Development of a Virtual Reality Based Chemistry Learning Environment with Integrated Simulation and Artificial Intelligence Driven Student Evaluation for Junior School Students

Individual Project Proposal

Submitted in Partial Fulfillment
of the Requirements for BSc (Hons) Computing

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Abstract

Embedding immersive technologies in early science education provides a transformative route to link the abstractness of theoretical chemistry with practical application. This project aims to build a Virtual Reality (VR) chemistry learning system targeted at junior school students with the following problems: lack of access to laboratories, safety risks and difficulty in understanding the complex concepts. Using Unity-based simulations and haptic feedback, the system uses experiential learning to create a safe space for learners to perform experiments and immediately see the physical reactions of complicated actions. Central to this environment is an artificial intelligence (AI) based assessment engine that tracks student performance and provides individualized feedback while measuring progress with data-based indicators. Based on Dual Coding Theory and embodied cognition, the system employs multi-modal prompts (3D visual cues and spatial audio) to increase conceptual retention while reducing cognitive load. Overall, this project seeks to deliver a scalable ethically-sound pedagogy that raises student engagement and equitable access to a high-quality science education.

Keywords

Figure 1: *Keywords*

Table of Contents

Table of Figures

Introduction

The rapid progress of immersive technologies has offered fresh possibilities for education, science teaching and learning in particular. Virtual Reality technology provides an immersive environment in which students can visualize abstract chemical principles as simulations or join the virtual world for investigation and experiential learning. However, traditional junior school chemistry teaching has a sense of theoretical education and even textbooks too much in the class, students' laboratory operation is insufficient thus poor at student engagement and conceptual understanding which leads to students having a smaller learning space.

This project introduces a Virtual Reality based chemistry learning environment which integrates interactive simulations with Artificial Intelligence driven assessment of student. Equipped with AI technology, the system is able to monitor student performance in real-time and deliver personalized feedback, adjusting learning experiences according to individual needs. This will not only increase engagement and understanding, but also bring in a new rigorous, data-driven approach to assessing what students are supposed to be learning. It is designed to provide an intermediate link between theory and practice, therefore allowing younger students to experience chemistry education in a more immersive way (Qorbani et al., 2024).

Figure 2: *Virtual Reality Based Chemistry Lab*

Aim

To design and develop a Virtual Reality based chemistry learning platform for junior school students that integrates interactive simulations and artificial intelligence driven evaluation to enhance conceptual understanding, engagement, and personalized learning.

Objectives

- To explore current teaching and learning of junior school chemistry, and its challenges, for gaps addressed by Virtual Reality.
- To investigate emerging global themes and model of practice in science education with Virtual Reality and student assessment using Artificial Intelligence, and existing tools, platforms, and approaches.
- To develop a Virtual Reality learning environment with interactive chemistry simulations that correspond to junior school curricula.
- To build Artificial Intelligence assisted assessment tools that can track how well students are doing, offer real time feedback and alter the course of learning based on user needs.
- To validate the efficacy, usability and engagement of the platform in a real-life testing environment with feedback from target users.
- To write a complete thesis report describing the design, implementation, results and possible future improvements.

Justification

This project is justified from educational, technological, and cognitive perspectives. In terms of technical aspect, the project uses Virtual Reality for school chemistry education which addresses limitations of traditional teaching learning methods, including restricted laboratory access, safety concerns, and difficulties in visualizing abstract chemical process. Virtual Reality provides an immersive learning environment for students to safely perform experiments and observe outcomes that are otherwise not safe to demonstrate in physical classroom.

From educational perspective, the project is supported by experiential learning theory, through which students learn more effectively through direct interaction and practical experience instead of passive observation (Lehrman, 2025). Virtual Reality allow students to engage in chemical processes, strengthening conceptual understanding and long term retention. Further, principles of embodied cognition suggest that learning improves when cognitive processes are connected to physical actions, which is a core feature of immersive VR environments.

As per Allan Paivio's Dual Coding theory, two interconnected subsystems in the human cognitive system exists, the verbal system and an imagery system. Paivio's theory suggests that combining verbal and pictorial information enhances memory retention due to the interconnected nature of these two systems (Schnotz & Horz, 2010). This theoretical framework supports the design of the

Virtual Chemistry Lab with the system integrating both verbal and pictorial information to help enhance the outcome.

In terms of cognitive aspect, the Illusion of Control is particularly relevant. Students often believe that they have mastered a topic simply because they have followed instructions or observed demonstrations, even when their conceptual understanding is incomplete (OpenLibrary.org, 2011). The Virtual Reality Based Chemistry Lab makes student actively conduct experiments and make decisions within the virtual environment, the system reveals gaps between perceived and actual understanding. Artificial Intelligence driven evaluation further minimizes the illusion by providing data-driven feedback.

Heuristic Availability also shapes students' perceptions of how well they understand chemistry. Learners are looking for easily remembered information such as the recent lessons covered in class, or eye-catching examples rather than understanding what is happening in reality. Virtual reality simulations make the learning sustainable and memorable, anchoring students in correct scientific models, so they have a more solid conceptual foundation.

Ethically and educationally, the system is compatible with an educational responsibility paradigm based on universal access to quality education. Virtual Chemistry Lab can be used to overcome gaps due to lack of resources in schools, delivering equitable learning experience regardless of the institutional resources (Prokopenko & Sapinski, 2024). But then the worry is about overdependence on technology or a lack of teacher involvement. These fears would be alleviated in a system that is introduced as assistance to teaching and not as a substitute for it, whereby the teacher could track progress and guide learning accordingly. In terms of user comfort, the Virtual Reality Chemistry Lab will make use of teleportation movement to ensure low motion sickness allowing users to point and move instead of locomotion.

Finally, the project emphasizes ethical Artificial Intelligence design by ensuring fairness, transparency, and age appropriate evaluation. The Artificial Intelligence models support learning through formative assessment rather than penalization. By integrating immersive technology with responsible Artificial Intelligence practices, the system aims to provide an effective and ethically sound solution for improving junior school chemistry education.

Research Questions

1. How can a Virtual Reality based chemistry learning environment with Artificial Intelligence driven evaluation enhance understanding and engagement for junior school students?
2. What ethical and cognitive challenges arise from using Virtual Reality and Artificial Intelligence in junior school education, and how can they be addressed?

Literature Review

Desk Based Research Methodology

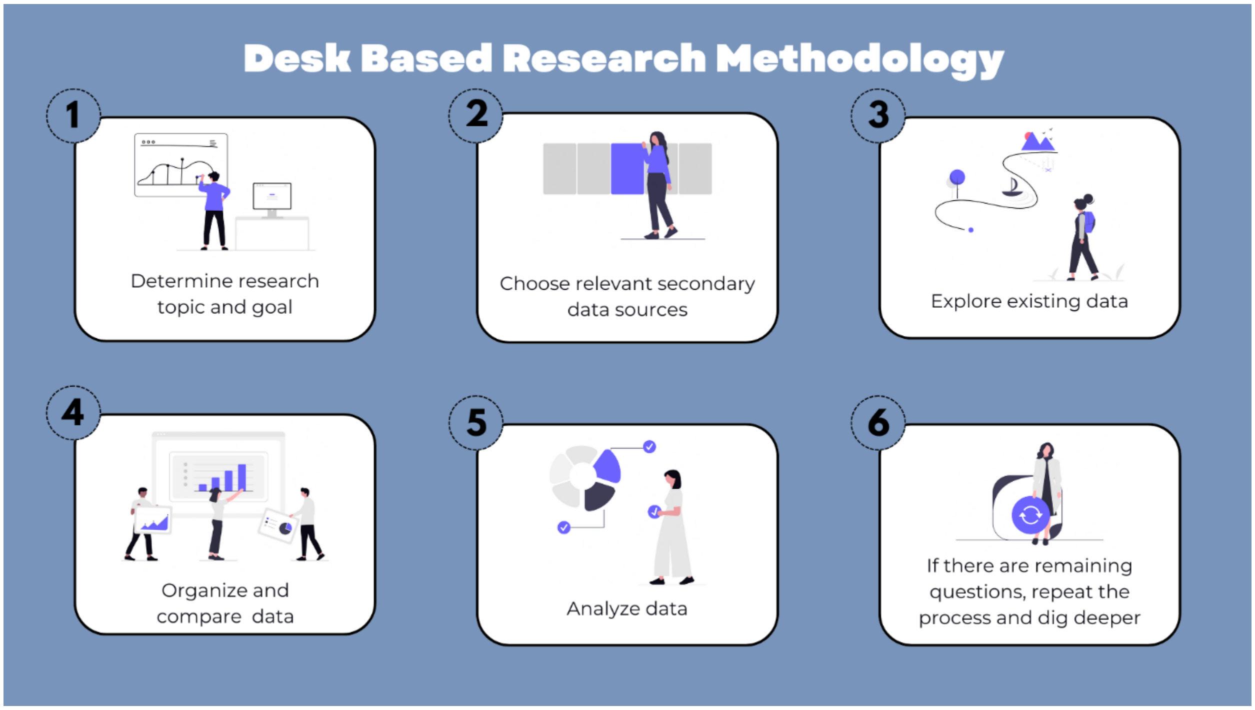

Figure 3: *Desk Based Research Methodology*

Desk Based Research is a research method that is based on the material published in reports and similar documents that are available in public libraries, websites, data obtained from surveys already carried out, etc (Havryshko, 2025). The proposed study will adopt a desk based research methodology to inform the design and development of the Virtual Reality based Chemistry Lab. The desk based research method is suitable for this study given the time constraints, ethical considerations, and restricted access to student participants. Academic literatures including journals and conference papers that are relevant to virtual learning environments, educational psychology, and science education will be reviewed to establish a theoretical foundation.

Design decisions regarding visual presentation, interaction and instructional flow will be influenced by the learning theories such as Dual Coding Theory and Cognitive Load Theory. n addition, insights from contemporary research on immersive and engaging digital technologies will be considered to ensure that the virtual laboratory promotes meaningful user engagement while avoiding cognitive overload (Alter, 2017). Besides, a set of analysis on available Virtual Learning Environment system and technical documentation for Virtual Reality development will be done to discover state of the art technology requirements. Literature results will be referenced at various points in the development process, facilitating an iterative re-factoring of the system. This way the Virtual Chemistry Lab will be based on existing research and still feasible within our project boundaries.

Case Studies

Virtual Reality has increasingly been used in educational field to address challenges such as limited laboratory access, safety concerns, and difficulties in visualizing abstract concepts. For instance, Arizona State University partnered with Dreamscape to let students learn biology through Virtual Reality enhancing the experience by incorporating hand tracking and haptic feedback. The post program data showed that the students who participated in the Virtual Reality labs had significantly higher engagement and improved lab grades compared to other students in traditional lab courses (Healy, 2025).

A study evaluated the impact of Virtual Reality on undergraduate students' self-efficacy, self-concept, interest, and laboratory anxiety in an introductory chemistry course. The study was concluded with findings that showed the use of the virtual reality application had an overall positive impact on students' self-efficacy, self-concept, interest, and anxiety further, the students who expressed some anxiety doing the lab reported to have reduced anxiety after the session (Gungor et al., 2022). The findings suggest the potential value of the use of the virtual reality applications in education, especially when the cost of real laboratories cannot be afforded.

Halimah Nur Andi Azis and Noorhaniza Wahid developed ChemisTry which is a Virtual Reality based chemistry lab designed for secondary school students to practice their experiments (Azis & Wahid, 2025). User acceptance testing was conducted with 30 participants showing strong positive feedback, indicating suitability and engagement from learners.

However, these platforms are designed and developed primarily to align with the educational curricula, infrastructure, and learning practices of the origin country. As a result, these systems are often highly contextualized and may not translate effectively to other national education systems. In Nepal, where chemistry education faces obstacles like limited access to laboratory, safety and budget constraints, there is a need for a Virtual Reality based solution specifically designed to support local educational requirements.

Integration

The planned prototype will combine a variety of technological and pedagogical elements for an immersive learning environment. The core simulation will be implemented in Unity allowing for 3D laboratory environments and interactive experiment interaction. Supported by VR hardware such as Oculus/Meta Quest headsets and tracked motion controllers, users will be able to pick up lab instruments, conduct chemical experiments, and interact with the virtual lab supported by haptic feedback for a final touch of tactile realism. Procedural logic will be programmed using C# scripts for correct chemical reactions, safety and equipment behavior specifications.

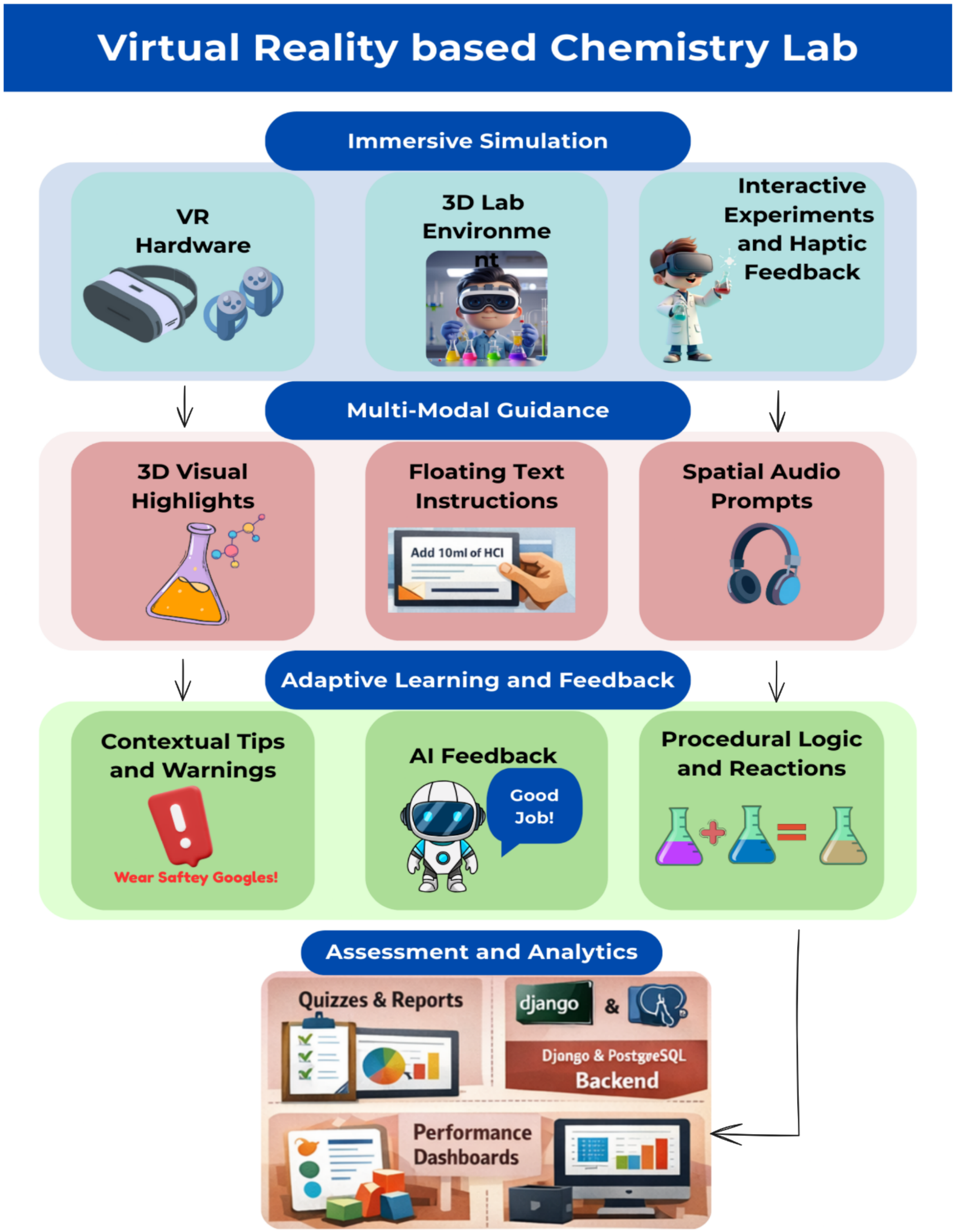

Figure 4: *Virtual Reality based Chemistry Lab Integration*

Teaching materials are going to be integrated in simulation by means of multi-cue modalities like 3D visual signals, floating textual labels and spatial sounds' clues. These features are derived from the Dual Coding Theory and Cognitive Load Theory, enabling learners to receive visual and auditory information at the same time with no cognitive overload. Event triggers in Unity will track the user event, providing context-aware instructions, behavioral alerts and AI based feedback mechanism about corresponding challenges as they occur in real time for adaptive learning.

The quizzes and the feedback provided are linked, being part of a generic quiz with assessment function. After doing an experiment, the users' answer is retrieved and sent via RESTful API endpoints to the Django backend server that process and store them securely in a PostgreSQL database. From the backend side, the platform provides analytics and reporting allowing instructors to track learner performance, error patterns and engagement metrics or adaptive experiment difficult based on previous results. This framework allows tracking of student progress and AI-based recommendations used to help optimize learning.

The system is further outfitted with data logging and telemetry modules to log interaction metrics, movement patterns, and time-on-task associated with each experiment; thereby facilitating iterative design refinements and investigation of VR pedagogy. By merging immersive simulation, multi-modal instructional supports, real-time analytics, AI feedback and haptic interaction the Virtual Chemistry Lab provides a scalable, technologically solid and pedagogically informed platform for experiments based chemistry learning in VR.

Conclusion

The VR-based Chemistry Lab is a tangible and novel solution to the challenges faced in teaching junior chemistry classes, especially in resource-poor environments like Nepal. Through an active, non-textbook based approach to education, the system is able to deliver an impactful learning tool that mitigates traditional constraints such as lack of laboratory access, safety concerns and underdeveloped visualization of abstract chemical concepts. Based on established learning theories or dual coding theory and embodied cognition, multi-modal instruction provides guidance like visuals, audio, 3D space and haptic interaction to assist in making sense of the object while preventing cognitive overload. A feature of Artificial Intelligence is included to provide real-time personalized feedback in order to assist learners to rectify their mistakes and reflect on the actions, so it does not lead the users into a sense that everything went good but rather honest reflection. Technically the system mixes in a unity based simulator and with a django and postgreSQL backend for performance monitoring and learning analytics. Whilst being aware of concerns about over-reliance on technology, the project is intended as a tool to support teacher-led learning. The Virtual Reality Chemistry Lab seeks to help close the gap between concept and reality by providing more engaging, accessible and effective ways for students to learn science concepts.

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Appendix

SWOT Analysis

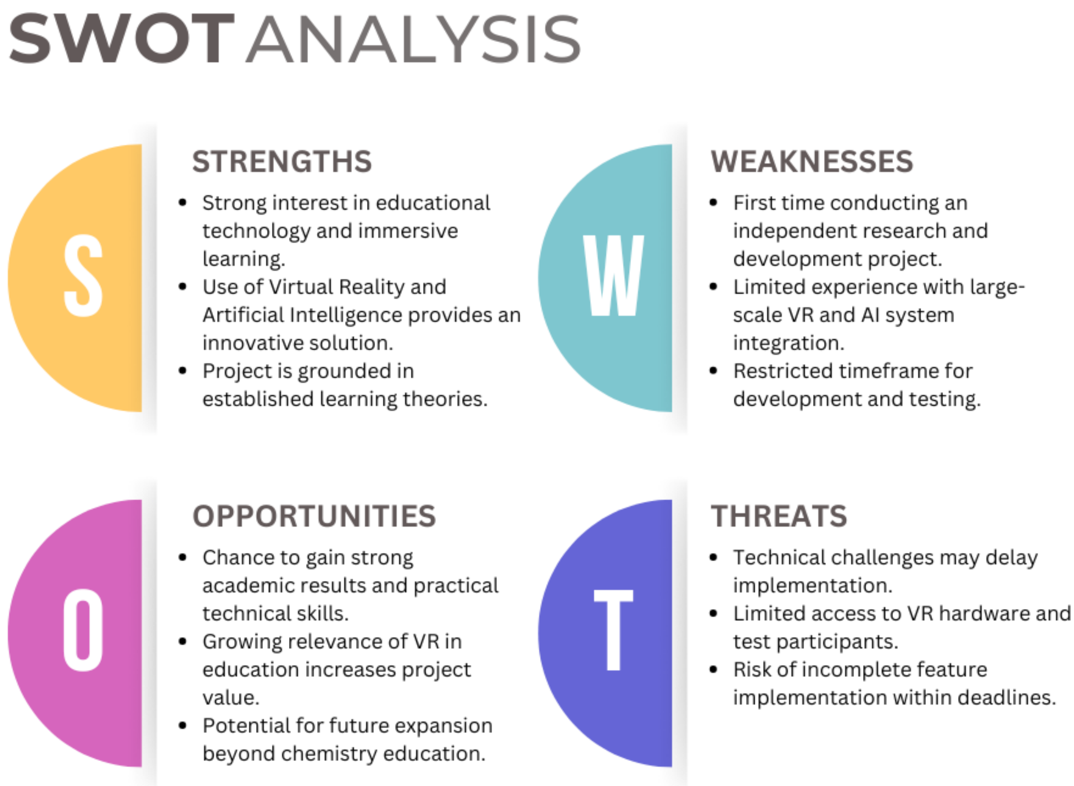

Figure 5: *SWOT Analysis*

Risk Log

Id	**Name**	**Occurrence**	**Impact**	**Plan B**
1	Health and wellbeing	Occasional	Medium	Maintain a balanced work schedule and avoid overworking
2	Limited technical expertise	Frequent	High	Use online tutorials, documentation, and seek guidance from supervisors
3	VR hardware availability	Rare	Medium	Use limited testing sessions and rely on simulation previews where possible
4	Time pressure from other modules	Frequent	High	Create a detailed weekly plan and prioritize critical tasks
5	System integration issues	Occasional	High	Implement features incrementally and test components separately