STEMxVR

Virtual Chemistry Lab Simulation

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1.00	2024-09-28	Initial draft, outlining project scope and requirements.
2.00	2024-09-06	Diagrams, tables and figures were added.
3.00	2024-10-14	Revised version with supervisor’s feedback.

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

Signature	***Date***	***Name***
	2024-10-14	Dr. Salman Ahmad

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1. INTRODUCTION

1.1. PURPOSE

The purpose of this Design and Architecture Document is to establish a comprehensive technical foundation for the development of the STEMxVR: Virtual Chemistry Lab Simulation. The document aims to guide the development process by clearly outlining the architectural components, design considerations, and the technological framework required to create an effective and scalable virtual chemistry lab platform.

The STEMxVR project is focused on addressing the lack of practical lab facilities in Pakistani high schools, especially in underfunded and rural areas. By simulating a fully functional chemistry lab using virtual reality (VR), STEMxVR allows students to engage in immersive, interactive experiments that replicate real-world conditions without the associated risks and costs of a physical lab. This platform will enable students to manipulate virtual lab equipment, mix chemicals, and observe chemical reactions within a safe, controlled virtual environment. Through hands-on interaction, students will learn proper lab procedures, experiment with different chemicals, and understand the scientific principles behind chemical reactions, all without the need for expensive lab setups or materials. STEMxVR will provide instant feedback during experiments, helping students learn from their actions and adjust, as they would in a real lab setting. This includes guidance on proper lab safety procedures, such as virtual goggles or handling chemicals safely.

This document is critical for several reasons. It ensures that the system is developed in a way that meets the outlined educational goals, functional requirements, and user needs. It serves as a reference for the development team, clarifying how different components, such as VR hardware, and user interfaces work together within the overall system architecture. It provides a detailed framework that allows for future scalability, particularly the potential for expanding into other STEM subjects like biology or physics, as mentioned in the SRS.

The key objectives outlined in this Design and Architecture Document include defining the system architecture like detailing how the VR system integrates with the Unity game engine and Oculus SDK to create a smooth, responsive virtual environment. It must be able to explain why certain architectural decisions were made, such as the client-server model, to ensure scalability and real-time processing for virtual experiments. It should identify the key modules (e.g., experiment simulation, user management, LMS integration) and detailing how each module contributes to the overall functionality of the system. It should also ensure that the system design supports ease of use for all target users, students, instructors, and administrators, while also making the platform accessible in regions with limited resources and infrastructure.

This document aligns closely with the requirements and constraints outlined in the Software Requirements Specification (SRS). According to the SRS, the focus is on:

- Providing an immersive, risk-free virtual lab experience.
- Addressing the educational needs of students in regions where traditional lab facilities are lacking.
- Ensuring cost-effectiveness by only requiring VR hardware and software, making it accessible to schools with budget constraints.
- Supporting localized learning by aligning the experiments and content with the Pakistani high school chemistry curriculum.
- Promoting safety and engagement through interactive and realistic virtual experiments, without introducing any actual hazards to the students.

At its core, the purpose of this document is to guide the project's development within the boundaries set by the SRS. The goal is not to go beyond the key features already defined in the SRS, such as offering simulations for real-world chemistry experiments, providing real-time feedback, and ensuring safe and scalable educational experiences. The project is designed to be a practical, affordable solution for enhancing chemistry education, and this document will ensure that the design process adheres strictly to that vision.

1.2. PRODUCT SCOPE

The STEMxVR: Virtual Chemistry Lab Simulation is designed as an immersive, virtual reality (VR) platform that replicates real-world chemistry laboratory experiments for secondary and high school students in Pakistan. The system aims to bridge the gap in practical science education where traditional lab facilities are either inadequate or unavailable. By offering a fully virtualized, interactive learning environment, STEMxVR provides students with a safe, cost-effective, and engaging way to conduct chemistry experiments.

The primary scope of this project is to develop a platform that simulates realistic chemistry lab experiences aligned with the national high school curriculum. STEMxVR focuses on enhancing student understanding of chemical concepts through experiential learning, enabling them to perform various experiments without the risks and financial costs associated with traditional labs. The following points summarize the key components of the Product Scope:

Core Features:

1. **Realistic Chemistry Lab Simulation:** The platform will offer students the opportunity to conduct a range of experiments that are typically performed in a traditional chemistry lab. This includes using virtual lab equipment (e.g., test tubes, beakers, Bunsen burners) and simulating chemical reactions in real-time. Each experiment will closely follow the safety protocols and procedures required in an actual lab, helping students learn proper lab techniques and safety practices.
2. **VR-Based Immersive Learning:** Using VR headsets such as the Meta Quest Pro, students will experience a 3D virtual environment that mimics a real chemistry lab. They will be able to manipulate objects and equipment within the VR space using hand controllers, perform experiments, and observe results, all while receiving visual and auditory feedback. This creates an engaging, hands-on learning experience that encourages active participation.
3. **Curriculum Alignment:** The experiments offered in STEMxVR are specifically tailored to the Pakistani high school chemistry curriculum. This ensures that students are not only engaged in a fun and interactive way but also learning key concepts that are critical to their educational requirements. All virtual experiments will follow the curriculum's structure and objectives to help students meet their academic goals.
4. **Risk-Free Experimentation:** A key advantage of STEMxVR is the ability to provide a completely risk-free learning environment. In a physical lab, students might face dangers such as chemical spills, fire hazards, or glass breakage. By shifting these activities to a virtual space, students can explore various chemical reactions safely, without the risks associated with handling actual chemicals.
5. **Cost-Effective Solution:** One of the biggest barriers to implementing high-quality lab facilities in Pakistani schools is the cost of lab equipment, materials, and ongoing maintenance. STEMxVR addresses this by offering a cost-effective alternative, requiring only the VR hardware and software to run the simulations. Schools that cannot afford fully equipped labs will now provide practical lab experiences for their students.
6. **Real-Time Feedback and Guidance:** During experiments, the system will offer real-time feedback to guide students through each step. If students make mistakes, such as incorrect mixing of chemicals or improper handling of lab equipment, the system will notify them and provide corrective actions. This feature ensures that students not only perform experiments but also learn the reasoning behind each step.
7. **Student Progress Tracking and Reporting:** The platform will track each student's progress and generate detailed reports based on their performance in the virtual lab. This will allow teachers to assess how well students are following lab procedures and understanding the scientific

principles behind the experiments. Reports will also provide insights into areas where students may need additional support or practice.

8. **Safety Protocols Built into Simulations:** To ensure students understand the importance of safety in the lab, STEMxVR will simulate safety procedures that must be followed before any experiment can begin. For example, students will be required to "wear" virtual safety goggles and gloves and follow instructions to handle virtual chemicals and equipment properly. This reinforces the importance of lab safety without exposing students to real hazards.

Scope Limitations:

STEMxVR, in its current scope, focuses exclusively on chemistry experiments for secondary and high school students. While the platform is designed with future scalability in mind, allowing for potential expansion into other STEM subjects (e.g., biology, physics), the initial version will concentrate on delivering a fully functional virtual chemistry lab experience.

Furthermore, the platform is primarily targeted at schools in Pakistan where physical lab resources are limited. The system will be localized to match the educational standards, terminology, and curriculum specific to this region. At this stage, the focus is not on developing content for other countries or educational systems, although this could be explored in future iterations.

Assumptions and Dependencies:

- **VR Hardware Availability:** Schools will need access to VR headsets and compatible hardware, such as computers capable of running VR software, to fully benefit from the STEMxVR platform. It is assumed that participating schools will either have access to such technology or plan to acquire it as part of an educational initiative.
- **Internet Connectivity:** Although certain features of the platform (such as individual experiments) can function offline, real-time feedback and collaborative experiments will require a stable internet connection. This is an important consideration for schools in rural areas with limited internet infrastructure.
- **Curriculum Alignment:** The platform assumes that the national chemistry curriculum in Pakistan will remain aligned with the content provided in STEMxVR. Regular updates may be required if the curriculum changes to ensure continued relevance.
- **Instructor Training:** While the platform is designed to be user-friendly, it assumes that instructors will receive adequate training to operate the system effectively and guide students through virtual lab activities.

Table 1: Terms used in this document and their description

Name	Description
STEMxVR	The name of the virtual reality platform designed to simulate chemistry lab experiments for educational purposes.
Virtual Reality (VR)	A computer-generated simulation that immerses users in a 3D environment, allowing interaction with virtual objects.
Meta Quest Pro	A VR headset used by students and instructors to experience the virtual chemistry lab simulation.
Unity Engine	A real-time 3D development platform used to create the virtual environment and interactions within STEMxVR.
Oculus SDK	Software Development Kit used to integrate VR functionalities (e.g., hand tracking, environment rendering) into the platform.
Experiment Simulation	The core feature of STEMxVR, enabling students to conduct virtual chemistry experiments that replicate real-world lab procedures.
Learning Management System (LMS)	A system used to track student progress, submit reports, and integrate with the broader educational infrastructure.
User Interface (UI)	The visual interface through which students and instructors interact with the virtual lab, including on-screen instructions and feedback.
Real-Time Feedback	The system's ability to provide immediate guidance and corrections during virtual experiments based on student actions.
Chemical Reaction Simulation	The system’s process of replicating real-world chemical reactions within the virtual environment, based on accurate chemical properties and behavior.
Instructor Dashboard	A tool used by instructors to monitor student progress, guide them through experiments, and provide feedback.
3D Lab Environment	A fully immersive virtual space that mimics a physical chemistry lab, complete with virtual lab equipment and safety protocols.
Safety Protocol Simulation	Virtual simulation of lab safety measures such as the requirement to use virtual goggles and gloves before starting an experiment.
VR Controllers	Handheld devices used by students and instructors to interact with virtual lab equipment in the VR environment.
Collaborative Learning	A feature allowing multiple students to participate together in virtual experiments within a shared virtual space.

User Roles	The different types of users (students, instructors, administrators) that have distinct access and permissions in STEMxVR.
Client-Server Architecture	The system architecture where the client (VR headset) communicates with the server for real-time feedback and data processing.

1.3. OVERVIEW

The STEMxVR system is built using the Unity game engine and integrates with the Oculus SDK to provide a seamless and responsive virtual environment. Students will use VR headsets (e.g., Meta Quest Pro) and hand controllers to interact with 3D lab equipment in the virtual space. The system is designed to provide real-time feedback, guiding students step-by-step through each experiment and offering corrective advice when errors occur, ensuring that students not only perform experiments but also understand the underlying chemistry principles.

This platform is primarily targeted at secondary and high school students in Pakistan, as well as their instructors and educational administrators. It is designed to function both as a standalone learning tool and as an integrated part of the broader educational system, with potential compatibility with Learning Management Systems (LMS) for tracking student progress and managing experiment reports. The platform will also allow instructors to monitor students' activities, provide real-time guidance, and assess performance based on detailed reports generated after each experiment.

The core goals of STEMxVR are to enable students to engage in realistic chemical experiments that mirror those performed in physical labs, but in a safe, virtual setting. By providing hands-on experience, students are expected to grasp difficult concepts more effectively through experiential learning. Offering a cost-effective solution that eliminates the need for expensive laboratory setups, making it possible for schools in resource-constrained environments to deliver high-quality science education. Students can conduct experiments without the risks of injury, chemical exposure, or damage to expensive lab equipment, making it ideal for younger learners or schools with limited access to safety measures.

System Architecture and Technical Approach:

The platform is built on a client-server architecture, with the Unity game engine serving as the core development environment. The Oculus SDK is used to handle the VR-specific aspects of the project, including hand tracking, head movement, and 3D environment rendering. The system ensures a smooth and responsive user experience, allowing students to engage with experiments in real-time, with minimal latency.

The user interface (UI) is designed to be intuitive, offering students clear on-screen instructions for each step of the experiment. The UI will include visual prompts for lab safety, helping students follow proper safety protocols, such as wearing virtual protective gear (e.g., goggles, gloves) before starting an experiment.

From a technical standpoint, the platform is designed to run on VR headsets (such as Meta Quest Pro) and computers with standard hardware specifications. The development environment (Unity) allows for high levels of interactivity and realism, ensuring that students can immerse themselves fully in the learning experience. Additionally, the system is designed to support both single-user experiments and collaborative experiments, where multiple students can participate together in a shared virtual space, mimicking real-world group lab activities.

Target Audience:

- **Students:** The primary users of STEMxVR will be high school students, typically aged 14-18, who require practical chemistry lab experiences to complement their theoretical learning.
- **Instructors:** Chemistry teachers who guide students through experiments, monitor their progress, and assess their performance.
- **Educational Administrators:** School administrators responsible for integrating the platform into the school's educational framework, managing user accounts, and ensuring the system runs smoothly.
- **Policy Makers:** Education policymakers interested in addressing the national gaps in science education, particularly in underfunded schools.

2. THE OVERALL DESCRIPTION

The STEMxVR is an innovative virtual reality platform aimed at providing a practical and immersive chemistry lab experience for high school students in Pakistan. It addresses the significant gap in hands-on science education caused by the lack of adequate laboratory facilities in many schools, particularly in rural and underfunded areas. By offering a safe, cost-effective, and interactive environment for conducting chemistry experiments, STEMxVR ensures that students can gain essential lab skills and deepen their understanding of chemistry concepts without the logistical and financial challenges of maintaining a physical lab.

2.1 Product Perspective

The STEMxVR platform is developed to function as an independent system, designed primarily for secondary and 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 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 Meta Quest 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.

2.2 Product Functions

The key features of STEMxVR include Virtual chemistry lab environments with detailed models of laboratory tools and accurate simulation of chemical reactions. Students should be able to use VR headsets and hand controllers to manipulate virtual lab equipment, offering a hands-on experience that mimics real-world lab activities. The platform should be able to provide students with instant guidance, helping them learn correct lab procedures and improving their understanding of experiment outcomes. The platform is designed in alignment with the Pakistani high school chemistry curriculum, ensuring that students can use it as a direct supplement to their classroom learning. Administration can track student progress, add or remove experiments, and provide real-time feedback during lab sessions. All experiments are conducted in a virtual environment, eliminating any risk of injury or chemical spills, while also providing a cost-effective alternative to physical labs. While the current focus is on chemistry, the platform’s architecture allows for future scalability to include other STEM subjects, such as biology or physics. Some basic experiments which our system aims to offer are listed below in Table 2.

Table 2: List of Experiments

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

2.3 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.

2.4 Constraints

1. **Hardware:**
   The system relies on VR hardware such as Meta Quest Pro headsets and high-performance computers capable of running VR software. In many schools, particularly in rural areas, access to such equipment may be limited. The project assumes that schools adopting STEMxVR will either have or acquire the necessary hardware.

2. **Internet Connectivity:**
   For certain features such as multiplayer experiments and real-time feedback, a stable internet connection is required. However, in areas with poor connectivity, offline modes will be necessary for individual experiments, though some functionalities may be restricted in such scenarios.

3. **Cost:**
   While the system offers a cost-effective alternative to physical labs, initial setup costs for VR hardware and compatible computers may be high for underfunded schools. The platform must remain accessible by considering partnerships or financial support options.

4. **Language and Cultural Relevance:**
   The platform is designed to align with the national chemistry curriculum in Pakistan. However, due to the linguistic diversity of the country, STEMxVR will need to support English, to ensure all students can fully engage with the system.

2.5 Assumptions and Dependencies

1. **Curriculum Alignment:**
   It is assumed that the national chemistry curriculum in Pakistan will remain consistent with the experiments and educational content provided by STEMxVR. Any significant curriculum changes may require updates to the platform.

2. **Training for Instructors:**
   It is assumed that instructors will receive adequate training on how to operate the STEMxVR platform, design custom experiments, and use the Instructor Dashboard to monitor and assess student performance.

3. **Hardware and Software Compatibility:**
   The platform is dependent on the availability of VR headsets and computers that meet the minimum system requirements for running STEMxVR. Schools must ensure they have compatible hardware for the system to function as intended.

4. **Sustainability and Funding:**
   Ongoing support and funding will be necessary to maintain the platform, provide updates, and potentially expand to other STEM subjects. Partnerships with educational institutions, government bodies, or private entities may be required to ensure the long-term sustainability of the system.

3. WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) for the STEMxVR project divides the development process into a structured hierarchy of tasks and deliverables. It helps ensure that the project is completed efficiently and on time by clearly defining all the essential components and activities necessary to build and deploy the system.

The following tasks are organized into major phases of the project, detailing the steps involved in each phase. This WBS will also be used for tracking progress and managing resources throughout the development cycle.

3.1. Major Project Phases

1. **Project Planning and Requirements Analysis**
    - **Task 1.1:** Requirements Gathering
        - Identify key stakeholders (students, instructors, administrators).
        - Conduct detailed research on curriculum alignment and required chemistry experiments.
    - **Task 1.2:** SRS Documentation
        - Compile the Software Requirements Specification (SRS) document, outlining functional and non-functional requirements.
    - **Task 1.3:** Project Scope Definition
        - Clearly define the project's scope, including key features, limitations, and assumptions.

2. **System Design and Architecture**
    - **Task 2.1:** Design and Architecture Documentation
        - Develop the design and architecture document, detailing the system's overall structure, technical approach, and integration with VR hardware and software.
    - **Task 2.2:** Define System Architecture
        - Design the client-server architecture, detailing how the VR system interacts with Unity and the Oculus SDK.
    - **Task 2.3:** Module Identification
        - Identify and define key modules such as experiment simulation, user management, and feedback mechanisms.
    - **Task 2.4:** User Interface Design
        - Design the user interface for students, instructors, and administrators, ensuring an intuitive and immersive VR experience.

3. **Development of Core VR Components**
    - **Task 3.1:** VR Environment Setup
        - Create the virtual 3D chemistry lab using the Unity game engine.
    - **Task 3.2:** Experiment Simulation
        - Develop chemistry experiment simulations, including chemical reactions, equipment handling, and real-time interactions.
    - **Task 3.3:** Oculus SDK Integration
        - Integrate the Oculus SDK to enable hand tracking, head movements, and interaction with virtual objects in the VR environment.
    - **Task 3.4:** Safety Protocol Simulation

        - Implement safety protocols, requiring students to follow lab safety procedures (e.g., wearing goggles and gloves) before performing experiments.

4. **Testing and Quality Assurance**
    - **Task 4.1:** Unit Testing
        - Perform unit tests on individual modules (e.g., chemical reactions, real-time feedback) to ensure proper functionality.
    - **Task 4.2:** Integration Testing
        - Test the integration of different components (e.g., VR environment, Oculus SDK, user interface) to ensure seamless operation.
    - **Task 4.3:** User Testing
        - Conduct user testing with students and instructors to ensure the platform meets educational and usability goals.
    - **Task 4.4:** Performance Testing
        - Test the platform's performance on various VR hardware setups to ensure smooth operation without lag.

4. Design

The design of the STEMxVR: Virtual Chemistry Lab Simulation focuses on creating an immersive, user-friendly, and scalable virtual reality platform for conducting chemistry experiments. This section outlines the architectural design, justifications for the chosen architecture, and the identification of key system modules.

4.1 Architectural Design

The architectural design of STEMxVR is based on a client-server model, which allows for efficient interaction between the VR client (the user's VR headset and controllers) and the server that processes data and manages the simulations. This architecture supports real-time communication, enabling students to interact with the virtual lab environment seamlessly.

Key Components of the Architecture:

1. **Client-Side (VR Headset and Controllers):**
   - The client is responsible for rendering the virtual environment using the Unity game engine and receiving input from the Oculus SDK. Students will use the Meta Quest Pro headset and hand controllers to engage with the virtual lab equipment and conduct experiments.
   - The client will handle user interface elements, provide feedback, and manage user interactions within the VR environment.

2. **Server-Side:**
   - The server processes incoming requests from the client, including user actions (e.g., mixing chemicals) and provides the necessary data for the VR experience.
   - It manages the database that stores user profiles, experiment data, and performance reports, allowing instructors to track student progress and provide assessments.
   - The server will also handle any multi-user interactions, enabling collaborative experiments and real-time feedback from instructors.

4.2 Why We Chose This Architecture

1. **Scalability:**
   - This architecture allows the platform to scale efficiently, accommodating multiple users performing experiments simultaneously without compromising performance. As demand increases, additional server resources can be allocated to manage more users.
2. **Real-Time Interaction:**

- The architecture facilitates real-time feedback and interaction between students and the virtual environment. The server can quickly process user inputs and update the VR experience, accordingly, ensuring an immersive and responsive learning experience.

3. **Centralized Management:**
    - By centralizing data management on the server, the system can efficiently store user data, progress reports, and experiment results. This structure also simplifies the integration of Learning Management Systems (LMS) for tracking and managing student performance.
4. **Enhanced Collaboration:**
    - The client-server model allows for real-time collaboration among students, enabling multiple users to engage in the same experiment within the VR environment. This fosters teamwork and enhances the learning experience.

4.3 Module Identification

The STEMxVR platform comprises several key modules that work together to deliver a cohesive user experience. Each module is designed to handle specific functionalities within the system:

1. **VR Environment Module:**
    - Responsible for rendering the 3D virtual chemistry lab, including detailed models of lab equipment and the interactive environment.
    - Integrates with the Unity engine to provide high-fidelity graphics and a seamless user experience.
2. **Experiment Simulation Module:**
    - Simulates various chemistry experiments, including chemical reactions and physical interactions with lab equipment.
    - Implements accurate chemical properties and behaviors to ensure realistic experiment outcomes.
3. **User Management Module:**
    - Manages user roles (students, instructors, administrators) and their respective permissions within the platform.
    - Facilitates user authentication and profile management, storing progress and performance data.
4. **Feedback Mechanism Module:**
    - Provides real-time feedback during experiments, alerting students to errors and guiding them through the correct procedures.
    - Generates post-experiment reports for students and instructors, detailing performance and areas for improvement.
5. **Collaboration Module:**

- Enables multiple students to participate in shared experiments, allowing them to work together in the same virtual environment.
- Supports real-time communication between students and instructors during collaborative sessions.

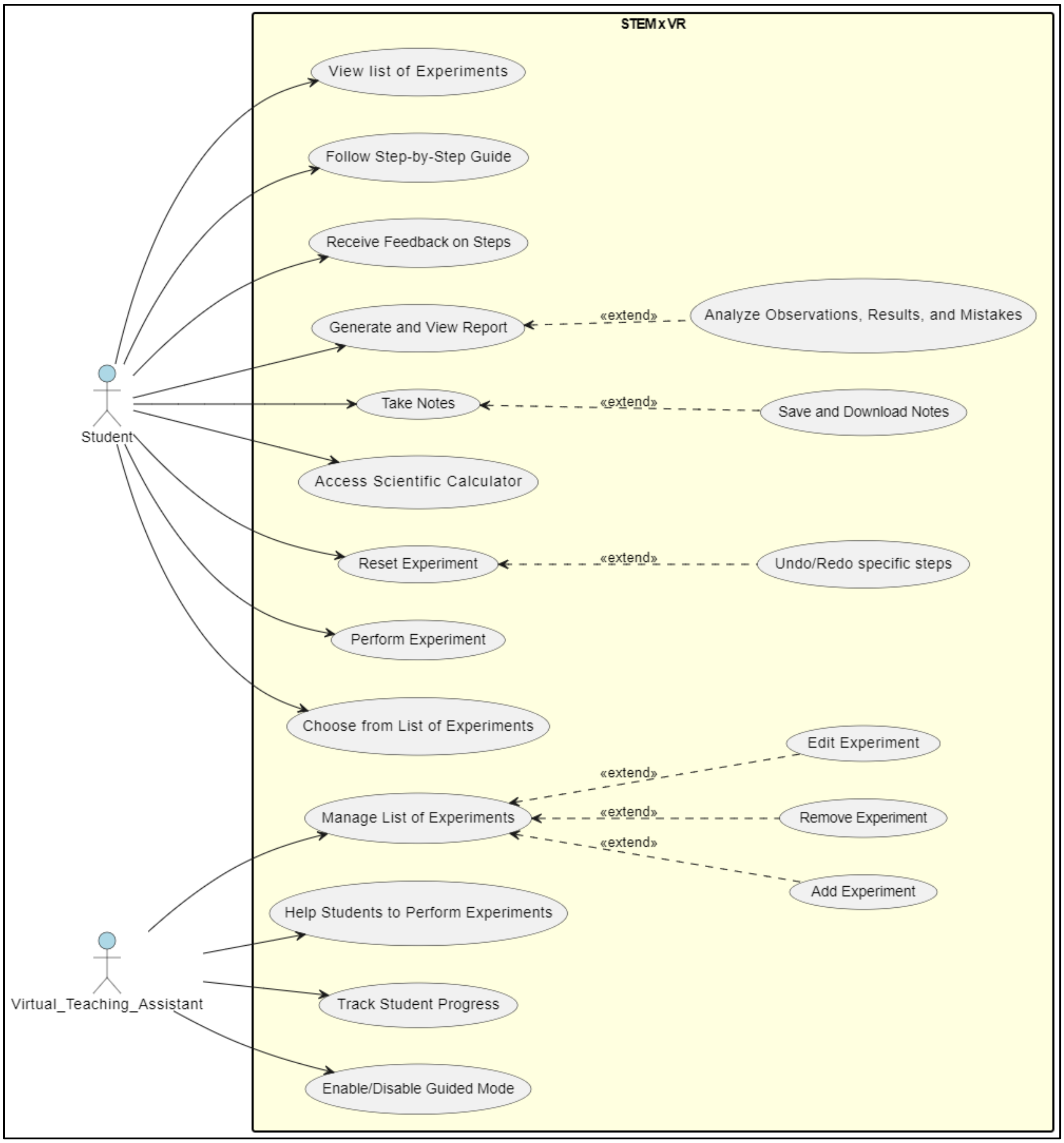
6. **Safety Protocol Module:**
   - Enforces virtual lab safety protocols, requiring students to adhere to safety measures before commencing experiments (e.g., wearing virtual goggles).
   - Simulates safety procedures to reinforce the importance of proper lab practices.
7. **Instructor Dashboard Module:**
   - Provides instructors with tools to monitor student activities, assess performance, and design custom experiments.
   - Allows instructors to interact with students in real-time, offering feedback and guidance as needed.

4.4 Summary of Design Choices

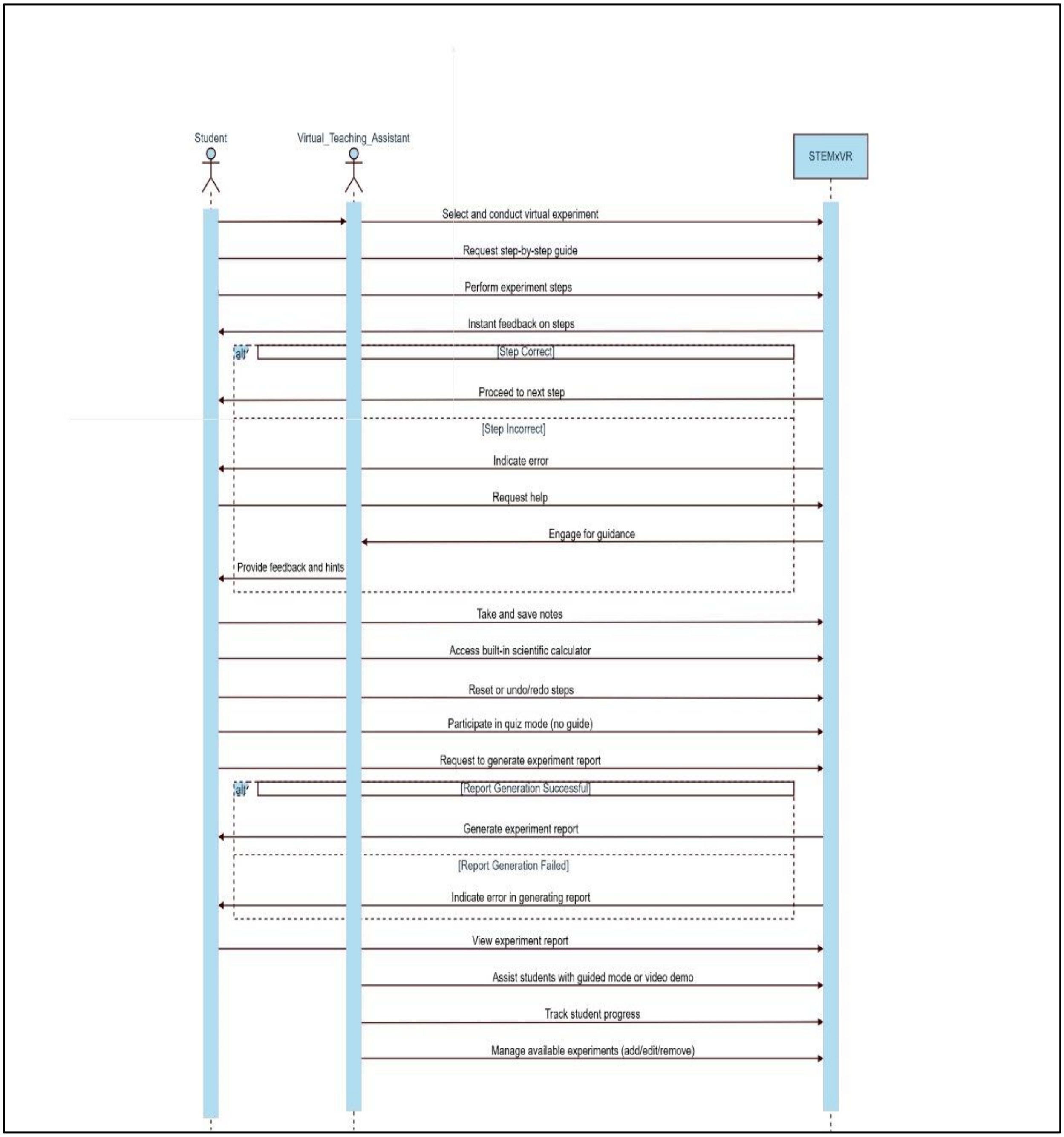
The design of STEMxVR is focused on creating an immersive, engaging, and educational experience for high school students studying chemistry. The chosen client-server architecture supports scalability, real-time interactions, and centralized data management, ensuring that both students and instructors can maximize the benefits of the platform. Each identified module is crucial to delivering the core functionalities of the system, enhancing user engagement, and promoting effective learning.

5. ARCHITECTURE VIEW MODEL

5.1. USE CASE VIEW



5.2. LOGICAL VIEW



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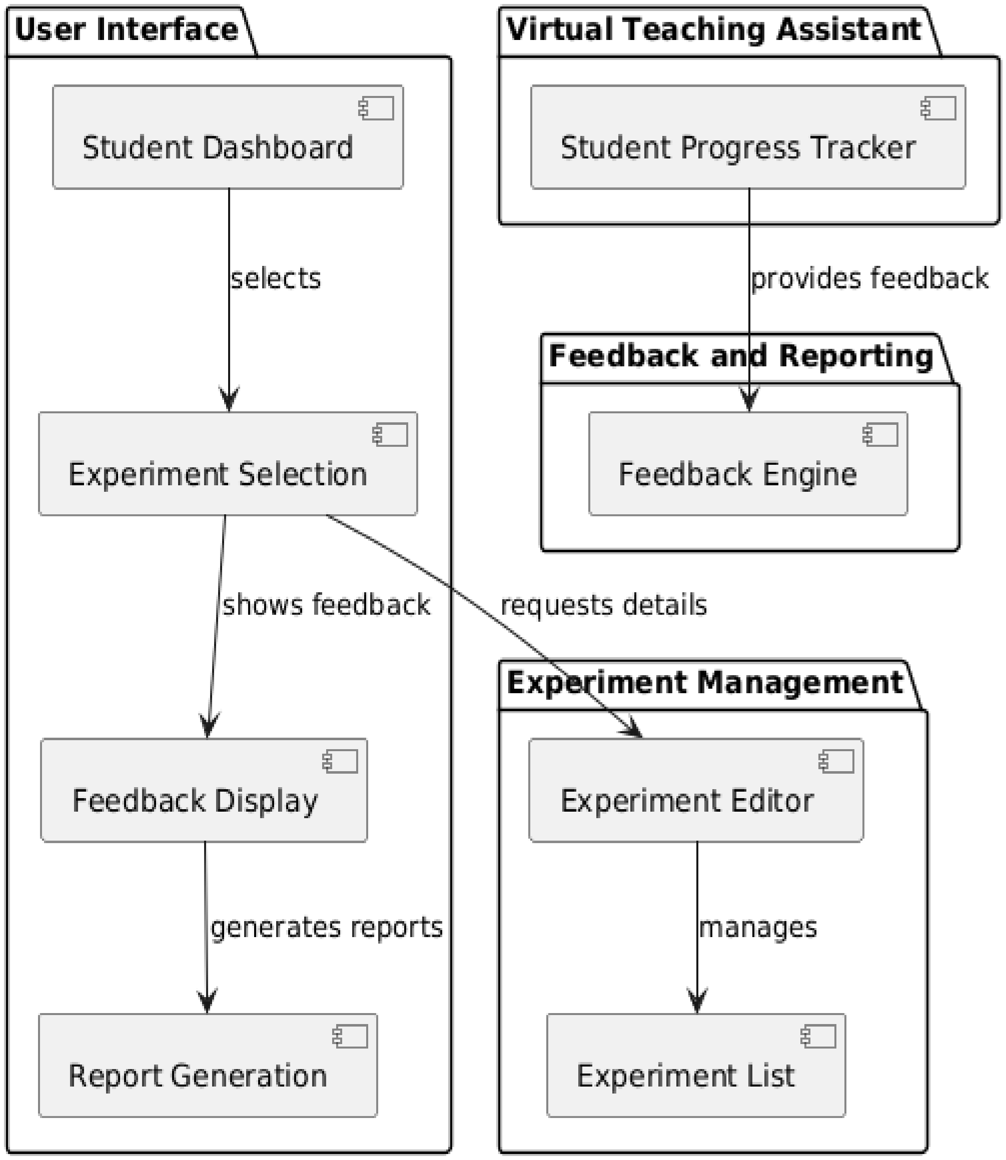

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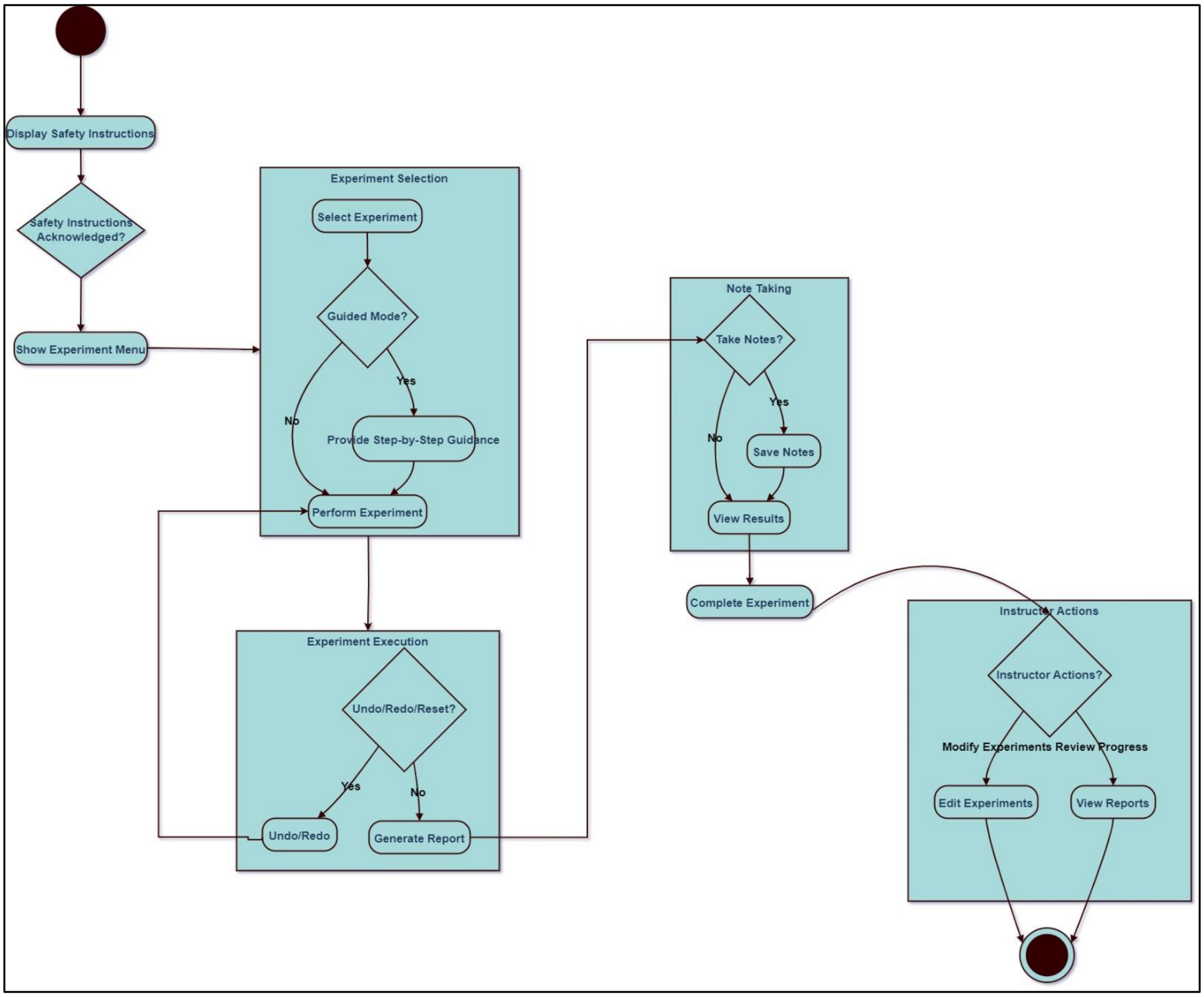

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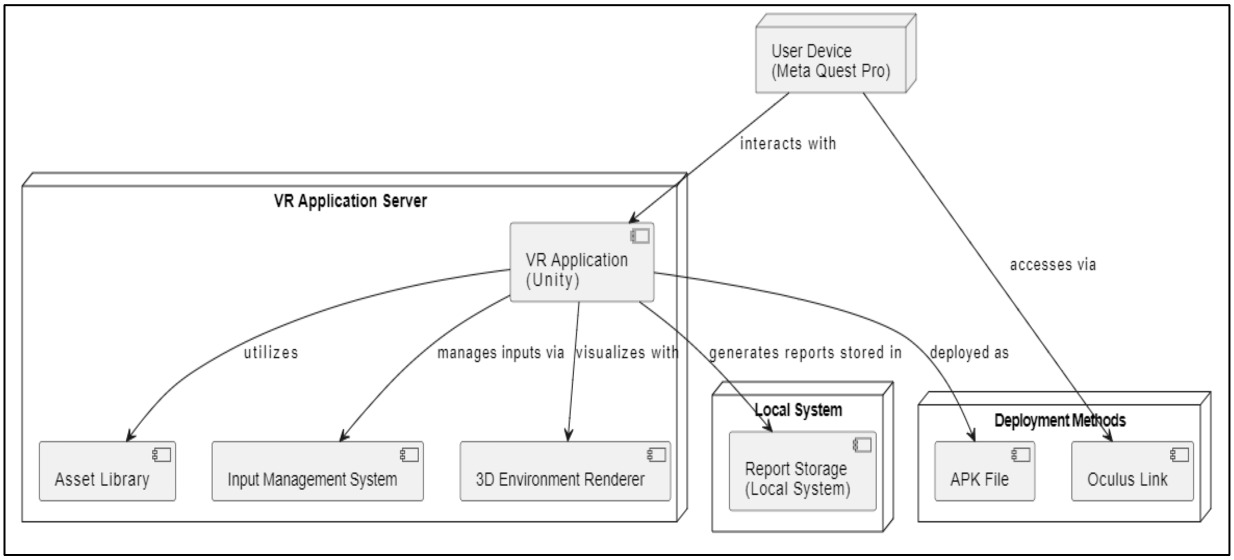

5.6. USER INTERFACE (UI) DESIGN