress tracking motivated users to engage deeply with the app, thereby increasing its overall effectiveness.

To make the application as intuitive and efficient as possible, user feedback has been carefully considered. Based on the information gathered, several improvements have been implemented to respond to user suggestions and preferences, which are listed in the previous section.

In conclusion, the usability testing not only affirmed the application's strengths but also provided valuable information for future improvements. The feedback received has been instrumental in refining the solution, and maintaining a focus on innovation, usability, and overall user satisfaction.

Chapter 6

Immersiveness and methods used for a better user experience

Within this application, a special emphasis was placed on immersiveness, wanting the visual interface and the interaction within this application to be as realistic, believable, as close as possible to a real one. In this sense, it was done by introducing sounds and different visual effects, such as the flow of liquids or the use of a Shader Graph.

- **Use of sound effects**: sounds play a crucial role in creating an immersive experience. Various sound effects have been integrated into the application that faithfully reflects the events in the virtual environment. For example, within the *Learn to make reactions* part, for each reaction and each step there is an audio sequence generated with the Text to Speech[1] tool that presents information about the reaction and provides instructions. As another example, specific sounds for pouring liquids, effervescent chemical reactions, and boiling reactions add a layer of realism and help users feel more connected to their surroundings. Each sound has been carefully selected and synchronized with the corresponding actions to enhance the authenticity of the experience.
- **Implementation of visual effects**: visual effects were also essential to achieve a high level of immersion. Using the Shader Graph, dynamic visual effects were created to simulate the real behavior of various materials and chemicals. For example, shaders that reproduce the movement of liquids parallel to the horizontal

[1]https://elevenlabs.io/text-to-speech

plane, the transparency and opacity effect of gases, and substances that change their appearance over time depending on chemical reactions were implemented.

- **User experience testing and optimization**: to ensure that users have the best possible experience, testing sessions with a diverse group of users were conducted. The feedback obtained allowed us to identify areas that needed improvement and to adjust the technical and visual aspects of the application. Continuous optimization of performance and smoothness of interactions were key priorities in the development of the application.

6.1 Conclusions

In conclusion, by combining realistic sounds, advanced visual effects, and continuous refinement, it was possible to create a VR chemistry application that provides an immersive and engaging experience, facilitating learning through a hands-on and interactive approach.

Chapter 7

Future directions

I want to continue the development of this application, proposing to implement an interactive Periodic Table in the future. It would be useful for users to know not only how substances react when combined, but also what the atoms of the chemical elements from which those substances are made look like. Thus, a Periodic Table could contain information such as:

- atomic number,
- atomic mass,
- the name of the chemical element,
- the chemical symbol,
- the element's radioactivity,
- the group of elements to which it belongs.

When interacting with an element on the periodic table, an atom of that element will be displayed, showing the nucleus made up of protons and neutrons, the electron shell along with the specific orbitals and electron filling at each level, and a brief description of the element, as well as the places or objects where it can be found in nature or the environment.

I have also proposed that in the future I integrate the virtual assistant so that it is permanently aware of the experiments carried out and can give directions even without the user's voice intervention.

Conclusions

Experimenting with chemical reactions in Virtual Reality is an eLearning application developed for the standalone headset Meta Quest 2. It was built not only for students but also for people who want to strengthen their ways of developing chemical reactions and the results of combining some chemical compounds.

It aims to make the study of chemistry interesting and attractive, wanting to emphasize the fact that chemistry is a discipline that is learned visually, more concretely, by graphically visualizing reactions, substances, and combinations. As mentioned in the Existing Work section, chemistry is seen as one of the most difficult subjects, having among the most abstract and challenging concepts to understand. In this regard, the application aims to provide an interactive and intuitive environment that facilitates learning through visual simulations and virtual experiments, thus helping students to better understand and appreciate complex chemical phenomena.

It is built in such a way as to be immersive, as close to reality as possible, and intuitive, representing the perfect solution for someone who wants to learn to make chemical reactions, but also for someone who wants to test his skill in performing these experiments in a quick time. In this context, gamification elements were introduced, such as offering a reward or providing feedback.

The problem that were identified before starting the implementation of this application was the very small number of practical chemistry lessons in schools, the lack of necessary substances or utensils, the impossibility of carrying out chemical experiments outside a laboratory or a specially designed space, the dangers to which students are sometimes exposed by carrying out experiments, some of which resulting in toxic substances, and the lack of attractiveness of the subject of chemistry among students.

The application comes to offer a solution to this problem, offering a safe virtual environment, without depending on the physical existence of a laboratory equipped with the necessary elements, and offers visual support to facilitate the learning process.

Moreover, thanks to the robot that offers both sound and text instruction, the process of making new reactions is easier for the students, due to the test module they can check if the information has been successfully accumulated, and with the help of the virtual assistant, they can clarify unclear things even more deeply.

The solution of the **Experimenting with Chemical Reactions in Virtual Reality** application brings, in addition to other applications currently on the market, a series of elements, including the optimization of the use of fluids, the use of a virtual assistant, assisting the realization of reactions by offering sound instructions or testing the practical knowledge, but not only the theoretical ones.

Being a very important science that is the basis of a field such as medicine the pharmaceutical industry and the food industry, we want to encourage a lot of people to try this application, especially pupils and students. With our application, *Experimenting with Chemical Reactions in Virtual Reality*, I want to increase everyone's curiosity about VR applications and increase interest in the science of chemistry, and also enjoy such new concepts that we believe will have a big impact and huge in the future of our life.

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