Designing and Development of AR Based Application for Science Education

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A R T I C L E I N F O

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A B S T R A C T

The use of augmented reality (AR) technology in education has increased recently and provides similar and interactive learning experiences that go beyond traditional education. AR apps, in particular, have the potential to enhance learning by giving students the opportunity to explore complex scientific concepts in a positive and interesting way. To provide the best learning experience, this article examines the design and implementation of a virtual reality application designed for science education. He does this by using the power of the Union and Vuforia. By integrating virtual objects into the physical world, virtual reality classrooms can help students see complex science concepts more clearly and in depth, thus promoting learning about information and understanding concepts. The program uses design to make experiments, 3D models, and data points based on the science curriculum to engage students of all ages and ability levels. This study examines the development process of virtual reality applications, including the integration of knowledge, performance evaluation, and investigation of changes in technology in science education. This study focuses on the role of AR technology in modernizing educational technology and influencing the educational process in the digital age through a comprehensive analysis of the design process and strategies used.

1. INTRODUCTION

As digitalization develops and enters the education sector, technology and devices are converging. AR is a major advancement that is increasingly used in science and engineering education. The increase in AR applications developed and researched for the purpose of teaching various subjects proves this. Users can interact with real-world digital content through AR technology and experience the best of both worlds. Science education often involves abstract and difficult-to-visualize concepts that require high levels of thinking and creativity. AR enables the visualization of complex content by combining virtual content with the real world [1]. Additionally, AR facilitates greater interaction, allowing students to play an active role in AR simulations and develop their understanding of relationships and context. AR can also personalize learning by adapting to each student's unique learning process or providing step-by-step assistance they can use as needed. Many needs and interests can be met this way. Thanks to AR, chemistry has new possibilities, including the ability to interact with molecules, simulate chemical reactions, and have a better chemistry laboratory. Safe experiments can replace dangerous experiments that are not allowed in schools or can be taught in a safe way, supporting content such as communication and simple interventions.

1.1 Background

The proliferation of AR is intricately linked to the widespread adoption of devices featuring cameras, sensors, and displays, exemplified by smartphones, tablets, and specialized AR glasses. The synergy between hardware capturing real-world environments and AR algorithms processing and augmenting information in real-time has given rise to a myriad of applications across industries [2]. Chemistry education, particularly at the molecular level, requires students to comprehend complex spatial relationships and molecular interactions. AR applications have the potential to transform how students engage with molecular structures, chemical reactions, and laboratory procedures. By providing three-dimensional visualizations and interactive simulations, AR enables students to explore molecular structures in real-time, fostering a deeper understanding of chemical phenomena that may be challenging to grasp through traditional methods.

Through an examination of the particular uses of AR in chemistry education, this study aims to add to the corpus of current knowledge. The study aims to identify effective

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implementations, evaluate their impact on student learning outcomes, and highlight areas that require additional research and improvement through a thorough analysis of pertinent literature. Another area of focus will be the technical issues of creating AR applications for chemistry education. This covers factors including content creation techniques, AR development platform selection, and integrating AR tools into the current chemistry curriculum.

1.2 Objectives

The main purpose of using AR in science education is to improve and differentiate our education. This includes providing new ways to interact with data, visualize data, and engage with everyday ideas. AR technology, particularly in chemistry, aims to change the way chemistry is taught, reinforced, coordinated and responsive to students' needs in the following ways:

1. Using AR to visualize complex chemical concepts in a three-dimensional space can improve students' understanding of molecular and chemical structures.

2. Put theoretical chemistry concepts into context using AR to show how chemical concepts are used in the real world.

3. Create an interactive AR simulation that shows different types of bonds, such as covalent, ionic, and metallic bonds. These simulations should allow students to move atoms and watch the development instantly.

4. Use AR to explain how atoms share electrons to form stable configurations in covalent bonds.

2. LITERATURE REVIEW

AR is changing the way science education is done by separating theoretical concepts from real-world applications through interactive and participatory methods [3]. This literature review explores the usability, effectiveness, and impact of AR technology on science education. It brings in research data from previous studies in the field and academic publications.

2.1 Visualization and Simulation of Molecular Structures

An early evaluation conducted by Chen et al., Johnson and Smith highlighted the potential of AR to analyze molecular structures [4]. In addition to improving the spatial concept, this also allows the important design to attract immediate attention. AR application based on the combination of simulation and visualization enhances understanding and experience.

2.2 Gamified and Adaptive Learning Approaches

Li, Zhang, Garcia, and colleagues worked on incorporating game-like elements into AR applications to manipulate molecular interactions. These workshops make learning interesting and stimulating by offering virtual experiments and interactive sessions. Meanwhile, Huang, Chen, and Liu et al. It highlights the value of augmented reality applications to adapt to the adaptive learning environment. Molecular binding education can make students more engaged by adjusting information to fit each student's unique learning [5].

2.3 Integration with Classroom Demonstrations and Real-Time Experimentation

Integrating AR use into classroom presentations and on-the-fly virtual experiments is the subject of a recent study by Patel, Sharma, and Cheng et al. This integration in live demonstrations allows teachers to explain molecular concepts, enhancing the overall learning experience in the classroom. Real-time virtual experiments allow students to observe and correct for differences in simulated drug reactions, accelerating the learning process and bridging the gap between thinking and execution.

3. PROPOSED WORK

In this study, we present a new concept for using augmented reality technology to transform learning. Our goal is to create and implement a dynamic AR learning environment that enhances students' understanding of complex chemistry concepts.

3.1 Problem Statement

Current methods of teaching the concept of chemical molecular bonding often have difficulty capturing students' imagination and deepening their understanding of 3D structures and interactions, chemical effects. As students strive to learn abstract concepts, physical arrangements, and dynamic processes related to molecular bonds, the shortcomings of traditional methods become apparent [6]. This highlights the need for change to improve student learning, close the gap in understanding, and close the gap between theory and practice in chemistry education. Many challenges were faced including:

- **Engagement and Comprehension Gaps:** molecular bonding notions are intrinsically complex and multifaceted, traditional teaching approaches find it difficult to completely engage pupils and promote a deep knowledge of these ideas.
- **Limited integration of AR:** Given the possible advantages, AR technology is not widely included into chemistry education, especially when it comes to the methodical teaching of molecular bonding ideas.
- **Holistic Evaluation:** A thorough assessment of the overall effects of AR applications, including how well they **enhance** student engagement, retention of information, and real-world application of molecular bonding ideas, is lacking in the current research.

This problem statement lays the groundwork for upcoming research projects and highlights how urgent it is to solve these issues in order to fully realize the promise of AR technology in revolutionizing the molecular bonding teaching and learning process in chemistry education.

3.2 Methodology

This study investigates the integration of AR technology in science education using Unity and Vuforia. The research design focuses on the development process and AR implementation to create immersive learning experiences for enhancing student engagement and understanding of scientific concepts.

3.2.1 Development Process

The development process entails creating interactive visualizations, simulations, and educational content within the AR environment using Unity and Vuforia. Educational content is curated and designed to align with science curriculum objectives, including molecular structures, ecological systems, and astronomical phenomena [7]. Unity serves as the primary platform for designing and implementing interactive AR experiences, while Vuforia's features are utilized to enable marker-based or marker less tracking, object recognition, and augmentation of digital content onto real-world surfaces.

3.2.2 Curriculum Selection

The decision to align the AR project with the Class Xth science curriculum stems from the recognition of the critical importance of foundational science education. By closely adhering to the NCERT board's curriculum, the AR application aims to reinforce key concepts presented in the "Carbon and its Compounds" chapter, which explores the diverse nature of carbon-based compounds, their structural arrangements, and the mechanisms behind chemical reactions.

3.2.3 Chapter Rationale - Carbon and its Compounds

In the context of AR applications representing molecular bonding and chemical reactions in Unity with Vuforia, the focus is on creating immersive experiences that vividly illustrate complex chemical processes. The experiments aim to showcase the movement of electrons, the formation of covalent bonds, and the dynamic rearrangement of atoms during chemical reactions [8, 9]. For instance, a specific experiment could simulate the covalent bond formation between hydrogen atoms to create a diatomic hydrogen molecule, visually depicting the sharing of electrons between the two atoms. Other scenarios might include showing how atoms rearrange and chemical forms form and break down during events such as the combustion of methane. Users can view and interact with virtual models via AR. This helps them gain a concrete understanding of the nuances of molecular dynamics, electron behavior, and chemical reactions. Because AR is so important, these concepts can be understood better than expected, thus supporting the relationship between theoretical knowledge and clinical practice. To improve the AR experience when viewing the different figures described in the chapter, a unique QR code is created for every figure. Throughout the text, these QR codes *(shown in Figure 1)* are placed thoughtfully next to the figures they correlate with. Serving as target images, these QR codes enable our application to accurately render the associated 3D models, ensuring a seamless and immersive AR representation of the content.

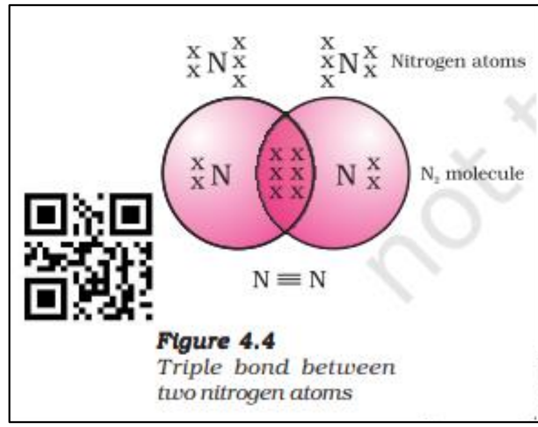

Fig. 1. Placement of QR codes near their respective practical's in the chapter pdf.

3.2.4 AR Implementation

Vuforia's capabilities enable the recognition of predefined images or objects and overlaying digital content onto real-world surfaces. Unity is utilized to develop interactive AR applications that seamlessly integrate Vuforia's features [10]. The AR implementation process involves designing user interfaces, incorporating interactive elements, and optimizing performance for various devices and platforms. The development of AR applications prioritizes usability, accessibility, and alignment with science education objectives.

4. IMPLEMENTATION

The implementation phase of our research focuses on translating the conceptual framework of AR in chemistry education into a tangible and effective learning tool. Through collaboration with different software and tools, we will develop an AR application tailored to the specific needs of chemistry students.

4.1 Softwares Used

4.1.1 UNITY (Version 2023.2.3f1)

Unity is a versatile and powerful game engine and development platform used by developers worldwide to create immersive 2D and 3D experiences. With its intuitive interface and robust set of tools, Unity enables developers to build interactive applications, including games, simulations, and AR experiences, for various platforms such as mobile devices, desktops, consoles, and AR glasses. Unity supports both visual scripting and traditional coding languages like C#, making it accessible to developers of all skill levels.

4.1.2 VUFORIA

AR SDK (software development kit) Vuforia empowers developers to design intelligent AR encounters on numerous stages. With Vuforia, designers can undoubtedly incorporate object recognition, marker-based, and markerless AR highlights into their projects. Vuforia is accessible to all since it upholds significant mobile devices including Android, iOS, and UWP (Universal Windows Platform).

4.2 Development of Augmented Reality Learning Environment (Arle)

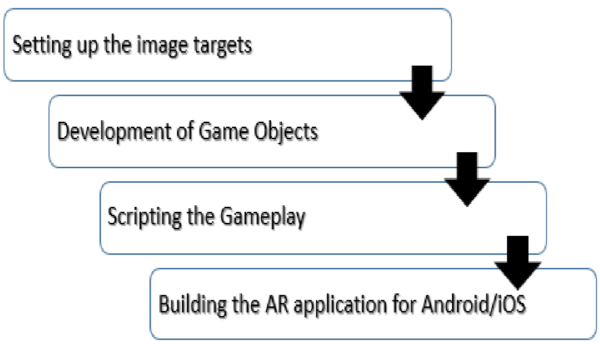

Fig. 2. Development Process of ARLE.

Figure 2 illustrates the sequential process of ARLE development. Let's look at each of the above steps in detail:

4.2.1 Setting up the Image Targets

Setting up image targets in Unity is a first important step in developing AR apps, especially when using AR frameworks such as Vuforia [11]. When the camera identifies and recognises image targets, they serve as markers that launch AR content. To set up image targets in Unity using Vuforia, follow these steps:

a. Create a New Unity Project
b. Import Vuforia Package
c. Set up Vuforia Configuration
d. Add AR camera
e. Create Image Target
f. Configure Image Target
g. Add Image Target

4.2.2 Development of Game Objects

In Unity, it is necessary to develop game objects in order to build engaging and interactive experiences. Game objects are the scene's building blocks; they can represent characters, props, barriers, lighting, cameras, and more. An outline of the Unity game object development process is provided below:

a. Hierarchy Window: A list of all the game objects present in the current scene are displayed in here. You can right-click in here to create new game objects.

b. Inspector Window: You may inspect and change the properties of the chosen game objects using this. You can adjust various parameters to enhance their functionality and appearance.

c. Transform Component: It controls the position, rotation, and scale of a game object. The object in the scene can be graphically adjusted by adjusting these values manually or directly or by using the Scene view handles.

d. Primitive Objects: Cubes, spheres, and cylinders can be incorporated inside the scene. These objects are easy to utilize as placeholders or for prototyping because they already include mesh renderers and default colliders.

e. 3D Modelling Software: For more complex and customized game objects, you can use external 3D modelling software like Blender or Maya. Import the models into Unity, and they will appear as game objects in your scene. Unity supports various file formats, including FBX and OBJ.

f. Materials and Shaders: The visual appearance of game objects is determined by their materials.

g. Scripting: Game objects can be made interactive and dynamic by attaching scripts. Unity supports scripting in C# and JavaScript. You can create scripts to define behaviour, handle user input, or control the movement and animation of game objects.

h. Physics Components: Unity's physics engine enables realistic interactions between game objects. Attach components like rigid-bodies for physics simulation, colliders for collision detection, and joints for creating complex physical interactions.

i. Prefabs: To reuse game objects with consistent properties and components, you can create prefabs. Prefabs are asset files that can be instantiated multiple times in your scenes.

j. Lighting: Lighting plays a crucial role in the visual appeal of game objects. Unity provides a range of lighting options, including directional lights, point lights, and spotlights. Adjusting lighting settings in the Scene view and using real-time or baked lighting enhances the overall scene aesthetics.

k. Particle Systems: For effects like fire, smoke, or rain, Unity's particle system allows you to simulate and control the behaviours of thousands of particles. Adjust parameters such as emission rate, size, and colour to achieve the desired visual effects.

l. Animation: Game objects can be animated using Unity's Animation window or Animator component. Create animations for movement, rotation, and scale changes, as well as more complex skeletal animations for characters.

m. UI Elements: Unity supports the creation of User Interface (UI) game objects such as buttons, text, and images. The Canvas component is used to organize and render UI elements in the scene.

n. Audio: Game objects can produce sound by attaching an Audio Source component. You can import audio clips and use scripts to control when and how the audio is played during runtime.

o. Collaboration and Version Control: Unity provides collaboration features and supports version control systems like Git. This is crucial when working in a team to manage changes to game objects and maintain a coherent project.

Developing game objects in Unity involves a combination of visual design, scripting, and interaction with various components. The flexibility and extensibility of Unity empower developers to create diverse and captivating experiences across different genres and platforms.

4.2.3 Scripting the Gameplay

Scripting gameplay in Unity involves using the C# programming language to define the behaviour and logic of game objects. By creating scripts as MonoBehaviours, developers attach them to specific game elements to dictate their actions and responses. Common methods like `Start () ` and `Update () ` manage the initialization and continuous execution of code (as shown in *Figure 3*), while functions such as `OnCollisionEnter () ` handle specific events like collisions.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class PlayerMovement : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {

    }
}
```

Fig. 3. Basic C# Script in Unity.

Using scripts, developers can control user interface interactions, control user input, control gesture-based settings, and access and modify the product. Unity's scripting capabilities provide a flexible framework for creating interactive and interactive games. This allows developers to bring game ideas to life by showing players' interactions, rules, and behaviors that affect the game.

Scripting can be done for various purposes such as: Accessing components, event handling, physics and movements, animation, input handling, UI interaction, scriptable objects, debugging, external libraries and APIs and optimization.

4.2.4 Building the AR Application for Android/iOS

Configuring your project for the appropriate platforms, adding AR frameworks if needed, optimising scenes for AR, and modifying player settings are all part of creating AR applications for Android and iOS using Unity. Unity provides an Xcode project for iOS that can be developed and executed on devices using Xcode, while it generates an APK file for Android that can be deployed [12]. Testing on actual devices is crucial, ensuring that AR features function correctly, and addressing performance considerations. For distribution, upload the APK to the Google Play Store for Android or follow Apple's App Store submission guidelines for iOS. Attention to platform-specific details, thorough testing, and adherence to best practices are essential for a successful export and deployment of AR applications on both Android and iOS platforms.

4.3 Procedure

Here's a step wise explanation of the building of AR based application for science education (as shown in *Figure 4-10*):

Step 1: Importing Vuforia package inside unity.

Step 2: Creating License Key in Vuforia.

Step 3: Generating QR codes using a Random QR code generator to use them as target images in the project.

Fig. 4. Random QR codes generated online and used as image targets.

Step 4: Capturing target images and uploading them on Vuforia database.

Target Name	Type	Rating
QR10	Image	★★★★★
QR9	Image	★★★★★

Fig. 5. Vuforia database giving rating to the image targets.

Step 5: Downloading database and importing it in unity project.

Step 6: Create different scenes for different image targets.

Step 7: Add game objects to the respective scenes and show movements using C# scripts.

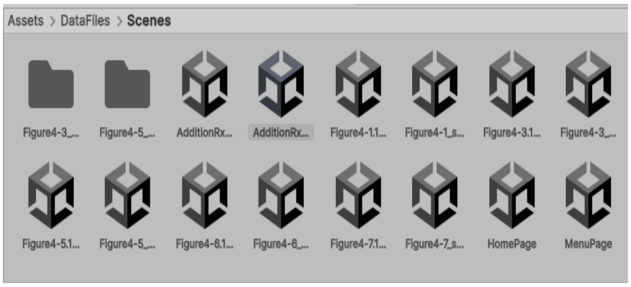

Fig. 6. Different scenes created in the project.

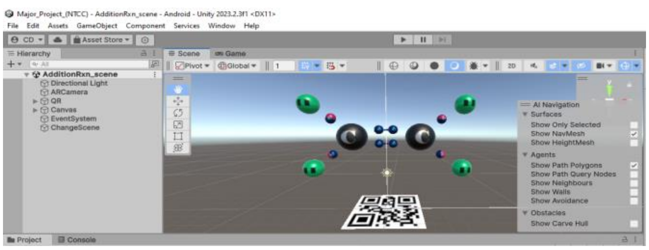

Fig. 7. Game objects arranged in to form various molecular structures.

Step 8: Create home page and menu page using canvas.

Fig. 8. Home page in Unity.

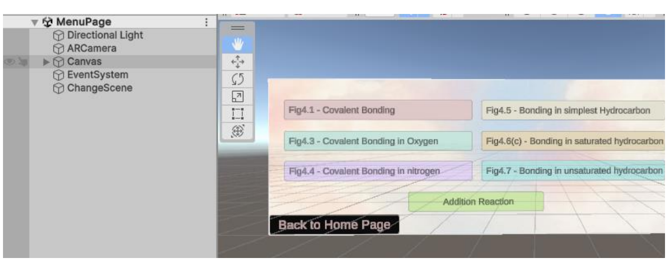

Fig. 9. Menu page in Unity.

Step 9: Create buttons in all the respective scenes and connect all the scenes using C# scripts.

Step 10: Check the final output using the webcam.

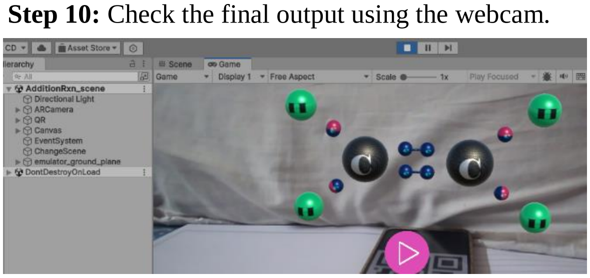

Fig. 10. Checking the output using webcam.

Step 11: Exporting the project for Android.

Step 12: Running the AR Application on Android device.

5. RESULTS AND DISCUSSIONS

As we traverse the culmination of our research journey into the integration of AR within the realm of chemistry education, this section marks a pivotal juncture—a synthesis of findings and thoughtful discourse. The subsequent exploration of results and discussions unveils the impact of AR implementation on student learning outcomes, engagement, and the broader educational landscape.

5.1 Results

After building the application, its "*apk"* for android will be generated which can be shared and opened up in any android device. When the application is installed in your device and opened, the home screen will be displayed (as shown in *Figure 11*).

Fig. 11. Home scene in android device.

When the "*menu button"* is clicked, the menu scene which contains the list of all the practicals will be displayed (as shown in *Figure 12*).

Fig. 12. Menu scene in android device.

When the user clicks on any of the activities given in the menu, the AR camera will be launched and when they keep it on the respective QR code (image target) provided in the pdf of the science chapter of "*Carbon and its Compounds",* the 3D model can be seen on the screen of their device (as shown in *Figure 13*).

Fig. 13. 3D Model being displayed on the screen.

When the user clicks on the "play" button, the scene will play out, exhibiting the movement of electrons, the formation of covalent bonds and the molecular structure of different compounds (as shown in *Figure 14*).

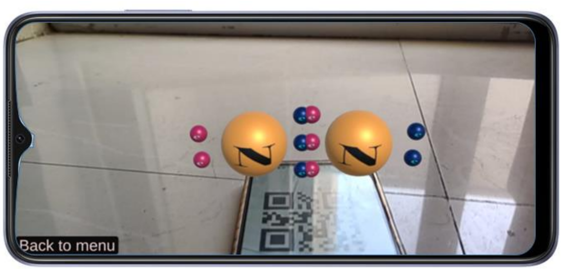

Fig. 14. Game objects showing movement on the screen.

The results of our research on designing an AR application for the chemistry carbon chapter revealed a notable enhancement in students' comprehension of carbon-related concepts [13]. The integration of 3D molecular models in the AR applications significantly improved the visualization of carbon compounds, aiding students in grasping intricate spatial arrangements and bond structures [14, 15]. User engagement and motivation were particularly high, as students found the interactive and gamified elements captivating. Educators positively acknowledged the potential of these AR tools to supplement traditional teaching methods, fostering a deeper understanding of carbon chemistry. While technical challenges and learning curves were identified, the overall positive feedback and the identified areas for improvement suggest a promising future for AR applications in advancing the learning experience within the carbon-focused realms of chemistry education.

5.2 Discussion

Analyzing the research already conducted on the benefits of introducing elements of AR in the educational process, we can identify the main points that show that AR in education [16]:

- Make learning easy
- Motivate to study
- Concretize abstract concepts
- Increase interest in learning

After the introduction of the developments in the educational process, a survey was conducted to analyse the effectiveness of the use of technology among 10^{th} grade students, which included the following questions [17]:-

1. Have you heard of augmented reality before?
2. Have you ever used augmented reality elements during the educational process?
3. Did you enjoy using augmented reality elements in chemistry lessons?
4. Does the use of augmented reality technology increase your motivation to study chemistry?
5. Do you feel that learning using augmented reality technology is better than learning through simple textbooks?

The analysis of the survey results is presented in the form of diagrams (*Figure 15-19*). 10 students took part in the survey and the results are as follows:

- ***Statistics for Question 1:***

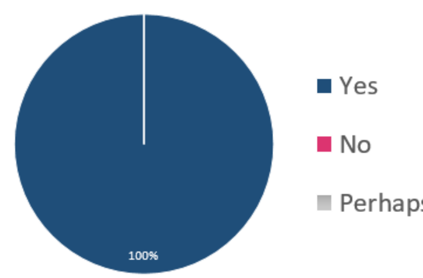

Fig. 15. Diagram to answers of question 1.

- ***Statistics for Question 2:***

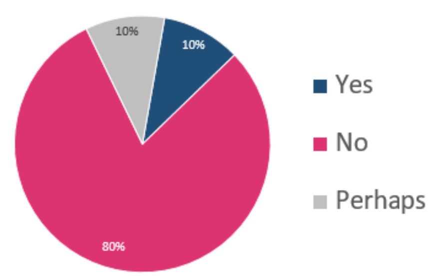

Fig. 16. Diagram to answers of question 2.

- ***Statistics for Question 3:***

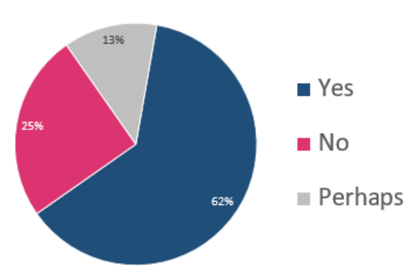

Fig. 17. Diagram to answers of question 3.

- ***Statistics for Question 4:***

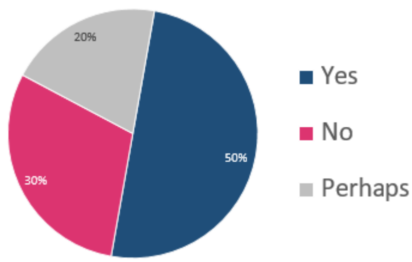

Fig. 18. Diagram to answers of question 4.

- ***Statistics for Question 5:***

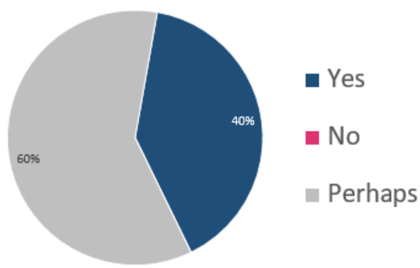

Fig. 19. Diagram to answers of question 5.

6. CONCLUSION AND FUTURE WORK

Our research on designing and implementing AR in science education signifies a promising leap towards enriching the learning experience for students. The implemented AR application showcases the potential to enhance comprehension, engagement, and retention of complex chemical concepts.

6.1 Conclusion

The integration of AR technology into science education represents a paradigm shift in pedagogy, offering immersive and interactive learning experiences that transcend traditional classroom boundaries. AR technology has enabled students to interact with abstract scientific phenomena in a tangible and experiential manner, bridging the gap between theoretical knowledge and real-world applications [18]. By visualizing complex concepts such as molecular structures, chemical reactions, and astronomical phenomena, AR has provided students with opportunities for hands-on exploration and inquiry-based learning.

The research underscores AR's effectiveness in promoting active learning and fostering deeper conceptual understanding among students. Immersing students in interactive AR environments cultivates critical thinking, problem-solving, and scientific literacy essential for 21st-century success [19, 20]. The project highlights aligning AR experiences with educational objectives and curriculum standards to maximize impact. Collaborative efforts among educators, researchers, and technology developers can tailor AR applications to diverse student needs and learning styles. As technology evolves, AR's potential in science education remains untapped. Future research should explore innovative ways, including AR glasses, spatial computing, and artificial intelligence integration, to enhance education and prepare students for a rapidly changing world.

6.2 Future Work

Currently this application can be used only for a specific chapter i.e., Class 10 NCERT chapter “Carbon and its Compounds”. To overcome this limitation, the application can be extended for all chapters of class 10^{th}. The application can even have sections for different classes right from Class 5 to Class 12. Each class section can have multiple subjects and within that subject, multiple chapters can be added which would be having various concepts to learn. A full-fledged mobile application can be built for the same, bringing students closer to the three-dimensional world of science technology using AR.

Also, while this research paper has presented an effective implementation of AR technology in the science education, there are several potential directions for future research and development which include [21, 22]:

- Investigating the long-term effects of using AR applications in chemistry education. Assess whether students who engage with AR content demonstrate sustained retention and application of knowledge over an extended period.
- Develop systems that can personalize content delivery based on individual student progress and learning styles, thereby catering to diverse educational needs.
- Further refine and explore gamification elements within AR applications. Investigate how incorporating game-like mechanics, challenges, and rewards can influence student motivation, participation, and knowledge retention.
- Focus on ensuring that AR applications are accessible to a broader range of students, including those with different learning abilities or disabilities. Investigate the usability of AR tools for students with diverse educational needs.
- Continue refining the user interface and experience of AR applications to ensure seamless and intuitive interactions. Consider feedback from users to enhance usability and engagement.

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