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Augmented Reality based DNA Learning: An Innovative Educational Tool for Students

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Abstract: With the advancement of technology, augmented reality (AR) has been used in almost every field of life, including entertainment, education, medicine, engineering, etc. The use of AR in education may overcome a lot of student problems related to traditional learning systems, like lack of interest, motivation, curiosity, attention, concentration, and learning effectiveness. During this research, we developed an AR app named "AR-DNA" for school level students to learn about DNA structure and its nitrogenous bases in an interactive and interesting way which overcome the challenges of traditional learning system. Three-dimensional models of the DNA helix, adenine, cytosine, guanine, and thymine were added to provide detailed knowledge about their molecular structures and increase the visual perception of students. For the development of AR-DNA, Unity 3D and the Vuforia SDK have been utilized. Vuforia uses the device's camera to take live video and to detect markers. After marker detection, the exact position of the marker has been tracked, and its pose (6 degrees of freedom – 6DOF) has been calculated, based on which computer-generated effects will be rendered and shown on the device screen. AR-DNA app focuses on two factors, namely, learning and assessment. For learning, marker-based AR technology has been implemented using Vuforia, whereas for assessment, interactive questions have been developed. AR-DNA was tested on 500 students of eighth grade from 20 different schools of Multan. Student feedback indicated strong support for the AR-DNA app, with 80% of students strongly agreeing it boosted motivation, 70% finding it aesthetically pleasing and transformative, while 60% strongly affirmed its effectiveness in sustaining interest and enhancing learning. Moreover, 70% believed AR apps offered a solution to common issues in traditional learning system. Results clearly suggest that the integration of Augmented Reality in education improves the effectiveness of the learning process.

Keywords: Augmented Reality technology, Education, Unity 3D, Vuforia SDK, Mobile Application.

1. Introduction

Augmented reality (AR) is an immersive technology that enriches the physical world with virtual data. Unlike virtual reality, it does not move the user away from reality, whether it combines the real world with a virtual world generated by computer-generated graphics, video, audio, etc. AR enriched world is too immersive that it captures the interest of users for maximum hours. According to Ronald T. Azuma, AR is a technology that has three basic features: 1. Combines real and virtual world, 2. Co-relates in real time, 3. And operates in 3D [2].

Because of advancements in hardware and software technologies, the use of AR has become simple, and it is now used in almost every field of life, including tourism, medical, entertainment, surgery, manufacturing, maintenance, logistics, education, and so on. The use of AR in education can produce the best results. One of the main problems, with our education system is that it's too boring, and doesn't grab the students' attention. Students perceive our educational system as putting additional strain on their minds as shown in Figure 1. Due to this, they cannot learn new things effectively. The use of technology, especially

AR, in the education system can create a fun-learning environment. This fun-learning environment, engages students' concentration, due to which students can learn effectively [8].

Figure 1. (a). Education without AR, **(b).** Education with AR. [8]

Two main traits that an education system should inculcate in students are imagination and curiosity. These two traits can change students' thinking patterns [3]. With these traits, one can think about the laws of the universe, ask questions about these laws, and discover any hidden aspect of our universe just like Newton discovered the concept of gravity. At first, he was just curious: Why do apples fall towards the ground? And this curiosity leads to the concept of gravity. So, these traits play an integral role in the development of our thinking patterns. One of the simplest ways to instill these traits in our students is through AR. So, AR should be integrated in education.

In this study, a marker-based AR Android application for school level students was developed. The main purpose of app was to provide the information about the structure of DNA and its nitrogenous bases in an interactive way. Unity 3D platform and Vuforia SDK was used for development of app. For marker development, Adobe Photoshop was used, and the marker was added in the Vuforia database. On scanning marker, students can visualize interactive 3D models and hear audio according to those models. This app provides an interactive and engaging environment for students to learn effectively.

The term "augmented reality" comes from the word "augmentation," which means "to improve or add value". Augmented reality has the ability to enhance our real world. It can make our reality too attractive and captivating with the help of computer-generated objects. It can turn our imaginations into reality. It's a technology to combine real world with virtual content. It generates an attractive augmented world, which we call "augmented reality" [1].

Figure 2. (a). Marker-based AR, **(b)**. Location-based AR, **(c).** Projection-based AR, **(d).** Superimposition-based AR. [18]

There are four types of AR techniques: marker-based AR, marker-less AR, projection-based AR, and superimposition-based AR as shown in Figure 2. In marker-based AR, computer-generated content

augments the physical pages, these pages are known as markers [15]. Marker-less AR maps virtual content in real-world environment with the help of advanced sensors, complex mathematics, and a camera, for example intersection points, a wall's location, etc. Marker-less AR maps and stay virtual content without any image. It uses GPS sensors, an accelerometer, a digital compass, and many other advanced technologies to map virtual content at a defined user location. Marker-less AR is also known as location-based AR. Projection-based AR uses a light and laser sensor to project virtual content on any surface, object, etc. Superimposition-based AR, superimpose Virtual content on a physical 3-dimensional (3-D) model or in 3-D space gives a realistic look to objects [9],[10],[18].

AR has the ability to transform our education system from dull to exciting as a result of these exciting features. Many researchers have proven that AR has ability to enhance the quality of education. AR allows students to visualize their imaginary concepts, which in turn helps them gain knowledge of new concepts more easily. AR not only helps professional students, but it also has the ability to change the way of learning, which helps every student from his childhood to professional life [8].

Various marker-based AR applications have been developed to help students learn different concepts easily. A review of some AR applications that help different grade levels of students from kindergarten through high school is given below.

There are a lot of AR applications designed for kindergarten children to help with basic learning. One such app, Animal Vocabulary, was created by Koca, B. A., ubukçu, B., and Yüzgeç, U. Animal cards were used as markers, on marker detection, 3D models of animals with their voices were shown. For the detection of markers and augmenting 3D models on cards, the Vuforia SDK (software development kit) was used, and an application was developed in Unity 3D [10]. To mitigate the fear of math and increase the learning efficiency, an AR application for learning basic counting concepts in math was developed, which increases the learning efficiency by twofold. This game consists of two modules, learning module and assessment module. Learning module based on Marker-based AR technology where numerical digits from 1-9 act as marker and 3d objects visualize on marker according to the count of that numeric digit. In the assessment module, there is a quiz on basic counting. This game assessment encourages the use of such games as school curriculum [13]. An interesting AR application was developed for children to learn Hijaiyah letters. This application is based on marker-based AR technology and has two features. One helps in learning and memorizing the shape of the Hijaiyah letter, and the other is the sound of the Hijaiyah letter. This application uses virtual buttons over the marker to listen to the pronunciation of Hijaiyah letters. For children, it's an appealing way to use the AR application for learning Hijaiyah [16]. For adding fun and entertainment to traditional coloring experience, AR is one the best way. One such app was developed by Clark and Dunser, in which the colors of a virtual model change as the color of a marker changes. Their prototype is based on three main phases: first, color removal; second, image registration; and third, texture extraction. The feedback for the app was overwhelmingly positive [6].

For memorizing difficult concepts from primary to high school, AR plays an important role. To teach astronomical concepts in an interesting way, an AR application for students was developed. This application has 2 modes: the first mode is a 3D view of solar system planets, their cross-sections, and textual information with the help of marker-based AR technology, while the second mode is for celestial bodies. Celestial bodies are lined with alphabets, and as students choose any letter of the alphabet, a virtual pupil narrates about that celestial body whose name starts with that alphabet. This application not only helps students get interesting information about the solar system, but it also develops curiosity, cognitive skills, motivation, and creative initiative among students [14]. AR has the ability to help students learn and get information related to lab experiments in chemistry, physics, and biology without performing them in labs. Among lab experiments, chemistry lab work is one of the biggest concerns for many institutions because of the hazardous chemicals that can cause explosions, chemical burns, etc. ARChemX is one such app that not only helps students learn the behaviors of different chemicals, but it's also safe. It also speeds up the chemical reaction and saves the time of students and teachers. It physically all the pouring and shaking activities that the students perform during the lab work and virtually overlay the reaction of the experiments. On testing ARChemX, researchers get positive feedback [11].

Researchers integrate AR technology in university education to explore the capabilities of AR and find overwhelming results. They determine the connection between interest, usability, presence, emotional investment, flow and focus of attention among university students learning science concepts using AR.

Results showed that an AR app with realistic objects and environment can easily capture students' attention and their perception about reality to generate flow in participants, which promotes the experience of being present, focus of attention, emotional investment, flow, and interest. Emotional investment helps in sustaining focus and level of attention while usability directly links with interest. Hence, AR applications with real-life situations and realistic visual effects and interactions should be encouraged among all levels of schooling [17].

AR technology also helps in professional training. One such training is cardiopulmonary resuscitation (CRP) training, which is lifesaving when someone's heartbeat stops due to cardiac arrest. Traditional CRP training is costly and not practical for mass training. It limits the trainee in both time and space, which is hectic for most of the trainees. Boonbrahm et al. developed a marker-based AR application connected with eye-goggles for CRP training. The specifications of app include realistic look of patient, location of hand on chest of patient, pressure on chest, number of compressions per minute on chest and status of activity. They used two markers (1st marker on floor and 2nd on above the hand) and a pillow for pressing. Trainee place 1st marker on floor besides that marker pillow is placed, where trainee gives pressure using hands and above hand 2nd marker is placed. The distance between the markers indicates the level of pressure on the chest (pillow). Eye googles provides a realistic view of patient instead of pillow which helps in better learning. Results indicate that the system is easy to use and helps in the practical training of mass trainees [4]. Flow of CRP app is presented in Figure 3.

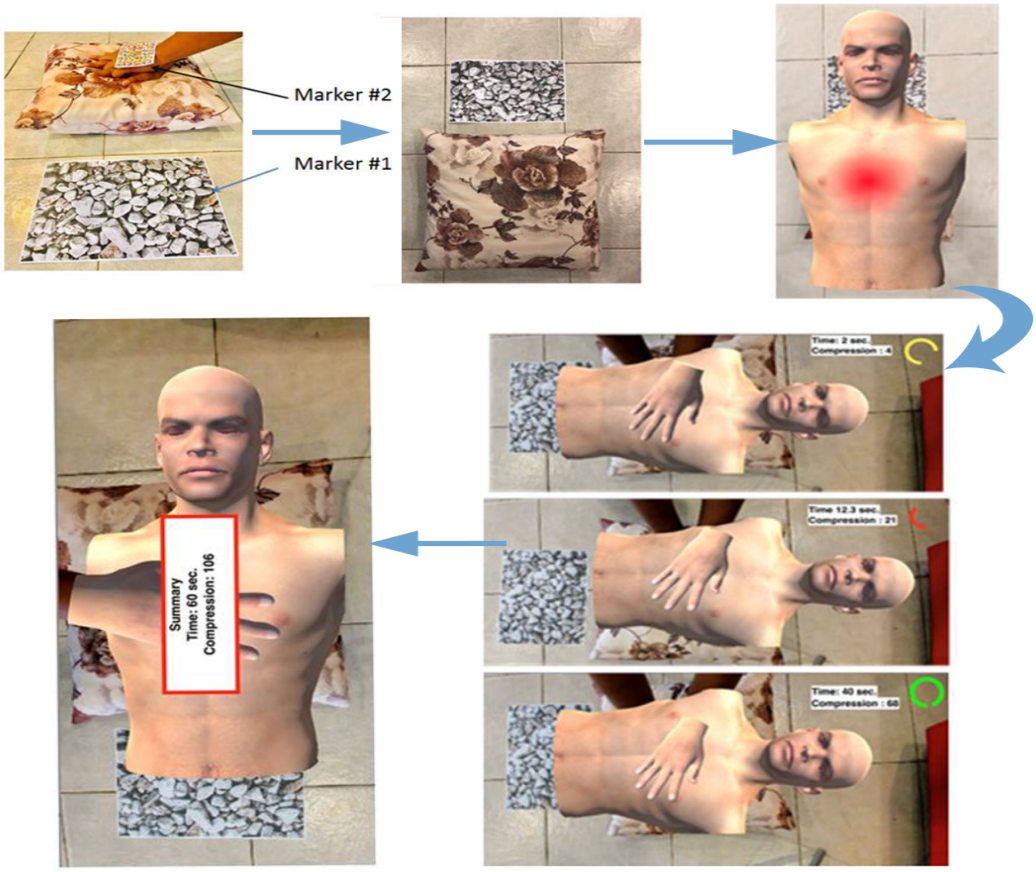

Figure 3. Flow of AR app for CRP training [4]

Review of Marker-based AR applications shows the potential of AR technology in educating students. Our focus during this research was on DNA structure and augmented reality technology, specifically marker-based AR. We also consider assessment of students' learning, which is mostly ignored in most of the AR apps. So, our app named "AR-DNA" has two main phases. First is learning about DNA with realistic 3D models of DNA, nitrogenous bases, etc. The second phase is for the assessment of student knowledge, for which multiple interactive questions were designed. The next section elaborates and describes the development of the AR-DNA app.

2. Materials and Methods

For the development of AR-DNA, the Unity 3D game engine and Vuforia SDK were utilized. Unity3D is one of the best platforms for creating video games, simulations, and computer-generated effects. Vuforia is a software development kit that can easily integrate computer vision functionality with applications, allowing them to recognize real-world objects and overlay information in a real-world environment. The flow diagram of the Vuforia SDK is shown below in Figure 4 [19].

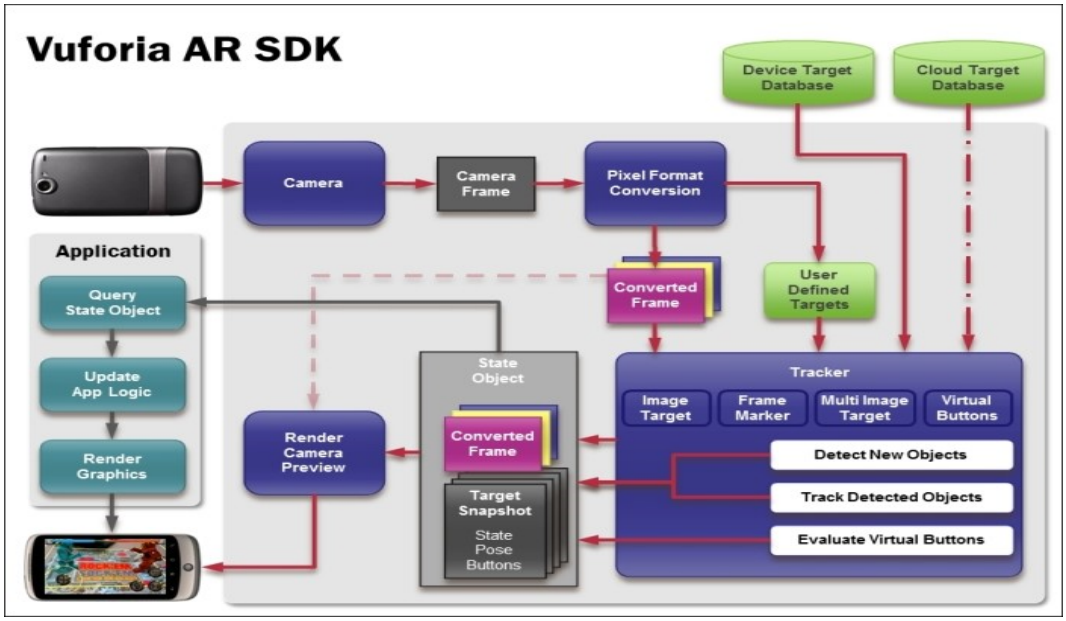

Figure 4. Flow diagram of Vuforia SDK [19]

Vuforia SDK is divided into 3 modules, i.e., input module, tracking module, and render output module. Input module consists of Camera and Image Capturing Module. Live video is fed into a camera, which inputs it to an image capture module that analyses each and every frame of video and converts it into a digital image. The tracking module detects markers and matches its feature points with Vuforia's database. On exact marker detection, the position of the marker tracked and its pose (6DOF – 6 degrees of freedom) have been calculated. Then the rendering module, renders computer generated objects over the original marker using a calculated pose, which displays on the screen of the mobile device [15].

2.1 AR DNA app development

For development of AR-DNA app, marker-based AR approach was used. Elements for graphical user interface (GUI) and Marker (Target image) of the app were developed using Adobe Photoshop. To initiate app development, a project was created in Unity 3D and vuforia SDK was added to this project. Marker of DNA was added into Vuforia database. Three dimentional models of DNA and its nitrogenous bases were imported to the unity project. To add user interaction within the app, scripting was done using visusal studio. AR-DNA has two modules,

Learn (Learning Phase)

Quiz (Assessment Phase)

Menu Screen of AR-DNA is shown in Figure 5.

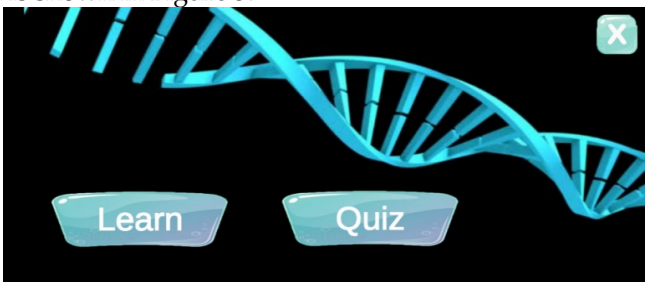

Figure 5. Menu Screen of AR-DNA app

2.1.1 Learning Phase

Learning phase was developed for getting information about DNA with the effects of AR. Marker-based AR technology was used for development. It uses a camera to recognize a target image (marker) and then overlay computer-generated content over that marker. Figure 6 shows the app marker and Figure 7 is about the Unity3D environment.

Figure 6. Marker of AR-DNA app

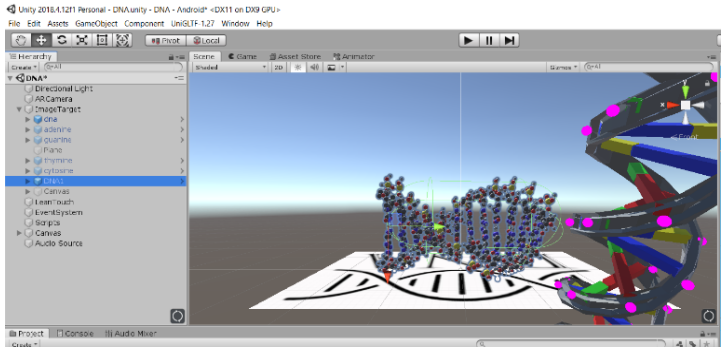

Figure 7. Unity 3D environment during development of AR-DNA app

As app starts, there comes two options – Learn and Quiz. In Learn module, camera continuously takes frames and sent to Vuforia SDK. Vuforia perform pixel transformation and match the frame pixels with Vuforia dataset. If frames got matched with dataset, then 3d model of DNA shown on the marker along with its voice. To provide detailed information about DNA, helical structure of DNA was added showing nitrogenous bases with the help of colored bands. Moreover, students can also explore 3D structures of nitrogenous bases (adenine, guanine, cytosine and thymine) and their chemical formulas using interactive buttons. Figure 8 shows the screenshots of the learning phase of the AR-DNA app.

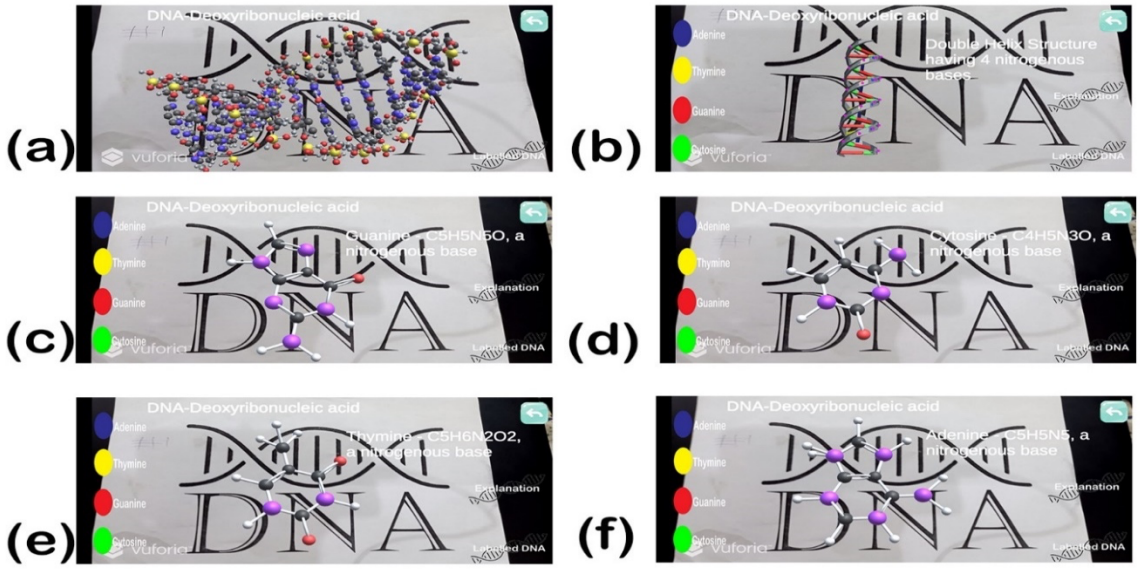

Figure 8. Screens of AR-DNA app Learning Phase **(a).** Visualization of DNA structure, **(b).** Detailed view of DNA structure, **(c), (d), (e) & (f).** Structure of Nitrogenous bases

2.1.2 Assessment Phase

An assessment phase was developed for determining the student output after using AR-DNA. This app has an interactive and interesting user interface that can easily attract the attention of students. Initially, 10 interesting questions about DNA having 3 options were developed. Students select an option depending upon that option GUI appears either for Right or Wrong answer. During all these scenes, we take care that the background is highly captivating. Screenshots of Assessment phase shown in Figure 9.

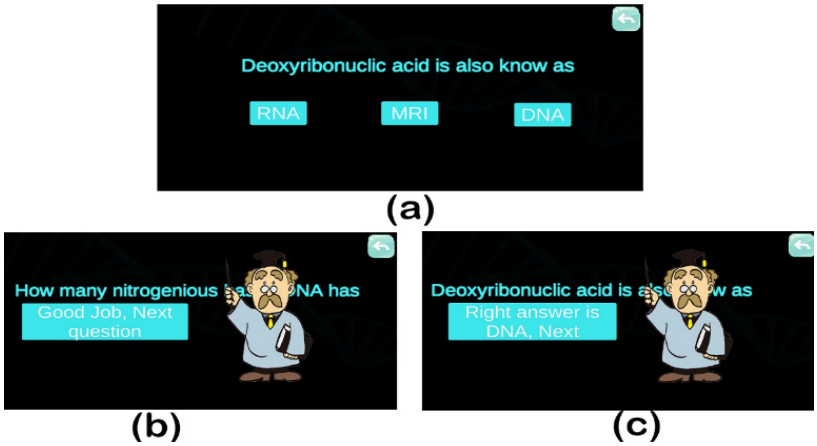

Figure 9. Screens of AR-DNA Assessment phase

2.2 Evaluation of AR DNA app

The developed AR-DNA app was evaluated in real-time to assess the potential of AR whether it helps students in learning new concepts easily or not. During evaluation phase, we visited multiple schools and engaged teachers in conducting interactive sessions on DNA structure using our app, "AR-DNA". Subsequent to these sessions, students were requested to provide feedback by rating comprehensive questionnaires. The questionnaires for the AR-DNA app primarily focused on eliciting qualitative feedback from students regarding their experiences. They assessed various aspects such as the app's likability, effectiveness in facilitating learning, sustaining interest, aesthetic appeal, comfort in learning via AR, curiosity levels, perceived changes in attitude towards learning, impact on motivation, enhancement in learning effectiveness, and its role in addressing issues in traditional learning systems. The questions were structured in alignment with usability principles, encompassing learnability, efficiency, memorability, error rate, and user satisfaction, ensuring a thorough assessment of the app's impact on students' learning experiences. These questions aimed to capture students' subjective perceptions and attitudes towards the AR-DNA app, offering insights into its multifaceted impact on their learning experiences and engagement.

Throughout the experiment, a total of 500 students participated, sourced from 20 different schools of Multan, all enrolled in the 8th grade. To mitigate potential bias in feedback collection, a strategic approach was implemented. Teachers were asked to select students based on their performance in an app assessment phase which focuses on comprehending DNA structure and nitrogenous bases. This method aimed to ensure a more objective evaluation by involving students who exhibited a strong understanding of the subject matter, thus minimizing potential bias in the feedback provided.

Notably, all students showcased proficiency in mobile device usage, utilizing them for activities like gaming and photography, showcasing their familiarity and ease with mobile technology. Due to this, no substantial challenges were encountered throughout the experiment. This familiarity contributed to their seamless engagement with the AR-DNA app during the experimental sessions. Consent was obtained from schools, teachers, and participating students, ensuring voluntary participation and respect for privacy to ensure ethical considerations.

The questionnaires developed for qualitative feedback were:

- Like the AR-DNA app.
- AR app helps you a lot in learning structure of DNA.
- AR app helps you to maintain your level of interest.
- AR-DNA app is aesthetically pleasing.

- You are comfortable to learn new concepts by using an AR app.
- Your level of curiosity increases with the use of AR-DNA app.
- Your attitude towards learning changes by using AR-DNA app. AR-DNA converts boring learning session to an interesting and interactive session.
- AR-DNA app raise your motivation.
- AR-DNA enhance your learning effectivity.
- AR-DNA is one of the best solution of problems that exists in traditional learning system.

3. Results

The Likert scale rating method was used with five options—Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. As 500 students were involved during the experiments, so we got 500 filled questionnaires' sheets. The number of students response towards a specific question shown in Table 1. We analyzed these questionnaires and calculate percentage of each response against every question. Figure 10 displays the highest percentage that each question obtained. The feedback of the AR-DNA app indicated a strong inclination towards the potential of AR applications in education, particularly highlighting the students' positive response towards the app. The questionnaires were designed to determine the psychological perspectives of the students towards AR education and AR-DNA app.

Table 1. Student's response against questionnaires

	Questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1.	Like the AR-DNA app.	350	50	50	50	0
2.	AR app helps you a lot in learning structure of DNA.	50	350	50	50	0
3.	AR app helps you to maintain your level of interest.	300	150	50	0	0
4.	AR-DNA app is aesthetically pleasing.	0	350	50	50	50
5.	You are comfortable to learn new concepts by using an AR app.	0	350	50	50	50
6.	Your level of curiosity increases with the use of AR-DNA app.	300	150	50	0	0
7.	Your attitude towards learning changes by using AR-DNA app. AR-DNA converts boring learning session to an interesting and interactive session.	350	100	0	50	0
8.	AR-DNA app raise your motivation.	400	50	50	0	0
9.	AR-DNA enhance your learning effectivity.	300	100	50	50	0
10.	AR-DNA is one of the best solution of problems that exists in traditional learning system.	0	350	50	50	50

The feedback gathered from the AR-DNA app resonates with a high level of student satisfaction. A substantial 80% of students strongly agreed that augmented reality (AR) significantly enhances their motivation. Moreover, 70% of students expressed satisfaction with the app's aesthetic appeal, noting its transformative effect on boring lectures, seamlessly turning them into interactive sessions conducive to learning

about DNA structure. Notably, student feedback highlighted the app's multifaceted benefits, showcasing its ability to sustain their level of interest, stoke curiosity, and enhance learning effectiveness, with a significant 60% strongly affirming these aspects. Additionally, 70% of students endorsed AR apps as a solution addressing prevalent issues in traditional learning systems, such as tedious sessions, lack of interest, motivation, curiosity, and diminished learning effectiveness.

These findings align cohesively with prior research. Multiple studies endorse the benefits of AR in education, emphasizing its role in improving learning performance, fostering student engagement, and nurturing positive attitudes and motivation among learners [3]. Another review by different researchers finds that "user satisfaction" is one of the most frequently mentioned positive factors in integrating AR technology with education [12]. Researchers also claim that AR technology does not only limit itself to education but becomes pervasive throughout society in general [7].

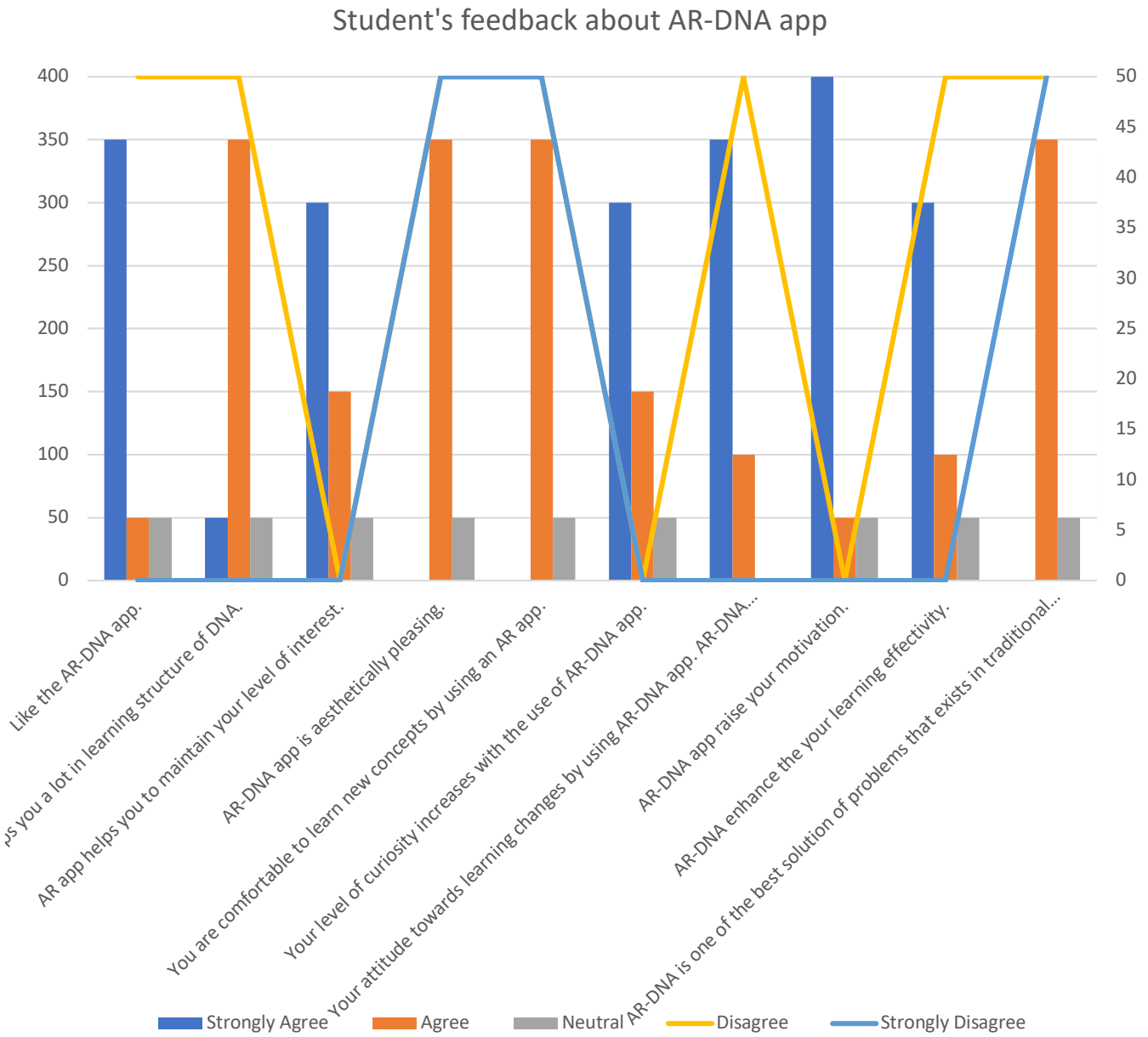

Figure 10. Student's feedback about AR-DNA app

4. Discussion

The findings presented in the feedback of the AR-DNA app, based on Likert scale ratings and student questionnaires, underscore a significant positive reception of augmented reality (AR) in educational settings. The results indicate a strong inclination towards the efficacy and appeal of AR technology, particularly in the context of DNA learning among students.

From the perspective of previous studies, these findings align with existing research that emphasizes the benefits of AR in education. The high percentage of students strongly agreeing that AR increases motivation, enhances aesthetic appeal, and transforms traditional lectures into interactive sessions corroborates the notion that AR holds immense potential in engaging learners and enhancing educational experiences. These findings resonate with prior research highlighting AR's positive impact on learning effectiveness, student engagement, and motivation [3]. Moreover, the alignment between the student feedback and established research further supports the notion that AR technology has broader implications beyond education. As mentioned in [12] and [7], user satisfaction with AR technology is a recurring theme, suggesting its pervasive and beneficial impact across societal domains.

Interpreting these results within the context of the working hypotheses, the overwhelmingly positive feedback reaffirms the hypothesis that integrating AR into educational frameworks can effectively address challenges inherent in traditional learning systems. The students' reported increase in interest, curiosity, and learning effectiveness supports the hypothesis that AR-based learning environments can mitigate issues related to disengagement and lack of interest in conventional educational settings. The implications of these findings extend beyond the immediate educational sphere. They signal a potential transformation in pedagogical approaches, emphasizing the importance of incorporating innovative technologies like AR to enhance learning experiences. Additionally, these results advocate for the continued integration of AR apps in educational practices to sustain and bolster students' engagement, curiosity, and motivation.

5. Conclusions

In this research, the authors presented the development of AR-DNA and testing of app with the students of eighth grade. This app has two basic features: learning and assessment. Learning is based on marker-based AR whereas assessment done on this basis of multiple-choice questions. For development, we used Unity 3D and the Vuforia SDK. Feedback shows that students love this app, and this app also helps students maintain levels of interest and motivation while developing curiosity about new concepts. Results clearly demonstrates the potential of AR apps in education and motivate researchers to develop new insights in the field of augmented reality and integrate these concepts with different fields of life for the benefit of society.

In future work, we will add a number of interactive modules other than the visualization and assessment modules. We will also add more 3D models to the app to provide maximum information. Different genome concepts are also added in the app, and the benefits of VR in education should be explored. Further, we will explore game-based learning elements and add these elements to the AR app to enhance its effectiveness for learning purposes.

Data Availability Statement: The data will be made accessible upon request.
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Conflicts of Interest: The authors declare no conflict of interest.

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