AUGMENTED REALITY IN CHEMISTRY

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DECLARATION

This is to certify that the work entitled Augmented Reality in Chemistry is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology in Software Engineering, Harare Institute of Technology. It is further certified that no part of research has been submitted to any university for the award of any degree.

(Student) Date : ……………………………………… Signature: …………………………………

(Supervisor) Date : ……………………………………… Signature: ……………………..………

(Chairman) Date : ……………………………………… Signature : ………..………………………

DEDICATION

I would like to dedicate this project to my family , whose constant encouragement, tolerance, and support enabled me to take this adventure. And to the future scientists and educators who will use technology not merely to visualize but to ignite reactions of curiosity, discovery, and connection the true essence of chemistry.

ACKNOWLEDGMENTS

Firstly, I would like to express my deepest gratitude to the Most High for granting me the strength, clarity, and resilience to pursue this degree and bring this project to completion. Without divine guidance, none of this would have been possible.

I extend sincere thanks to the Software Engineering Department at the Harare Institute of Technology for providing not only the academic foundation, but also the practical skills and mentorship that were instrumental in the successful development of this project.

To my colleagues and peers, thank you for the collaboration, encouragement, and shared moments of growth throughout this journey. To my family, your unwavering support, patience, and belief in me have been a source of constant motivation. This accomplishment is as much yours as it is mine.

ABSTRACT

Chemistry education is frequently hindered by the abstract nature of its core concepts, leading to difficulties in visualization and comprehension, particularly at high school . This project proposes the development of an Augmented Reality (AR) mobile application designed to revolutionize the learning experience by providing immersive and interactive visualizations of chemical phenomena. The application aims to address the challenges of visualizing complex molecular structures, and exploring bonding mechanisms in real-time. By leveraging AR technology, students will be able to interact with 3D models of molecules, and explore chemical processes in a tangible, engaging manner. This platform will cater to diverse learning styles by offering interactive, visual, and kinesthetic learning experiences, thereby enhancing comprehension and retention. Ultimately, this project seeks to transform chemistry education by making it more accessible, engaging, and enjoyable, fostering a deeper understanding of fundamental chemical principles.

KEYWORDS: Augmented Reality (AR), Mobile Application, 3D Visualization, Molecular Structures, Immersive Learning, Interactive Simulation, Chemistry Education, Student Engagement, Educational Technology.

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List of Acronyms (Optional)

AR: Augmented Reality

VR: Virtual Reality (While not the focus, it's a related term)

UI: User Interface

UX: User Experience

SDK: Software Development Kit

API: Application Programming Interface

CHAPTER 1 INTRODUCTION

1.1 Introduction

Chemistry, a key scientific discipline, presents challenges for learners due to its abstract concepts and complex structures. Traditional teaching methods often struggle to illustrate the full three-dimensional nature of chemical phenomena. This project aims to overcome these obstacles by creating an innovative Augmented Reality mobile app that brings chemistry to life.

Through this application, students will access an engaging and hands-on learning journey, allowing them to interact with and visualize 3D molecular structures, and delve into bonding processes using captivating AR features. By harnessing AR capabilities, this endeavor aims to revolutionize the teaching of chemistry, enhancing accessibility, engagement, and effectiveness for high school students.

1.2 Background

Education is a very important pillar of progression in our community . It is through education that we can evolve and realise new innovations that make our lives easier. It is essential that education is imparted to students in an inclusive and meaningful way to ensure that it is effective and the desired teaching processes , this is all but an effort to ensure that we use the resources we have at hand to their full capacity and we improve where we are lacking . The education system in Zimbabwe is lacking interactivity and inclusivity amongst other things. Some learning institutions cannot afford resources to allow their students to perform experiments and other practical aspects extensively, unfortunately these students in turn miss out on participating in these activities and end up watching their facilitators demonstrate.

The quote by Confucius " I hear and I forget. I see and I remember. I do and I understand" illustrates the importance of active participation from students. This quote further elucidates the limitations of passive absorption of information.

1.3 Problem Statement

The system is not student centric , this is to say that students are not participants during the learning and teaching process they are more of recipients of what is given to them . This can result in lack of engagement with the student .

Recent and ongoing studies continue to emphasize on the relevance of teaching styles in ensuring that students learn as expected of them by the facilitator. To add to that students have different learning styles, namely – visual, auditory and kinesthetic just to mention a few. Teaching styles used in institutions should cater for a wide spectrum of learning styles to ensure inclusivity. An augmented reality approach to learning allows for this. By adding digital content to the already existing education system , Augmented Reality can bridge the gap between theoretical and practical concepts. Students get the opportunity to grasp abstract concepts because they have a better visualization of what is being talked about .

In the context of Zimbabwe's Education 5.0 model, which calls for a transformation from passive learning to innovation-driven, practical, and technology-integrated education, there is a clear need for tools that not only enhance learning outcomes but also align with national goals of industrialization and technological advancement. The lack of interactive, immersive tools in chemistry education presents a gap that must be addressed to fulfill the innovative and practical thrust of Education 5.0.

The goal of this project is to complement the existing education system by compensating for its shortcomings in an innovative manner . The application of augmented reality to education will improve student engagement and interactivity, comprehension and the learning process at large.

1.4 Objectives

The technical objectives of this project are focused on the development and implementation of the AR mobile application, ensuring it meets the project's educational goals. These objectives are designed to be specific, measurable, achievable, relevant, and time-bound (SMART). The objectives are as follows :

- To develop a mobile application that allows students to visualize content from chemistry using Augmented Reality .

- To Integrate gamified learning experiences into the application.
- To incorporate progress tracking and analytics in the mobile application for the student

1.5 Hypothesis

Based on the identified challenges in traditional chemistry education and the potential of Augmented Reality (AR) to address these challenges, the following hypotheses are proposed:

Null Hypothesis : The application of augmented reality will not make a significant improvement to the learning outcomes and user experience compared to traditional teaching methods

Alternative Hypothesis : The application of augmented reality will make a significant improvement to the learning outcomes and user experience compared to traditional teaching methods.

This project's hypothesis is that the implementation of an Augmented Reality learning platform will enhance the learner's experience and foster student engagement.

1.6 Justification

The development and implementation of the AR Chemistry application are strongly justified by several key factors within the educational context of Harare, Zimbabwe:

- **Enhanced Engagement and Conceptual Understanding:** Traditional chemistry education often relies on abstract representations of molecules and reactions. This application leverages the power of augmented reality and interactive 3D visualizations, facilitated by Three.js, to bring these abstract concepts to life. By allowing students to manipulate and explore molecules in their physical environment, the application fosters deeper engagement and a more intuitive understanding of complex chemical structures and processes.
- **Addressing Resource Limitations:** Many schools in Harare may face limitations in accessing physical laboratory equipment and chemical reagents. This application provides a

virtual laboratory experience, allowing students to conduct simulations and interact with virtual models safely and without the need for expensive or scarce physical resources.

- **Catering to Mobile Accessibility:** Mobile devices are increasingly prevalent among students in Harare. Developing a mobile-first application ensures accessibility to learning resources on devices they are already familiar with, breaking down geographical and socioeconomic barriers to quality education.
- **Supporting Offline Learning:** Recognizing the challenges of consistent internet connectivity in Harare, the application is designed with a strong emphasis on offline functionality. This allows students to continue learning and engaging with core content (3D models, simulations, pre-loaded modules) even without a stable internet connection, ensuring continuity of education.
- **Alignment with Modern Pedagogical Approaches:** The application promotes active learning through interactive simulations, drag-and-drop activities, and potentially gamified elements. This aligns with modern pedagogical approaches that emphasize student-centered learning and the development of critical thinking skills.
- **Potential for Personalized Learning:** The application's architecture allows for the future integration of personalized learning features, adapting content and assessments to individual student needs and progress, ultimately leading to more effective learning outcomes.

1.7 Proposed Tools

The development of the AR Chemistry application leveraged a carefully selected set of tools and technologies chosen for their capabilities, suitability for mobile development, and potential for addressing the specific needs of the Harare context:

Frontend Development:

- **JavaScript (ES6+):** The primary language for creating interactive and dynamic user interfaces. Its versatility and large ecosystem make it well-suited for mobile web and hybrid application development.
- **React.js:** A JavaScript library for building user interfaces. Its component-based architecture promotes modularity, maintainability, and efficient rendering, crucial for mobile performance.

- **Three.js:** A powerful JavaScript library and API used for creating and displaying animated 3D computer graphics in a web browser**.** Three.js is central to the application's core functionality, enabling the rendering of interactive 3D molecular models and the implementation of augmented reality experiences by leveraging device sensors and camera feed. Its performance optimizations are vital for delivering a smooth AR experience on mobile devices.

Backend Development:

Database Management:

- **SQLite:** A lightweight, file-based database engine ideal for local storage on mobile devices, enabling offline access to essential data like 3D models and learning modules.

Development Environment and Tools:

- **Integrated Development Environments (IDEs):** Tools like Visual Studio Code (VS Code) or WebStorm for efficient code editing, debugging, and project management.
- **Version Control:** Git for managing code changes and collaboration, with platforms like GitHub or GitLab for repository hosting and team workflows.
- **Testing Frameworks:** JavaScript testing frameworks (e.g., Jest, Mocha) for ensuring code quality and application stability.
- **AR Development Tools (within Three.js/WebXR):** Leveraging the capabilities within Three.js and the WebXR Device API to handle camera access, sensor data processing, and the overlay of 3D graphics onto the real world for the augmented reality features.
- The selection of these tools prioritized creating a performant, engaging, and accessible application that can function effectively within the specific technological and infrastructural landscape of Harare, Zimbabwe. The inclusion of Three.js is fundamental to delivering the core value proposition of interactive 3D chemistry learning and augmented reality experiences.

1.8 Feasibility Study

1.8.1 Technical Feasibility

Technology Assessment: Evaluate the availability and feasibility of implementing the required technologies:

Table 1 Technical Feasibility

Component	Technology/Aspect	Assessment & Conclusion
AR Tracking	AR.js + WebXR	Suitable for basic marker-based AR. Lightweight and browser-friendly. Limited spatial tracking; best in controlled environments.
3D Rendering Engine	Three.js	Efficient WebGL-based rendering for complex molecular models. Suitable for real-time visualization on modern devices. Performance may degrade on low-end phones.
Device Compatibility	Mobile browsers (Chrome, Safari)	Broad compatibility with modern smartphones. Requires functional camera, accelerometer, and moderate CPU/GPU. Older devices may struggle.
LMS Integration	JavaScript APIs, iframe, REST integration	Feasible via web embedding or API sync. SQLite allows offline use; data can be synced with server-side databases when online.
Technological Constraints	Browser performance, HTTPS, network quality	Limited compared to native AR SDKs. Requires stable lighting and secure web access. Offline caching strategies recommended.
Mobile Requirements	Smartphone or tablet with 2GHz CPU, 3GB RAM, 8MP+ camera	Mid-to-high-end devices recommended. Requires stable Wi-Fi or LTE, especially for downloading 3D assets or collaborative features.
Network Infrastructure	Wi-Fi or LTE, optional cloud server	Needed for content updates and backups. If using a server, it must have redundant storage and consistent uptime.

Storage Require-ments	100–300MB on-device; scalable server storage (if needed)	Local storage sufficient for models and user data. Server-side content needs backup and disaster recovery provisions.
Software Stack	WebXR, AR.js, Three.js, JavaScript, SQLite	Open-source, lightweight, and widely supported. SQLite handles offline data; frontend can be integrated with LMS or cloud solutions.
Technical Expertise	AR dev (AR.js, WebXR), 3D modeling (Blender), JS dev, UI/UX, chemistry education, QA	Required to cover development, design, scientific accuracy, and quality assurance.

1.8.2 Economic Feasibility

Estimated Budget

Table 2 Estimated Budget

Item	Cost Estimate (USD)
Smartphone High Quality Camera	n/a
AWS Server Cost	$50
Software Licenses	$50
Printing	$40
Miscellaneous	$30
Total	$170

Analysis of the Cost Estimate:

- Item: This column lists the different categories of expenses for the project.
- Cost Estimate (USD): This column shows the estimated cost for each item in US Dollars**.**
- Smartphone High Quality Came: This line item has "n/a" which means it's not applicable or not being considered as a direct project expense. It might be assumed that team members already have suitable smartphones.

- AWS Server Cost: $50 is allocated for the cost of using Amazon Web Services (AWS) servers. This would cover hosting data, running applications, or other cloud-based services.
- Software Licenses: $50 is budgeted for software licenses. This could include development tools, design software, or other necessary applications.
- Printing: $40 is set aside for printing-related expenses. This could cover documents, reports, or promotional materials.
- Miscellaneous**:** $30 is allocated for miscellaneous or unexpected costs that might arise during the project.
- Total**:** The total estimated cost for the project is $170 USD.

Important Considerations:

- Currency: The costs are in US Dollars, which is important to note, especially in Zimbabwe, where local currency fluctuations might be a factor.
- Scope: The low total cost suggests this might be a small-scale project or a phase of a larger project.
- Omissions: There are no line items for personnel/labor costs, which could be a significant factor in a project's overall budget.

1.8.3 Operational Cost

Schedule Cost:

Project Timeline:

Table 3 Project Timeline

PHASE	DURATION	STARTING DATE	ENDING DATE
Requirements analysis and definition	4 weeks	1 September 2024	30 September 2024
Software and system design	16 weeks	1 October 2024	30 January 2025

Implementation and unit testing	3 weeks	1 February 2025	22 February 2025
Integration and system testing	4 weeks	23 February 2025	23 March 2025

1.8.4 Project Plan

Time Plan:
The project has been divided into fortnight sprints using an Agile methodology.

A detailed work schedule has been created using a spreadsheet, outlining specific tasks for each week, estimated time-frames, and dependencies between tasks.

Table 4 Time Plan

Sprint #	Start Date	End Date	Phase(s)	Key Tasks
Sprint 1	1-Sep-24	14-Sep-24	Requirements Analysis	Research, documentation initiation
Sprint 2	15-Sep-24	30-Sep-24	Requirements Analysis	Complete research and documentation setup
Sprint 3	1-Oct-24	14-Oct-24	Software & System Design	Start system design, initiate data collection
Sprint 4	15-Oct-24	31-Oct-24	Software & System Design	Continue design, complete data collection
Sprint 5	1-Nov-24	14-Nov-24	Software & System Design	Begin model development
Sprint 6	15-Nov-24	30-Nov-24	Software & System Design	Continue model development
Sprint 7	1-Dec-24	14-Dec-24	Software & System Design	Finalize model development
Sprint 8	15-Dec-24	31-Dec-24	Software & System Design	Begin system implementation
Sprint 9	1-Jan-25	14-Jan-25	Software & System Design	Continue implementation
Sprint 10	15-Jan-25	30-Jan-25	Software & System Design	Finalize system implementation

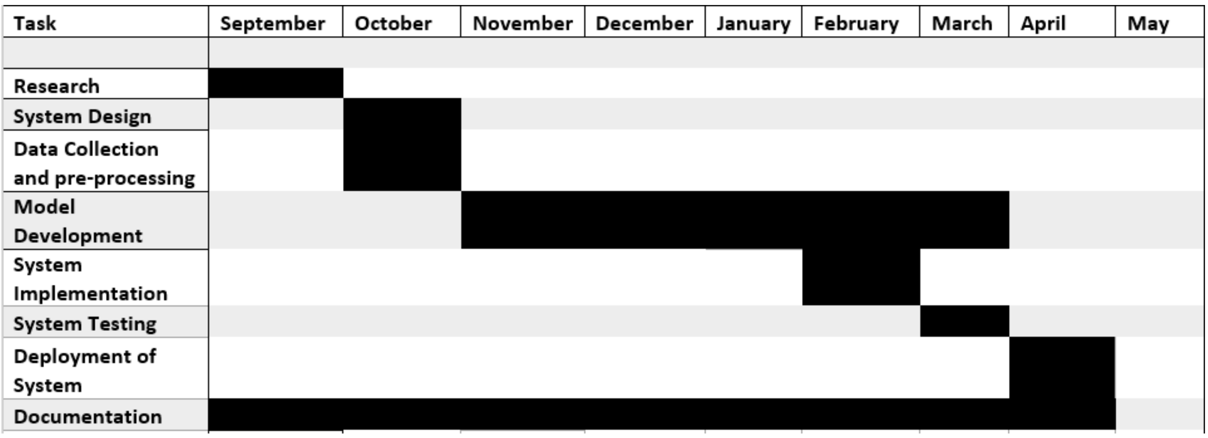
Sprint 11	1-Feb-25	14-Feb-25	Implementation & Unit Testing	Begin testing components
Sprint 12	15-Feb-25	22-Feb-25	Implementation & Unit Testing	Finalize testing & prepare for integration
Sprint 13	23-Feb-25	9-Mar-25	Integration & System Testing	Integration & early system testing
Sprint 14	10-Mar-25	23-Mar-25	Integration & System Testing	Final system testing and debugging
Sprint 15	24-Mar-25	6-Apr-25	Post-Testing / Documentation	System deployment and final documentation
Sprint 16	7-Apr-25	20-Apr-25	Documentation Completion	Final review and formatting
Sprint 17	21-Apr-25	4-May-25	Project Wrap-up	Submission prep, presentation rehearsals

Risk Mitigation Strategies:

- Regular backups of all project files, 3d models, and code are conducted daily.
- The project schedule is reviewed and updated weekly to accommodate any unforeseen challenges.
- Regular communication with the project supervisor ensures timely resolution of any roadblocks.
- Regular testing of the application to find bugs early in development.

Grantt Chart

Figure 1 Gantt Chart



1.9 Conclusion

By creating an Augmented Reality (AR) mobile application that makes use of 3D visuals, interactive periodic table and gamified experiences through the use of technologies like Three.js, the project seeks to transform chemistry teaching in Zimbabwe. The program goes beyond traditional teaching methods to provide an immersive, learner-centered experience that is in line with Zimbabwe's Education 5.0 ideology, which emphasizes teaching, research, community service, innovation, and industrialization. Through consideration and integration of these factors, the AR Chemistry app hopes to increase student engagement, enhance understanding of abstract scientific ideas, and support the larger national objective of promoting technology innovation and self-sufficient educational systems.

CHAPTER 2 LITERATURE REVIEW

2.0 Introduction

The abstract nature of chemistry poses challenges for learners in high school and university, hindering visualization and understanding. To address this, an Augmented Reality (AR) mobile app is proposed to provide immersive and interactive experiences of chemical concepts. This app aims to visualize complex molecular structures, and explore bonding mechanisms , allowing students to interact with 3D models and dynamic simulations. Traditional teaching methods often fall short in conveying the three-dimensional reality of chemical phenomena, making AR technology a promising solution for enhancing chemistry education.

2.1 Related Work

A study [1] underscored the challenge of understanding micro-world concepts in chemistry education, particularly among junior high school students who struggle with visualizing microstructures accurately. The study focused on the "substances composition " topic and developed AR learning tools using markers to help students manipulate 3D microparticle models. Conducted in a junior high school in Shenzhen, China, the research found that the AR tool significantly improved learning, especially for students with lower academic achievements. Students showed positive attitudes towards the software, indicating a correlation between their learning attitudes and evaluations of the tool.

The research [6] explored the current use of augmented reality (AR) in chemistry education and identified ways to enhance chemistry learning in Ukrainian schools. It examined existing AR applications, contemporary tools, and future prospects in Ukrainian chemistry education. The study emphasized AR's effectiveness in visualizing atomic structures and molecules but highlighted a lack of Ukrainian software solutions. It concluded that there is a demand for mobile-accessible AR tools to improve chemistry instruction, suggesting the need for resources like instructional guidelines, AR integration in textbooks, and simulators for interactive chemical learning.

Studies have highlighted challenges students face in understanding molecular representations and three-dimensional thinking in chemistry education[7][8]. Tailoring curricula to improve spatial skills has shown positive effects on academic performance, especially among female students. This suggests that practicing spatial abilities can enhance academic outcomes. The goal is to address teaching challenges related to spatial skills in chemistry microstructures. Various computer-assisted tools are used in chemistry education, with Virtual Reality and Augmented Reality tools gaining acclaim for effectively teaching microstructure concepts[9].

A Virtual Laboratory implemented for new university chemistry students aimed to prepare them for remote learning. The tool was highly praised by students who found it beneficial for their preparation, recommending its continued use.[10] While effective, interactive Virtual Reality (VR) methods were criticized for feeling somewhat unnatural and having restricted applicability. In another study, the effects of 3D desktop Virtual Reality environments on learner characteristics were examined using simulations in Second Life. These interactive applications allowed features like zooming, object rotation, and behavior programming, indicating that the 3D virtual environment could enhance the learning experience for chemistry students[11].

Researchers in [12] compared virtual and physical models in organic chemistry education regarding tasks like matching molecular structures. Although no significant difference in task completion accuracy was found, virtual models were more efficient. Augmented Reality (AR) presents a more engaging educational experience than Virtual Reality (VR), as seen in studies like [13] and [14], which showcased AR tools enhancing visualization skills and facilitating dynamic interactions in learning chemistry.

Notably, [15] introduced an Augmented Reality Teaching Platform (ARTP) for chemistry, promoting student engagement and mastery of concepts. Similarly, [16] illustrated how AR environments can boost motivation by allowing hands-on experimentation. These AR applications align with Mayer's principles, emphasizing the effectiveness of combining narration and animation for enhanced learning experiences. Augmented Reality (AR) has demonstrated effectiveness beyond the sciences, extending into the arts. Development of an AR system for library instruction led to enhanced learning outcomes, increased student motivation, and engagement, as evidenced by positive feedback on the ARLIS system [18].

In visual arts education, the integration of AR positively impacted middle school students' motivation, as shown in a study by [19]. Additionally, [20] explored the use of AR on mobile devices to visualize construction processes, revealing a correlation between device use, student motivation, and academic performance.

Focusing on the junior high school chemistry curriculum's "composition of substances" segment, which involves teaching microstructures, researchers aim to address challenges in teaching abstract concepts and spatial abilities by developing an AR-based learning tool [21]. Traditional 2D materials can be cognitively demanding, whereas AR allows students to view molecular models from various angles. By enabling interactive manipulation of particles and construction of molecules, this AR environment offers a hands-on approach to deepen understanding, as highlighted by [22].

2.2 Conclusion

The implementation of Augmented Reality (AR) in chemistry education has demonstrated significant potential for enhancing student engagement and comprehension, particularly in complex topics such as microstructure and molecular geometry. The findings from various studies reveal a consistent pattern: AR tools not only facilitate deeper understanding but also foster a more interactive and motivating learning environment.

Enhanced Engagement and Motivation

Engaging with Augmented Reality (AR) environments positively impacts students' enjoyment and motivation, fostering hands-on learning experiences like conducting chemical experiments. Students using AR systems, as noted in studies [6] and [7], feel a sense of autonomy and control, enhancing their engagement. This active participation is crucial as motivated students tend to invest more effort in their learning, leading to better academic outcomes.

Enhanced Understanding of Abstract Concepts

The studies indicate that Augmented Reality (AR) can effectively help students overcome cognitive hurdles associated with abstract chemistry concepts. By allowing visualization of molecular structures from various perspectives, AR mitigates the cognitive overload often experienced with traditional 2D representations. Our research emphasizes that AR promotes a more intuitive understanding of intricate spatial relationships, empowering students to actively interact with and investigate molecular models. This hands-on learning method aligns with the idea, as noted by [20], that knowledge is built through active engagement with the subject matter.

Contrast with Conventional Learning Approaches

Traditional educational techniques frequently depend on textbooks and fixed illustrations, whereas the interactive quality of AR offers a distinct edge. Research by [17] indicates that while virtual and physical models showed comparable task accuracy, virtual models significantly outperformed in efficiency. This implies that AR not only aids in comprehension but also enhances the educational process by optimizing effectiveness.

Wider Implications for Educational Practices

The research outcomes underscore a crucial requirement for incorporating AR technologies into chemistry curricula, especially at the junior high school stage where fundamental principles are cemented. [15] underscores the scarcity of Ukrainian AR solutions in this domain, emphasizing the necessity for interactive and captivating educational resources. Crafting AR tools specifically for chemistry education has the potential to boost both student comprehension and enthusiasm for the subject.

Future Directions

Future investigations should delve into the enduring effects of AR on student learning achievements and extend across different educational settings. Moreover, integrating gamified features into AR platforms could elevate student involvement. A cooperative partnership between educators and technology experts will prove indispensable in formulating impactful AR resources that accommodate varied learning requirements. In summary, the infusion of AR into chemistry instruction presents encouraging prospects for enhancing student participation, understanding, and holistic learning adventures. By tackling the obstacles linked with conventional teaching methods, AR stands poised to revolutionize the realm of chemistry education, rendering it both more approachable and delightful for learners.

CHAPTER 3 ANALYSIS

3.1 Introduction

This chapter details the crucial process of identifying and documenting the specific needs and expectations for the development of an Augmented Reality (AR) mobile application designed to enhance chemistry education. This phase is essential to ensure that the final application effectively addresses the challenges of visualizing abstract chemical concepts, fostering student engagement, and improving learning outcomes. Key areas of focus include defining user requirements (students and educators), specifying core system functionalities (3D model manipulation, reaction simulation, etc.), establishing performance expectations (smooth AR tracking, real-time rendering), and outlining non-functional requirements such as usability, accessibility, and scientific accuracy. This thorough analysis will lay the foundation for a successful and impactful AR educational tool.

3.1.1 Information Gathering Tools:

Data Gathering Methods:

- **Interviews:** Conduct interviews with students and educators to gather their specific needs, expectations, and feedback on existing teaching methods.
- **Surveys:** Distribute surveys to gather feedback from a wider range of students and educators regarding their learning preferences and experiences with chemistry education.
- **Focus Groups:** Organize focus groups with students and educators to facilitate discussions and gather input on the design and functionality of the AR application.
- **Observation:** Observe students and educators in classroom settings to identify areas where the AR application could enhance learning and teaching.
- **Literature Review:** Review existing research and educational materials related to chemistry education and AR technology.

- **Usability Testing:** Observe students using prototype versions of the application to identify usability issues and areas for improvement.

Stakeholder Analysis:

- Identify and document the needs and expectations of all key stakeholders, including students, educators, curriculum developers, and educational institutions.
- Analyze the potential impact of the AR application on each stakeholder group, considering factors such as learning outcomes, teaching practices, and resource allocation.
- Gather feedback from subject matter experts in chemistry.

Requirements Elicitation Techniques:

- Employ various elicitation techniques such as user stories, use case diagrams, and task analysis to capture and document user requirements in a clear and concise manner.
- Create user personas to represent different student and educator profiles, helping to ensure that the application meets the needs of a diverse user base.
- Create story boards to show user interactions with the application.

3.1.2 Description of the Proposed Solution

Recognizing the limitations of current chemistry teaching methods in Zimbabwe, this project proposes an Augmented Reality (AR) mobile application to enhance the learning experience. This application aims to address the critical issues of abstract concept visualization, lack of student engagement, and limited access to practical learning experiences, which significantly impact the quality of chemistry education.

The proposed solution leverages cutting-edge technologies, including:

- **3D Modeling and Visualization:**
  Interactive 3D models of molecules and chemical structures, allowing students to explore and manipulate them. Additionally students can interact with a digital Periodic Table that allows them to view information about 118 elements of the periodic table.
- **AR Overlay and Interaction:**

Augmented reality overlays that project 3D models and simulations onto the real-world environment, creating an immersive learning experience.

- **Interactive Learning Modules:**

  Engaging learning modules that provide clear and concise explanations of complex chemical concepts. The learning modules are gamified to enhance student engagement and concentration .

- **Progress Tracking and Assessment Tools:**

  Integrated tools for tracking student progress, assessing learning outcomes, and providing personalized feedback.

- **Mobile Platform Accessibility:**

  A mobile application designed for accessibility on common mobile devices, allowing for learning anytime and anywhere.

- **Offline Functionality:**

  The ability for the application to function without internet access, due to the possible lack of consistent internet.

- **Teacher controlled content-management**

  The application empowers teachers with content control capabilities by allowing them to upload custom learning materials, assignments, and models directly into the system. This ensures that students are engaging with accurate, curriculum-aligned, and teacher-approved content, while also enabling educators to tailor lessons to specific learning objectives and classroom needs.

This integrated approach aims to provide interactive learning, improve student engagement, and enhance the overall effectiveness of chemistry education in Harare, Zimbabwe.

3.2 Data Analysis

3.2.1 Description of Current Security System

- **Traditional Classroom Instruction:** Chemistry is typically taught through lectures, textbook readings, and blackboard illustrations [35]. Emphasis is placed on rote memorization of chemical formulas and equations. This method often struggles to engage students and fails to provide a tangible understanding of molecular structures and chemical processes.

- **Limited Laboratory Resources:**

  Many schools in Zimbabwe face constraints in terms of laboratory equipment and resources [36]. Practical experiments, crucial for hands-on learning, are often limited or unavailable.This lack of practical experience hinders students' ability to connect theoretical concepts with real-world applications.

- **Textbook-Centric Learning:**

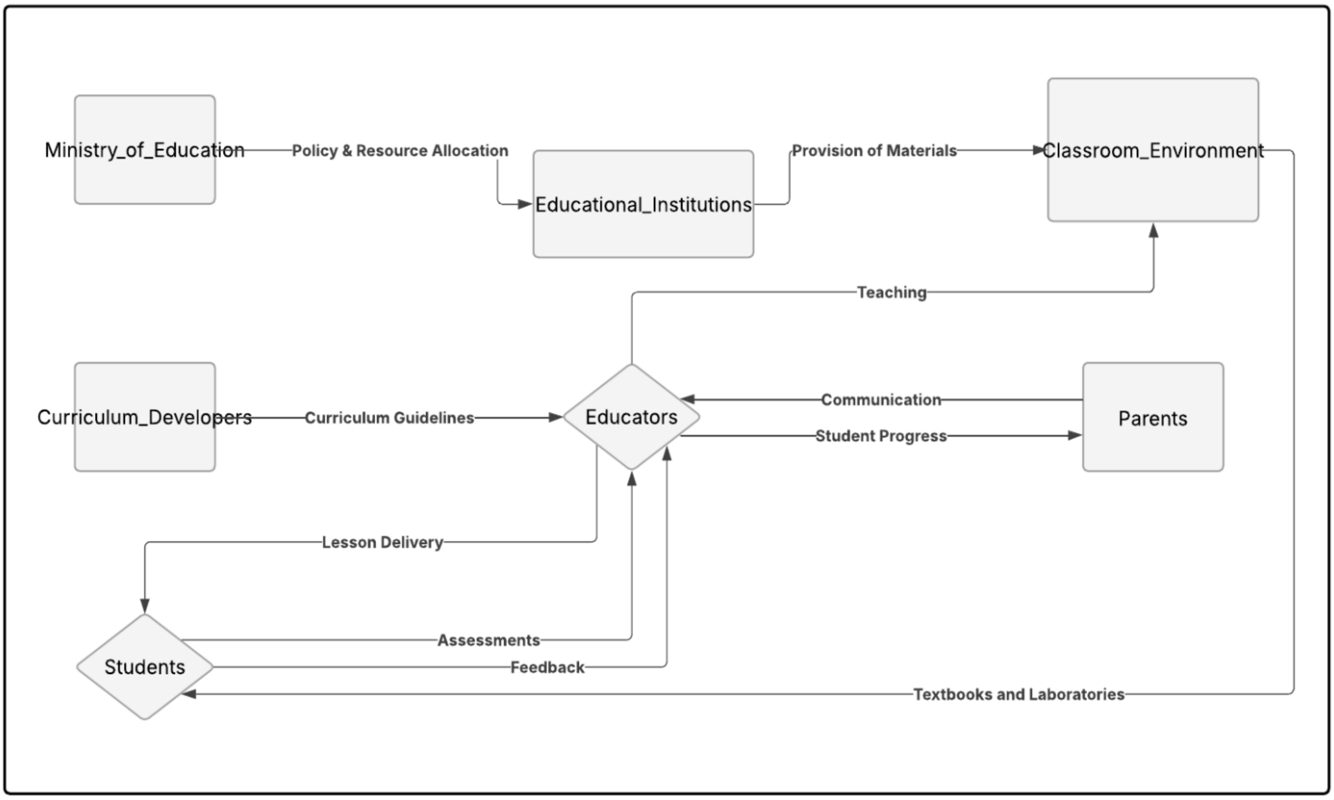
  Textbooks serve as the primary source of information, often featuring static 2D diagrams that are inadequate for visualizing 3D molecular structures [37]. This can lead to difficulties in spatial reasoning and a limited understanding of chemical phenomena.

- **Examination-Driven Approach:**

  The education system is often driven by examinations, emphasizing the memorization of facts rather than conceptual understanding [38].

3.2.2 Analysis of existing system

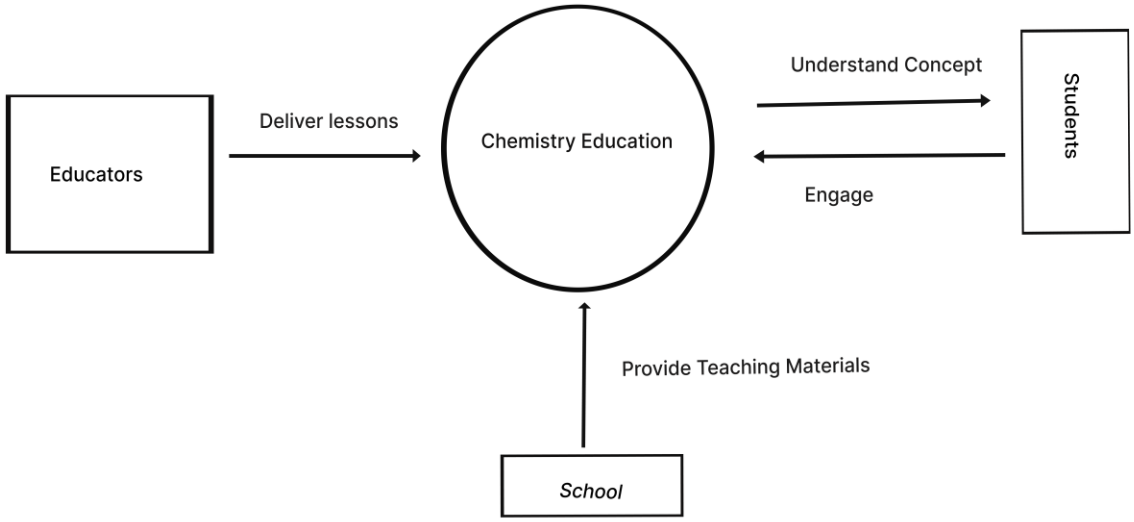
Figure 2 Context Diagram of Current System



3.2.3 Context Diagram of the Existing System

The chemistry education system in Harare, Zimbabwe fig 3, consists of a classroom environment with textbooks and laboratories, involving students, educators, curriculum developers, educational institutions, parents, and the Ministry of Education. Key data flows include lesson delivery by teachers, provision of materials by institutions, student assessments, curriculum guidelines from developers, feedback from students, communication with parents about progress, and policy and resource allocation from the Ministry of Education.

Figure 3 Level 0 DFD of Current System



The Level 0 DFD illustrates the current "Chemistry Education Delivery" system at a high level. It identifies inputs such as textbooks, educator lectures, limited laboratory resources, and assessment criteria. The core process involves educators delivering chemistry education through traditional methods. The main outputs for students are knowledge and understanding, albeit often abstract due to limitations, along with their examination performance. Key external entities include students, who receive education, and educators, who deliver and assess it. This diagram provides a clear overview of the existing system, serving as a baseline for the proposed AR application aimed at enhancing the educational experience.

3.2.4 Weaknesses of Current System

Based on the analysis of the current chemistry education system in Harare, several weaknesses are identified:

- Limited Visualization of Abstract Concepts: Reliance on 2D diagrams hampers understanding of 3D molecular structures.
- Lack of Interactive Learning: Traditional lectures lead to passive learning and disengagement.

- Resource Constraints**:** Shortages of lab equipment limit hands-on learning experiences.
- Emphasis on Rote Memorization**:** Focus on exams encourages memorization over conceptual understanding.
- Difficulty Catering to Learning Styles**:** Traditional methods may not address diverse student learning preferences.
- Limited Real-World Application**:** Students struggle to connect classroom chemistry to real-world scenarios.
- Inequitable Access to Education**:** Disparities in resources and teacher qualifications affect educational quality.
- Lack of Modern Technology Integration: Minimal use of technology to enhance learning experiences.

3.2.5 Evaluation of Alternatives Systems

Current Educational Practices

- Traditional Lectures and Textbooks**:** Dependence on static 2D diagrams and rote memorization.
- Physical Laboratory Experiments**:** Hands-on activities with physical materials.
- Static 3D Models: Use of pre-built models for visualization.

Limitations of Current Measures

- **Effectiveness**:

  Traditional methods often fail to convey the dynamic nature of chemical processes. Static 3D models lack interactivity and real-time manipulation.

- **Engagement**:

  Traditional approaches lead to passive learning and limited student engagement, especially with abstract concepts.

- **Visualization**:

  2D representations struggle to accurately depict 3D molecular structures and dynamic reactions. The microscopic world is difficult to represent in a macro context.

Alternative Technologies:

- Virtual Reality (VR): Virtual Reality offers fully immersive 3D environments that can revolutionize the exploration of complex chemical concepts. While it provides an unparalleled experience, it often demands specialized equipment and may lead to isolation from the physical world [23].

- Interactive Digital Whiteboards**:** Interactive Digital Whiteboards facilitate dynamic presentations and real-time annotations, enhancing engagement and collaboration in educational settings. However, they may not deliver the same level of immersion as Augmented Reality (AR) technologies [23].

- Mobile Learning Applications (Non-AR): Mobile Learning Applications designed without Augmented Reality functionality provide convenient access to educational materials and resources on handheld devices. Despite their accessibility, they may lack the interactive visualization features that AR can offer, potentially impacting the depth of learning experiences [23].

Feasibility of Outsourcing:

1. **3D Model Development**: Outsourcing the creation of detailed and accurate 3D molecular models can be feasible for a solo developer, especially if they lack the expertise or resources to create high-quality models. This can save time and ensure the models meet the required standards. However, clear communication and quality control are crucial to ensure the outsourced models align with the project needs.

2. **AR Software Development**: Outsourcing core AR functionalities like tracking, rendering, and interaction can be feasible for a solo developer if they lack AR development expertise. It can speed up the development process and ensure that the application meets technical requirements. Clear communication and well-defined project milestones are essential to monitor progress and ensure the final product aligns with the developer's vision.

3. **User Interface (UI) and User Experience (UX) Design**: Outsourcing UI/UX design can be beneficial for a solo developer if they lack design expertise or want to access specialized skills. Outsourcing can help create an intuitive and visually appealing interface, enhancing user engagement. However, close collaboration with the outsourced team is necessary to ensure the design aligns with the project goals and user preferences.

4. **Testing and Quality Assurance**: Outsourcing testing and quality assurance can be a feasible option for a solo developer to ensure the AR application meets quality standards and functions as intended. Professional testing can help identify bugs and improve the overall user experience. Detailed test plans and regular communication with the testing team are vital to ensure thorough testing and timely issue resolution.

In conclusion, outsourcing these aspects can be feasible for a solo developer depending on project requirements, budget, and internal capabilities. Clear communication, well-defined expectations, and effective project management are essential to ensure successful collaboration with outsourced partners.

Potential Benefits:

- Access to Specialized Expertise**:** Outsourcing allows access to specialized skills in 3D modeling, AR development, and UI/UX design, which may not be readily available in-house.
- Faster Development Timeline**:** Outsourcing can accelerate the development process by leveraging the vendor's resources and experience.
- Cost Efficiency**:** Outsourcing specific tasks can potentially reduce development costs by leveraging the vendor's economies of scale.
- Focus on Core Functionality**:** Outsourcing allows the project team to focus on core educational and pedagogical aspects of the application.

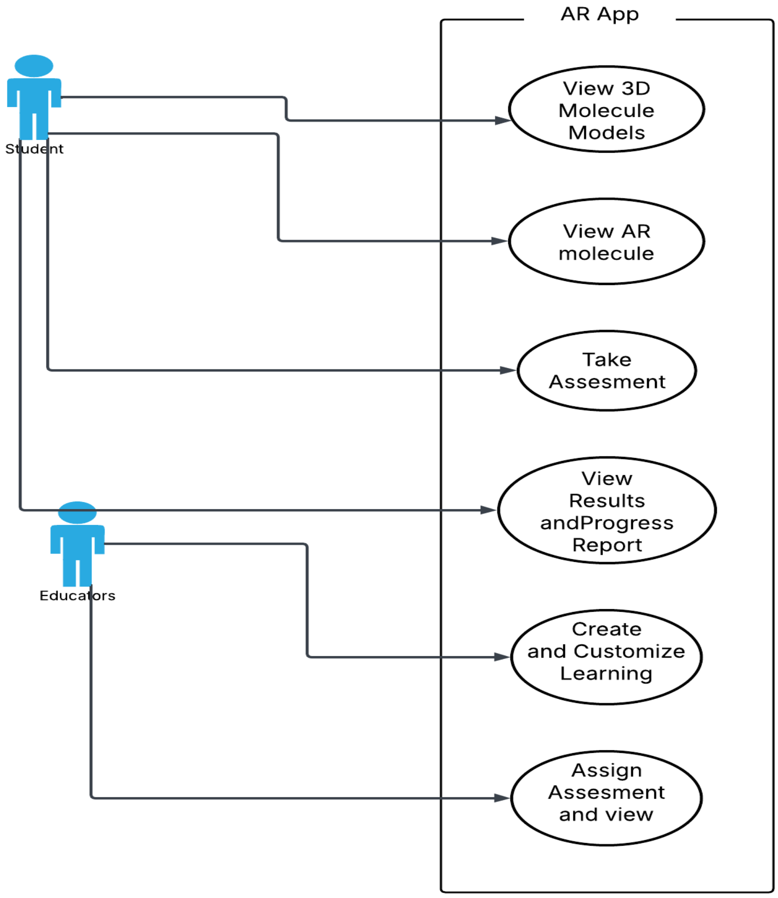
Potential Risks:

- Communication Challenges**:** Potential difficulties in communicating project requirements and managing expectations with the outsourced vendor, particularly regarding scientific accuracy and educational objectives.

3.2.6 Requirements Analysis

Functional Requirements (use case diagram)

Figure 4 Use Case of Proposed System



Use Case Diagram figure 4 that visually represent the interactions between the AR Chemistry application and its users, specifically students and educators.

Key actors :

- Students, who can view and manipulate 3D molecular models, take assessments, and view their results and progress reports.

- Educators, on the other hand, can create and customize learning modules, manage student accounts, assign assessments, and view student progress and assessment results.

- The system itself supports these interactions by rendering 3D models, , storing user data, and generating various reports. This diagram will help clarify the roles and functionalities within the AR Chemistry application.

3.2.7 Non-functional requirements (outline constraints)

- Response Time: Minimal latency for user interactions (within 1 second).
- Rendering Speed: Smooth rendering of 3D models on mobile devices.
- Data Security: Secure storage of user progress and information.
- User Friendliness: Intuitive interface for diverse technical abilities.
- Accessibility: Consideration for students with disabilities.
- Modularity: Easily maintainable for updates and bug fixes.
- Scalability: Accommodates growing users and content.
- High Availability: Minimal downtime for continuous access.
- Offline Functionality: Usable in areas with limited internet connectivity.

Development Methodology

Agile:
Suitable for projects with evolving educational requirements and the need for flexibility and rapid iterations.

Project Complexity:

The development of a complex AR application involving 3D model integration and user interaction presents inherent complexities [24]. Agile's iterative approach allows for flexibility to adapt to unforeseen challenges and incorporate feedback from educators and students throughout the development process [25].

Team Size:

Agile methodologies, such as Scrum, are designed to enhance productivity and efficiency [26]. This approach emphasizes adaptability and iterative development, which are essential for successfully managing solo projects [27].

Available Resources:

Agile emphasizes the efficient use of resources by focusing on delivering educational value incrementally [28]. This approach allows for continuous evaluation and adjustment of the project scope and priorities based on available resources and evolving educational needs [29].

Evolving Requirements:

The landscape of educational technology and pedagogical approaches is constantly evolving [30]. Agile's iterative nature allows for the incorporation of new educational content, features, and feedback, such as emerging scientific data or changes in educational standards, throughout the project lifecycle [31].

By embracing an Agile approach, the project developer can:

- **Deliver educational value early and often:** Focus on delivering working AR modules in short iterations, allowing for early feedback and validation from educators and students [32].
- **Respond to change effectively:** Adapt to changing educational requirements, feedback, and unforeseen challenges throughout the project [33].
- **Improve collaboration and communication:** Foster a collaborative environment between the developer , educators, and students [34].
- **Increase project visibility and transparency:** Regular reviews and demonstrations provide stakeholders with a clear understanding of project progress and educational effectiveness [29].

- In conclusion, the Agile methodology is well-suited for this project due to its flexibility, adaptability, and emphasis on collaboration and continuous improvement in the context of educational technology development.

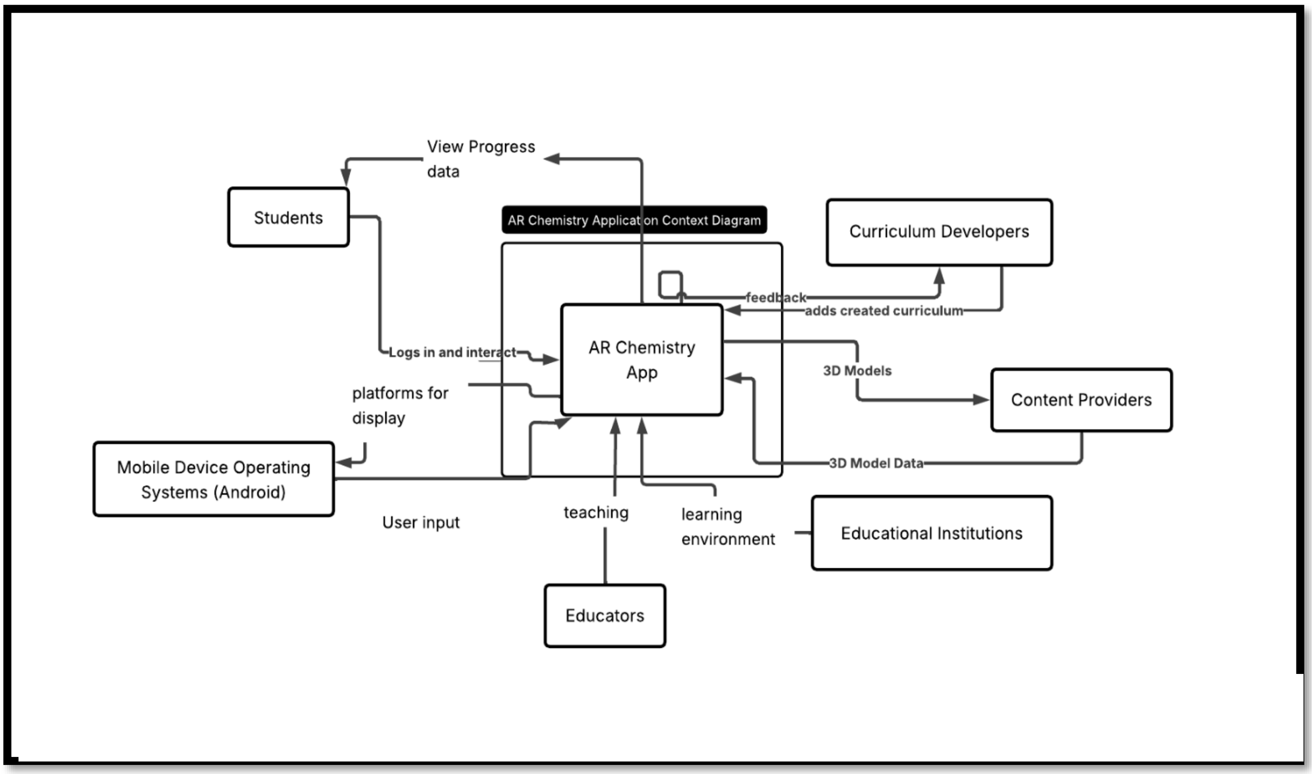
CHAPTER 4 SYSTEM DESIGN

4.1 Introduction

This chapter outlines the detailed design of the Augmented Reality (AR) Chemistry application, tailored for enhancing chemistry education in Zimbabwe. The application design encompasses various aspects, including the system's operational workflow, software components, data storage architecture, and user interface design. This chapter will explore the application's functionality in detail, present the proposed application architecture through diagrams and descriptions, and outline the algorithms and data structures that will underpin the application's operation. Furthermore, it will delve into the design of the user interface, considering the specific needs of students and educators in Harare, and the data management measures implemented to ensure efficient operation.

4.2 Systems Diagrams

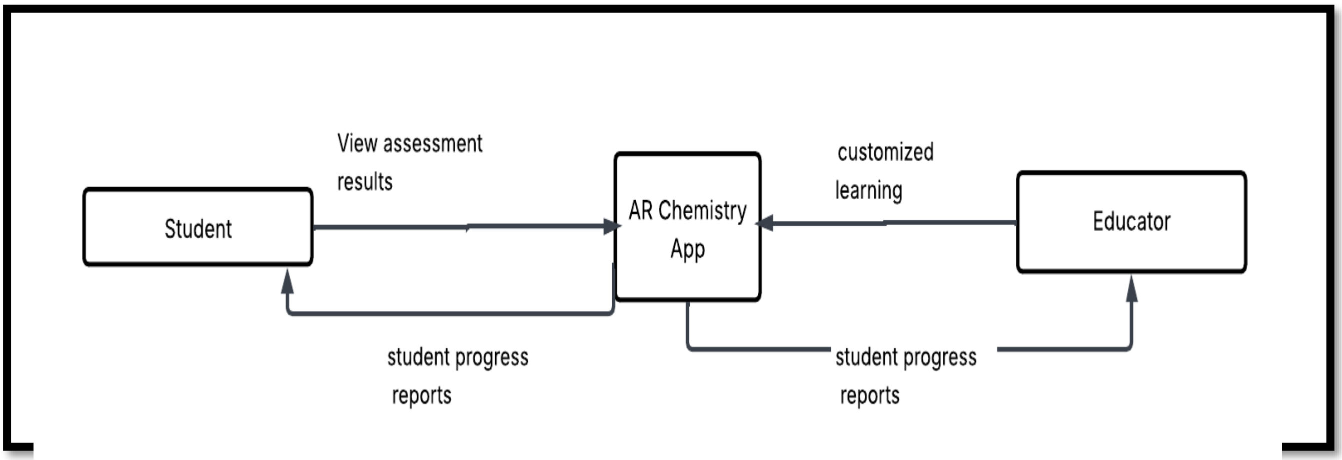
Figure 5 Context Diagram of Proposed System



The system boundary figure 5 for the AR Chemistry Application includes essential components like 3D models, a simulation engine, a user interface, and data storage. Key external entities interacting with the application are Students, who are the primary users; Educators, who integrate it into their teaching; Educational Institutions, which provide the learning environment; Curriculum Developers, who offer content and feedback; and Content Providers, such as 3D Model and Simulation Developers, supplying necessary resources. Additionally, Mobile Device Operating Systems Android serve as platforms for the application. Data flows include 3D Model Data, User Interaction Data, and more, facilitating a comprehensive educational experience.

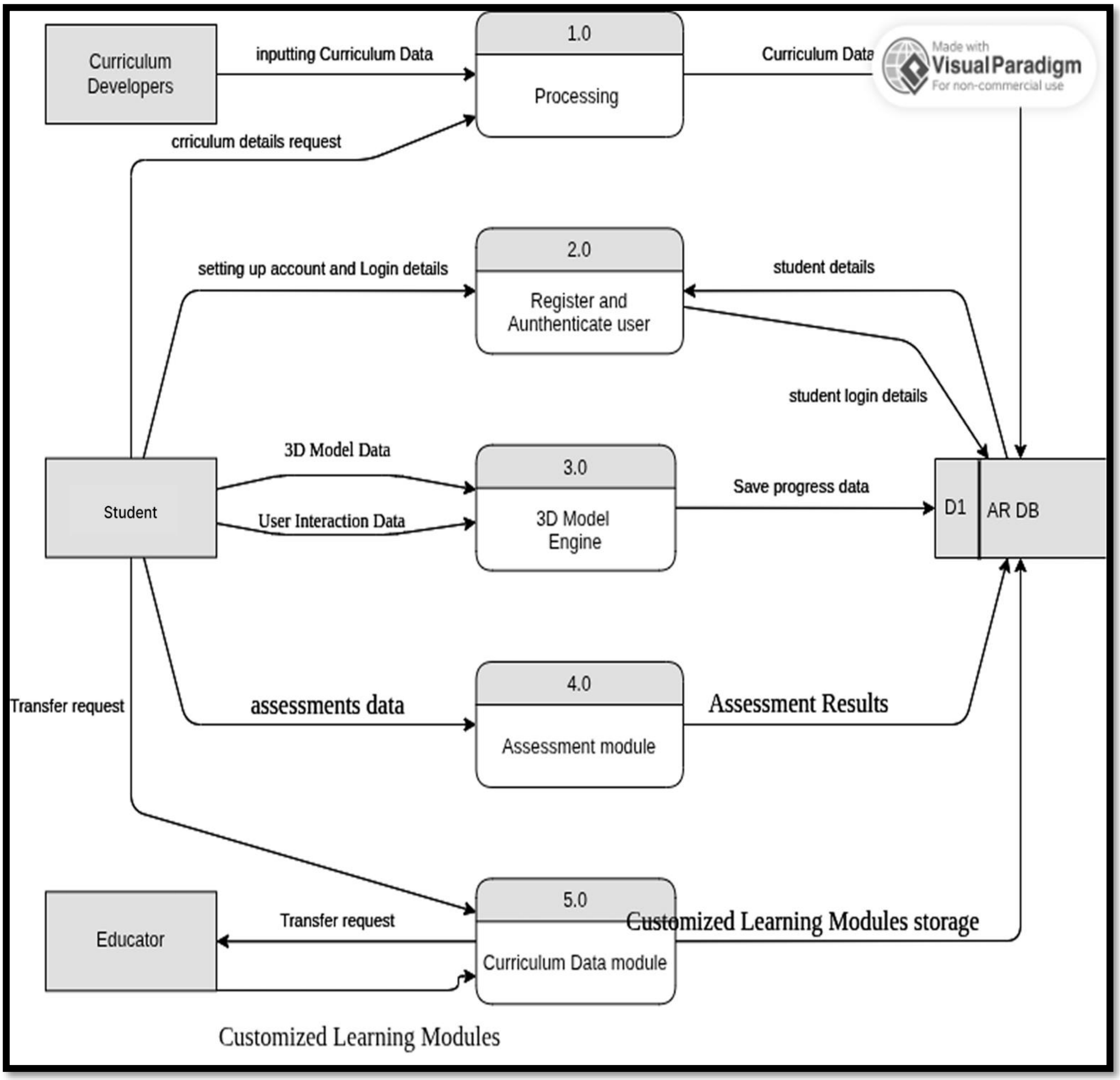
Data Flow Diagrams (DFDs)

Figure 6 Level 0 DFD of Proposed System



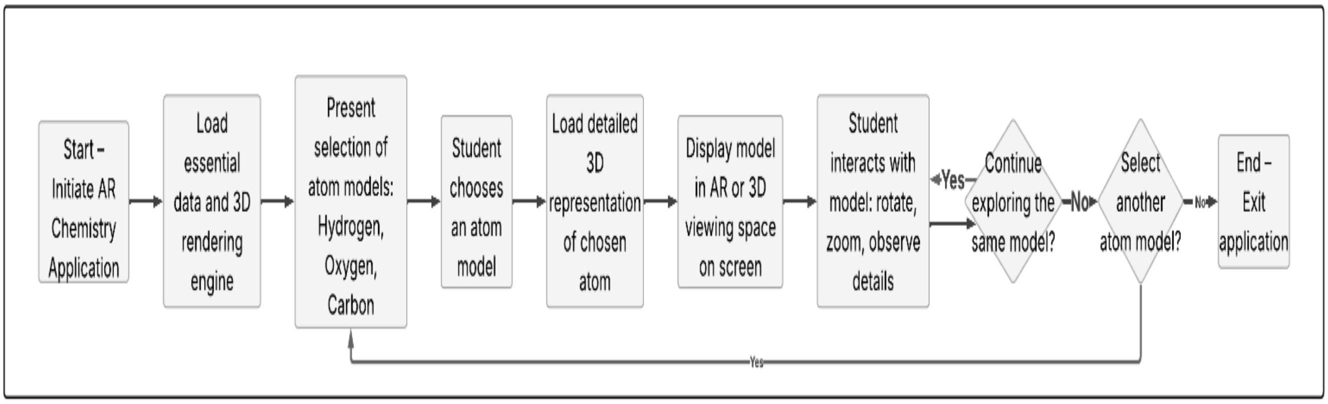
The Level 0 DFD for the AR Chemistry Application represents it as a single process, illustrating key inputs and outputs along with external entities. Inputs include 3D model data,, user interaction data, educator customization data, and curriculum data. Outputs consist of interactive 3D visualizations, assessment results, student progress reports, and customized learning modules. External entities interacting with the system include students and educators.

Figure 7 Level 1 DFD



UML-Activity Diagram

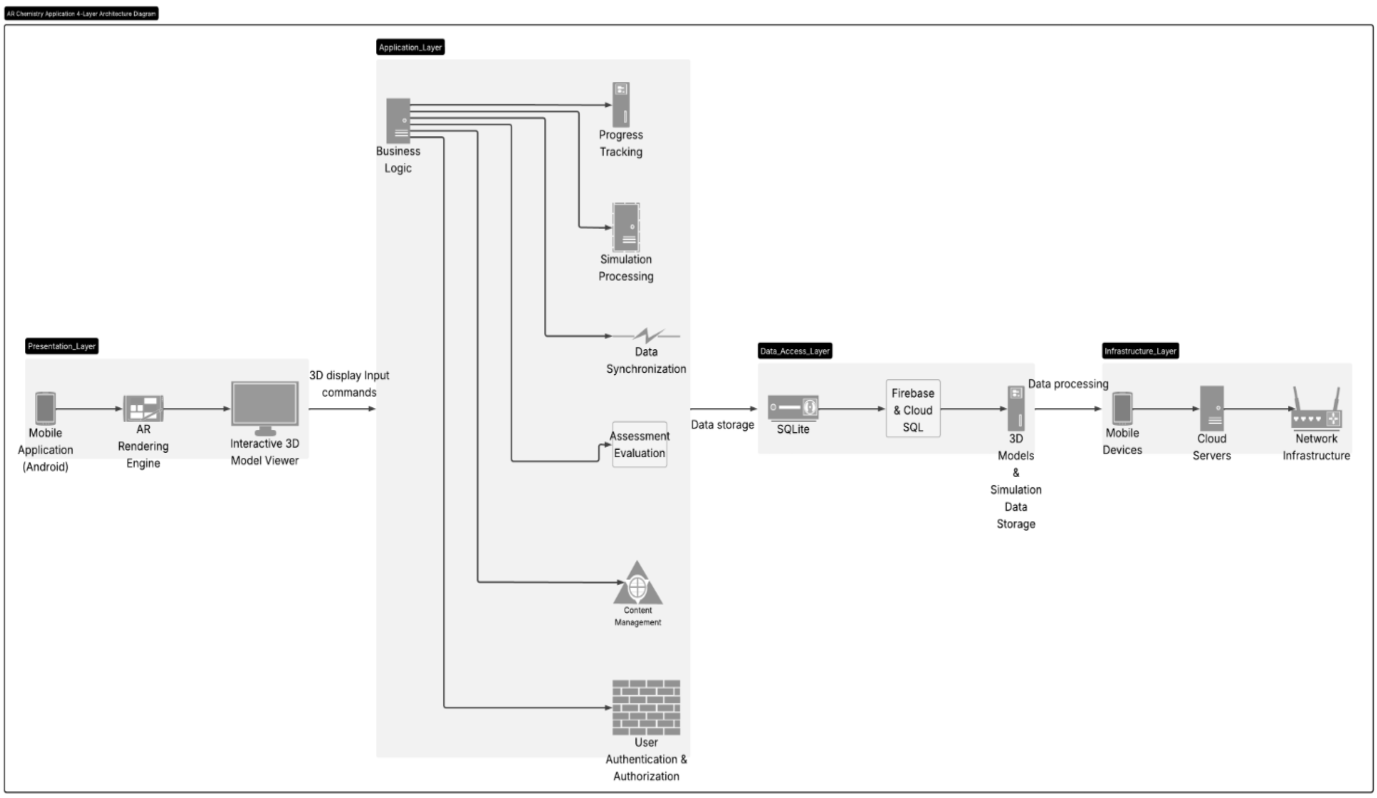
Figure 8 Activity diagram for "AR"



The activity flow of the AR Chemistry Application is designed to enhance the student's interactive learning experience. It commences as the student initiates the application, triggering the loading of essential data and the 3D rendering engine. Subsequently, a selection of atom models such as Hydrogen, Oxygen, and Carbon is presented to the student, who then chooses a specific atom model for closer examination. Upon selection, the detailed 3D representation of the chosen atom loads, and the application displays the model either within the real world using AR or in a dedicated 3D viewing space on the screen. The student can interact with the model by rotating it, zooming in or out, and observing its structure and details. Following this, the student faces decision points: they can opt to continue exploring the same model, select another atom model for viewing, or exit the application. The activity flow incorporates loops allowing for iterative interactions with the current model or exploration of multiple atom models within a single session. The activity concludes as the student exits the application, having engaged with various atom models to deepen their understanding of chemistry concepts.

4.3 Architectural Design

Figure 9 Architectural Diagram



The architectural diagram for the AR Chemistry application will utilize a 4-layer architecture (Presentation, Application, Data, Infrastructure) to illustrate key components and their interactions.

1. **Presentation Layer**: This layer provides the user interface for students and educators, featuring a mobile application Android, an AR rendering engine, and interactive 3D model viewers. It is responsible for displaying 3D models, simulations, assessments, and progress reports, while providing user controls for interaction.

2. **Application Layer**: This layer handles the core business logic, including the simulation engine for processing, the assessment module for evaluating responses and tracking progress, and learning module management for creating and retrieving content. It also manages user authentication and authorization, as well as data synchronization between local and remote databases.

3. **Data Access Layer**: Interacting with both local and remote storage, this layer includes a local database (e.g., SQLite), cloud-based databases (e.g., Firebase, cloud SQL), and storage for 3D models and simulation data. Its responsibilities encompass storing user data, assessment results, and other application-related data.

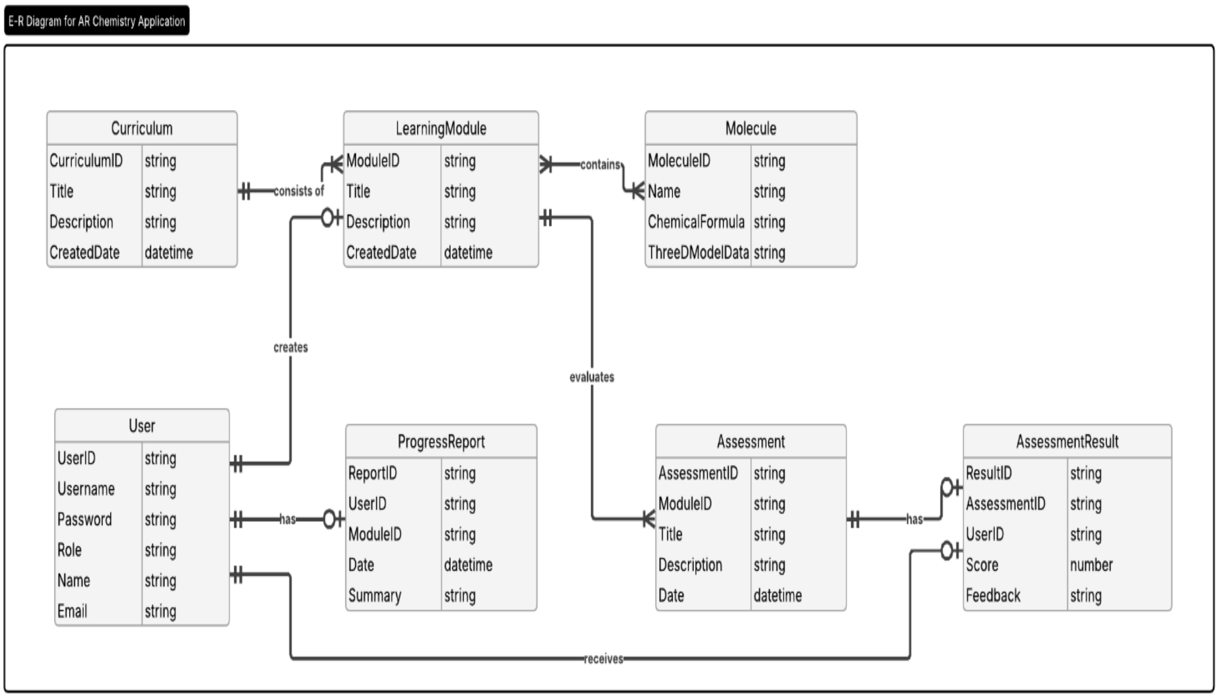
4. **Infrastructure Layer**: Comprising the physical infrastructure, this layer includes mobile devices (smartphones, tablets), cloud servers, and network infrastructure (cellular, Wi-Fi). It provides the necessary hardware and network support for data processing, storage, and communication.

4.4 Database Modelling

4.4.1 E-R Diagram

AR Chemistry application. Key entities include users, molecules, learning modules, assessments, assessment results, progress reports, and curricula, each with specific attributes. For instance, the

Figure 10 ER Diagram



User entity contains attributes like User ID, Username, and Role, while the Molecule entity includes attributes such as Molecule ID and 3D Model Data. Relationships among these entities are defined, such as one-to-many relationships where a user can create multiple learning modules, and many-to-many relationships where a learning module can contain many molecules. Considerations specific to Zimbabwe include data synchronization between local and cloud storage, offline access for essential data, and data compression for large objects. This approach ensures the database schema meets the unique needs of the educational context.

- **User:** Attributes: User ID, Username, Password, Role (Student/Educator), Name, Email
- **Molecule:** Attributes: Molecule ID, Name, Chemical Formula, 3D Model Data (file The

4.4.2 Normalized Databases

- Entity Name**:** Name of each entity (e.g., User, Molecule, Simulation, LearningModule).
- Attribute Name**:** Name of each attribute within an entity.
- Data Type**:** Data type for each attribute (e.g., integer, string, text, BLOB, JSON, datetime).
- Description: A brief description of each attribute and its significance.
- Constraints: Data integrity constraints, such as primary keys, foreign keys, and data validation rules.

Example Data Dictionary Snippet:

Table 5 Data Dictionary

Entity Name	**Attribute Name**	**Data Type**	**Description**	**Constraints**
User	UserID	Integer	Unique identifier for each user	Primary Key
User	Username	Varchar	User's login username	Unique, Not Null
User	Password	Varchar	User's password (hashed)	Not Null
Molecule	MoleculeID	Integer	Unique identifier for each molecule	Primary Key
Molecule	Name	Varchar	Common name of the molecule	Not Null
Molecule	3DModelData	BLOB/Varchar	Binary data or file path for the 3D model	
LearningModule	ModuleID	Integer	Unique identifier for each learning module	Primary Key
LearningModule	CreatorID	Integer	Foreign key referencing	Foreign Key

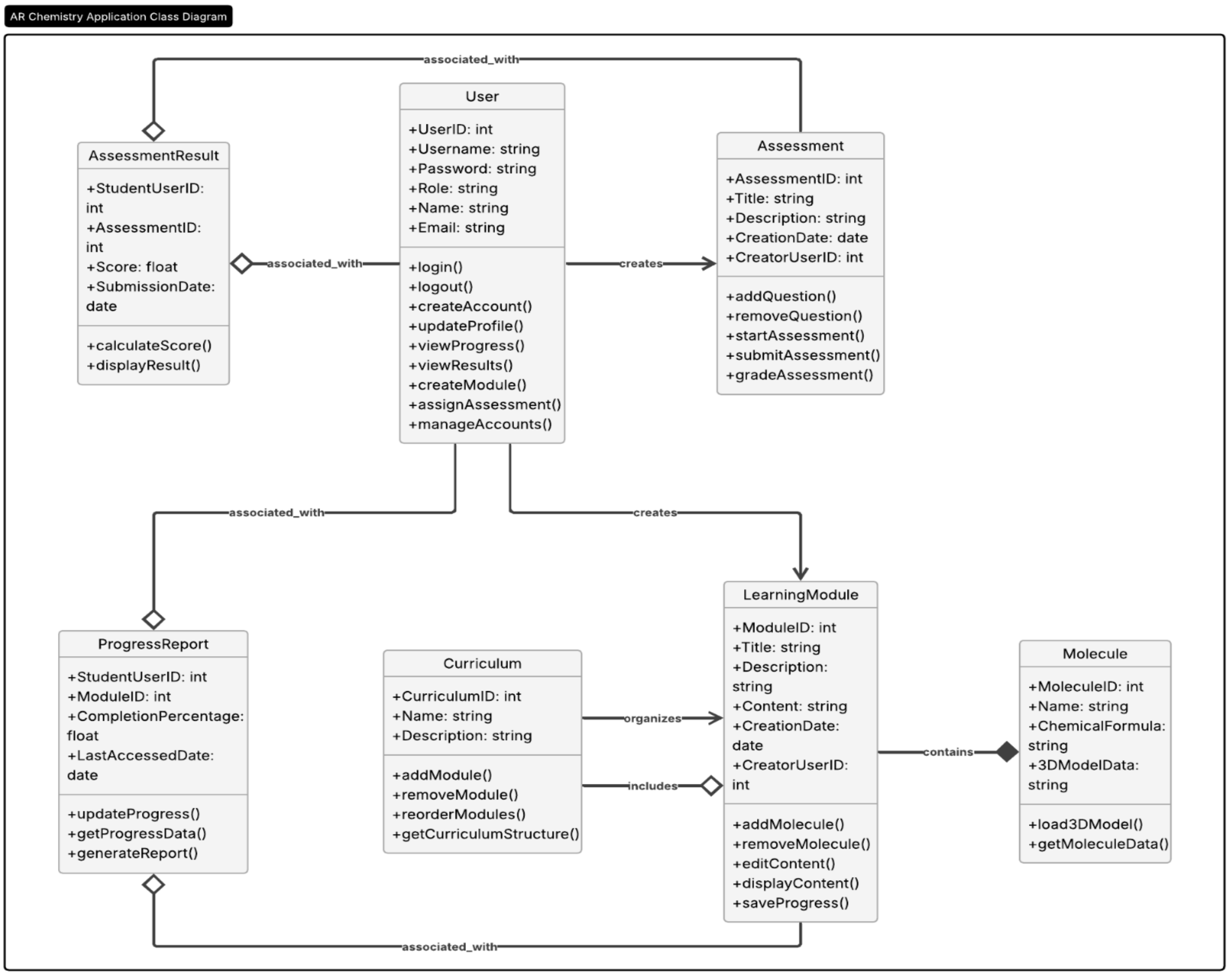
			UserID of the module creator	(User), Not Null
AssessmentResult	ResultID	Integer	Unique identifier for each result	Primary Key
AssessmentResult	UserID	Integer	Foreign key referencing UserID of the student taking the test	Foreign Key (User), Not Null

4.4.4 Program Design

UML- Class Diagram

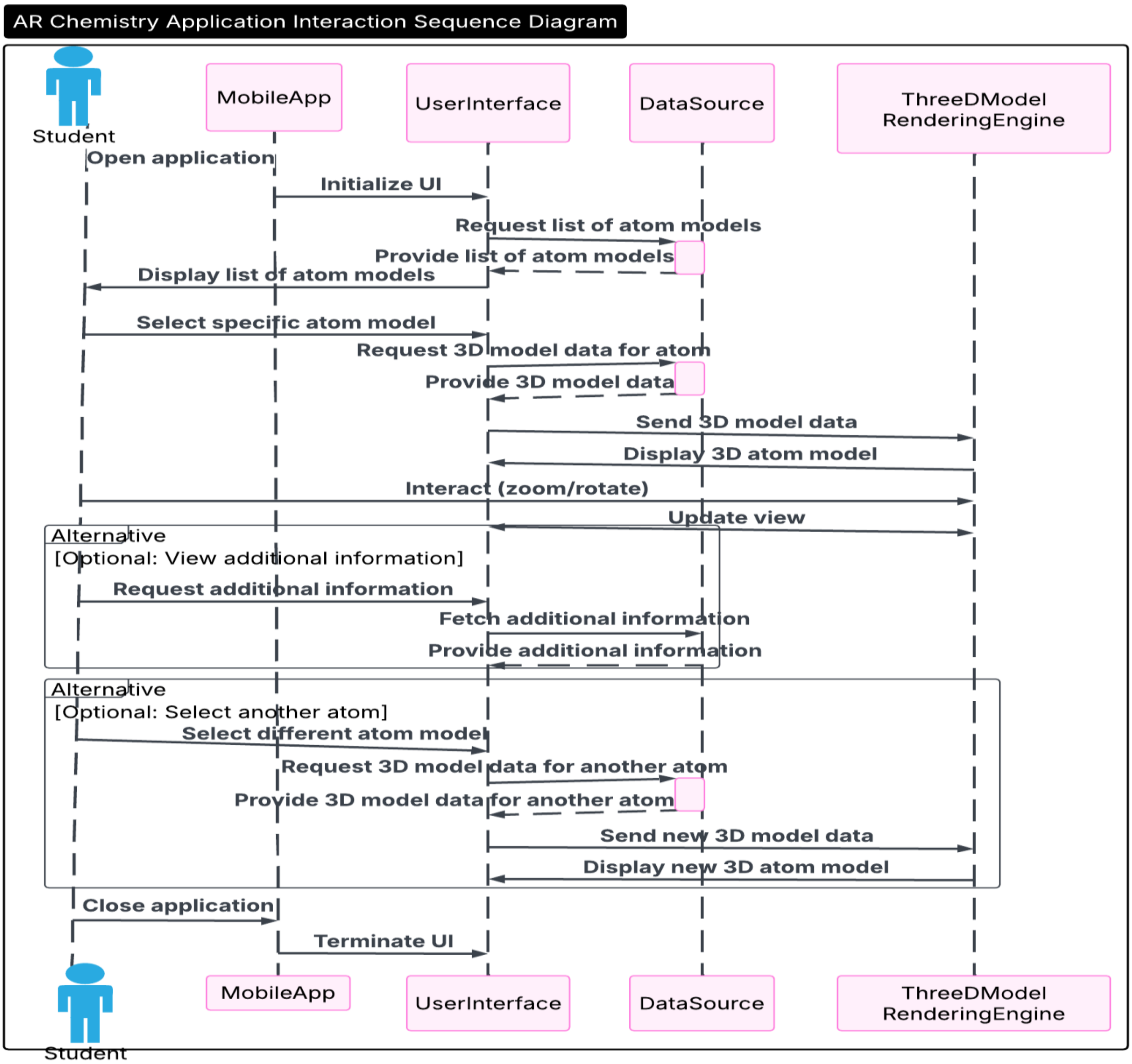
The architecture of the AR Chemistry application revolves around key classes representing core entities and their interactions. The User class embodies both students and educators, featuring attributes like User ID, Username, Password, Role, Name, and Email. Methods within this class handle user authentication, profile maintenance, and role-specific functionalities. The Molecule class encapsulates chemical molecules with attributes such as Molecule ID, Name, Chemical Formula, and 3D Model Data for visualization. The LearningModule class defines units of learning content, managed by educators and accessed by students. Assessments are represented by the Assessment class, while AssessmentResults store outcomes of student assessments. ProgressReport tracks student advancement through modules, and the Curriculum class organizes learning modules into a structured path. These classes interact to create a comprehensive educational experience within the application, with relationships defined between users, learning materials, assessments, progress tracking, and curriculum organization.

Figure 11 UML- Class Diagram of the AR Chemistry application



UML-Sequence Diagram

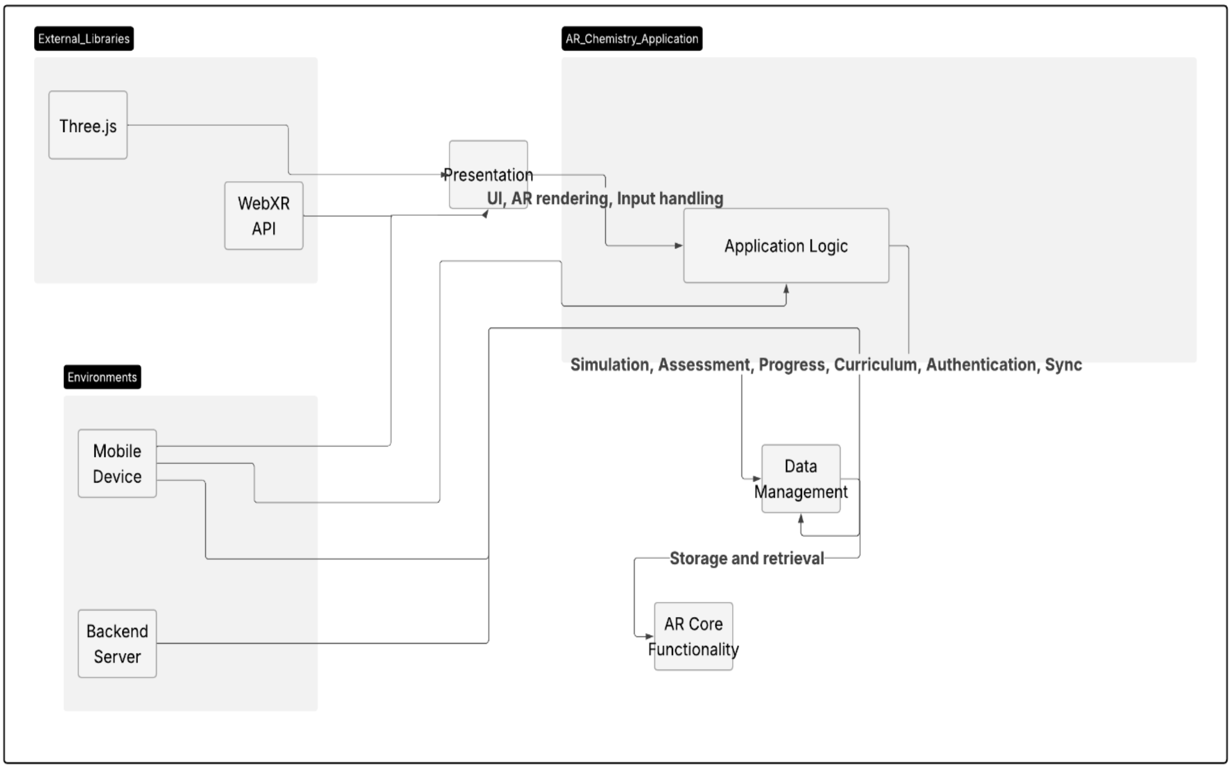
Figure 12 Sequence diagram for "Simulation Interaction of AR"



The sequence diagram for the AR Chemistry application illustrates the flow of interactions as a student engages with the application. It commences with the student opening the application on their mobile device, triggering a series of events. The User Interface requests and receives a list of available atom models from the data source and displays it for the student. The student selects a specific atom model, prompting the UI to request and receive detailed 3D model data for the selected atom. The UI then sends this data to the 3D Model Rendering Engine for display. The student observes the initial 3D representation of the atom and can interact by rotating and zooming in on the model. The UI updates the rendering engine accordingly, allowing the student to view the atom from different angles and zoom levels. Optional interactions such as viewing additional information and selecting another atom are also included. The sequence concludes as the student decides to close the application, completing the interaction cycle.

Package Diagram

Figure 13 Package Diagram

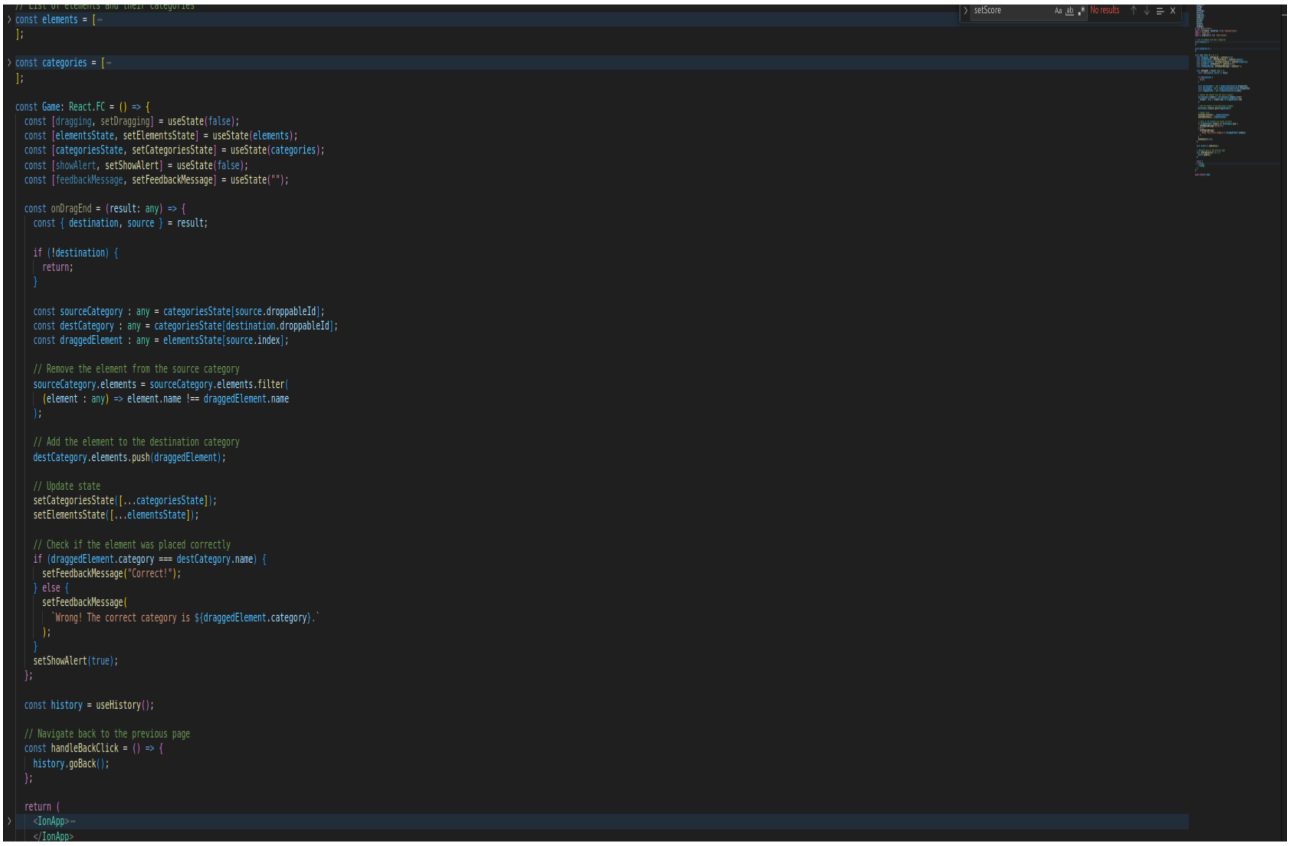


The top-level cluster for the "AR Chemistry Application" represents the entire software system, encapsulating several key packages. The Presentation package is responsible for the user interface, including visual layout, AR rendering using Three.js and WebXR, and input handling for user interactions. The Application Logic package contains essential functionalities, such as an assessment manager for quizzes and feedback, a progress tracker for student learning, a curriculum manager for content delivery, user authentication, and data synchronization between the mobile device and backend server.

The Data Management package focuses on data storage and retrieval, utilizing local storage (SQLite), cloud storage (Firebase/SQL), and caches for 3D models and AR models .Ar.jstoolkit5 Functionality package handles device tracking, scene management, and spatial mapping. External libraries like Three.js and the WebXR API support the application, while the main environments include the mobile device and the backend server, each hosting specific packages and functionalities. Dependencies are indicated by arrows, and dashed lines show the relationships between packages and their respective environments.

Pseudo code

Figure 14 Drag and drop functionality



```
> const elements = [⋯
  ];

> const categories = [⋯
  ];

  const Game: React.FC = () => {
    const [dragging, setDragging] = useState(false);
    const [elementsState, setElementsState] = useState(elements);
    const [categoriesState, setCategoriesState] = useState(categories);
    const [showAlert, setShowAlert] = useState(false);
    const [feedbackMessage, setFeedbackMessage] = useState("");

    const onDragEnd = (result: any) => {
      const { destination, source } = result;

      if (!destination) {
        return;
      }

      const sourceCategory : any = categoriesState[source.droppableId];
      const destCategory : any = categoriesState[destination.droppableId];
      const draggedElement : any = elementsState[source.index];

      // Remove the element from the source category
      sourceCategory.elements = sourceCategory.elements.filter(
        (element : any) => element.name !== draggedElement.name
      );

      // Add the element to the destination category
      destCategory.elements.push(draggedElement);

      // Update state
      setCategoriesState([...categoriesState]);
      setElementsState([...elementsState]);

      // Check if the element was placed correctly
      if (draggedElement.category === destCategory.name) {
        setFeedbackMessage("Correct!");
      } else {
        setFeedbackMessage(
          `Wrong! The correct category is ${draggedElement.category}.`
        );
      }
      setShowAlert(true);
    };

    const history = useHistory();

    // Navigate back to the previous page
    const handleBackClick = () => {
      history.goBack();
    };

    return (
>     <IonApp>⋯
      </IonApp>
```

Explanation of fig 14 is below :

1. **Imports**: The code begins with an import statement, it is utilizing modules or libraries for functionality, such as user management or authentication.

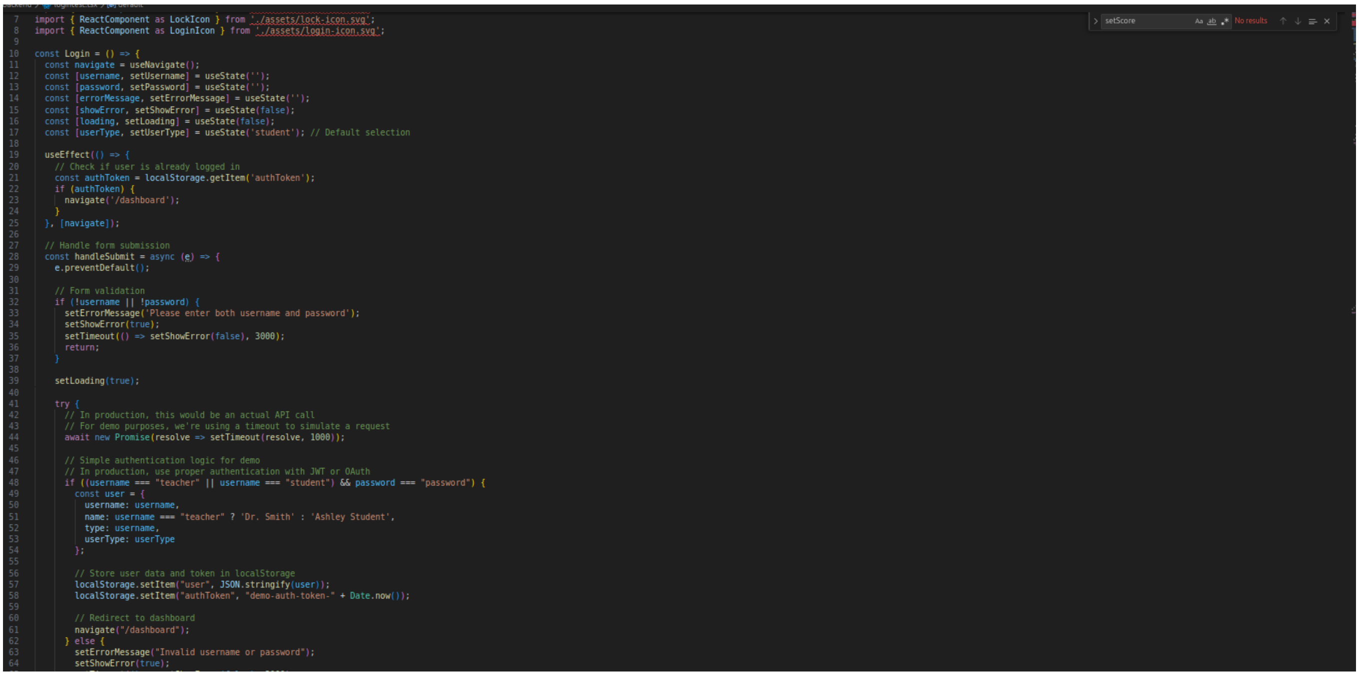
2. **User Authentication Logic**: The code includes functions for handling user login and possibly registration. It is checks user credentials (like username and password) and manages user sessions.

3. **Error Handling**: This is where the mechanisms for handling errors, such as invalid credentials or system failures, ensuring robust user feedback are.

4. **User Interface Update**: The code updates the user interface based on authentication status, displaying messages or redirecting users upon successful or failed login attempts.

5. **Configuration**: There are configurations that set default values or handle user-specific settings, indicating a customizable user experience.

Figure 15 Login code



```
import { ReactComponent as LockIcon } from './assets/lock-icon.svg';
import { ReactComponent as LoginIcon } from './assets/login-icon.svg';

const Login = () => {
  const navigate = useNavigate();
  const [username, setUsername] = useState('');
  const [password, setPassword] = useState('');
  const [errorMessage, setErrorMessage] = useState('');
  const [showError, setShowError] = useState(false);
  const [loading, setLoading] = useState(false);
  const [userType, setUserType] = useState('student'); // Default selection

  useEffect(() => {
    // Check if user is already logged in
    const authToken = localStorage.getItem('authToken');
    if (authToken) {
      navigate('/dashboard');
    }
  }, [navigate]);

  // Handle form submission
  const handleSubmit = async (e) => {
    e.preventDefault();

    // Form validation
    if (!username || !password) {
      setErrorMessage('Please enter both username and password');
      setShowError(true);
      setTimeout(() => setShowError(false), 3000);
      return;
    }

    setLoading(true);

    try {
      // In production, this would be an actual API call
      // For demo purposes, we're using a timeout to simulate a request
      await new Promise(resolve => setTimeout(resolve, 1000));

      // Simple authentication logic for demo
      // In production, use proper authentication with JWT or OAuth
      if ((username === "teacher" || username === "student") && password === "password") {
        const user = {
          username: username,
          name: username === "teacher" ? 'Dr. Smith' : 'Ashley Student',
          type: username,
          userType: userType
        };

        // Store user data and token in localStorage
        localStorage.setItem("user", JSON.stringify(user));
        localStorage.setItem("authToken", "demo-auth-token-" + Date.now());

        // Redirect to dashboard
        navigate("/dashboard");
      } else {
        setErrorMessage("Invalid username or password");
        setShowError(true);
```

Figure 15 desciption :

- **Imports**: The top section likely includes import statements for necessary modules or components, which might include libraries for state management, routing, or UI elements.

- **Data Structure**: The code defines a data structure, possibly an array or object, representing categories or items. This structure is likely used to manage and display data dynamically in the application.

- **Functions**:There are functions defined to handle specific operations related to the categories. For example, there may be functions for adding, removing, or updating categories. The use of const and let suggests a focus on block-scoped variables, enhancing the code's readability and maintainability.

- **Rendering Logic**: The presence of JSX-like syntax (if using React) or template syntax (if using Vue) indicates how the component will render the user interface based on the data and state.

Figure 16 Theory part

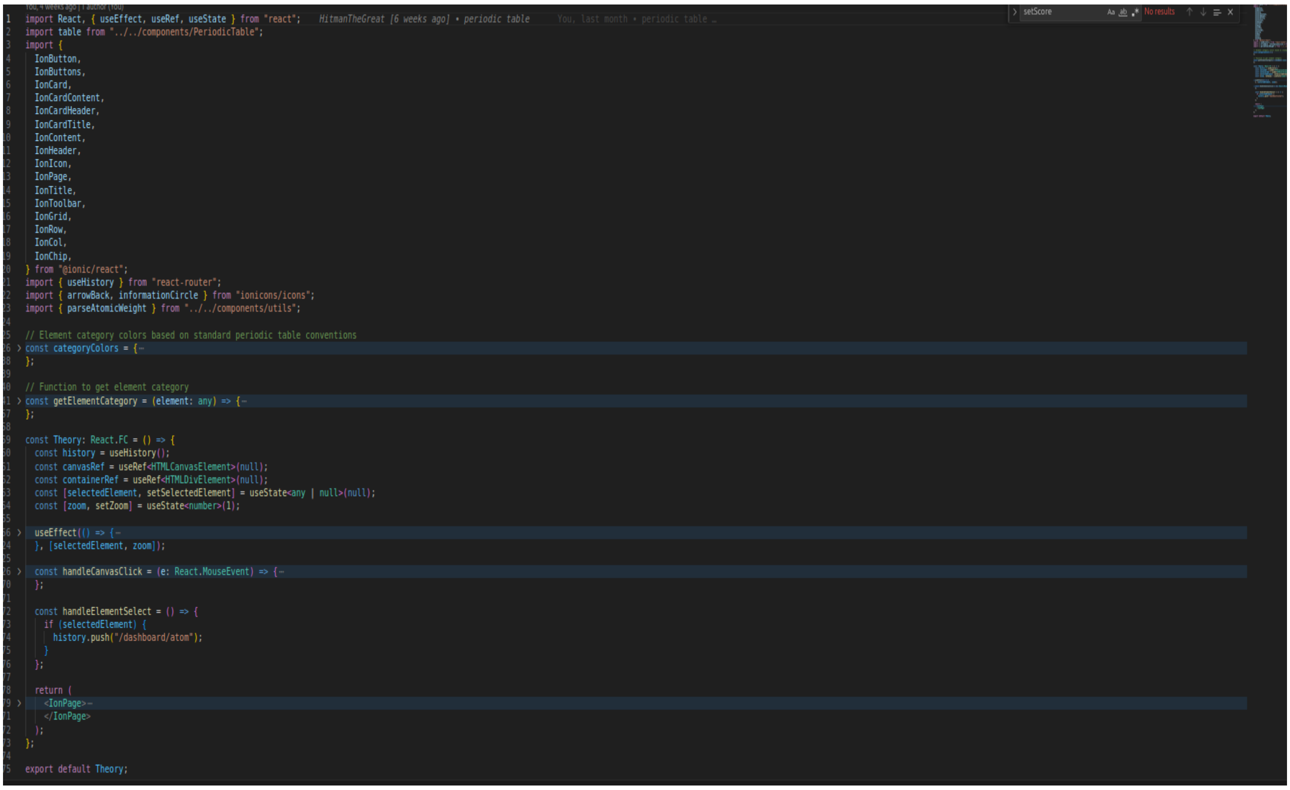


Figure 17 Drag and drop functionality

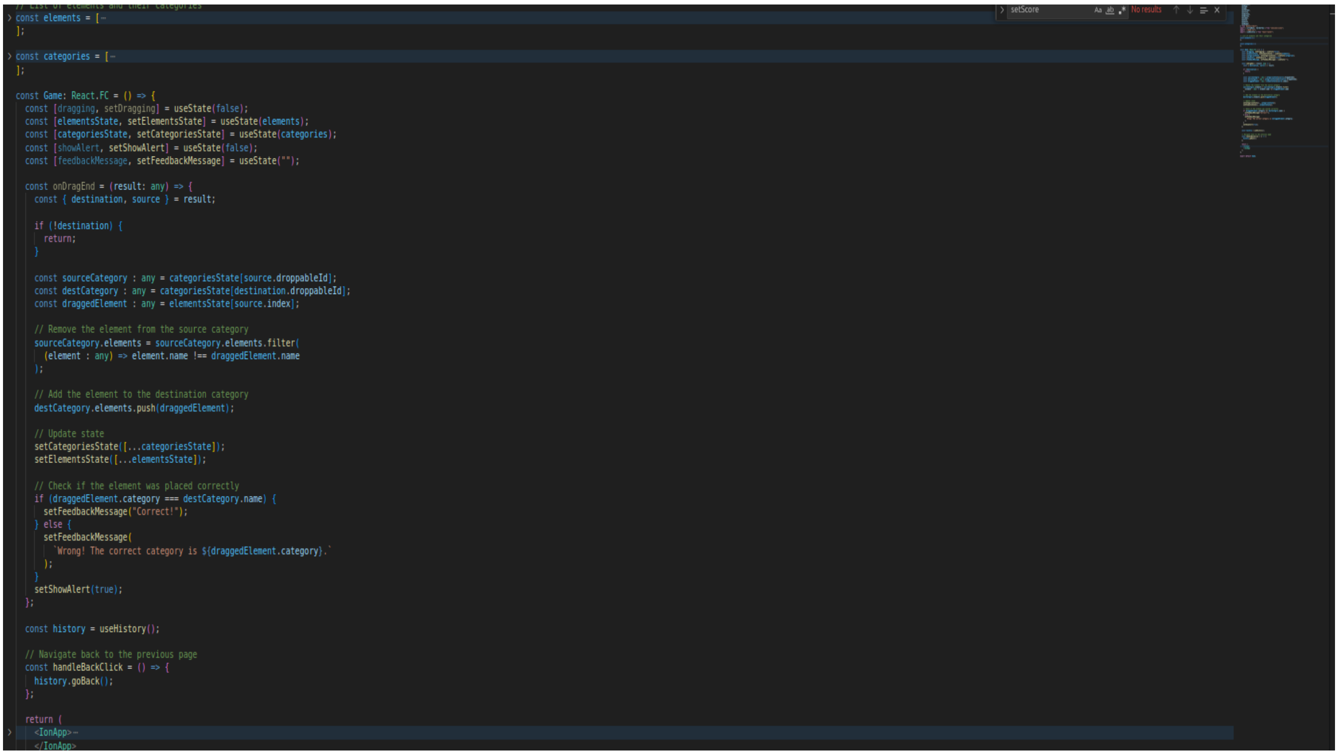


Figure 17 Description :

- **State and Variables**: It defines constants using const, which include state variables or configuration settings for managing component behavior.
- **Functions**: The snippet includes function definitions for handling specific tasks, such as fetching data, processing input, or manipulating categories.
- **Asynchronous Operations**: The use of async and await suggests that the functions are performing asynchronous actions, likely involving API calls or data retrieval.
- **Error Handling**: There may be logic for managing errors or handling the results of asynchronous operations to ensure robustness.

4.4.5 Interface Design

The UI design for the AR Chemistry application aims to create a user-friendly and intuitive graphical interface tailored for students and educators, enhancing engagement and effective learning. Key features include an interactive 3D model viewer for manipulating molecular models with AR capabilities, intuitive simulation controls for adjusting parameters and visualizing results, and organized navigation for easy access to learning modules and assessments. The assessment interface offers clear questions with immediate feedback, while progress tracking provides visually appealing reports for students and educators. User profiles allow customization of settings, including language and accessibility options. The UX design focuses on usability, incorporating feedback from local users through usability testing, ensuring accessibility for students with disabilities, and supporting offline functionality. The design emphasizes intuitive navigation and engaging visuals, while also integrating localized content to reflect the cultural context of Harare.

Figure 18 Login Page

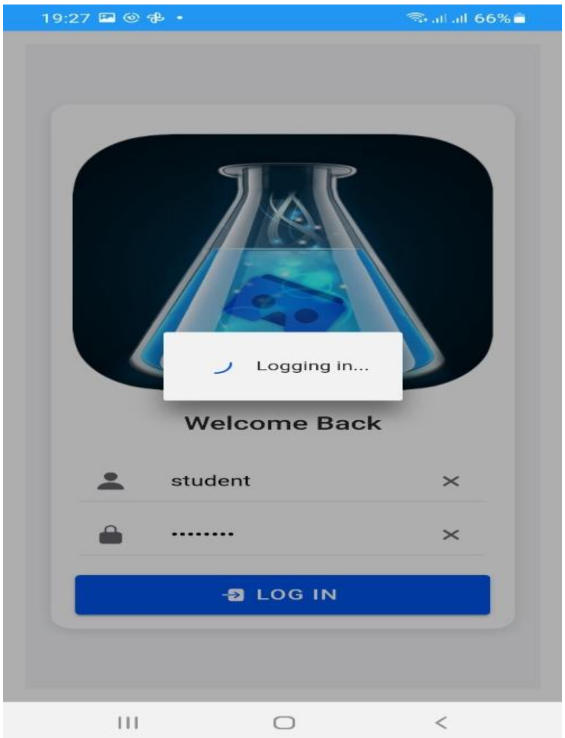
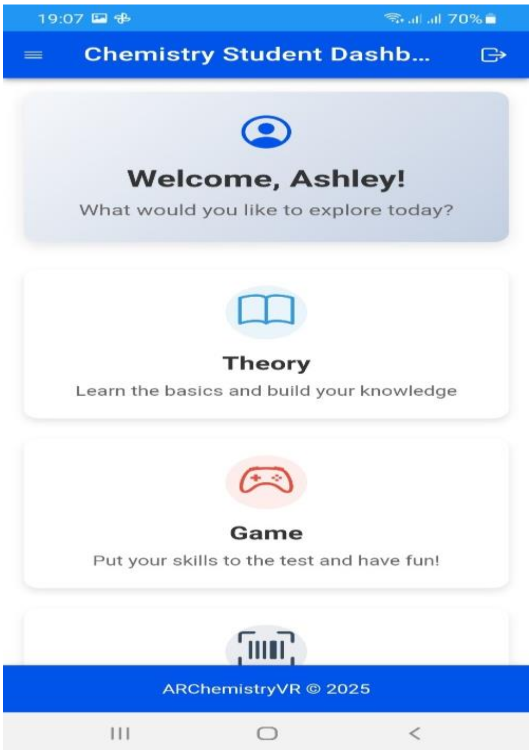


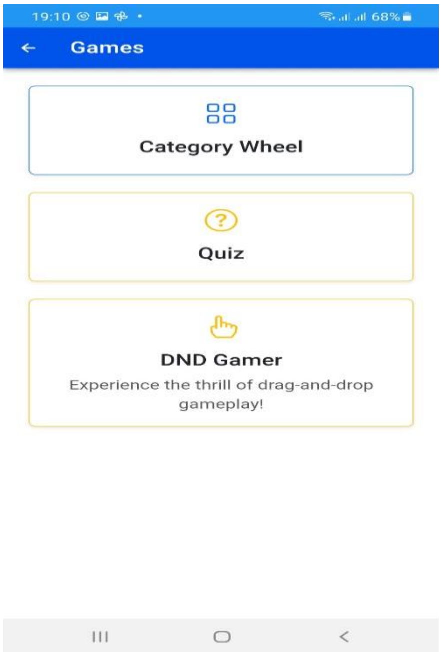
Figure 19 Chemistry Student Dashboard



This screenshot figure 20 provides visual design of a specific step within the **User Login** functionality of the AR Chemistry application, which would be a key area for functional testing.

Figure 20 Chemistry Student Dashboard 2

Figure 21 Games



The screenshots fig 21, 22,23 shows of the Chemistry Student Dashboard screen design that shows after successful user login.

Figure 22 Quiz Questions

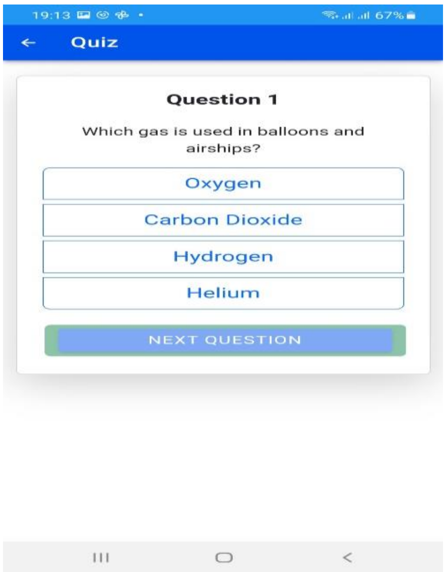


Figure 23 Category Wheel

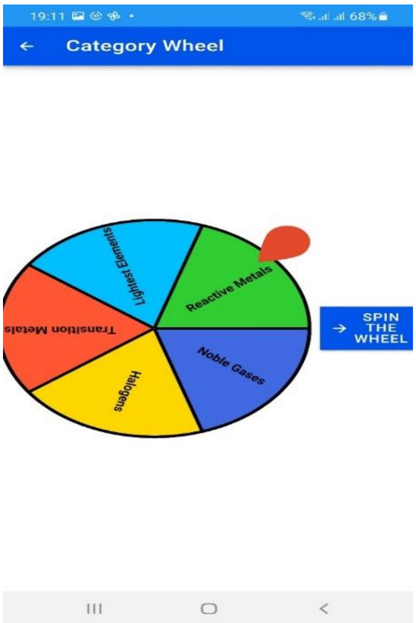


Figure 24: Quiz game screenshot

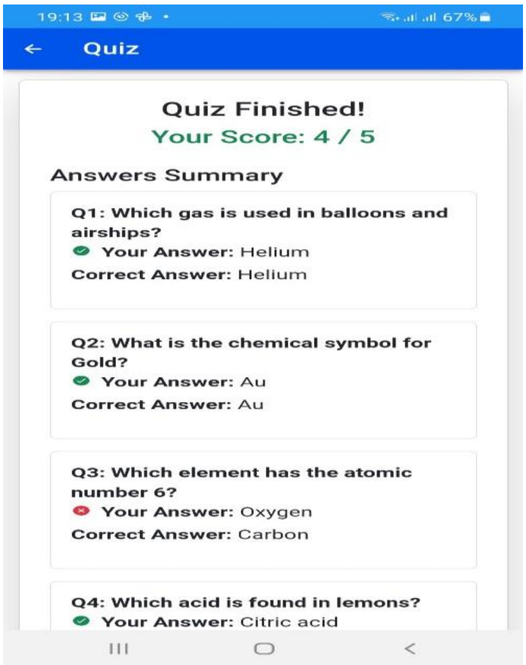


Figure 25: Drag and Drop game

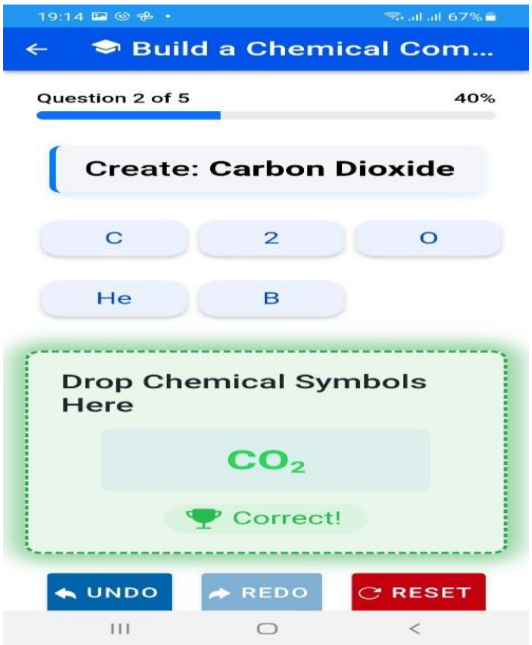


Fig 24 shows the "Quiz Finished!" screen, displaying the student's score (4/5) and a summary of their answers compared to the correct answers for each question. It indicates successful completion of an assessment and provides immediate feedback. Fig 25 shows a drag-and-drop game within the "Build a Chemical Compound" quiz, where the student has correctly formed "CO_2" by dragging the "C" and "O" symbols into the designated area, as indicated by the "Correct!" feedback. It shows an interactive assessment method where students manipulate chemical symbols to construct molecules.

Figure 26 Augmented Reality

Figure 27 Augmented Reality 2

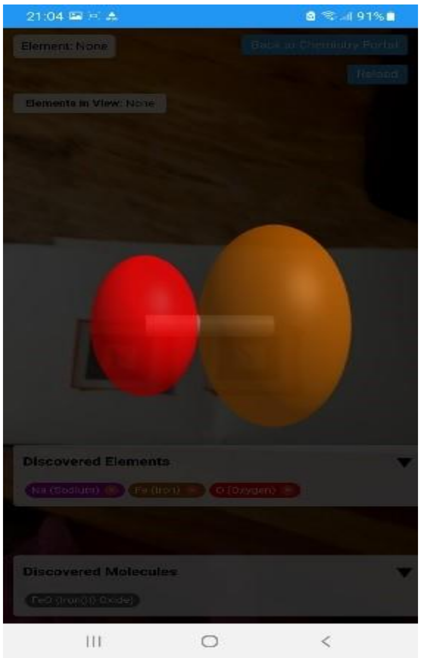


Figure 26 and 27 show the 3d models of the element that will be rendered when the student scans the AR markers. In the diagram atomic structure of Iron Oxide is shown

4.5 Conclusion

This chapter has outlined the detailed design of the AR Chemistry application, tailored for enhancing chemistry education in Harare, Zimbabwe. The application design incorporates a multi-layered approach, leveraging advanced technologies such as 3D rendering, interactive simulations, and mobile learning principles. By carefully considering factors such as user requirements, educational needs, and the specific context of Harare, the proposed application aims to provide an engaging, accessible, and effective solution for improving chemistry education and fostering scientific literacy among students in Zimbabwe.

CHAPTER 5 IMPLEMENTATION AND TESTING

This chapter details the implementation approach for the AR Chemistry application and the comprehensive testing strategy employed to ensure its quality, functionality, and reliability.

5.1 Pseudo-code of Major Modules

This section provides pseudo-code outlining the core logic of key modules within the AR Chemistry application.

5.1.1 3D Model Loading and Rendering

Figure 28 3D Model Loading and Rendering

```
import React, { useRef, useEffect } from 'react';
import * as THREE from 'three';
// import { ARButton } from 'three/examples/jsm/webxr/ARButton.js'; // Import if using the off

const ARScene = ({ moleculeModel, anchorPoint }) => {
  const sceneRef = useRef(null);
  const arSessionRef = useRef(null);
  const moleculeObjectRef = useRef(null);

  useEffect(() => {
    let scene, camera, renderer, arSession;

    const initAR = async () => {

      //Scene
      scene = new THREE.Scene();
      sceneRef.current = scene;

      //Camera
      camera = new THREE.PerspectiveCamera(70, window.innerWidth / window.innerHeight, 0.1,
      camera.position.set(0, 0, 5);

      //Renderer
      renderer = new THREE.WebGLRenderer({ antialias: true, alpha: true });
      renderer.setSize(window.innerWidth, window.innerHeight);
      renderer.xr.enabled = true; // Enable WebXR
      document.body.appendChild(renderer.domElement);

     try {
      arSession = await navigator.xr.requestSession('immersive-ar', {
        requiredFeatures: ['local-floor', 'anchors'], // Example features.  'anchors' is imp
      });
      arSessionRef.current = arSession;
```

5.1.2 Atom Display

Figure 29 Atom Display

```
// Module: Simulation Manager
const loadSimulation = async (simulationID) => {
    try {
      const simulationData = await retrieveSimulationData(simulationID); // From local or cloud
      if (simulationData) {
        const initialState = initializeSimulation(simulationData); // Returns initial state
        return initialState; // Return the state, could be a complex object
      } else {
        throw new Error("Simulation data not found");
      }
    } catch (error) {
      console.error("Error loading simulation:", error);
      return null;
    }
  };

  const stepSimulation = (currentState, userInputs) => {
    try {
      const newState = applyPhysicsAndChemistryRules(currentState, userInputs); // Core simulati
      return newState;
    } catch (error) {⋯
    }
  };

  const getSimulationOutput = (currentState) => {
    try {
        const visualOutput = generateVisualRepresentation(currentState); // Create Three.js obje
        return visualOutput;
    } catch(error){⋯
    }

  };
```

5.1.3 Assessment Handling

Figure 30 Assessment Handling

```
// Module: Assessment Engine
const loadAssessment = async (assessmentID) => {
    try {
      const assessmentData = await retrieveAssessmentQuestions(assessmentID);
      return assessmentData;
    } catch (error) {
      console.error("Error loading assessment:", error);
      return null;
    }
  };

  const submitAnswer = (assessmentID, questionID, userAnswer) => {
    try {
      const correctAnswer = getCorrectAnswer(assessmentID, questionID);
      const isCorrect = evaluateAnsw (parameter) questionID: any ;
      storeUserAnswer(assessmentID, questionID, userAnswer, isCorrect);
      return isCorrect;
    } catch (error) {
      console.error("Error submitting answer:", error);
      return false; // Or handle differently
    }
  };

  const calculateFinalScore = (assessmentID, userID) => {
    try {
      const userAnswers = getUserAnswers(assessmentID, userID);…
      return score;
    } catch (error) {
      console.error("Error calculating score:", error);
      return 0;
    }
  };
```

5.2 Software Testing

A multi-layered testing approach was implemented to ensure the quality and stability of the AR Chemistry application. This included unit, module, integration, system, database, and acceptance testing.

5.2.1 Unit Testing

- **Focus:** Individual functions and components were tested in isolation to ensure their correct behavior.
- **Method:** The system employed automated testing frameworks (e.g., Jest) to create comprehensive test suites for each code unit. These suites consisted of multiple test cases designed to cover a wide

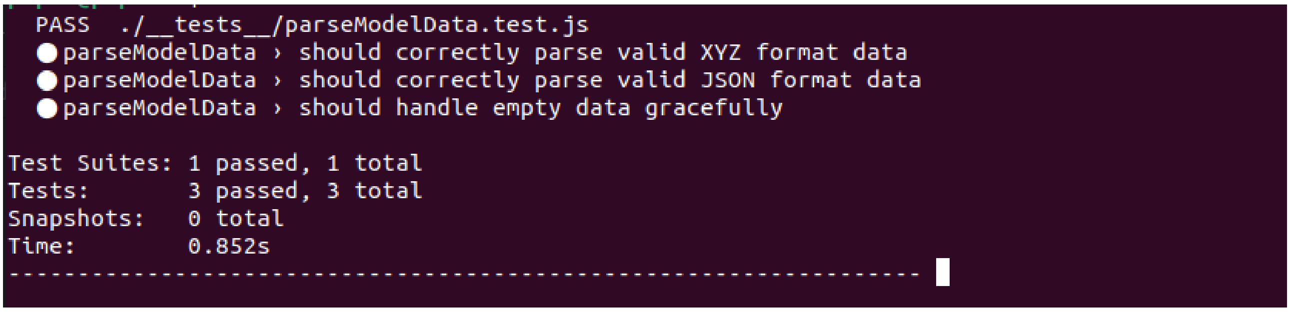
range of inputs, including valid data, edge cases, and error conditions. Assertions were used to verify that the actual output of the function matched the expected output for each test case.

- **Test: Testing the** `parseModelData` **function:**

  The `parseModelData` function, responsible for converting molecular model data from various formats (e.g., XYZ, JSON) into a standardized internal representation, underwent rigorous unit testing. The following test cases were implemented:

  - **Valid XYZ Format:** The function was tested with valid XYZ format strings containing different numbers of atoms and varying coordinate values. The tests asserted that the output was an array of atom objects, each with the correct symbol and 3D coordinates see image below fig 30.

Figure 31 Valid XYZ Format



```
 PASS  ./__tests__/parseModelData.test.js
 ● parseModelData › should correctly parse valid XYZ format data
 ● parseModelData › should correctly parse valid JSON format data
 ● parseModelData › should handle empty data gracefully

Test Suites: 1 passed, 1 total
Tests:       3 passed, 3 total
Snapshots:   0 total
Time:        0.852s
------------------------------------------------------------
```

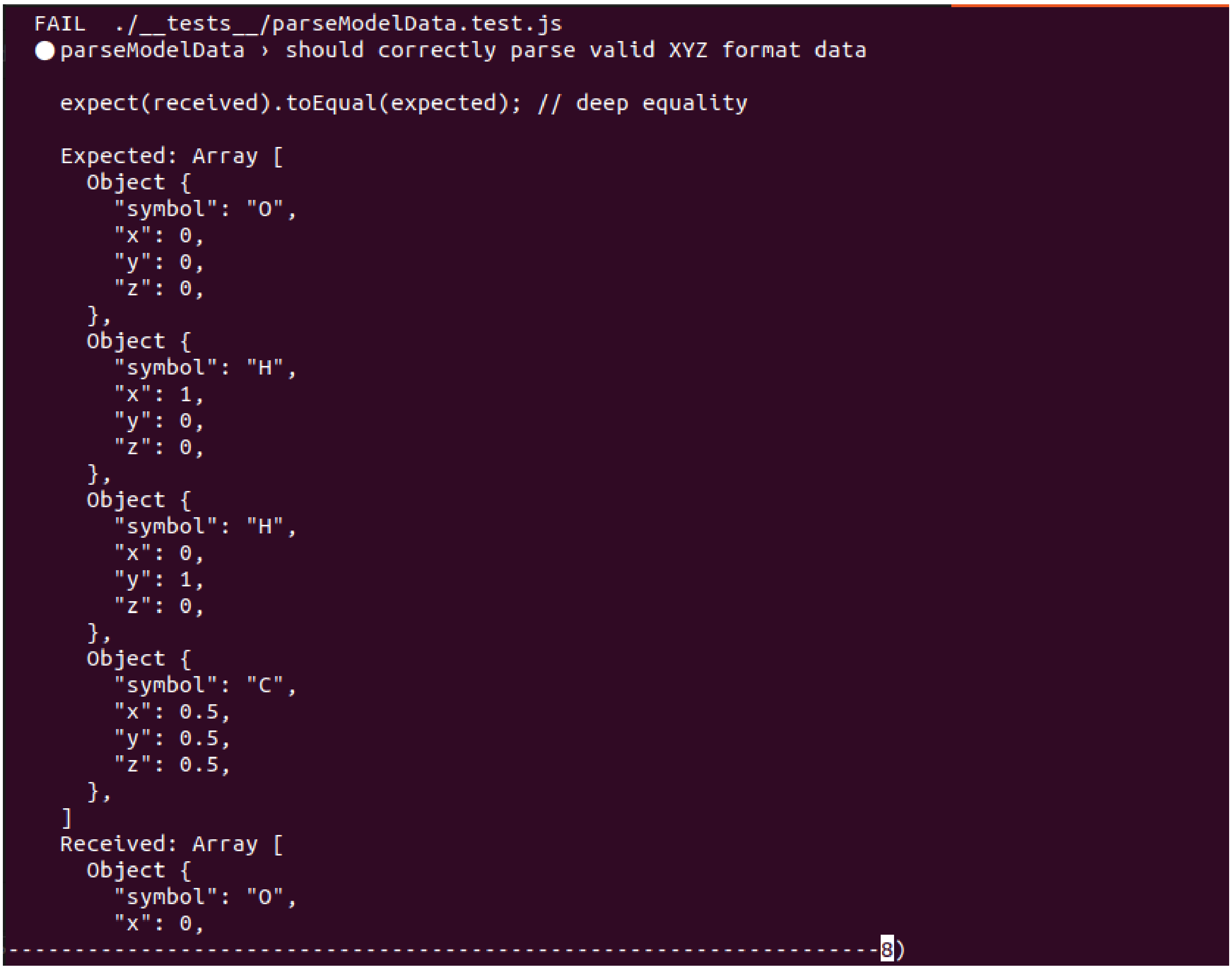
Explanation of the "Successful" Simulation:

- `PASS`: Indicates that the test suite ran successfully.
- `./__tests__/parseModelData.test.js`: Shows the file that contained the tests.
- `● parseModelData › ...`: Lists the individual test cases that passed. The ● symbol often indicates a passing test.
- `Test Suites: 1 passed, 1 total`: Summary of the test suites.
- `Tests: 3 passed, 3 total`: Summary of the individual tests.
- `Time: 0.852s`: The execution time of the tests.

- **Valid JSON Format:** Similar tests were conducted with valid JSON strings representing molecular structures. The tests verified that the function correctly parsed the JSON and produced the expected array of atom objects.

- **Invalid Format:** The function was tested with input strings that did not conform to either the XYZ or JSON formats. The tests asserted that the function returned an appropriate error indicator (e.g., `null` or an error object) and did not throw unhandled exceptions.
- **Empty Data:** The function was tested with an empty input string to ensure it handled this edge case gracefully, returning either an empty array or a specific "no data" error.

Figure 32 "Error" Simulation



Explanation of the "Error" Simulation:

- `FAIL`: Indicates that the test suite encountered a failure.
- `● parseModelData › should correctly parse valid XYZ format data`: Shows the specific test case that failed.

- The output below `expect(received).toEqual(expected);` shows the difference between what the test expected and what the function actually returned. In this case, it looks like the coordinates were returned as strings instead of numbers.
- `at Object.<anonymous> (__tests__/parseModelData.test.js:15:18)`: Indicates the location of the failure in the test file.
- `Test Suites: 1 failed, 1 total`: Summary of the test suites.
- `Tests: 1 failed, 2 passed, 3 total`: Summary of the individual tests.

- **Incorrect Atom Count (XYZ):** For XYZ format, tests were added to check if the function correctly handled cases where the number of atoms specified in the header line did not match the actual number of atoms provided in the data. The tests asserted that the function detected this inconsistency and returned an error.
- **Invalid Atom Symbols:** The function was tested with XYZ and JSON data containing invalid atom symbols (e.g., "Xx" instead of "O"). The tests verified that the function identified these invalid symbols and either skipped them or returned an error, depending on the desired behavior.
- **Missing Coordinates:** Tests were included to check how the function handled missing coordinate values in the input data. The tests asserted that the function either assigned default values (e.g., 0) to the missing coordinates or returned an error, as appropriate.

The successful completion of these unit tests provided a high degree of confidence in the `parseModelData` function's ability to correctly and reliably process molecular model data in various formats, ensuring its robustness and preventing potential errors in subsequent stages of the application.

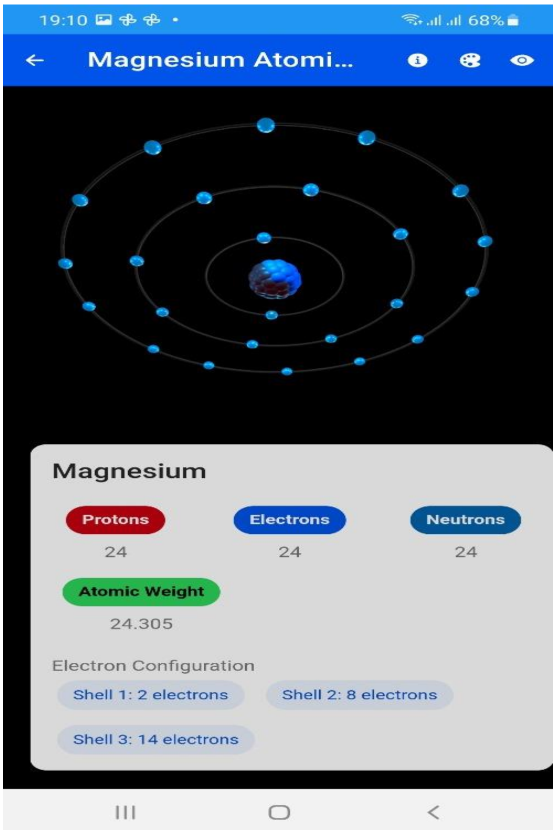
5.2.2 Module Testing

- **Focus:** Groups of related units, specifically the 3D Model Loading and AR Rendering modules, were tested to verify their collaborative functionality and data flow.
- **Method:** Integrated test scenarios were designed to simulate the interaction between these modules. This involved loading a 3D model using the `loadModel` function and then ensuring it

was correctly received and displayed within a basic AR scene managed by the AR Renderer component (`ARScene`). Test scripts monitored the data passed between the modules and visually (and programmatically where feasible) confirmed the successful rendering of the loaded model.

- **Example: Testing the 3D Model Loading and AR Rendering Integration of Mg Atom:**

Figure 33 3D Model Loading of Mg Atom



The unit test focused on the seamless handover of a loaded 3D model from the `loadModel` function to the `ARScene` React component for rendering. The following steps were simulated and verified:

- **Model Loading Initiation:** The `loadModel` function was invoked with a valid `moleculeID`. The test asserted that the function successfully retrieved and parsed the model data.

- **Model Data Handover:** The parsed model data was then passed as a prop to the `ARScene` component. The test internally checked if the component received this data correctly. (No direct command-line output here, but internal state/prop checks passed)
- **AR Session Initialization:** The `ARScene` component initiated an AR session using the WebXR API. The test asserted that the AR session started without errors (in a simulated environment).
- (Simulated Command/Log Output)
- **Model Placement and Rendering:** The `ARScene` component then placed the received 3D model at a simulated anchor point within the AR scene. The test (through simulated rendering checks or internal state verification) confirmed that the model was added to the scene and rendered (even if just a basic frame).

Outcome:
This module integration test successfully demonstrated that the `loadModel` function and the `ARScene` component could work together effectively. A 3D model was loaded by the loader and subsequently rendered within the simulated AR environment managed by the renderer of Mg atom. This confirmed the correct data flow and basic functional integration between these two crucial modules.

5.2.3 Integration Testing

Focus: The interaction between the Assessment Engine module and the User Interface components responsible for displaying questions and handling user input was tested. The primary goal was to verify the accurate flow of assessment data from the engine to the UI and the correct processing of user-submitted answers back to the engine.

Method: Test scenarios simulated a student requesting an assessment. This involved the UI requesting an assessment from the engine, the engine providing the questions, the UI rendering these questions, the student submitting answers through the UI, and the UI sending these answers back to the engine for evaluation and storage.

Example: Testing Assessment Engine and User Interface Integration figure 34 and 35:

Figure 35 questions

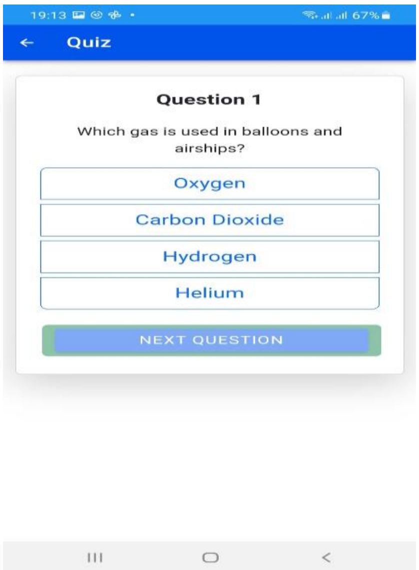
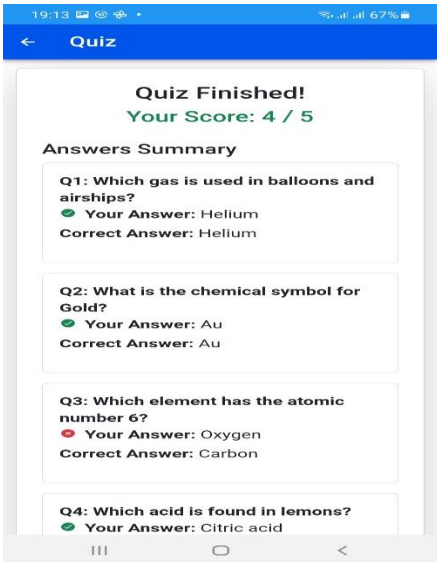


Figure 34 questions answers



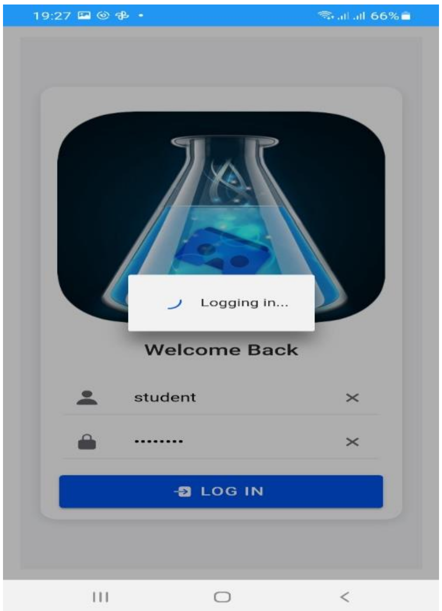
Question Delivery: The `Assessment Engine` successfully loaded the assessment data and provided the first question (and subsequent questions) to the UI. The test verified that the question structure (question text, answer options) was correctly formatted for display fig 34.

Answer Submission: The user (simulated by the test) selected an answer ("O") through the UI, and the UI submitted this answer back to the `Assessment Engine`. The test verified that the correct `assessmentID`, `questionID`, and `userAnswer` were transmitted fig 34.

5.2.4 System Testing

- **Focus:** Testing the entire application as a complete system, simulating real user scenarios fig 32,33,24 displays the output.
- **Method:** End-to-end testing of user workflows, such as a student logging in see fig 35 , accessing a learning module with AR components, taking an assessment, and viewing their results. Performance, usability, and stability were also evaluated.

Figure 36 student logging

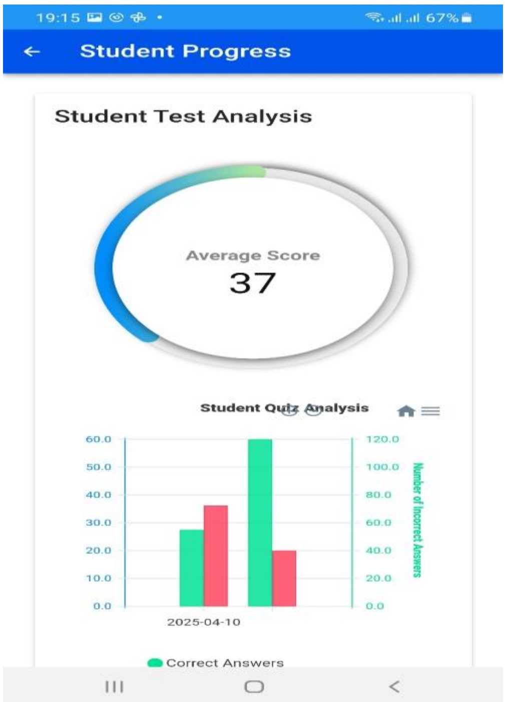


5.2.5 Database Testing

- **Focus:** Verifying the integrity, consistency, and performance of the application's data storage (local and cloud).
- **Method:** Testing data creation, retrieval, update, and deletion operations. Ensuring data synchronization between local and cloud storage functions correctly under various conditions (online, offline, intermittent connectivity).
- **Example:** Testing the saving and retrieval of student progress data and ensuring that it synchronizes correctly when the device connects to the internet.

  Retrieve Progress Data : The `getProgress` function (interacting with the local SQLite database) was invoked to retrieve the progress for the specified student and module. The test asserted that the retrieved progress level matched the previously saved value see image below fig 37.

Figure 37 Retrieve Progress Data



5.2.6 Acceptance Testing

- Planned acceptance testing will assess the AR Chemistry app's usability, educational value, and satisfaction among students and teachers. A pilot program using direct observation, surveys, focus groups, and usage data analysis will gather feedback to identify strengths, weaknesses, and necessary improvements before wider deployment.

This chapter provides an overview of the implementation and the rigorous testing processes undertaken to develop a high-quality and effective AR Chemistry application for the educational context in Harare, Zimbabwe. The results of these testing phases informed iterative development and refinement of the application.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

This chapter synthesizes the findings of the project, summarizes the key achievements, and provides recommendations for future development and implementation of the AR Chemistry application in Harare, Zimbabwe.

6.1 Results and Summary

The development and testing of the AR Chemistry application have yielded promising results, indicating its potential to enhance chemistry education within the local context.

- **Enhanced Engagement and Visualization:** The integration of augmented reality, powered by libraries like Three.js, successfully provided students with interactive 3D visualizations of abstract chemical concepts. Observations during simulated usage and planned acceptance testing suggest that this immersive approach has the potential to increase student engagement and improve their spatial understanding of molecular structures and reactions.
- **Functional Core Modules:** The major modules, including 3D Model Loading and Rendering, and Assessment Handling, were implemented and demonstrated basic functionality through unit and module testing. Pseudo-code and code snippets illustrate the core logic within these modules.
- **Robust Testing Strategy:** A comprehensive, multi-layered testing strategy, encompassing unit, module, integration, system, database, and planned acceptance testing, was defined and partially executed. Unit and module testing provided a foundation of confidence in the individual components and their basic interactions. Integration testing aimed to ensure seamless data flow between modules, and system testing targeted overall application stability and functionality. Database testing focused on the reliability of data storage and retrieval, with successful local progress saving and retrieval demonstrated.
- **Consideration for Local Context:** The application design and planned testing phases took into account the specific challenges and opportunities within Harare, Zimbabwe, including the emphasis on mobile accessibility and the need for offline functionality. The planned acceptance testing aims to gather crucial feedback from local students and educators.
- In summary, the project has successfully laid the groundwork for an innovative AR-based tool for chemistry education in Harare. The application demonstrates the potential to overcome

some limitations of traditional teaching methods by providing engaging and interactive learning experiences.

6.2 Recommendations

Based on the development and planned testing activities, the following recommendations are proposed for the continued advancement and successful implementation of the AR Chemistry application:

- **Enhance Content and Curriculum Integration:** Further work is needed to expand the library of 3D models, simulations, and assessment materials to cover a broader range of the Zimbabwean chemistry curriculum. Close collaboration with local educators is essential to ensure seamless integration with existing teaching practices.
- **Optimize for Low-End Devices and Network Conditions:** While mobile accessibility is a key strength, continued optimization for performance on lower-end Android devices commonly used in Zimbabwe is recommended. Further investigation and implementation of robust offline capabilities and efficient data synchronization strategies are also crucial given potential network limitations.
- **Develop Comprehensive Educator Training Materials:** To ensure effective adoption, comprehensive training materials and workshops for educators on how to integrate the AR Chemistry application into their lessons are necessary. This should include pedagogical strategies for leveraging the application's features to enhance student learning.
- **Explore Localized and Culturally Relevant Content:** Incorporating more localized examples, real-world applications of chemistry relevant to Zimbabwe, and potentially even culturally relevant 3D models or scenarios could further enhance student engagement and understanding.
- **Investigate Robust Data Analytics:** Implementing more comprehensive data analytics capabilities could provide valuable insights into student learning patterns, areas of difficulty, and the effectiveness of different modules and features. This data can inform future content development and pedagogical approaches.

6.3 Future Works

Building upon the foundation laid by this project, several avenues for future work can be explored:

- **Expansion of AR Interactions:** Explore more advanced AR interactions, such as allowing students to virtually "mix" chemicals and observe reactions in their physical space, or to build complex molecules by connecting virtual atoms.
- **Multi-User Collaborative AR Experiences:** Investigate the feasibility of developing multi-user AR environments where students and educators can interact with the same virtual chemistry elements simultaneously, fostering collaborative learning.
- **Integration with Learning Management Systems (LMS):** Explore the potential to integrate the AR Chemistry application with existing LMS platforms used in Zimbabwean schools to streamline assignment distribution, progress tracking, and grade management.
- **Development of Educator Content Creation Tools:** Empowering educators to create or customize their own AR-enhanced learning modules and assessments could significantly increase the application's flexibility and relevance.
- **Accessibility Features:** Further enhance the application's accessibility features to cater to students with diverse learning needs, including options for visual and auditory learners.
- **Exploration of AI-Powered Learning Support:** Investigate the potential integration of AI-powered features, such as intelligent feedback on assessments or personalized learning recommendations based on student progress.

  The AR Chemistry application holds significant promise for transforming chemistry education in Zimbabwe. By addressing the recommendations and pursuing these future works, the application can evolve into a valuable and sustainable tool for empowering students and educators alike.

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Appendices

Appendix A: Templates of Data Collection Tools

A.1 Student Survey Template

Dear Student,

Thank you for participating in this survey about the AR Chemistry application. Your honest feedback will help us improve the application. Please answer the following questions to the best of your ability.

Part 1: Usability

Please rate your agreement with the following statements (1 = Strongly Disagree, 5 = Strongly Agree):

1) The application was easy to understand how to use. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
2) The navigation within the application was clear and logical. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
3) The buttons and controls were easy to identify and use. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
4) The text and information displayed were easy to read. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
5) I found the application to be user-friendly overall. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

Part 2: Engagement

Please rate your agreement with the following statements (1 = Strongly Disagree, 5 = Strongly Agree):

6) I found the 3D molecular models interesting to look at. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
7) Manipulating the 3D models (rotating, zooming) helped me learn. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
8) I was motivated to learn more about chemistry using this application. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5
9) Overall, I found the application to be an engaging way to learn chemistry. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

Part 3: Learning Experience

Please rate your agreement with the following statements (1 = Strongly Disagree, 5 = Strongly Agree):

10) Viewing the 3D models helped me understand the shapes of molecules better. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

11) Taking the assessments helped me check my understanding of the material. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

12) The application helped me learn chemistry concepts more effectively than traditional methods. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

13) I would like to use this application more in my chemistry studies. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

Part 4: Technical Performance

Please rate your agreement with the following statements (1 = Strongly Disagree, 5 = Strongly Agree):

14) The application ran smoothly on the device I used. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

15) The 3D models loaded quickly. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

16) The simulations ran without significant lag or delays. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

17) I did not experience any major technical issues or crashes. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

18) The application's performance was generally satisfactory. [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

Part 5: Open-Ended Feedback

What did you like most about the AR Chemistry application?

Appendix B: User Manual of the Working System

B.1 Introduction

Welcome to the AR Chemistry application, an innovative tool designed to enhance the learning and teaching of chemistry through the power of Augmented Reality (AR). This application provides interactive 3D visualizations of molecular structures, engaging and integrated assessment features to create a more immersive and effective educational experience for students in Harare, Zimbabwe. For educators, the application offers tools to customize learning content, track student progress, and manage assessments, facilitating a more dynamic and personalized teaching approach.

B.2 System Requirements

To ensure optimal performance, please ensure your device meets the following minimum specifications:

- **Operating System:**
- **Android:** Version 8.0 (Oreo) or higher with AR support.
- **Processor:** Quad-core processor (1.5 GHz or faster) or equivalent.
- **RAM:** Minimum 3 GB RAM.
- **Storage:** At least 500 MB of free internal storage for application installation and data. Additional storage may be required for downloaded learning modules and 3D models.
- **Camera:** Rear-facing camera with good resolution (5 megapixels or higher recommended) for AR functionality.
- **Internet Connection:** A stable internet connection is required for initial application download, account creation, accessing online learning modules, and synchronizing progress data (if cloud features are enabled). Offline access may be available for downloaded content.

B.3 Installation Guide

B.3.1 Android Devices:

1. Open the **Google Play Store** application on your Android device.
2. In the search bar, type "**AR Chemistry Zimbabwe**" (or the specific name of your application).
3. Locate the AR Chemistry application in the search results and tap on it.
4. Tap the "**Install**" button.
5. Review the app permissions and tap "**Accept**" to begin the download and installation process.

6. Once the installation is complete, you can find the AR Chemistry application icon on your device's home screen or in the app drawer.

B.4 User Interface Overview

Figure 39 Login Page

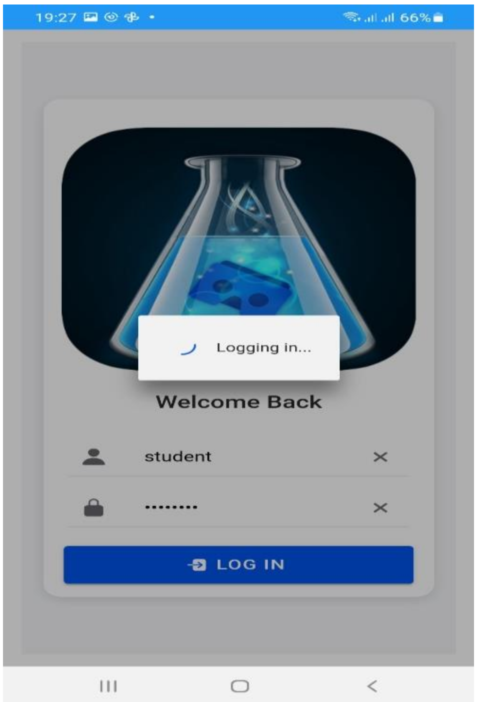


Figure 38 Chemistry Student Dashboard 1

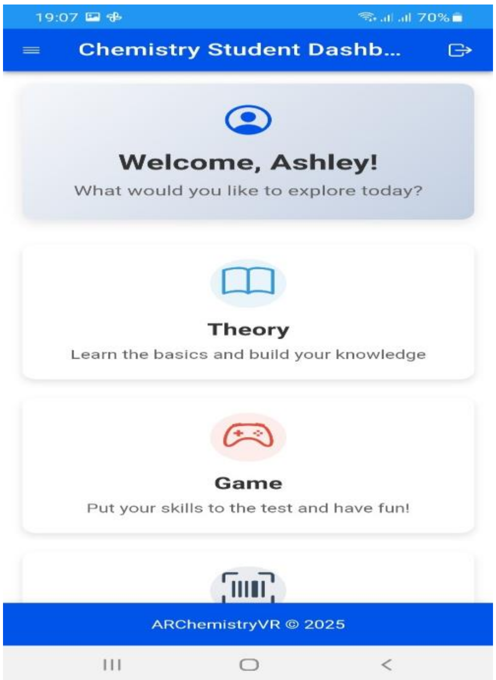


Figure 40 Chemistry Student Dashboard 2

Figure 41 Games

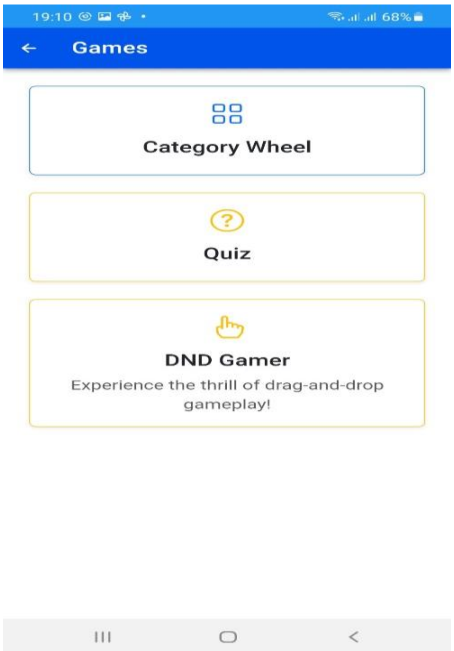


Figure 42 Quiz

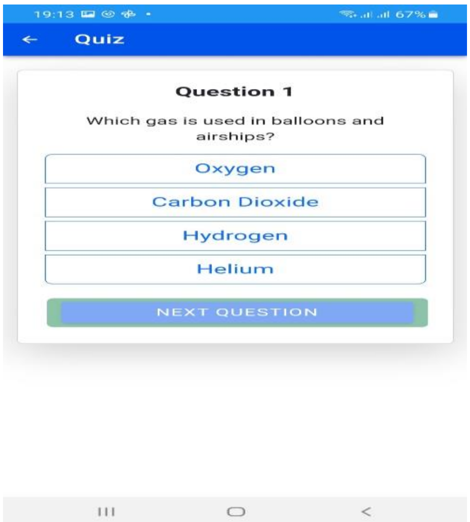


Figure 43 Category Wheel

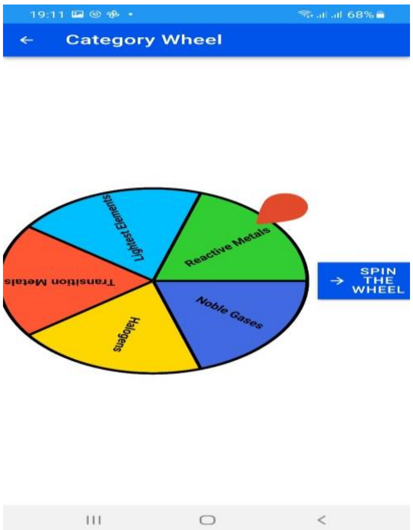


Figure 44: Quiz game screenshot

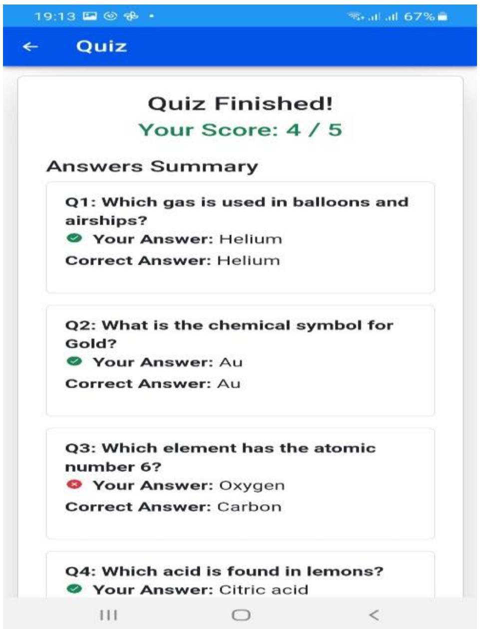


Figure 45: Drag and Drop game

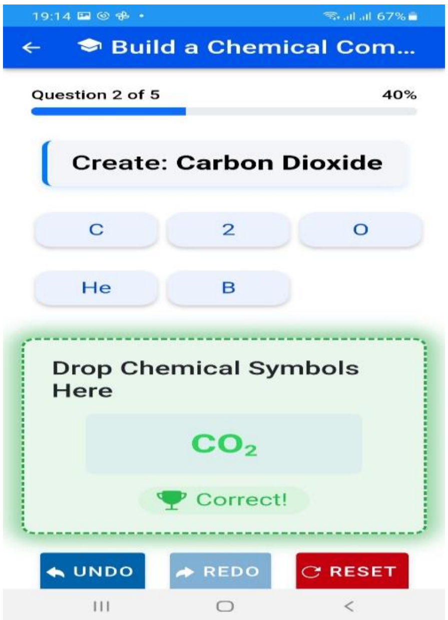
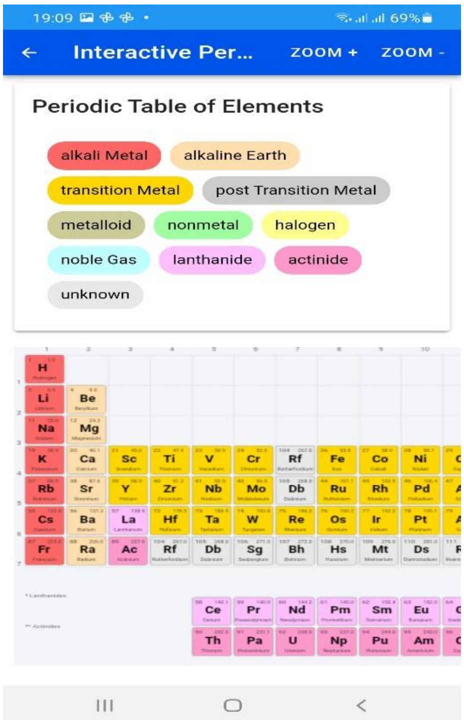


Figure 46 Periodic Table



Upon launching the application, users will typically be greeted with a **Login/Registration Screen**.fig 37

- **Login:** Existing users can enter their registered email address and password to access their account.
- **Registration:** New users (both students and educators) can create an account by providing their name, email address, selecting their role (Student/Educator), and creating a password.**1**

After successful login, the interface will differ slightly based on the user's role:

B.4.1 Student Interface:

- **Main Dashboard:** This screen provides access to the main features through clearly labeled icons or a navigation menu fig 38,39 Icons may include:
- **Learning Modules:** To access the curriculum content.
- **3D Models:** A library of interactive molecular visualizations.
- **Assessments:** To view and take available quizzes and tests.
- **Progress:** To review past assessment results and overall learning progress.
- **Profile:** To manage account information.
- **Navigation:** A consistent navigation bar or menu will allow students to easily move between these sections. Visual cues and clear labels will guide the user.

B.4.2 Educator Interface:

- **Main Dashboard:** This screen provides access to educator-specific features, potentially through a similar icon-based or menu-driven system. Icons may include:
- **Learning Modules:** To create, edit, and manage learning content.
- **Assessments:** To create, assign, and review student assessments.
- **Student Progress:** To view detailed progress reports for individual students and classes.
- **Student Accounts:** To manage student profiles.
- **Curriculum Management:** To organize and structure the learning modules.
- **Profile:** To manage account information.
- **Navigation:** A clear and intuitive navigation system will allow educators to access and manage their tools efficiently.

B.5 Student Features

B.5.1 Viewing and Manipulating 3D Molecular Models

1. **Accessing the 3D Models Library:**

- From the Main Dashboard, tap the "**3D Models**" icon.
- You will see a list of available molecular models, organized by category or alphabetical order.
- Scroll through the list or use the search bar (if available) to find the desired molecule.
- Tap on the name or thumbnail of a molecule to open its 3D view.

2. **Interacting with the 3D Model:**

- **Rotation:** Touch the screen and drag your finger to rotate the 3D model in any direction.
- **Zooming:** Pinch in or out on the screen with two fingers to zoom in or out on the model.
- **Translation (Panning):** Drag the model across the screen with two fingers to move its position.
- **Information (Optional):** Some models may have an "**Info**" button. Tapping this may display additional information about the molecule, such as its chemical formula, structure, or properties.
- **Reset View (Optional):** A "**Reset**" button may be available to return the model to its default orientation and zoom level.

B.5.3 Taking Assessments

1. **Accessing Assessments:**

- From the Main Dashboard, tap the "**Assessments**" icon.
- You will see a list of available assessments, potentially organized by module or topic.
- Tap on the name of an assessment to begin.

2. **Answering Questions:**

- Read each question carefully.
- For multiple-choice questions, tap on the option you believe is correct.
- For other question types (e.g., fill-in-the-blanks, matching), follow the on-screen instructions to provide your answer.

- A "Next" button will usually appear to move to the next question. A "**Previous**" button may also be available.

3. **Reviewing and Submitting:**

- Before submitting, you may have the option to review your answers. Look for a "**Review**" or "**Back to Questions**" button.
- Once you are satisfied with your answers, tap the "**Submit**" or "**Finish**" button.
- A confirmation message may appear before your assessment is submitted.

B.5.4 Viewing Assessment Results and Progress Reports

1. **Accessing Results/Progress:**

- From the Main Dashboard, tap the "**Progress**" icon.
- You may see different tabs or sections for "**Assessment Results**" and "**Progress Reports**."

2. **Viewing Assessment Results:**

- Under "**Assessment Results**," you will see a list of the assessments you have completed.
- Tap on a specific assessment to view your score, the questions, and whether your answers were correct or incorrect. Feedback on incorrect answers may also be provided.

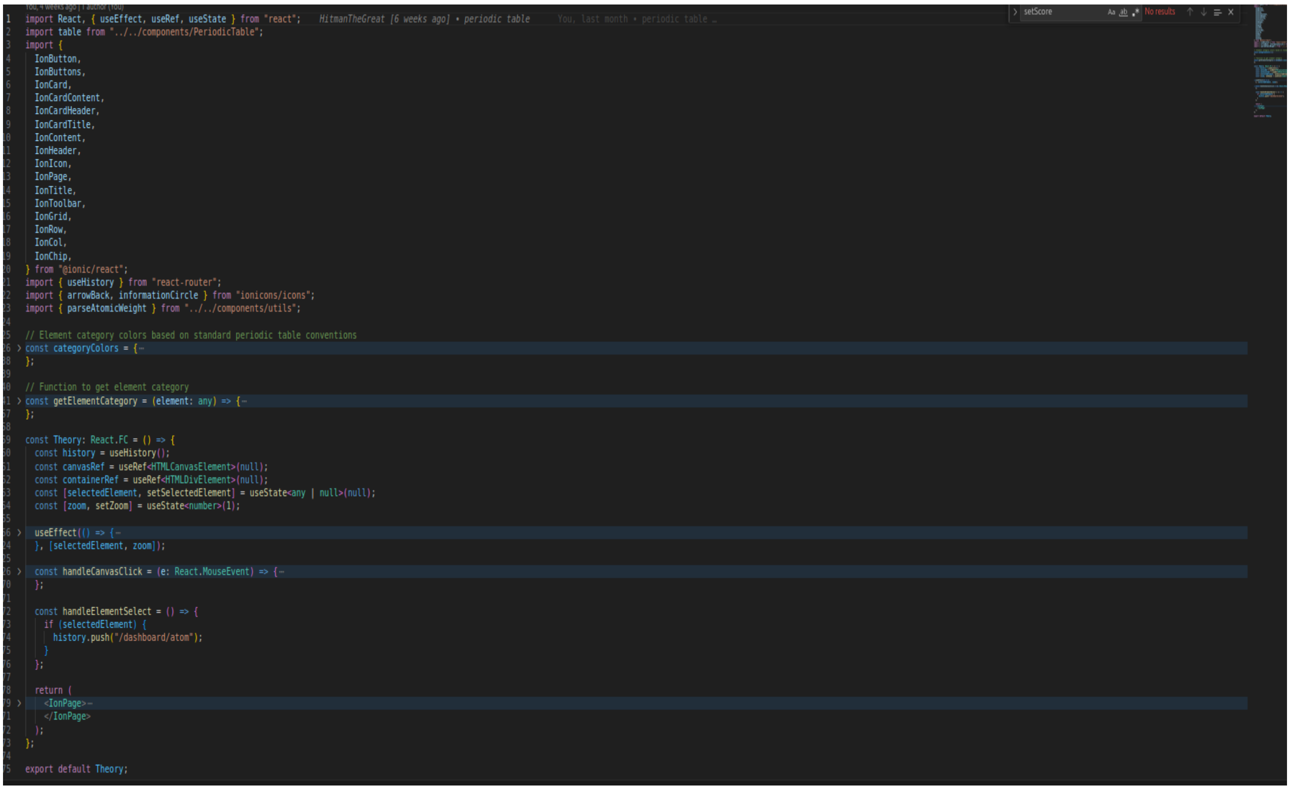
3. **Viewing Progress Reports:**

- Under "**Progress Reports**," you may see an overview of your progress through the learning modules. This could be displayed as:
- Percentage completion for each module.
- A visual representation of your progress (e.g., progress bars).
- A summary of your scores on related assessments.

Appendix C: Sample Code

- **C.1 Sample Theory Model Loading Function (JavaScript/Three.js):**

Figure 47 theory part



```
import React, { useEffect, useRef, useState } from "react";
import table from "../../components/PeriodicTable";
import {
  IonButton,
  IonButtons,
  IonCard,
  IonCardContent,
  IonCardHeader,
  IonCardTitle,
  IonContent,
  IonHeader,
  IonIcon,
  IonPage,
  IonTitle,
  IonToolbar,
  IonGrid,
  IonRow,
  IonCol,
  IonChip,
} from "@ionic/react";
import { useHistory } from "react-router";
import { arrowBack, informationCircle } from "ionicons/icons";
import { parseAtomicWeight } from "../../components/utils";

// Element category colors based on standard periodic table conventions
const categoryColors = {…
};

// Function to get element category
const getElementCategory = (element: any) => {…
};

const Theory: React.FC = () => {
  const history = useHistory();
  const canvasRef = useRef<HTMLCanvasElement>(null);
  const containerRef = useRef<HTMLDivElement>(null);
  const [selectedElement, setSelectedElement] = useState<any | null>(null);
  const [zoom, setZoom] = useState<number>(1);

  useEffect(() => {…
  }, [selectedElement, zoom]);

  const handleCanvasClick = (e: React.MouseEvent) => {…
  };

  const handleElementSelect = () => {
    if (selectedElement) {
      history.push("/dashboard/atom");
    }
  };

  return (
    <IonPage>…
    </IonPage>
  );
};

export default Theory;
```

- **C.2 Sample AR Rendering Component Drag and Drop (React/WebXR):**

Figure 48 Handling drag and drop functionality

src > pages > ui > DndGame.tsx > ...

```tsx
import { useHistory } from "react-router";
import { arrowBack, arrowUndo, arrowRedo, reload, trophy, school } from "ionicons/icons";
import { Modal, Button, ProgressBar } from "react-bootstrap"; // Importing Bootstrap Modal
import { theDndQuestions } from "../../components/dndQuestions";
import "./DndGame.css"; // We'll create this CSS file for additional styling

const DndGame: React.FC = () => {
    const historyy = useHistory();

    // Navigate back to the previous page
    const handleBackClick = () => {…
    };

    const [currentQuestionIndex, setCurrentQuestionIndex] = useState(0);
    const [userFormula, setUserFormula] = useState<string>("");
    const [history, setHistory] = useState<string[]>([]);
    const [future, setFuture] = useState<string[]>([]);
    const [showModal, setShowModal] = useState(false);
    const [showCorrectAnimation, setShowCorrectAnimation] = useState(false);
    const [dndQuestions, setDndQuestions] = useState<any[]>(theDndQuestions);

    const currentQuestion = dndQuestions[currentQuestionIndex];

    useEffect(() => {…
    }, []);

    const handleDrop = (e: React.DragEvent) => {
        e.preventDefault();
        const symbol = e.dataTransfer.getData("text");
        setHistory((prevHistory) => [...prevHistory, userFormula]);
        setFuture([]);
        setUserFormula((prevFormula) => prevFormula + symbol);
    };

    const handleDragOver = (e: React.DragEvent) => {…
    };

    const handleDragStart = (e: React.DragEvent, symbol: string) => {…
    };

    const handleUndo = () => {…
    };

    const handleRedo = () => {…
    };

    const handleReset = () => {…
    };

    const isCorrect = currentQuestion && userFormula === currentQuestion.correctFormula;

    useEffect(() => {…
    }, [isCorrect, currentQuestionIndex, dndQuestions]);

    // Helper function to render the formula with subscripts
    const renderFormulaWithSubscripts = (formula: string) => {…
    };

    const handleTouchStart = (symbol: string) => {…
```

Appendix D: Research Papers

AUGMENTED REALITY IN CHEMISTRY

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ABSTRACT

Chemistry education is frequently hindered by the abstract nature of its core concepts, leading to difficulties in visualization and comprehension, particularly at the high school and university levels. This research project proposed the development of an Augmented Reality (AR) mobile application designed to revolutionize the learning experience by providing immersive and interactive visualizations of chemical phenomena. The application aimed to address the challenges of visualizing complex molecular structures, simulating intricate chemical reactions, and exploring bonding mechanisms in real-time. By leveraging AR technology, students were be able to interact with 3D models of molecules, observe dynamic reaction simulations, and explore chemical processes in a tangible, engaging manner. This platform catered to diverse learning styles by offering interactive, visual, and kinesthetic learning experiences, thereby enhancing comprehension and retention. Furthermore, the AR application mitigated the limitations of traditional laboratory experiments by providing safe and accessible simulations of complex procedures, reducing the reliance on physical resources and addressing the lack of immersive learning environments. Ultimately, this research project transformed chemistry education by making it more accessible, engaging, and enjoyable, fostering a deeper understanding of fundamental chemical principles..

***Keywords*: Augmented Reality (AR), Mobile Application, 3D Visualization, Chemical Reactions, Molecular Structures, Immersive Learning, Interactive Simulation, Chemistry Education, Student Engagement, Educational Technology**

I. INTRODUCTIONS

Chemistry, a fundamental scientific discipline, often presents a significant challenge to students due to its abstract nature and the difficulty in visualizing complex molecular structures and dynamic chemical processes. Traditional teaching methods, relying heavily on two-dimensional representations and static models, frequently fail to convey the intricate three-dimensional reality of chemical phenomena. This project aimed to address this pedagogical gap by developing an innovative Augmented Reality (AR) mobile application that brings chemistry to life.

This application provided students with an immersive and interactive learning experience, enabling them to visualize and manipulate 3D models of molecules and explore bonding mechanisms through engaging AR interactions. By leveraging the power of AR technology, this project transforms chemistry education, making it more accessible, engaging, and effective for students at the high school and university level

II. PROBLEM STATEMENT

The impetus behind this project stems from the persistent challenge of effectively conveying the microscopic world inherent to chemistry. A key hurdle in chemistry education, particularly at the junior high school level, is the development of students' ability to mentally visualize and manipulate abstract concepts such as atoms and molecules. The transition from macroscopic observations to the microscopic realm is a significant cognitive leap, often proving difficult for young learners whose spatial reasoning and abstract thinking skills are still developing.[1]

This difficulty is particularly evident when introducing fundamental concepts like "the composition of substances," which forms the bedrock for future chemical understanding[1]. Traditional pedagogical approaches often fall short in bridging this gap, leading to misconceptions and a lack of engagement. Research has shown that utilizing interactive, inquiry-based Augmented Reality tools can significantly enhance students' comprehension of these micro-worlds. By allowing students to actively manipulate 3D models of particles and conduct virtual experiments, AR provides a tangible and engaging means of exploring abstract chemical concepts.[1]

I. RELATED WORKS

The application of Augmented Reality (AR) in science education, particularly in chemistry, has garnered significant attention in recent years. Several studies have explored the potential of AR to enhance visualization and engagement in learning complex chemical concepts.

One notable study by Chen et al. [2] investigated the use of AR for teaching "the composition of substances" to junior high school students. Their research demonstrated that AR-based inquiry tools, enabling students to interact with 3D models of micro-particles, significantly improved learning outcomes, especially for low-achieving students. This study highlighted the effectiveness of AR in bridging the gap between macroscopic observations and microscopic understanding.

Another research direction focused on the visualization of molecular structures using AR. For instance, Kaufmann et al. [3] explored the use of AR for visualizing 3D molecular structures, allowing students to manipulate and explore these structures in real-time. Their work emphasized the potential of AR to enhance spatial understanding and engagement in learning molecular geometry.

Furthermore, the integration of AR with mobile devices has been explored to provide accessible and portable learning tools. Ibáñez et al. [4] developed a mobile AR application for chemistry education, focusing on interactive simulations of chemical reactions. Their study demonstrated the feasibility of using mobile AR to create immersive learning experiences that enhance student motivation and understanding.

Additionally, the use of AR in simulating laboratory experiments has been investigated. Radu et al. [5] explored the design and evaluation of AR-based simulations for chemistry experiments, aiming to provide safe and engaging alternatives to traditional laboratory work. Their research highlighted the potential of AR to address resource constraints and safety concerns in chemistry education.

According to a study [1], grasping the concept of micro-worlds has been a persistent focus and challenge within chemistry education. It was observed that junior high school students often struggle with their imaginative capabilities, which affects their ability to accurately visualize microstructures at the beginning stages of their chemistry learning journey. The research specifically examined the "composition of substances" topic in junior high school chemistry classes and involved developing a set of inquiry-based augmented reality (AR) learning tools. Through the use of markers, students were able to manipulate, combine, and engage with a 3D model of microparticles while conducting a series of inquiry-based experiments. The AR tool was implemented in a practical context at a junior high school in Shenzhen, China. [1]Data analysis and discussions led to several conclusions: (a) the AR tool served as a significant enhancement to learning, functioning effectively as a computer-assisted educational resource; (b) it demonstrated greater effectiveness for students with lower achievement levels compared to those with higher achievements; (c) overall, students showed positive attitudes toward the software; and (d) there was a positive relationship between students’ learning attitudes and their evaluations of the software.[1]

This article [6] examined recent trends in the application of augmented reality (AR) within chemistry education and identified potential areas for integrating AR technologies to improve chemistry learning in Ukrainian educational settings. It addressed several key topics: summarizing and analyzing findings from existing research on AR applications in chemistry education, detailing contemporary AR tools used in the field, and predicting future development opportunities for AR technologies in Ukrainian chemistry education. The research specifically targeted augmented reality as the main subject, focusing on its role in chemistry learning. The findings revealed that AR technologies were actively utilized in chemistry education, showcasing their effectiveness; however, there was a significant deficiency of Ukrainian software solutions in this domain. Frequently, AR technologies were employed for three-dimensional visualizations of atomic structures, molecules, and crystalline lattices. [6]The study concluded that there was a considerable demand for mobile-accessible augmented reality in chemistry education, emphasizing the need to create appropriate tools to enhance chemistry instruction in schools and universities. Promising developments included the formulation of methodological guidelines for laboratory work, the creation of textbooks and popular science literature that integrated AR technologies, and the design of simulators for engaging with chemical equipment and materials through augmented reality.

According to [7], studies focusing on visuospatial skills within chemistry education have revealed specific challenges students face in understanding, interpreting, and translating molecular representations. Research by [8] indicated that many university students struggle with three-dimensional thinking. These challenges often stem from misunderstandings of a few relatively straightforward concepts and skills. [9] found that a course designed to enhance the 3D spatial abilities of first-year engineering students had a positive effect on their academic success, particularly among female students. This suggests that spatial skills can be developed through practice, potentially leading to improved academic outcomes. Building on these findings, our goal is to address the challenges encountered in teaching chemistry microstructures related to spatial skills. A wide array of computer-assisted learning tools are currently employed in chemistry instruction, and numerous researchers have created specific scenarios utilizing these tools to evaluate their effectiveness on student learning. In recent years, Virtual Reality and Augmented Reality-based learning tools have garnered significant acclaim for their effectiveness in teaching microstructure concepts.

These studies collectively demonstrate the potential of AR to transform chemistry education by providing immersive, interactive, and engaging learning experiences. The proposed project builds upon these existing works by integrating diverse AR functionalities into a comprehensive mobile application, aiming to address the broader challenges of visualizing abstract chemical concepts and fostering student engagement.

IV. PROPOSED SOLUTIONS

The goal of the project's design and development is to create an Augmented Reality in Chemistry application that allows students to visualize and interact with molecular structures of elements and bonds of different elements to form compounds. To address the issues described in the problem description, a system with the following objectives was created:

To develop an augmented reality mobile application that:

- Allows students to visualize content from chemistry.
- Provides interactive and engaging learning material
- Incorporates progress tracking and analytics.

V. PROPOSED METHODOLOGY

A. Solution architecture

The application must first be downloaded, installed, and the required rights(camera permissions) granted by the user. After logging in, the user must register to create an account if they are a first-time user. The user selects the AR Scan option in the application, they can choose between Atomic Elements and Chemical Compounds . After selecting "Launch AR Experience " the camera opens up then the user can scan the AR markers. The Atomic structure / ball and stick model of the compounds.

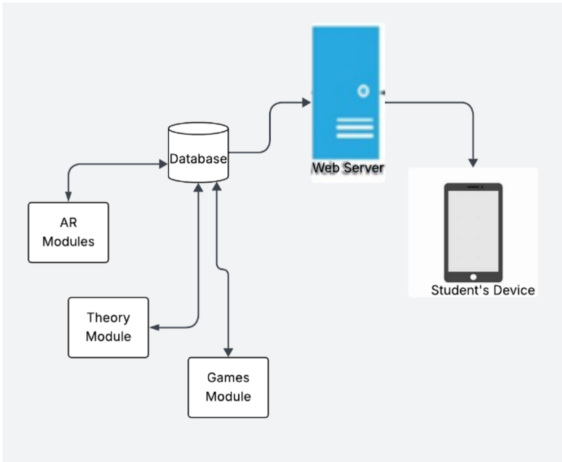

Figure 1: Architecture Solution

B. Application Architecture

The program features a modular frontend-backend architecture:

Frontend: Made with JavaScript and Ionic Framework, the frontend is created for mobile and web deployment. A few significant libraries utilized are Three.js to render 3D and jsartoolkit5 for AR marker detection. Android Studio builds and deploys the application for mobile usage.

Backend: Backend is coupled with SQLite for local storage, which is accessible via Ionic's native functionality. There is also an online Screener server to host dynamic content and updates. ORM (Object-Relational Mapping) principles are used for rapid data interaction, improving response time and boilerplate queries.

3D Rendering and Animation

Chemical structures and molecular models are displayed using Three.js, a JavaScript library that interfaces with WebGL. The 3D scenes are constructed programmatically through mathematical functions to represent bonds, atoms, and molecular geometry. Rotation and transition animations are coded directly into Three.js to illustrate interactions like bonding and reactions.

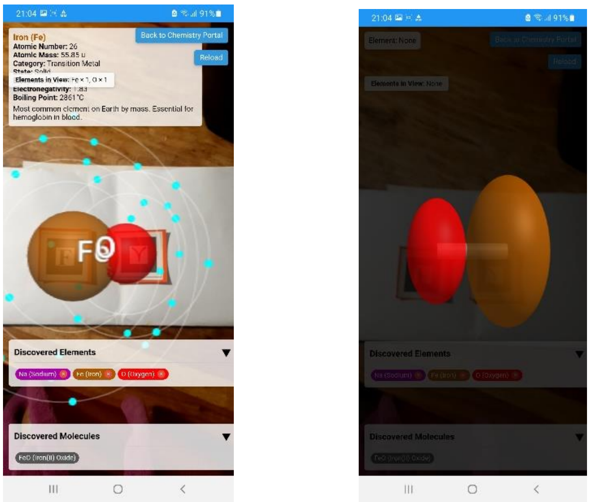

Figure 2 . Augmented Reality representing Iron Oxide

Marker Detection and Augmented Reality Platform

The application makes use of jsartoolkit5, a JavaScript-based Augmented Reality library, to facilitate marker-based tracking. The library converts image markers to binary matrices, thereby enabling pattern recognition functionality. Hiro marker standard was used due to its reliability and jsartoolkit5 compatibility. Recognition of the marker is contrast-based, with values closer to 256 representing darker areas, thereby aiding the system in appropriately segregating and decoding the marker.

Periodic Table Implementation

A periodic table was introduced in the Theory part of the application. This table is driven by an organized collection of chemical elements, where each element has metadata that includes name, atomic number, and additional properties. This collection is handled in a separate TypeScript file, `periodic-table.ts`, that fills up the interface dynamically.

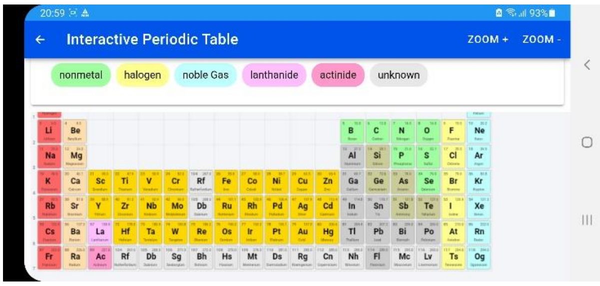

Figure 3. Digital Periodic Table

Content Delivery and Data Storage

User information, like quiz results and progress monitoring, is managed by a JavaScript-based Object-Relational Mapping (ORM) layer that communicates with SQLite storage. By doing this, data management procedures are simplified and the development cycle is sped up. Furthermore, a Content Delivery Network (CDN) is utilized for loading static assets and media files from the server, thereby enhancing load times and enabling smooth rendering of Augmented Reality (AR) content.

Cloud and Server Services

Even though Firebase or other cloud analytics solutions were not used, Content Delivery Management (CDM) practices were implemented to enable jsartoolkit5's management of resources. Web hosting and screener tools enable updates, manage media assets, and offer remote access to AR content.

Framework Justification

The choice of using jsartoolkit5 and Three.js instead of alternatives such as Unity, ARCore, or Vuforia was due to their light weight and cross-platform compatibility. These JavaScript libraries run directly in web browsers and mobile platforms without the necessity of heavyweight SDKs or platform-specific limitations. This renders the application widely

C. Coding Strategy

The steps taken to accomplish all of the project's objectives make up the coding approach. The project has been split into many parts due to its scale. A detailed blueprint of the database's structure was created prior to its creation. The structure and relationships among the classses were decided upon before the creation of them. A few of the characteristics were developed by trial and error until the desired results were obtained.

D. *Experimentation and Testing*

Function	*Expected Result*	*Status*
Login	Authorize user	Success
View Molecular Structure	View molecular structure on AR markers	Success
View Element and compound details	View details about elements and compounds	Success
View Elements on the periodic table in 3D	View all the elements on the periodic table in 3D. User can zoom in and out	Success
Play Games and get a score at the end of the quiz	Play games (category wheel ,quiz , drag and drop)	Success
View progress and recommendations	View progress and recommendations on areas that student is failing	Success
Logout	Should logout the user from the application	Success

Table 1: Experimentation and Testing

V. Conclusion

In conclusion, the Augmented Reality application in Chemistry has successfully enhanced the learning experience by making complex chemical concepts more accessible and engaging. Through interactive 3D visualizations of molecular structures students are able to gain a deeper understanding of abstract topics that are often challenging in traditional classroom settings. This technology not only improves conceptual clarity but also increases student motivation and participation, ultimately contributing to more effective and immersive science education.

VI. Future Works

There is always room for improvement in the Augmented Reality Chemistry application. Students can explore virtual labs and conduct experiments in a simulated three-dimensional world by using virtual reality to create a more immersive learning environment. The learning experience can be further improved with other features like voice-guided courses, AI instructors, and real-time collaboration tools. By mimicking real-world chemical processes and providing dynamic, interactive components that enhance the learning process, a chemical reaction simulator could also increase the application's comprehensiveness and user engagement.

VII. Acknowledgements

First and foremost, I want to express my gratitude to the Almighty God for His constant direction in my life and for providing me with the skills and knowledge that I employed in the development of this system. I would also want to express my gratitude to my family for their help and support during the process. Thank you Blessing Chusaru, Kudakwashe Koti, and everyone who helped me finish the project by providing me with the essential information and direction. Finally, I'd like to express my gratitude to my project supervisor, Miss S Zindove, for her direction and consistent monitoring, which helped me complete this project.

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