AUGMENTED REALITY IN CHEMISTRY

Zvinavashe Ashley ; Makondo Wellington

Department of Software Engineering, School of Information Sciences and Technology

Harare Institute of Technology, Harare, Zimbabwe

zvinavasheashley@gmail.com; wmakondo@hit.ac.zw

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]

III. 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.

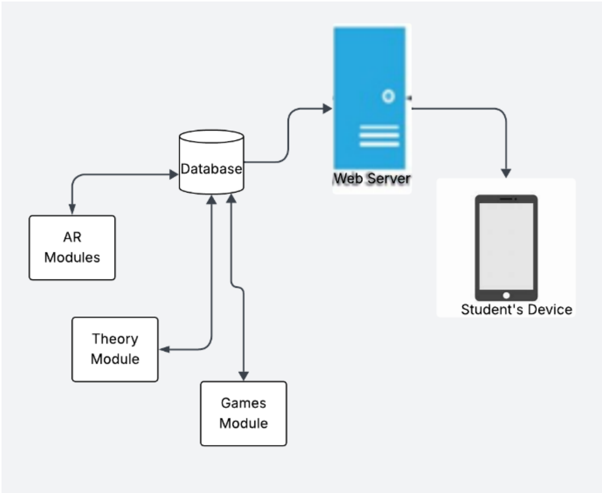

Figure 1: Architecture Solution

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.

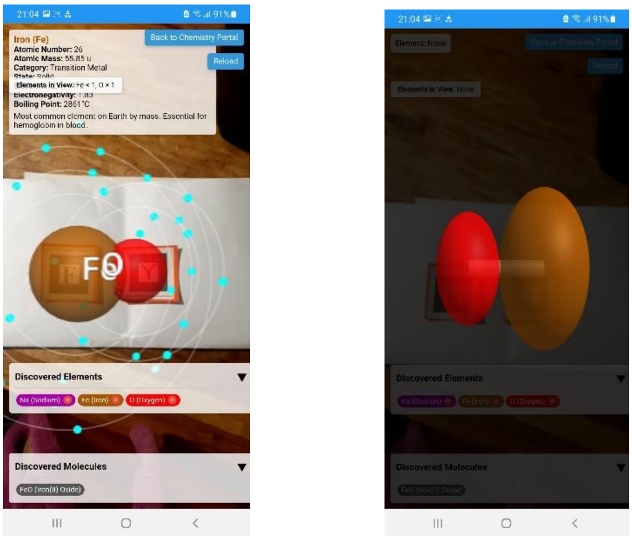

Figure 2 . Augmented Reality representing Iron Oxide

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.

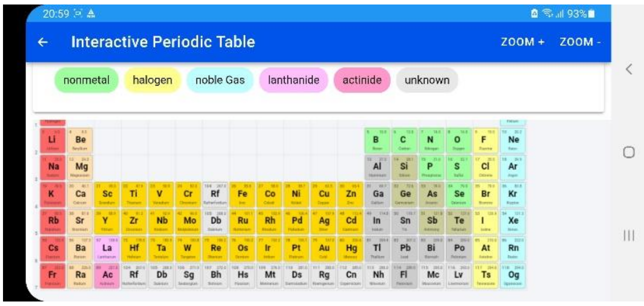

Figure 3. Digital Periodic Table

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

VI. 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.

VII. 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.

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8. Kryvyi Rih Metallurgical Institute of the National Metallurgical Academy of Ukraine,5, Stephana Tilhy St., Kryvyi Rih, 50006, Ukraineacinonyxleo@gmail.com, simaneneko@ukr.net,{vitro090, anna.tomilina.anna}@gmail.com, o.d.uchitel@i.ua
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