STEMxVR

Virtual Chemistry Lab Simulation

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Document Approval:
The following document has been accepted and approved by the following:

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Contents

INTRODUCTION

1.1. PURPOSE

The Software Requirements Specification (SRS) document for STEMxVR aims to present a comprehensive and detailed description of the system to be developed. STEMxVR is designed to address the gap in practical chemistry lab learning for students in Pakistan, especially those in high schools and secondary institutions where traditional lab facilities are either non-existent or inadequate. This virtual reality platform will enable students to perform simulated chemistry experiments in a highly immersive and interactive environment, bringing the advantages of experiential learning to regions and schools with limited resources.

This document outlines all the necessary technical and functional requirements that the development team, stakeholders, educators, and administrators need to understand to ensure the successful implementation of the STEMxVR platform. By offering a virtual alternative to expensive and sometimes dangerous physical chemistry labs, STEMxVR seeks to democratize access to quality science education in Pakistan, potentially revolutionizing the way students engage with practical science subjects like chemistry.

Target Audience for this document could be:

- **Development Team:** Engineers, designers, and developers responsible for building and maintaining the platform.
- **Project Stakeholders:** Project managers, investors, and academic institutions overseeing and funding the initiative.
- **Students:** The primary end-users, typically high school students in Pakistan, who will use STEMxVR to perform virtual experiments.
- **Instructors:** Teachers and educators who will manage students, design custom experiments, and assess student performance within the platform.
- **Educational Administrators:** School and district-level authorities looking to incorporate the platform into the curriculum.
- **Policy Makers:** Government officials interested in scaling this project to address national educational gaps.

Key objectives of this document include detailing the functional and non-functional requirements of STEMxVR, ensuring that the platform is developed to meet its educational goals effectively. It also serves as a formal agreement between developers, stakeholders, and end-users, including students, instructors, and administrators, to maintain a unified understanding of the project's purpose and functionality. Additionally, the document provides a clear roadmap for developers to follow, ensuring that the project is built with scalability, user needs, and future enhancements in mind. Moreover, it aims to assist instructors and educational institutions in comprehending how the system will be integrated into existing learning environments, ensuring smooth adoption and use. Finally, this document will be referenced throughout the project lifecycle, serving as a blueprint from the initial planning stages through design, development, testing, and deployment, ensuring all goals are consistently met.

1.2. PRODUCT SCOPE

The scope of the STEMxVR platform is to simulate realistic chemistry laboratory experiments using Virtual Reality (VR). This immersive platform will replicate real-world chemical reactions, equipment, safety protocols, and lab environments to enhance students' understanding of chemistry, particularly in educational institutions where traditional lab resources are unavailable or inadequate.

At its core, STEMxVR targets the Pakistani education system's current deficiency in providing practical lab experiences for students at the high school levels. Due to economic limitations, many schools cannot afford to maintain fully functional laboratories, which greatly affects students' ability to perform experiments and understand scientific concepts beyond rote memorization. This system will enable students to virtually perform chemistry experiments safely, interact with lab equipment, and receive instant feedback on their actions.

Key Features of the Product Scope Include:

- **Realistic Simulation of Chemistry Experiments:** The system will replicate real-world chemistry experiments based on the high school chemistry curriculum in Pakistan. By incorporating accurate chemical reactions, VR simulations will provide students with a realistic and hands-on learning experience.
- **Engagement Through Interactivity:** Unlike traditional theoretical learning, the platform promotes active student participation. Users will be able to manipulate virtual lab equipment, mix chemicals, and observe reactions in real-time.
- **Safety and Risk-Free Learning:** The inherent risks of traditional chemistry labs (e.g., handling toxic chemicals, fire hazards, and glass breakage) are mitigated in STEMxVR. Students can safely experiment without the danger of injury or damage, making it a perfect tool for risk-free education.
- **Cost-Effectiveness:** Implementing physical chemistry labs in underfunded schools is often prohibitively expensive due to the cost of equipment, materials, and safety gear. STEMxVR offers a cost-effective solution by requiring only the VR hardware and software, making it accessible even to resource-constrained institutions.
- **Future Scalability:** While the initial focus of STEMxVR is on chemistry experiments, the platform has been designed with scalability in mind. Future

versions of the software could include biology, physics, and other STEM subjects, allowing the system to evolve into a comprehensive virtual science laboratory.

STEMxVR is a critical educational tool that addresses many of the existing challenges faced by Pakistani schools. It aims to make science education more engaging, accessible, and practical, ensuring that students develop a deeper understanding of core scientific concepts. In addition to chemistry, the platform's modular structure ensures that it can be adapted for other subjects and educational contexts, allowing it to scale across STEM disciplines in the future.

Table 1: Terms used in this document and their description

Name	Description
VR (Virtual Reality)	A computer-generated simulation that immerses users in a three-dimensional environment, allowing them to interact with elements in a way that mimics real-world activities.
STEMxVR	The name of the virtual reality platform. STEM here stands for Science Technology Engineering Mathematics while VR is Virtual Reality. The 'x' in the middle shows the collaboration of STEM with VR.
Chemistry Lab Simulation	The core feature which is providing a virtual environment where students can conduct chemistry experiments that follow real-world procedures and chemical reactions.
Oculus SDK	A software development kit that developers use to create VR experiences for Oculus devices, including features such as controller input, graphics rendering, and tracking.
Unity Engine	A real-time 3D development platform used for creating virtual environments and simulations, enabling high-fidelity interaction and customization of lab experiments.
Meta Quest Pro	A high-end VR headset that will be used by students and instructors to experience this simulation, providing advanced visual, auditory, and interactive feedback.
Instructor	A system role which is responsible for overseeing student progress, managing lab activities, and assessing student performance within the virtual chemistry lab environment.
Student	The primary user of the system, typically a high school student in Pakistan, using this platform to perform virtual chemistry experiments.

LMS	An integrated Learning Management System that may connect with this project, allowing for the submission of reports, tracking student progress, and coordinating with institutional grading systems.
MS (ms)	Milli-seconds
C#	The primary programming language used to develop the system's interactive features in Unity, such as chemistry reactions, experiment management, and user feedback mechanisms.
DBMS	Database Management System
FR/ NFR	Functional Requirements/ Non-functional Requirements

OVERVIEW

2.1. THE OVERALL DESCRIPTION

STEMxVR is a cutting-edge virtual reality platform designed to address the significant gaps in practical chemistry lab learning within Pakistani high schools. Traditional laboratory experiences are often limited due to the high costs of setting up and maintaining physical labs, along with safety concerns and a lack of resources. The goal of STEMxVR is to provide an affordable, scalable, and immersive alternative to physical chemistry labs by simulating real-world experiments in a virtual environment. This approach is expected to enhance students' understanding of chemistry concepts through experiential learning and interactive engagement, allowing them to perform experiments in a risk-free environment.

The platform is designed as a standalone product that can easily integrate with existing Learning Management Systems (LMS) to track student performance, submit experiment reports, and facilitate communication between students and instructors. STEMxVR is also intended to be scalable, with plans to extend its capabilities beyond chemistry into other STEM subjects like biology and physics. The system supports both individual learning and collaborative experiments, allowing students to work together in shared virtual spaces.

From a technical perspective, STEMxVR is developed using the Unity game engine with C# as the core programming language. The platform utilizes VR hardware such as MetaQuest Pro headsets, providing students with a highly interactive and realistic experience. Integration with the Oculus SDK ensures compatibility with a range of VR devices, and the system is designed to run smoothly on standard hardware setups.

2.2. PRODUCT PERSPECTIVE

The STEMxVR platform is developed to function as an independent system, designed primarily for high school students studying chemistry. It is an alternative to traditional lab setups that are often inaccessible due to financial or infrastructural limitations. The system can also be integrated into existing educational structures, such as Learning Management Systems (LMS), to track student performance and progress in real-time.

From a technical perspective, the product utilizes the Unity game engine to create an immersive, 3D virtual environment, while the Oculus SDK handles the virtual reality (VR) functionalities. Students interact with the virtual chemistry lab using MetaQuest Pro VR headsets and hand controllers, allowing them to perform real-time experiments and observe the results. Instructors can guide students through experiments using the Instructor Dashboard, which also allows for monitoring and assessment of student performance.

2.3. PRODUCT FUNCTIONS

STEMxVR provides a wide range of functionalities aimed at replicating the experience of a real chemistry lab in a virtual setting. The system allows users to log in with different roles, such as student, or administrator, each with distinct access rights and capabilities. Students, the primary users of the system, can select from a list of pre-defined chemistry experiments aligned with their curriculum. Once an experiment is chosen, they are guided through the process with detailed, step-by-step instructions.

In the virtual lab, students interact with various lab equipment using VR controllers, allowing them to perform tasks like mixing chemicals, heating solutions, and measuring reactions. The system simulates real-world chemical reactions based on accurate formulas and principles, offering an educational experience that closely mirrors reality. In case of incorrect actions, the system provides immediate corrective feedback, helping students learn from their mistakes. The list of experiments which we are targeting is given below in table 2.

CHEMISTRY – SSC

LIST OF PRACTICALS

S #	PRACTICAL	STATUS
1.	**Fundamentals of Chemistry**	
1.	Separate the given mixture by physical method.	Minor
5.	**Physical States of Matter**	
2.	Determine the Melting Point of Naphthalene.	Major
3.	Determine the Boiling Point of Ethyl Alcohol.	Major
4.	Separate naphthalene from the given mixture of sand and naphthalene by sublimation.	Major
5.	Separate the given mixture of alcohol and water by distillation.	Major
6.	Demonstrate that a chemical reaction release energy in the form of heat.	Minor
6.	**Solutions**	
7.	Prepare 100 cm^3 of 0.1M NaOH solution.	Major
8.	Prepare 100 cm^3 of 0.1M Na_2CO_3 solution.	Major
9.	Prepare 250 cm^3 of 0.1M HCl solution.	Major
10.	Prepare 250 cm^3 of 0.1M of oxalic acid solution.	Major
11.	Prepare 100 cm^3 of 0.1M NaOH solution from the given 1M solution.	Major
12.	Prepare 100 cm^3 of 0.01M Na_2CO_3 solution from the given 0.1M solution.	Major
13.	Prepare 100 cm^3 of 0.01M HCl solution from the given 0.1M solution.	Major
14.	Prepare 100 cm^3 of 0.01M oxalic acid solution from the given 0.1M solution.	Major
15.	Prepare pure copper sulphate crystals from the given impure sample.	Minor
16.	Demonstrate that miscible liquids dissolve in each other and immiscible liquids do not.	Minor
17.	Demonstrate that temperature affects solubility.	Minor
7.	**Electrochemistry**	
18.	Demonstrate the conductivity of different given solutions.	Minor
19.	Demonstrate a metal displacement reaction in aqueous medium.	Minor
8.	**Chemical Reactivity**	
20.	Demonstrate that two elements combine to form a binary compound.	Major
21.	Demonstrate that compounds can be products of a decomposition reaction.	Minor
22.	Demonstrate that an element and a compound can react to form a different element and a different compound.	Minor
23.	Demonstrate that some chemical reactions absorb energy.	Minor
10.	**Acids, Bases and Salts**	
24.	Identify sodium, calcium, strontium, barium, copper, potassium radicals by flame test.	Minor
25.	Standardize the given NaOH solution volumetrically.	Major
26.	Standardize the given HCl solution volumetrically.	Major
27.	Determine the exact molarity of the Na_2CO_3 solution volumetrically.	Major
28.	Determine the exact molarity of a solution of oxalic acid volumetrically.	Major
29.	Demonstrate that some natural substances are weak acids.	Minor
30.	Classify substances as acidic, basic or neutral	Minor

Figure 1: List of Experiments

Virtual Teaching Assistant, which is admin role, can monitor the progress of their students in real-time, assess their performance, and even intervene during experiments. They can design custom experiments, tailoring the virtual lab experience to match specific learning objectives or curriculum requirements. The platform also supports multiplayer functionality, enabling students to collaborate on experiments in shared virtual spaces, fostering teamwork and communication skills.

The system generates detailed experiment reports for students after each session, which instructors can review to evaluate performance. These reports include data on how well students followed instructions, adhered to safety protocols, and understood the chemical principles involved. Additionally, STEMxVR incorporates safety mechanisms to simulate proper lab procedures, including wearing virtual safety gear and handling chemicals carefully, with penalties for non-compliance.

2.4. USER CHARACTERISTICS

The users of STEMxVR span several distinct categories, each with unique characteristics and needs. The primary users are students, typically between the ages of 14 and 18, who are enrolled in secondary and higher secondary educational institutions in Pakistan. These students are expected to have basic familiarity with technology and basic chemistry knowledge, but they may not have prior experience with virtual reality systems. Therefore, the platform must be user-friendly, with intuitive navigation and clear instructions. The goal is to enhance students' conceptual understanding of chemistry through active participation in virtual experiments.

Virtual Assistants, who are typically administration staff, play a key role in guiding students through the platform. They are responsible for selecting or designing experiments, monitoring student progress, and providing feedback during the experiments. Instructors must have a moderate level of technical proficiency to manage the system and create custom lab setups that align with the curriculum.

2.5. CONSTRAINTS

The development and deployment of STEMxVR will face several constraints that need to be carefully managed throughout the project. One major constraint is the availability of VR hardware, such as MetaQuest Pro headsets, particularly in underfunded or rural schools where budgets for advanced technology are limited. This could significantly impact the adoption of the platform unless cost-effective hardware solutions are explored, or financial support is provided through government initiatives or private partnerships.

Another critical constraint is the quality and reliability of internet connectivity. For real-time feedback, a stable internet connection is necessary. However, in many parts of Pakistan, especially in rural areas, internet infrastructure may not be sufficient to support continuous, high-bandwidth VR interactions. Offline modes will need to be considered for individual experiments, although certain features like real-time collaboration will be restricted in such scenarios.

Cost is another significant constraint. The high cost of developing and maintaining a VR platform, coupled with the need for continuous updates and technical support, may limit the scalability of STEMxVR in resource-poor environments. Financial sustainability plans, including partnerships with educational institutions or government bodies, will be essential to ensure long-term viability.

Cultural and language barriers also present potential challenges. Pakistan is home to a linguistically and culturally diverse population, and many students are more comfortable learning in local languages such as Urdu. To address this, the platform must support multilingual functionality to ensure that students from different backgrounds can fully engage with the content.

Lastly, the system will need to comply with educational and safety standards, both locally and internationally, to ensure that the simulations reflect real-world safety protocols and that students are adequately protected, even in a virtual setting.

2.6. ASSUMPTIONS AND DEPENDENCIES

There are several key assumptions and dependencies underlying the development and success of STEMxVR. First, it is assumed that schools adopting the platform will have access to the necessary VR hardware, including headsets and compatible computers. Without this equipment, the platform will not be able to function as intended. It is also assumed that users, both students and instructors, will have or will receive sufficient training to operate the system effectively, though the interface will be designed to minimize the learning curve.

Another assumption is that the chemistry curriculum in Pakistani schools will align with the experiments provided in STEMxVR. This alignment is critical to ensure that the virtual lab experience complements the theoretical concepts taught in classrooms and that students derive meaningful educational benefits from using the system. Moreover, it is also assumed that user is familiar with basic chemistry concepts to be able to perform experiments in chemistry lab.

The success of the platform also depends on the availability of stable internet connections in schools. Although certain functionalities will be available offline, features like real-time feedback and multiplayer collaboration will rely on reliable internet access. Schools will need to ensure that their infrastructure supports these capabilities.

Finally, there is an assumption that ongoing funding will be available to support both the development and maintenance of the platform. Without adequate financial resources, it will be difficult to ensure continuous updates, content expansions, and technical support, all of which are necessary to keep the platform relevant and functional over time.

STATE OF THE ART

3.1. LITERATURE REVIEW

The integration of Virtual Reality (VR) in educational environments has gained significant traction over the past decade. Research indicates that VR has the potential to transform traditional learning experiences, particularly in STEM (Science, Technology, Engineering, and Mathematics) subjects, by providing immersive, interactive, and safe environments for students to conduct experiments and explore concepts that might otherwise be inaccessible in real-world settings. Numerous studies have been conducted to evaluate the effectiveness of VR in improving learning outcomes, engagement, and retention of scientific concepts, particularly in subjects like chemistry, physics, and biology. As outlined in **Table 2**, several platforms such as MEL VR Science Simulations, HoloLAB Champions, and Labster have demonstrated significant potential in improving hands-on learning through virtual simulations, although they also present certain limitations, particularly when applied to the Pakistani educational context.

Table 2: Literature Review Summary

Platform	Source	Focus	Key Features	Limitations
MEL VR Science Simulations	MEL Science, London, UK	Provides interactive VR science simulations.	Immersive chemistry experiments. 3D molecular visualization. Risk-free learning.	Not tailored to the Pakistani curriculum. Expensive for resource-limited schools
HoloLAB Champions	Schell Games, Pittsburgh, USA	Educational VR game emphasizing lab safety and procedures.	Competitive gameplay. Focus on lab safety. Real-time feedback.	Not curriculum specific. Focus on individual tasks rather than experiment on the whole.
VR Lab Academy	Virtual Reality for Education	VR platform for bridging classroom and lab learning.	Immersive, realistic lab simulations. Broad range of subjects.	Lacks customization for the Pakistani education system. Limited

				language support
Labster	Labster, Denmark	Virtual labs for higher education.	Large library of experiments. Supports multiple subjects. High interactivity.	Geared toward higher education. High costs may prevent widespread use in schools.
Parong and Mayer (2018)	Research Study	VR enhances student engagement in chemistry.	Demonstrated improved retention and understanding. Increased student engagement	Study focused on VR in general, not specific to any platform.

3.2. LIMITATIONS OF EXISTING SYSTEMS

While the existing systems like MEL VR, HoloLAB Champions, Labster, and others have significantly contributed to improving practical science education using VR, they present some limitations when applied to the Pakistani educational context. These systems are not designed specifically for the needs of students in underfunded and resource-limited schools. They either lack alignment with local curricula, are too advanced for high school levels, or come with prohibitive costs. Moreover, most of these systems focus on individual use rather than collaborative learning, which is an important aspect of science education.

STEMxVR seeks to address these gaps by providing a localized solution specifically designed for Pakistani high schools. It will be tailored to align with the national chemistry curriculum and provide support in multiple languages, including Urdu, making it accessible to students from various backgrounds. By focusing on cost-effectiveness and scalability, STEMxVR aims to overcome the financial barriers faced by most schools in the country. Furthermore, the system will incorporate collaborative learning environments, where multiple students can perform experiments together, mimicking real-world classroom settings.

USER & SYSTEM REQUIREMENTS

4.1. USER REQUIREMENTS

STEMxVR is designed to provide an immersive virtual reality experience for students and administrators. The user requirements cater to the needs of each user group, ensuring a seamless interaction with the platform.

For students, the system must allow them to select and conduct various chemistry experiments using a VR headset and controllers. The platform will guide students through each experiment with clear, step-by-step instructions, ensuring they perform the correct procedures. One of the critical aspects of the platform is the ability to provide real-time feedback, helping students identify and correct mistakes such as improper chemical handling or ignoring safety protocols. The system will simulate realistic lab safety measures, requiring students to wear virtual protective gear like goggles and gloves before starting experiments. Additionally, students should be able to track their progress over time, allowing them to see their improvement as they complete multiple experiments. To encourage exploration and learning, the system will offer the option to undo or redo actions during experiments.

Administration will have the ability to monitor students' progress and actions in real-time. They can assess how well students are following instructions and adhering to safety protocols. The system will also allow admin to manage chemistry experiments tailored to specific learning objectives. Another key function for instructors is the ability to provide feedback, both during and after experiments, helping students improve their understanding of chemical principles. Detailed experiment reports will be generated for each student, providing instructors with valuable data on performance and areas for improvement.

4.2. SYSTEM REQUIREMENTS

The STEMxVR platform must meet several system requirements to ensure optimal performance, security, and scalability. Performance-wise, the system must be able to provide real-time feedback to users, ensuring that there are no noticeable delays during experiments. The platform should be scalable, capable of supporting multiple users simultaneously, particularly when students are performing collaborative experiments in shared virtual environments. Complex chemical reactions must be processed in real-time, ensuring that the results accurately reflect real-world chemistry principles. Additionally, maintaining low latency is essential, especially in multiplayer settings where students and instructors interact in real-time.

EXTERNAL INTERFACE REQUIREMENTS

5.1. USER INTERFACES

The user interface of STEMxVR will be tailored to the needs of different users, including students, instructors, and administrators. For students, the interface will be immersive and intuitive, allowing them to interact with virtual lab equipment through VR headsets and hand controllers. Clear, on-screen instructions will guide students through each step of an experiment, while visual and auditory feedback will enhance the learning experience.

Admin will have access to a dashboard where they can monitor student activities, view performance reports, and design custom experiments. The interface will allow administration to provide feedback in real-time or after an experiment is completed. Instructors should also have an easy-to-use interface for add or modify an experiment, making it possible to align the virtual labs with specific lessons or curriculum goals.

5.2. HARDWARE INTERFACES

The hardware interface for STEMxVR is critical to the success of the platform, as it relies on VR technology to deliver an immersive learning experience. The platform will require compatibility with VR headsets such as the MetaQuest Pro, which enables users to view and interact with the virtual lab environment. Students will use VR hand controllers to manipulate lab equipment, such as picking up test tubes, mixing chemicals, and controlling other lab apparatus. The system must also run on computers with the necessary specifications to handle the graphics and processing demands of a VR platform. Minimum system requirements will include an Intel i7 processor, 16GB of RAM, and a high-performance GPU like the NVIDIA RTX 20 Series*. Additionally, the platform will include tools for calibrating the VR equipment, ensuring that students can interact precisely with the virtual environment.

5.3. SOFTWARE INTERFACES

The software interfaces for STEMxVR will integrate several critical components to ensure seamless operation. The system is built using the Unity game engine, which is responsible for rendering 3D environments and processing user interactions in real-time. Unity's flexibility allows for the integration of complex chemistry simulations, ensuring that students experience accurate representations of chemical reactions.

The platform will also interface with the Oculus SDK to manage VR-specific functionalities, including hand tracking, environment rendering, and controller input. This integration ensures compatibility with a range of VR headsets. Additionally, STEMxVR will integrate with Learning Management Systems (LMS) to streamline the submission of experiment reports, track student progress, and facilitate communication between instructors and students. This ensures that the virtual lab fits seamlessly into the broader academic workflow. Secure database management systems (DBMS) will be used to store user data and experiment reports, ensuring secure and reliable data handling.

5.4. COMMUNICATION INTERFACES

STEMxVR requires a robust communication interface to enable real-time interactions, particularly during multiplayer experiments or when instructors need to guide students remotely. The platform will rely on a stable internet connection to support these interactions. Minimum network requirements will include at least 10 Mbps per user for smooth real-time collaboration and less than 100 ms latency to prevent delays in feedback and interaction.

The system will also include both voice and text communication features, allowing students and instructors to communicate effectively during experiments. This functionality is essential for teamwork and instructor intervention in group experiments. For scalability and remote accessibility, the platform will integrate cloud-based services for data storage and real-time processing, allowing users to collaborate from different locations without the limitations of local server setups.

Functional Requirements

For Students:

- **FR1**: Students should be able to select and conduct virtual experiments from a list of available experiments.
- **FR2**: Students must be able to use a step-by-step guide to follow instructions for each experiment.
- **FR3**: Students should be able to receive instant feedback on the accuracy of their steps during the experiment.
- **FR4**: Students should be able to generate and view a report of the experiment, including observations, results, and mistakes.
- **FR5**: Students should be able to take notes during the experiment, with the option to save and retrieve these notes.
- **FR6**: Students should be able to access a built-in scientific calculator to perform calculations during experiments.
- **FR7**: Students should be able to reset an experiment at any point or undo/redo specific steps.
- **FR8**: Students shall be able to participate in a quiz mode, where they perform experiments without step-by-step instructions.

For Virtual_Teaching_Assistant:

- **FR9**: Assistant should be able to track students' progress and completion of experiments.
- **FR10**: Assistant shall be able to assist students in performing experiments (guided mode, video demo).
- **FR11**: Assistant should be able to manage the list of experiments available to students, including adding, removing, or editing experiments.

6.1. FUNCTIONAL REQUIREMENTS WITH TRACEABILITY INFORMATION

Table 3.1.: FR1: Students should be able to select and conduct virtual experiments from a list of available experiments.

Requirement ID	FR-001	**Requirement Type**	Functional		**Use Case #**				
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-	
Parent Requirement #	None								
Description	A menu of experiments will allow students to choose and run various virtual chemistry experiments.								
Rationale	Provides flexibility and access to a variety of experiments, enhancing their learning experience.								
Source	None			**Source Document**	-				
Acceptance/Fit Criteria	Students can view a list of available experiments and successfully run the chosen one in the virtual environment.								
Dependencies	None								
Priority	***Essential***	***	***Conditional***	-	***Optional***	-			
Change History	None								

Table 3.2.: FR2: Students must be able to use a step-by-step guide to follow instructions for each experiment.

Requirement ID	FR-002		**Requirement Type**	Functional		**Use Case #**		
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-
Parent Requirement #	None							
Description	Each experiment will include a guided instructional system to walk students through every step.							
Rationale	Ensures accurate execution of experiments and reinforces learning by providing clear instructions.							
Source	None			**Source Document**	-			
Acceptance/Fit Criteria	The system correctly displays step-by-step instructions for all available experiments, guiding students without errors.							
Dependencies	None							
Priority	***Essential***	***	***Conditional***	-	***Optional***	-		
Change History	None							

Table 3.3.: FR3: Students should be able to receive instant feedback on the accuracy of their steps during the experiment.

Requirement ID	FR-003		**Requirement Type**		Functional		**Use Case #**	
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-
Parent Requirement #	None							
Description	As students perform actions in an experiment, the system will provide real-time feedback on whether steps are performed correctly or not.							
Rationale	Improves learning by helping students understand mistakes immediately, allowing them to correct their actions.							
Source	None				**Source Document**	-		
Acceptance/Fit Criteria	Students receive feedback within 2 seconds of performing an action, detailing whether it was correct or not, with suggestions for improvement.							
Dependencies	None							
Priority	***Essential***	***	***Conditional***	-	***Optional***	-		
Change History	None							

Table 3.4.: FR4: Students should be able to generate and view a report of the experiment, including observations, results, and mistakes.

Requirement ID	FR-004		**Requirement Type**		Functional	**Use Case #**		
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-
Parent Requirement #	None							
Description	After an experiment, the system generates a detailed report containing key findings, observations, and any mistakes made.							
Rationale	Provides a summary of the experiment for students to reflect on and improve.							
Source	None			**Source Document**	-			
Acceptance/Fit Criteria	Upon completion of an experiment, a report is automatically generated with a breakdown of results, observations, and any errors made.							
Dependencies	None							
Priority	***Essential***	***	***Conditional***	-	***Optional***	-		
Change History	None							

Table 3.5.: FR5: Students should be able to take notes during the experiment, with the option to save and retrieve these notes.

Requirement ID	FR-005		**Requirement Type**		Functional		**Use Case #**	
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-
Parent Requirement #	None							
Description	A note-taking feature will allow students to jot down observations or thoughts during the experiment and save them for later reference.							
Rationale	Encourages active engagement and reflection during experiments.							
Source	None				**Source Document**	-		
Acceptance/Fit Criteria	Students can save notes during an experiment and retrieve them at any point, both during and after the session.							
Dependencies	None							
Priority	***Essential***	***	***Conditional***	-	***Optional***	-		
Change History	None							

Table 3.6.: FR6: Students should be able to access a built-in scientific calculator to perform calculations during experiments.

Requirement ID	FR-006	**Requirement Type**	Functional	**Use Case #**					
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-	
Parent Requirement #	None								
Description	A built-in scientific calculator will be accessible to students at any point during an experiment.								
Rationale	Provides necessary tools for calculations without requiring external devices.								
Source	None	**Source Document**	-						
Acceptance/Fit Criteria	Students can open and use the scientific calculator at any stage of the experiment with full functionality.								
Dependencies	None								
Priority	***Essential***	***	***Conditional***	-	***Optional***	-			
Change History	None								

Table 3.7.: FR7: Students should be able to reset an experiment at any point or undo/redo specific steps.

Requirement ID	FR-007		**Requirement Type**		Functional		**Use Case #**		
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-	
Parent Requirement #	None								
Description	Students will have the ability to either reset the entire experiment or undo/redo specific actions taken during the process.								
Rationale	Offers flexibility and ensures students can recover from mistakes or retry portions of the experiment without starting from scratch.								
Source	None				**Source Document**	-			
Acceptance/Fit Criteria	The reset function fully resets the experiment, and the undo/redo functions apply correctly to individual steps, with no data loss or malfunction.								
Dependencies	None								
Priority	***Essential***	***	***Conditional***	-	***Optional***	-			
Change History	None								

Table 3.8.: FR8: Students shall be able to participate in a quiz mode, where they perform experiments without step-by-step instructions.

Requirement ID	FR-008		**Requirement Type**		Functional	**Use Case #**		
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-
Parent Requirement #	None							
Description	In quiz mode, students will conduct experiments without guidance, testing their understanding and ability to follow procedures independently.							
Rationale	Enhances assessment by allowing students to demonstrate their knowledge without relying on instructions.							
Source	None				**Source Document**	-		
Acceptance/Fit Criteria	The system switches to quiz mode where all instructions are hidden, and students must complete the experiment independently, with results graded for accuracy.							
Dependencies	None							
Priority	***Essential***	***	***Conditional***	-	***Optional***	-		
Change History	None							

Table 3.9.: FR9: Assistant should be able to track students' progress and completion of experiments.

Requirement ID	FR-09		**Requirement Type**	Functional		**Use Case #**			
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-	
Parent Requirement #	None								
Description	Instructors will have access to real-time progress tracking for each student, including which experiments were started, completed, and their results.								
Rationale	Helps instructors monitor students' engagement and performance in virtual labs.								
Source	None			**Source Document**	-				
Acceptance/Fit Criteria	Instructors can view real-time progress reports for each student, including details of completed experiments and overall performance.								
Dependencies	None								
Priority	***Essential***	***	***Conditional***	-	***Optional***	-			
Change History	None								

Table 3.10.: FR10: Assistant shall be able to assist students in performing experiments (guided mode, video demo etc.).

Requirement ID	FR-010		**Requirement Type**		Functional		**Use Case #**		
Status	***New***	***	***Agreed-to***	-	***Baselined***	-	***Rejected***	-	
Parent Requirement #	None								
Description	Instructors or the system can assist students by providing guided mode or video demonstrations for complex experiments.								
Rationale	Helps students better understand complex steps and experiments they struggle with.								
Source	None				**Source Document**	-			
Acceptance/Fit Criteria	Students can access either a guided mode or video demo for experiments upon instructor activation, improving understanding of the experiment.								
Dependencies	None								
Priority	***Essential***	***	***Conditional***	-	***Optional***	-			
Change History	None								

Table 3.11.: FR11: Assistant should be able to manage the list of experiments available to students, including adding, removing, or editing experiments.

<table>
<tr><td>Requirement ID</td><td colspan="2">FR-011</td><td colspan="2">Requirement Type</td><td colspan="2">Functional</td><td colspan="2">Use Case #</td><td></td></tr>
<tr><td>Status</td><td>New</td><td>***</td><td>Agreed-to</td><td>-</td><td>Baselined</td><td>-</td><td>Rejected</td><td>-</td><td></td></tr>
<tr><td>Parent Requirement #</td><td colspan="9">None</td></tr>
<tr><td>Description</td><td colspan="9">Instructors will have control over the experiments offered to students, with options to add, remove, or modify them as needed.</td></tr>
<tr><td>Rationale</td><td colspan="9">Allows instructors to tailor the learning experience and ensure experiments align with the curriculum.</td></tr>
<tr><td>Source</td><td colspan="4">None</td><td colspan="2">Source Document</td><td colspan="3">-</td></tr>
<tr><td>Acceptance/Fit Criteria</td><td colspan="9">Instructors can successfully add, remove, or edit experiments, and the changes are reflected in the student interface without delay.</td></tr>
<tr><td>Dependencies</td><td colspan="9">None</td></tr>
<tr><td>Priority</td><td>Essential</td><td>***</td><td>Conditional</td><td>-</td><td>Optional</td><td>-</td><td colspan="3"></td></tr>
<tr><td>Change History</td><td colspan="9">None</td></tr>
</table>

Nonfunctional Requirements & Software System Attributes

7.1. PERFORMANCE REQUIREMENTS

- The system must provide real-time feedback to users during chemistry experiments to ensure immediate error detection and correction.
- The platform must have low latency, ideally below 100 ms, to support real-time multiplayer collaboration without delays.
- The platform should handle multiple users simultaneously in shared virtual environments without performance degradation.
- The system should be capable of rendering complex chemical reactions and 3D environments in real-time, maintaining smooth and immersive user experiences.

7.2. USABILITY REQUIREMENTS

- The user interface must be intuitive and user-friendly, especially for students who may not have prior experience with VR systems.
- Instructions, feedback, and navigation for students should be clear and accessible, using both visual and auditory cues for enhanced learning.
- Administration should have a dashboard for monitoring student progress, providing real-time feedback, and customizing chemistry experiments.

7.3. SECURITY REQUIREMENTS

- User authentication must be implemented to ensure that only authorized users (students, and administrators) can access the platform based on their roles.
-

7.4. SCALABILITY REQUIREMENTS

- The platform must be able to scale to support multiple users during collaborative experiments and individual sessions.
- The system should be capable of handling increasing user loads, especially in multiplayer environments, without compromising performance.

7.5. NETWORK REQUIREMENTS

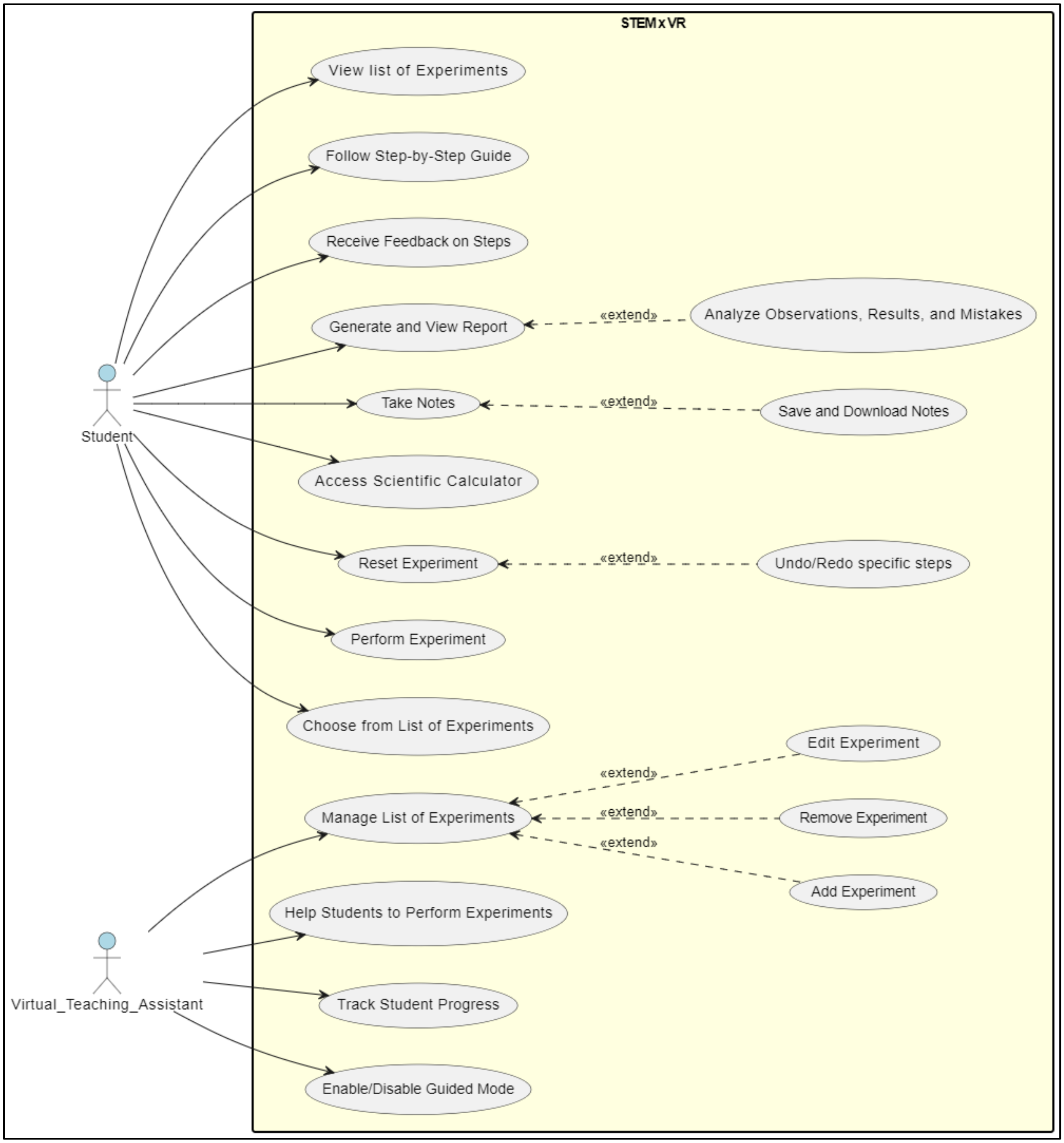
- The platform must function over a stable internet connection with at least 10 Mbps per user to support smooth real-time collaboration.
- The network latency must remain below 100 ms during multiplayer sessions to ensure seamless interaction between users.

7.6. HARDWARE REQUIREMENTS

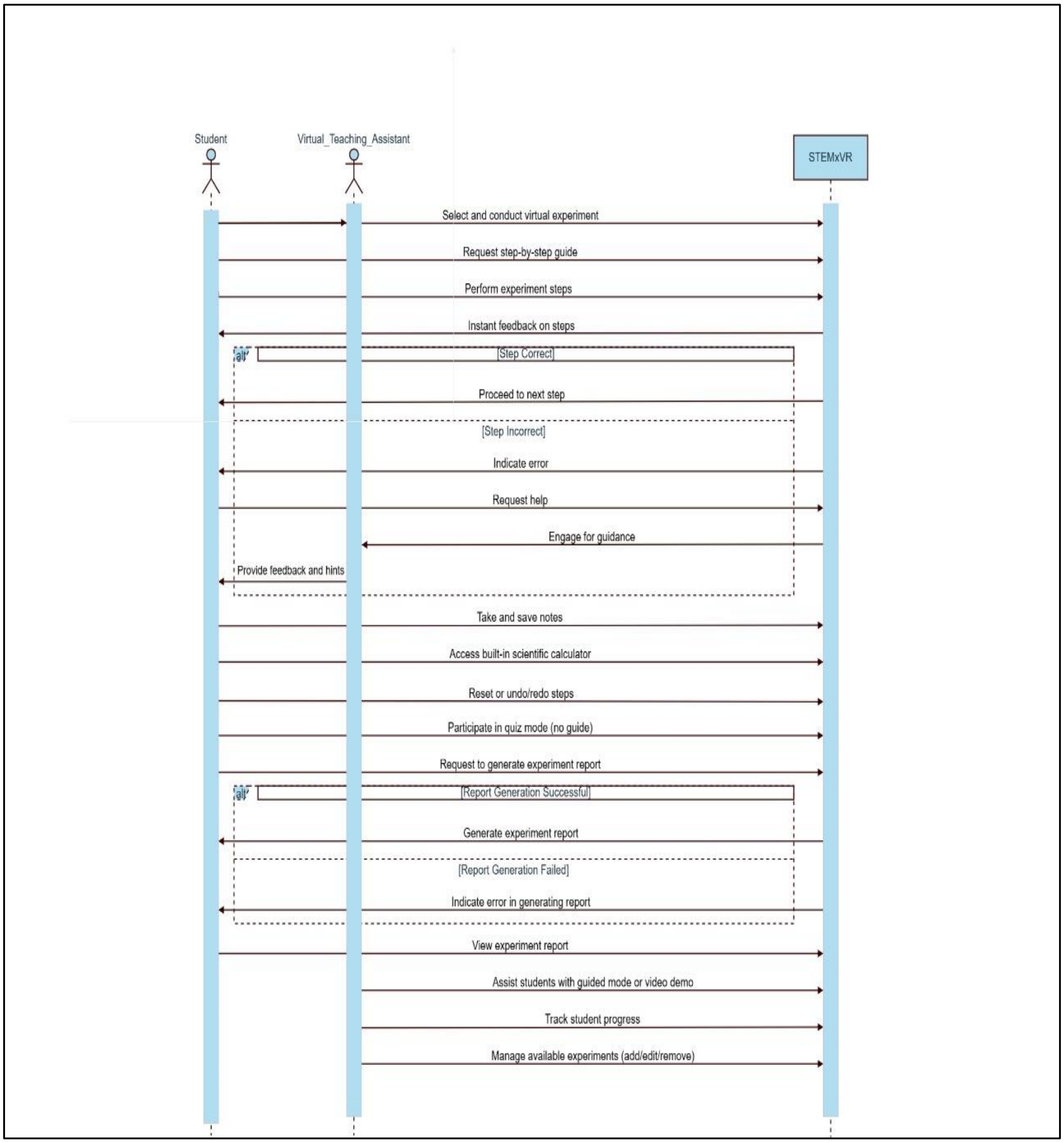
- The system must be compatible with MetaQuest Pro VR headsets for immersive chemistry experiment simulations.
- The platform must run on computers with at least an Intel i7 processor, 16GB RAM, and NVIDIA RTX 20 Series* or better to handle the VR environment and processing demands.

Project Design/Architecture

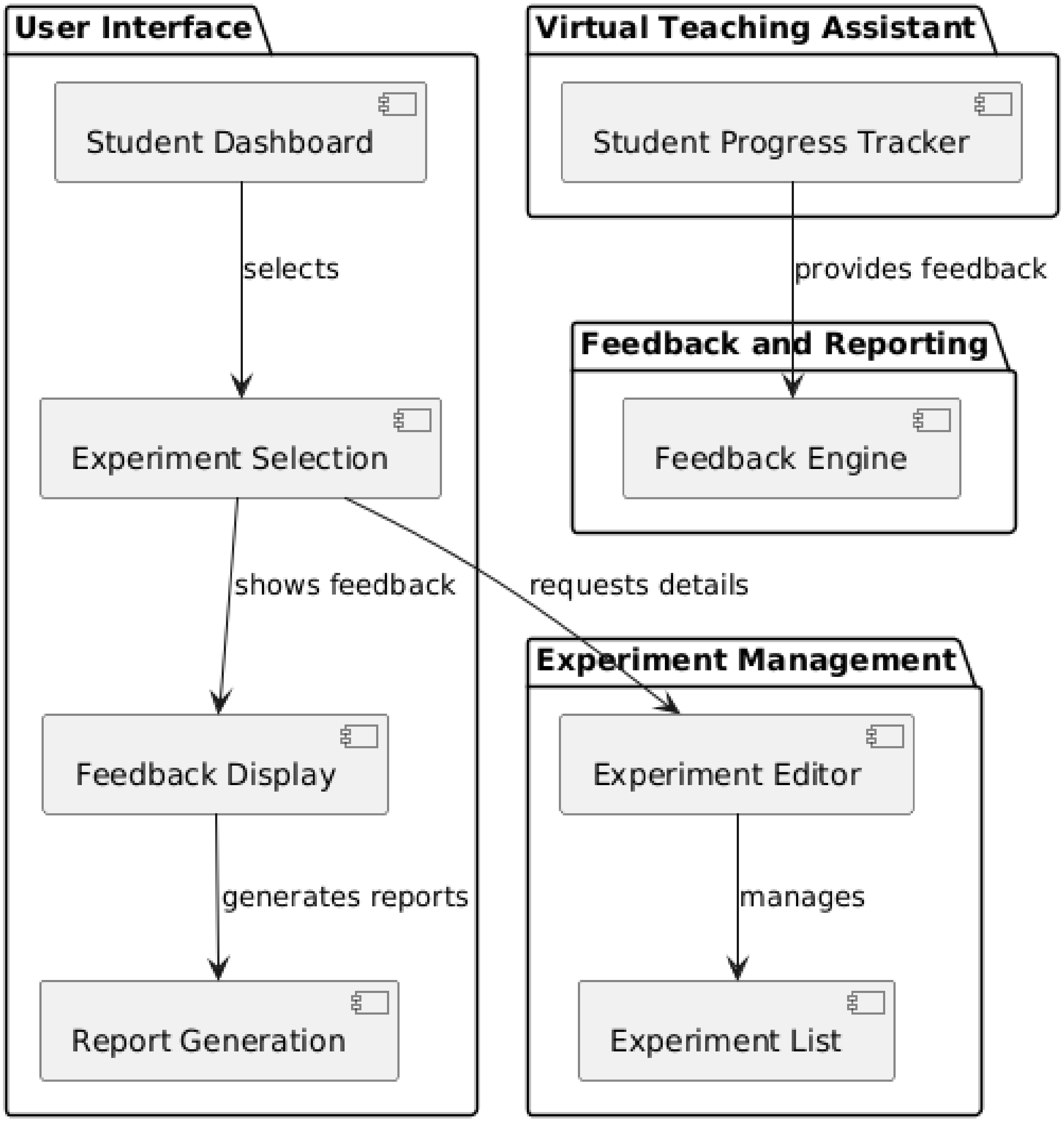
8.1. USE CASE VIEW



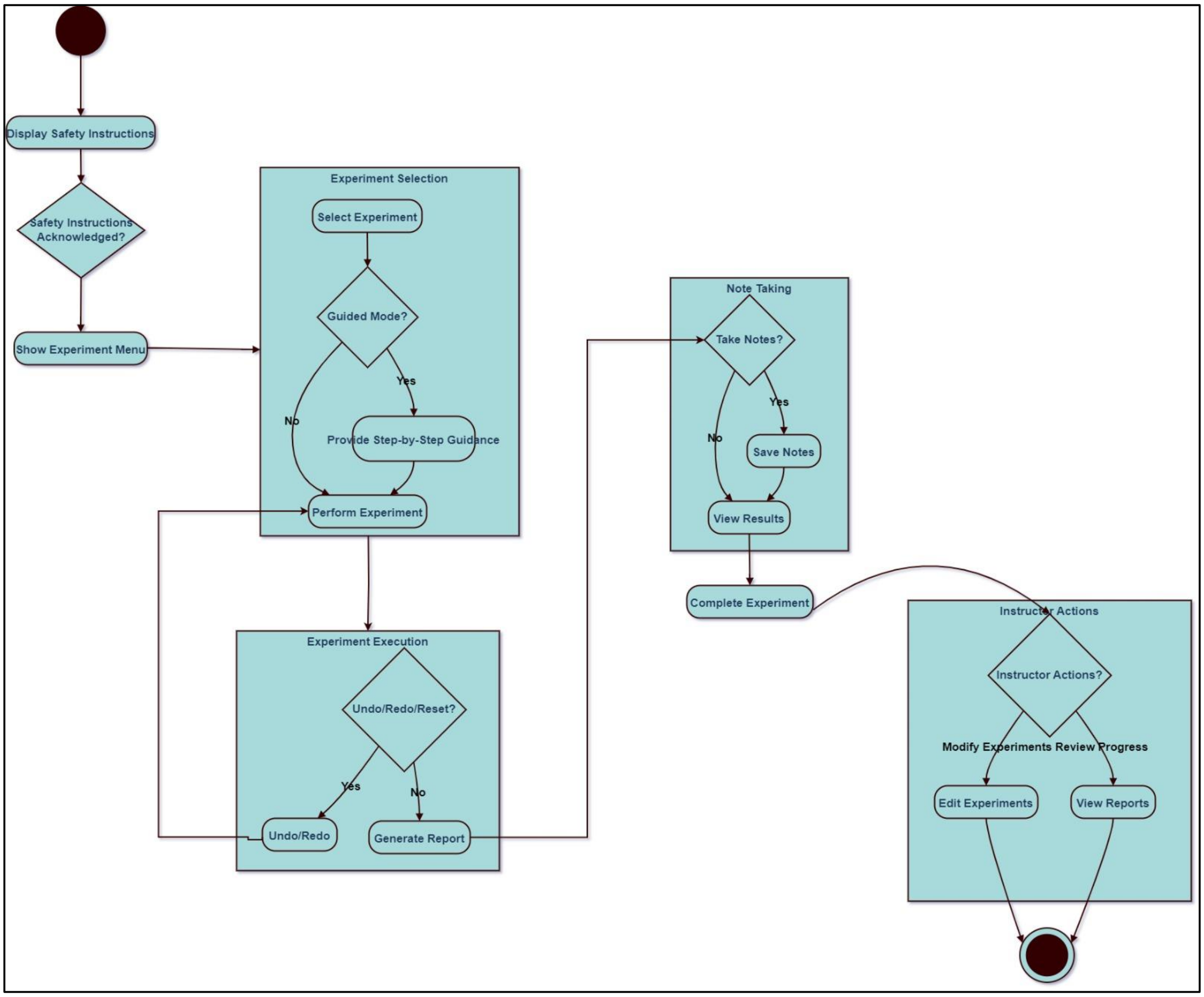
8.2. LOGICAL VIEW



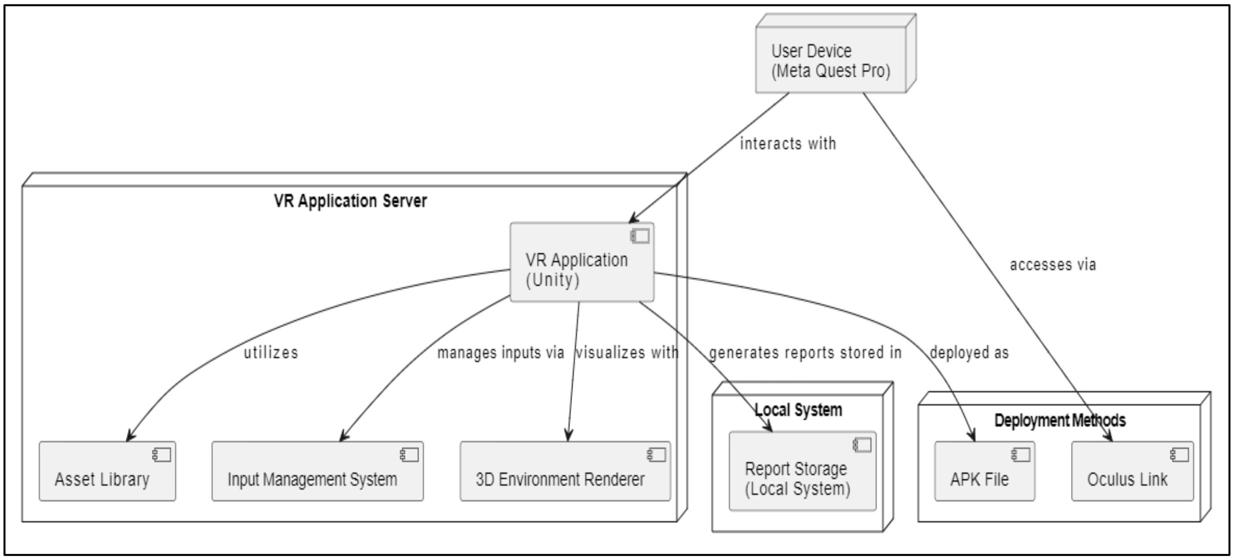
8.3. DEVELOPMENT VIEW



8.4. PROCESS VIEW



8.5. PHYSICAL VIEW



8.6. USER INTERFACE (UI) DESIGN