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Interactive Learning through Augmented Reality, Enhancing Textbook Engagement with QR Code- Based 3D Visualizations of Educational Content in the Real World

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Abstract: Traditional textbooks often lack interactive elements, making it difficult for students to understand complex 3D concepts. This project integrates WebAR technology with QR codes to enhance textbook learning experiences. By scanning a QR code, students can instantly access interactive 3D models via a web browser—without requiring additional applications. The system is developed using A-Frame, AR.js, and WebXR API, ensuring smooth rendering and real-time interactions like pinch-to-zoom, swipe-to-rotate, and tap-for-info. This paper discusses the implementation, advantages, and impact of WebAR-based learning compared to traditional and app-based AR solutions. Augmented Reality (AR) has revolutionized educational experiences by providing interactive, immersive learning environments.

Keywords—*Augmented Reality (AR), WebAR, QR Codes, Interactive Learning, A-Frame, Educational Technology.*

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I. INTRODUCTION

Education has evolved with digital tools, yet textbooks remain largely static, making it difficult for students to visualize complex scientific concepts. Augmented Reality (AR) enhances learning by making abstract topics more interactive and engaging.

However, most AR applications require dedicated software, which limits accessibility. This project proposes a WebAR-based system, where students scan QR codes in textbooks to instantly access 3D educational models in a web browser. The system enables students to interact with 3D objects without requiring any app installation, bridging the gap between traditional and digital learning.

➢ *Objective*

The main objective is to bridge the gap between textbooks and interactive learning using QR codes by creating and evaluating a system that utilizes augmented reality technology to improve the learning experience for students with real-world experience of the book. This paper delivers a high quality of education content that enhances the critical thinking of the children and young minds by developing innovative and interactive platform for education using AR.

This project enhances the student engagement through interactive 3D learning experiences, which eliminates the need for app installations by using WebAR technology. It enables real-time interaction (zoom, rotate, and retrieve information), that improves the accessibility by ensuring compatibility across devices and browsers.

II. LITERATURE SURVEY

Rajath K, Rohith R Kashyap, Sindhu K, Roopesh Reddy C [1] developed a mobile application featuring different subsections, such as the solar system, human anatomy, and the skeletal framework using AR technology, where students can visualize these sections as 3D models using the mobile application.

Senthil Kumar Jagatheesaperumal, Kashif Ahmad, AlaAl-Fuqaha [2] provides an overview of metaverse - based educational applications focusing on education, training, and skill development and analyzes the technologies they are built upon.

Marian Vladuț TOMA, Cristina Elena TURCU [3] proposed a solution that connects learning materials with the technologies that students use every day can lead to a better understanding and involvement in the classroom.

Amareshwar Karatagi, Babu Peter R, Chinnareddy Geetha sai, Manjula R Bharamagoudra, Palem Niharika [4] developed a technique which involves 3D learning that aids the learning process and provides greater impact for the children, which helps them to remember the facts and concepts they learned.

Chi-Yi Tsai and Yu-Cheng Lai [5] proposed an augmented reality (AR) logic programming teaching system that combines AR technologies and game-based teaching material designs on the basis of the fundamental concepts for seventh-grade structured programming. This system was served as an articulation curriculum for logic programming.

Pallikonda Subhashini, Raqshanda Siddiqua, Aitha Keerthana, Pamu Pavani [6] have utilized AR technology to provide interactive and fascinating learning experiences by developing and application, when the application is focused on image or text, it generates a 3D model or video on the smart phone screen. It also gives some assistance as a graphical guide for encouraging them to understand the complex concepts.

Fatima Zulfiqar, Rehan Raza, Muhammad Owais Khan, Muhammad Arif, Atif Alvi, Tanvir Alam, [7] they surveyed and discusses the concept of AR and its types, the need for AR applications in education, analyzed various state of the art AR applications in terms of platform, augmented virtual content, interactions, usability, usefulness, performance, effectiveness, and ease-of-use under a single taxonomy.

Fridolin wild, Christine Perey, benedict Hensen, Ralf Klamma, [8] have defined a IEEE standard ARLEM which was developed with a help of a reference implementation, MIRAGE XR, to demonstrate how real-life training applications can be created and edited using an AR editor for learning experiences. With this ARLEM and Mirage.XR, standardized and interoperable learning content cab be created and exchanged.

Compared to prior research in the field of AR based Education, our project addresses certain issues and limitations where students has to download and update the apps which leads to limited usability and less interactivity. Moreover those apps are platform dependent and has limited gestures controls.

The proposed project encounters the limitations by using QR codes for instant access to 3D models which supports WebAR for app-free, browser-based learning that enables real-time interactions for better engagement.

III. IMPLEMENTATION

The proposed project consists of three modules, 3D educational model creation, loading on cloud based hosting platforms such as Firebase, Github pages and each model is link with the QR code embedded on the book, by scanning the QR codes students visualize the models that are embedded in the real world

The Fig.1. represents the implementation process of this project which involves developing an interactive WebAR-based learning system that integrates QR codes and 3D visualizations into textbooks. The first step is creating 3D educational models, such as a solar system, using Blender, and optimizing them in GLB/GLTF format for WebAR compatibility. These models are then uploaded to a cloud-based hosting platform like Firebase, GitHub Pages, or Google Drive, ensuring seamless access across different devices.

To enable easy access, QR codes are generated and embedded into textbooks, each linked to a specific WebAR model. When scanned, the QR code redirects students to a WebAR page, where they can interact with 3D models directly in their browser. The system is built using A- Frame, AR.js, and WebXR API, allowing users to engage with features like pinch-to-zoom, swipe-to-rotate, and tap- for-info without requiring any additional software installation.

Finally it involves testing and optimizing the system for performance, accessibility, and user engagement. WebAR ensures compatibility with multiple browsers, making it an effective and scalable solution for enhancing textbook- based learning.

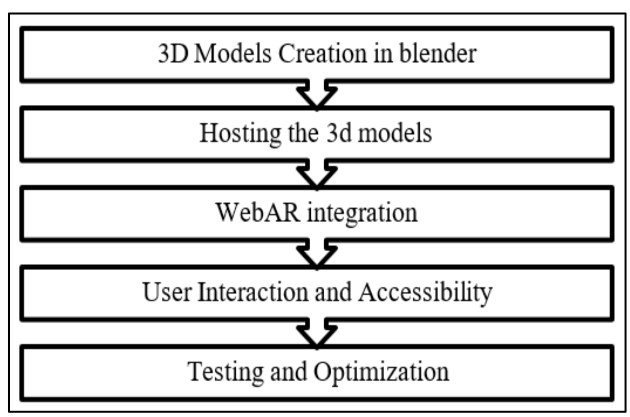

Fig 1: Implementation Architecture

The Fig. 2 Represents the project work plan where the teachers Assists the students to scan the QR code and experience the AR Content in the real world.

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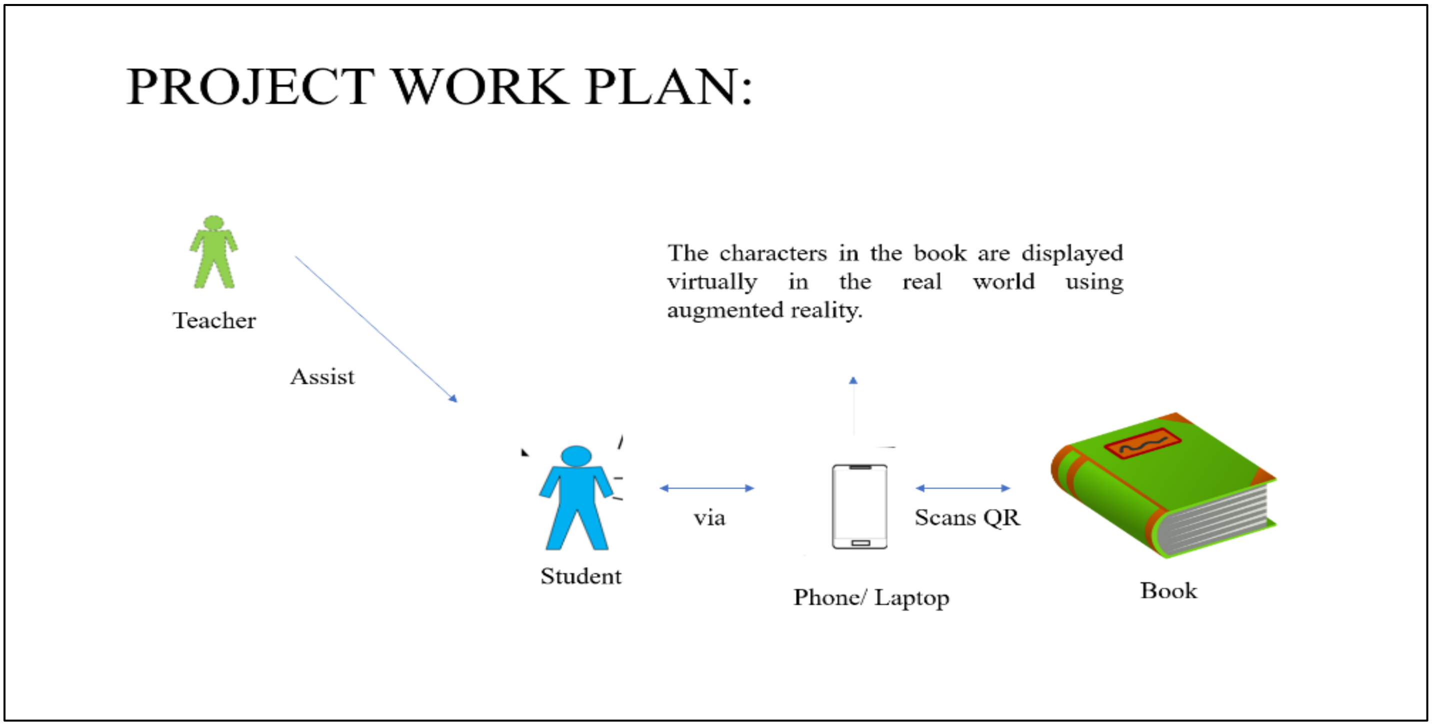

Fig 2: Work Plan

The Fig. 3. represents the creation of 3D models using blender, and optimizing them in GLB/GLTF format for WebAR compatibility. To enhance realism and engagement, high-quality textures (images) are applied to the models, ensuring that planetary surfaces, colors, and details closely resemble their real- world counterparts. Additionally, animations are incorporated, such as planetary rotation and orbiting motions, to create a more dynamic and immersive experience.

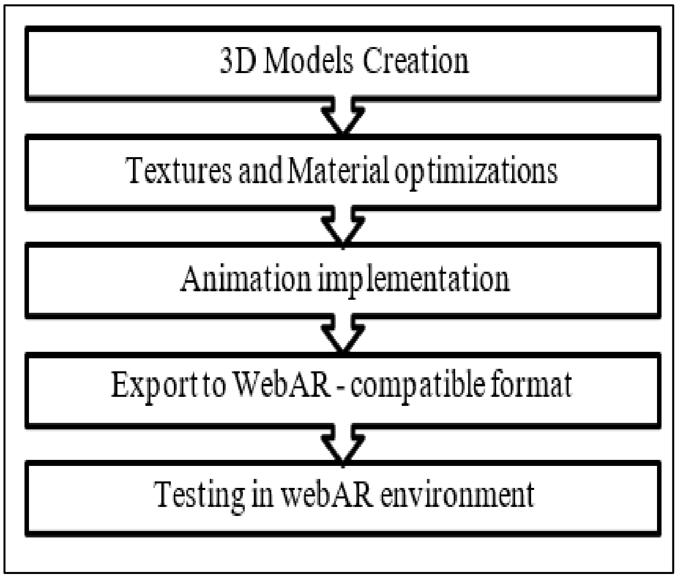

Fig 3: 3D Model Creation Architecture

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The Fig. 3A. and Fig. 3B. represents the output of 3D model creation.

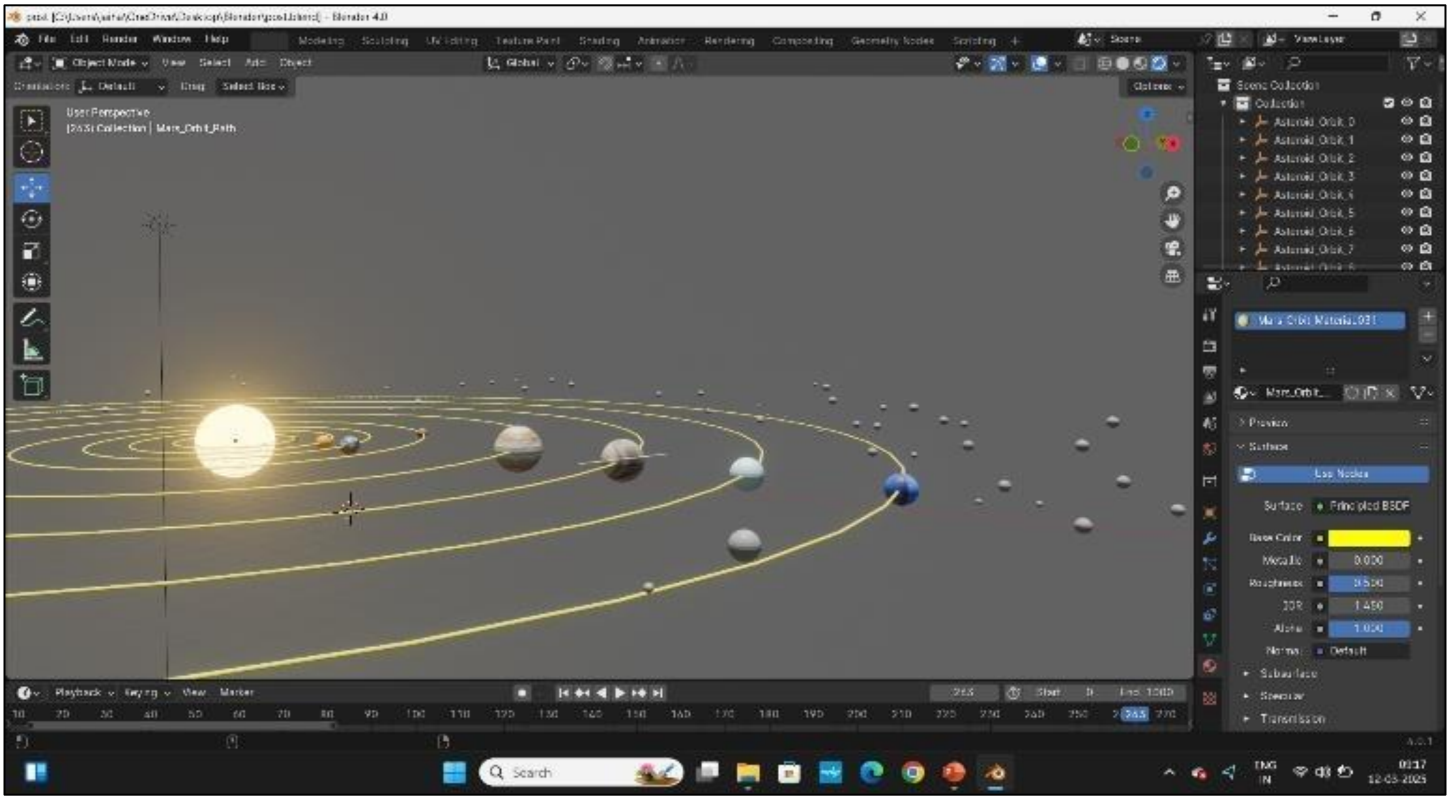

Fig 3(A): 3D Model Creation

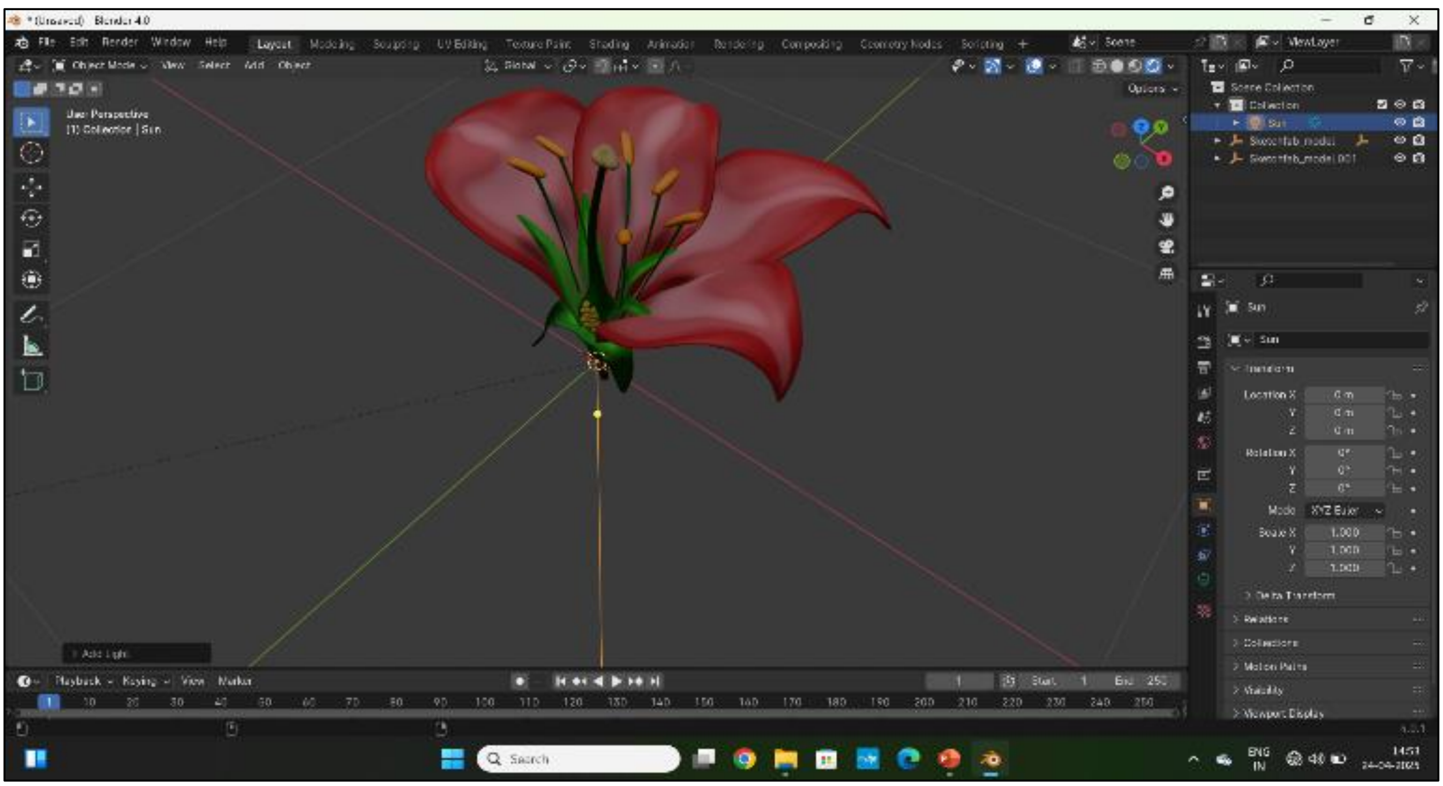

Fig 3(B): 3D Model Creation

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Fig 3(C): 3D Model Creation

The Fig. 4. represents the development of WebAR page, which focuses on making the augmented reality content accessible through a web-based platform. The first step involves selecting a suitable WebAR framework, such as A-Frame or Google Model Viewer, which allows for seamless rendering of 3D models in a browser without requiring additional software installations. Once the WebAR platform is chosen, the optimized GLTF/GLB models created in the previous module are uploaded to a hosting service like Firebase, GitHub Pages, or a similar cloud-based platform. This ensures that the models can be accessed from any device with an internet connection.

After hosting, a web page is developed where the 3D models can be displayed interactively. This webpage integrates A-Frame or Model Viewer, allowing users to interact with the AR models through gestures like pinch-to-zoom, swipe-to-rotate, and tap-for- information.

The page is then linked to a QR code, which is generated and printed on educational materials such as textbooks. By scanning the QR code, students can instantly view and interact with the 3D models in their web browsers, eliminating the need for separate AR applications.

To ensure a smooth user experience, the WebAR page undergoes testing and optimization. Compatibility across different browsers and devices is checked to avoid performance issues. Additionally, rendering speed and interaction fluidity are optimized so that students can engage with the content effortlessly. The result is an accessible and immersive learning experience, making complex topics more engaging and interactive.

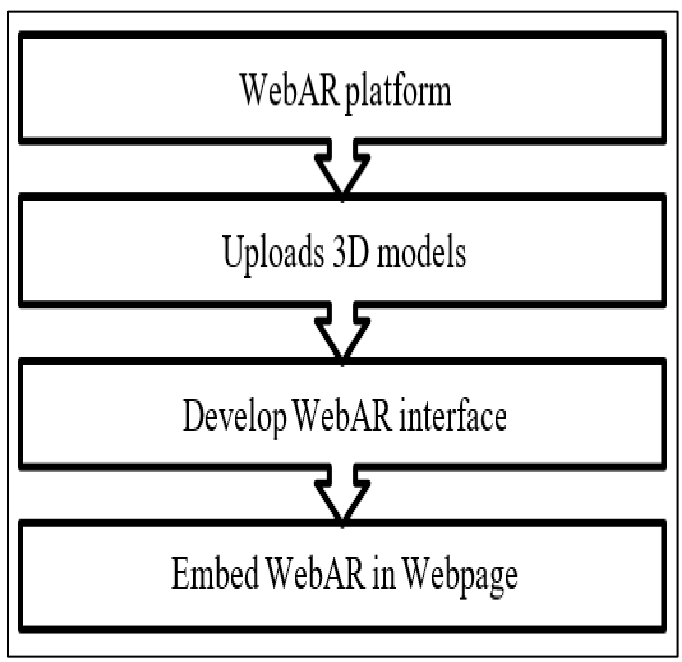

Fig 4: WebAR Page Development Architecture

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The Fig. 4A. and Fig. 4B. represents the output of WebAR page development

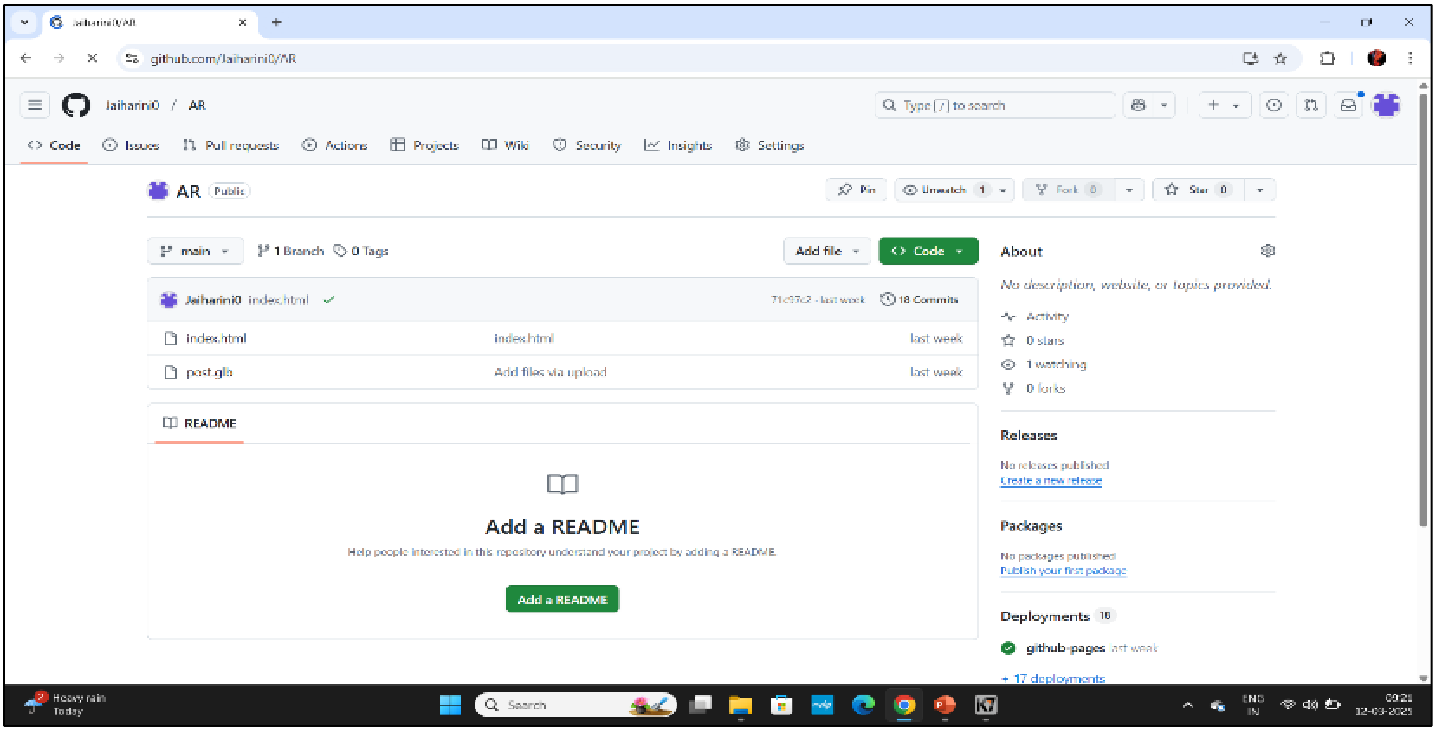

Fig 4(A): Uploaded 3D Models

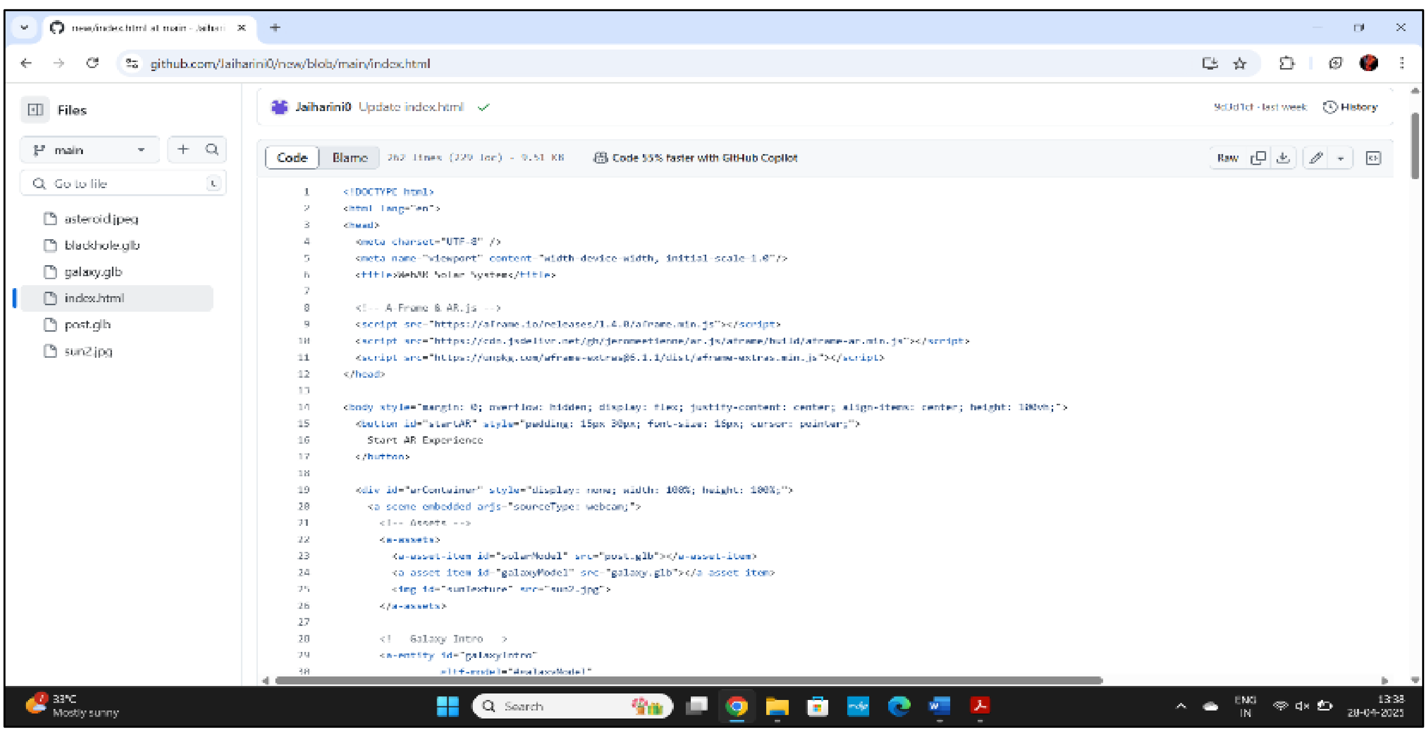

Fig 4(B): Developing AR Content

The Fig.5. represents QR code generation which is responsible for linking the WebAR content with physical learning materials through QR codes. The process begins with generating unique QR codes that correspond to the WebAR pages hosting the 3D models. Each QR code is programmed to redirect users to a specific WebAR link when scanned with a smartphone or tablet.

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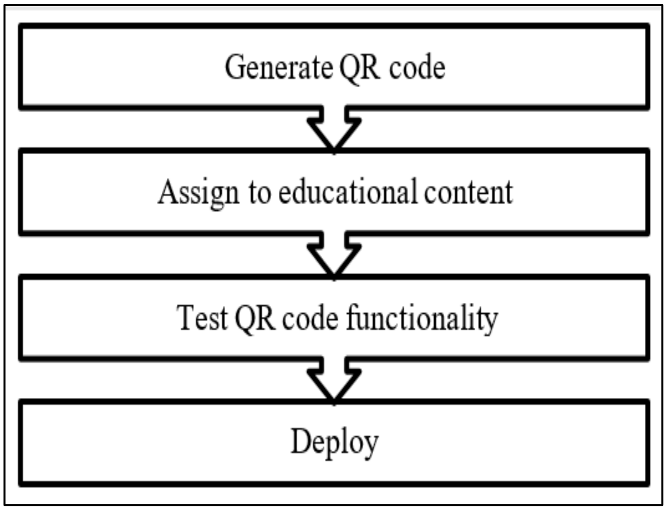

Fig 5: QR Code Generation Architecture

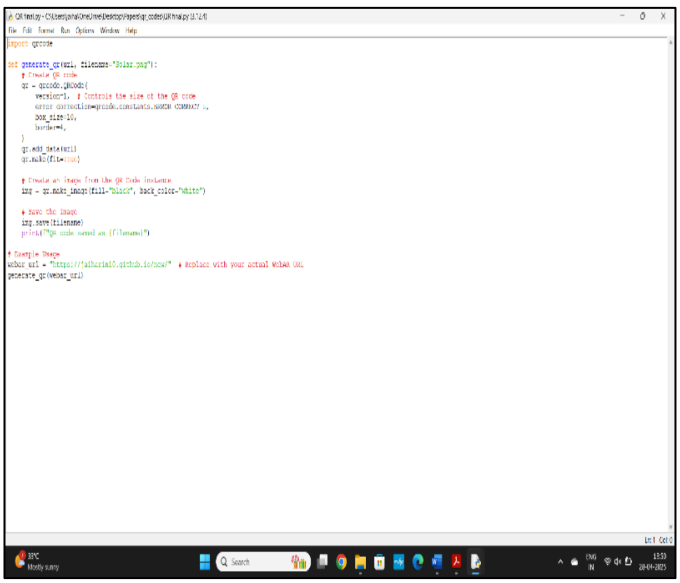

Fig 5(A): Python Script for QR Code

Fig 5(B): QR Code

Once the QR codes are generated, they are strategically placed within textbooks, worksheets, or other educational resources. The placement is done in a way that ensures easy access and usability, usually next to relevant topics where the 3D models enhance comprehension. For example, a QR code next to a chapter on the solar system will direct students to an interactive AR model of planets, allowing them to explore their structure, rotation, and relative positions.

To maintain accessibility and compatibility, the QR codes are tested across multiple devices and browsers to ensure smooth redirection to the WebAR content. Additionally, design considerations such as size, contrast, and scanning distance are optimized to make the QR codes easily readable.

By integrating QR codes into traditional learning materials, this module bridges the gap between physical textbooks and digital interaction, providing a seamless way for students to engage with interactive 3D content without the need for external applications. This approach enhances learning by offering a hands-on, immersive experience, improving student engagement and comprehension.

Whenever the QR codes are scanned, it directs to the webpage where the WebAR loads the 3D models and place it in the real world.

IV. RESULTS

The implementation of the WebAR-based interactive learning system has demonstrated significant improvements in student engagement and comprehension. By integrating QR codes with WebAR**,** students can seamlessly access interactive 3D models without the need for additional applications. The use of Blender- created models with realistic textures and animations enhances visual learning, making abstract concepts more tangible.

The Fig. 5. Represents the Interface of the WEB PAGE, when the children clicks the button, the AR content is loaded and rendered in the real world using Marker-less AR technology.

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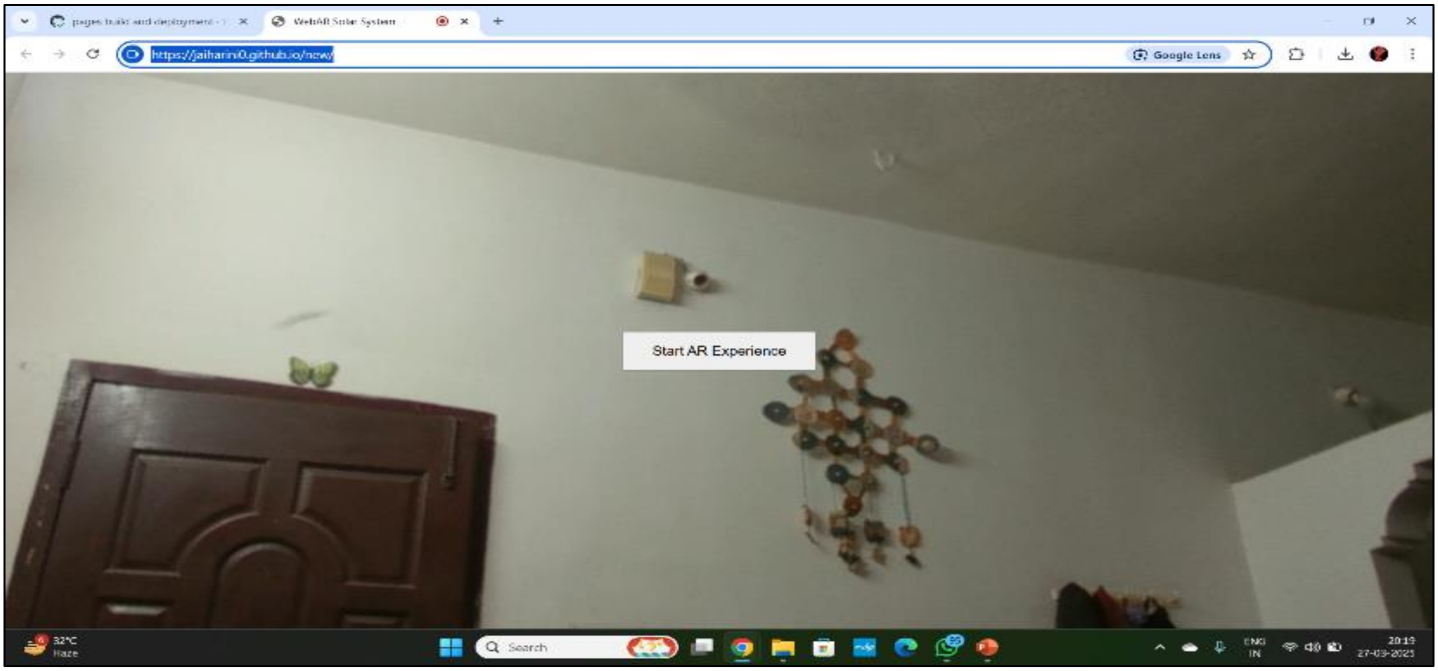

Fig 5(C): Web Page

The Fig. 5A. and Fig. 5B. Represents the Solar system with textures and animations applied. It shows further details and labels on the top when the objects are tapped, we can take quiz, listen to the voiceovers and we can zoom it in and out.

The Fig. 5C. and Fig. 5D. Represents the Hibiscus and Anatomy models with labels and animations on tapping each parts of the models.

Fig 5(D): Solar System Model

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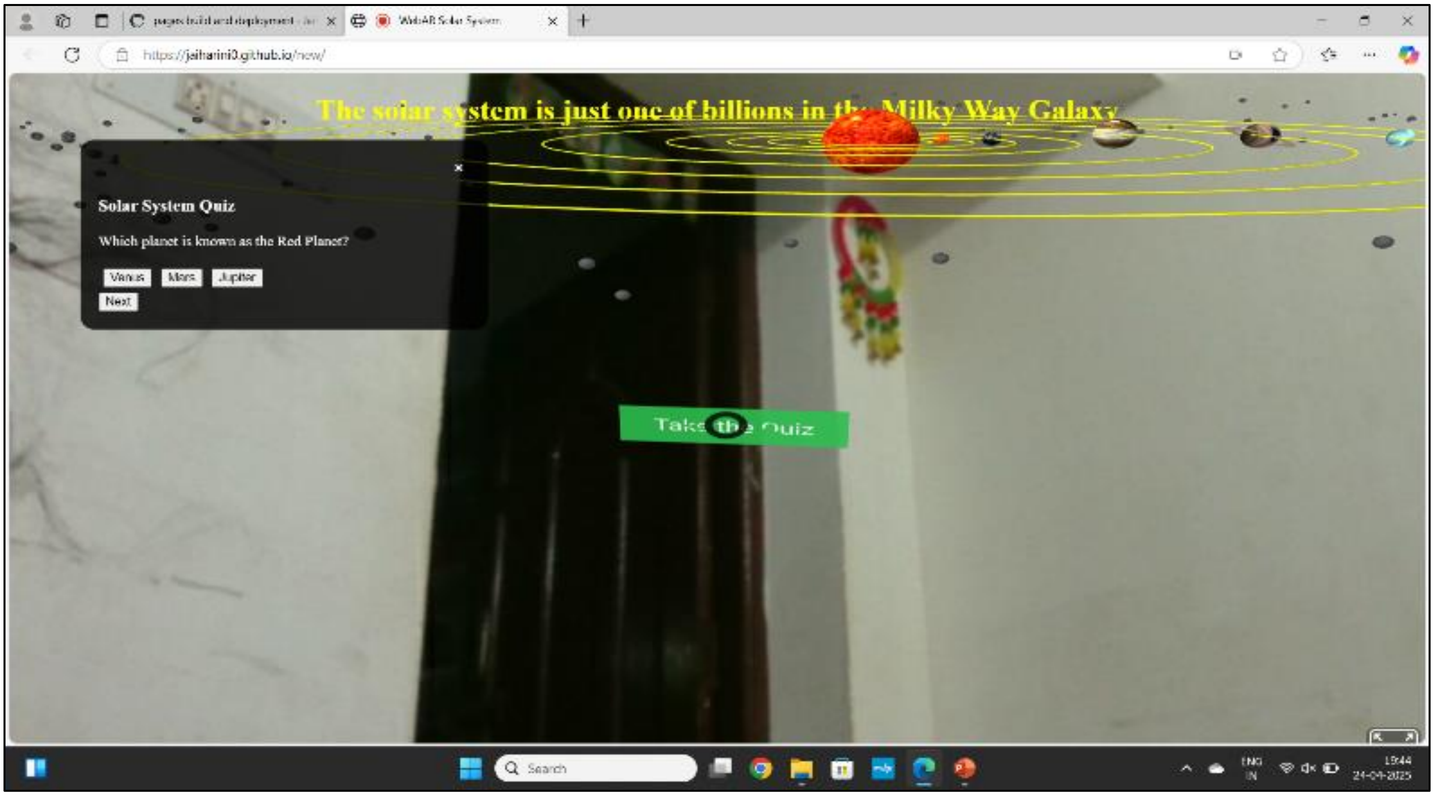

Fig 5(E): Solar System With Quiz

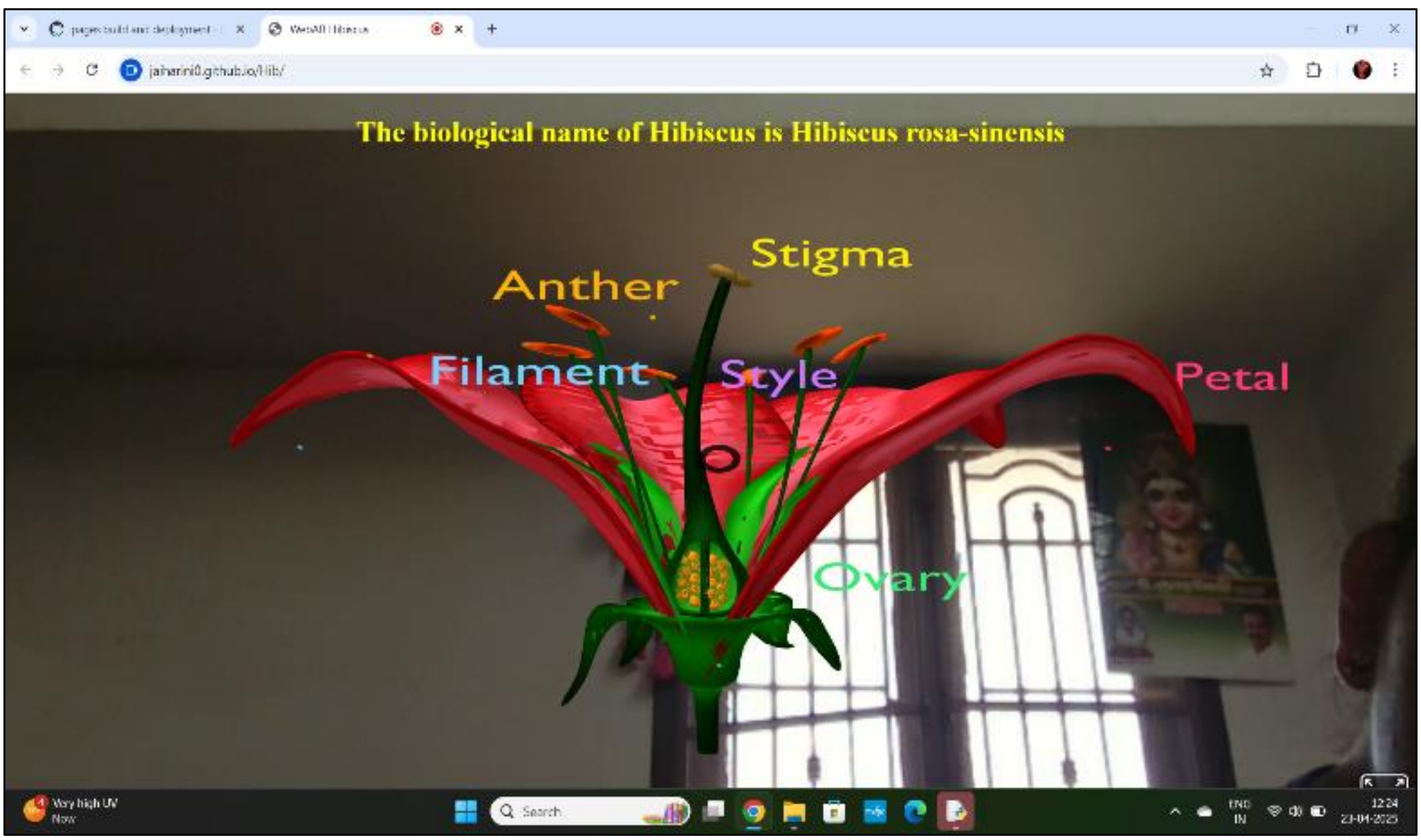

Fig 5(F): Hibiscus Model

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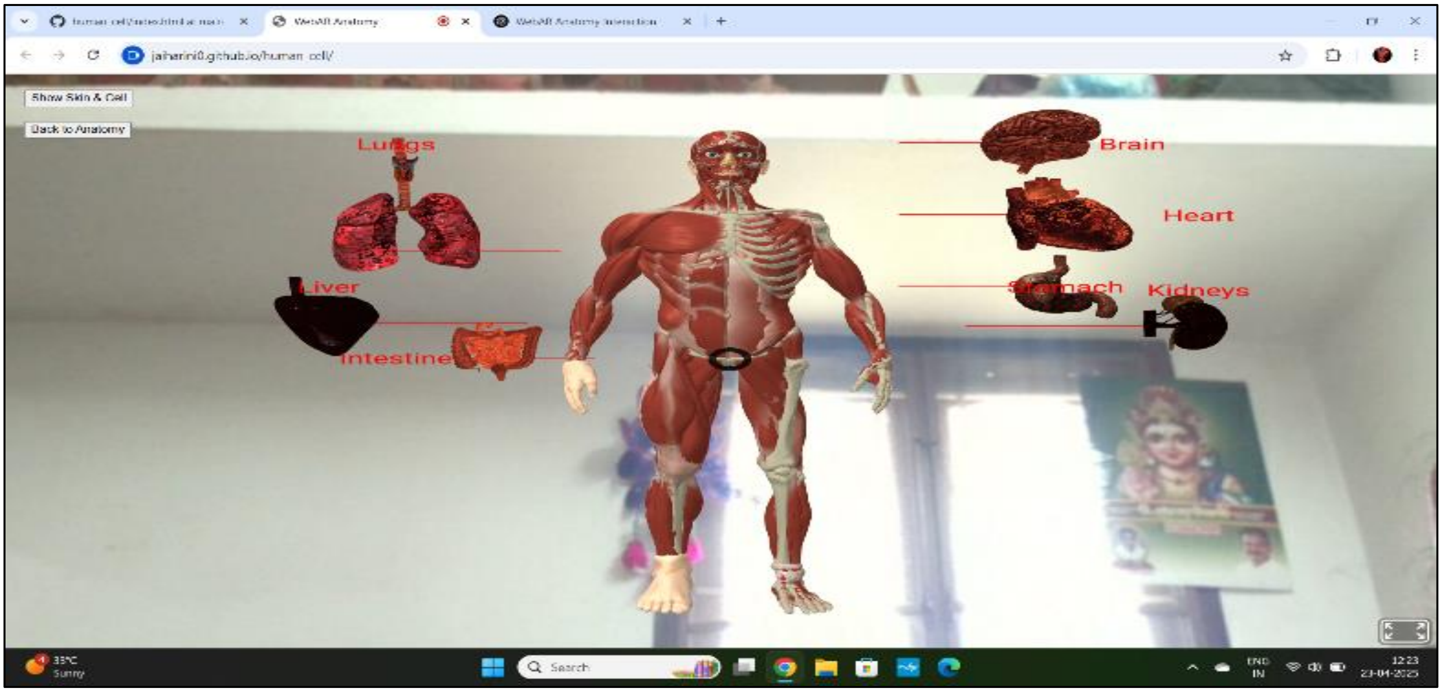

Fig 5(G): Human Anatomy Model

The results of this project indicate a significant improvement in the way students engage with educational content. For example, when studying the solar system, students traditionally rely on textbooks and static images**,** which often make it difficult to understand concepts like planetary orbits, rotation, and scale differences**.** With the integration of WebAR and QR codes**,** students can now scan a QR code in their textbook and instantly interact with a 3D solar system model in their web browser. They can zoom in on planets, rotate them for different perspectives, and tap on each one to view additional information. This hands-on experience makes learning more engaging, interactive, and visually immersive**.**

During testing, students found it easier to grasp the relative sizes and positions of planets compared to traditional learning methods. The addition of realistic textures and animations**,** such as planets orbiting around the sun, created a more lifelike experience**,** helping students retain information more effectively. The system was also tested across different browsers and devices, ensuring smooth performance and accessibility without requiring any app installations. Overall, the WebAR-based learning approach proved to be a scalable, efficient, and highly engaging educational tool.

V. CONCLUSION

Augmented Reality (AR) has become an increasingly powerful tool in education, transforming traditional learning methods into interactive and immersive experiences. This project successfully integrates WebAR technology and QR codes, enabling students to access realistic 3D models of complex subjects such as the solar system and human anatomy directly from their textbooks. Unlike traditional AR applications that require separate software installations, this WebAR-based approach ensures seamless accessibility, allowing students to interact with dynamic, high-quality models through a simple QR code scan in their browser.

The integration of AR-based learning significantly enhances engagement, comprehension, and retention by making abstract concepts more visually tangible. Features like pinch-to-zoom, swipe-to-rotate, and tap-for-info provide an intuitive way for learners to explore educational content in a hands-on manner, fostering better understanding than static textbook illustrations. The addition of realistic textures and animations further enhances the visual appeal, making learning more interactive and enjoyable.

Today, AR is revolutionizing various industries, including education, healthcare, retail, and manufacturing. In education, AR is widely used in virtual labs, historical reconstructions, medical training, and language learning to provide students with real-world simulations and immersive environments. Universities and schools are adopting AR-based tools to create interactive classrooms, while online learning platforms integrate AR to enhance remote education. The growing adoption of WebAR removes the dependency on high-end devices, making interactive learning accessible to a broader audience.

This project demonstrates that AR-powered learning can bridge the gap between traditional and digital education, offering a scalable and efficient solution for students and educators.

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FUTURE SCOPE

Future advancements will focus on expanding the WebAR content library, improving compatibility with lower-end devices, and conducting large-scale research to measure the long-term impact of AR-based education. As AR technology continues to evolve, its integration with artificial intelligence (AI), machine learning (ML), and virtual reality (VR) will further enhance personalized learning experiences, making education more engaging, accessible, and effective worldwide.

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