Educational Applications of Augmented Reality (AR) and Virtual Reality (VR) to Enforce Teaching the "National Academy of Engineering Grand Challenges for Engineering in the 21st Century"

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Abstract — **The National Academy of Engineering's "Fourteen Grand Challenges for Engineering in the Twenty-First Century" identifies challenges in science and technology that are both feasible and sustainable to help people and the planet prosper. Four of these challenges are: advance personalized learning, enhance virtual reality, make solar energy affordable and provide access to clean water. In this work, the authors discuss developing of applications using immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR) and their significance in addressing four of the challenges. The Drinking Water AR mobile application helps users easily locate drinking water sources inside Auburn University (AU) campus, thus providing easy access to clean water. The Sun Path mobile application helps users visualize Sun's path at any given time and location. Students study Sun path in various fields but often have a hard time visualizing and conceptualizing it, therefore the application can help. Similarly, the application could possibly assist the users in efficient solar panel placement. Architects often study Sun path to evaluate solar panel placement at a particular location. An effective solar panel placement helps optimize degree of efficiency of using the solar energy. The Solar System Oculus Quest VR application enables users in viewing all eight planets and the Sun in the solar system. Planets are simulated to mimic their position, scale, and rotation relative to the Sun. Using the Oculus Quest controllers, disguised as human hands in the scene, users can teleport within the world view, and can get closer to each planet and the Sun to have a better view of the objects and the text associated with the objects. As a result, tailored learning is aided, and Virtual Reality is enhanced. In a camp held virtually, due to Covid-19, K12 students were introduced to the concept and usability of the applications. Likert scales metric was used to assess the efficacy of application usage. The data shows that participants of this camp benefited from an immersive learning experience that allowed for simulation with inclusion of VR and AR.**

Keywords-Augmented Reality; Engineering Challenges; Immersive Technology; Virtual Reality.

I. Introduction

The "Fourteen Grand Challenges for Engineering in the Twenty-First Century" published by the National Academy of Engineering, lists science and technological challenges that are both attainable and sustainable to help people and the planet prosper [1]. The grand challenges of engineering were announced in 2008 by a committee of leading technological thinkers, considering the fact that the earth's resources are finite and that the world's population is depleting them at an unsustainable rate. These challenges were broadly classified into fourteen game-changing goals. Working towards these goals, as per the committee, is a way for improving life on the planet [2]. This research makes use of immersive technologies to addresses four of such challenges: 1. Advance personalized learning, 2. Enhance virtual reality, 3. Make solar energy affordable, and 4. Provide access to clean water.

AR and VR are two emerging, immersive technologies in recent times. AR creates a composite view by adding digital content to a real-world view, often by using the camera of a smartphone while VR creates an immersive view where the user's view is often cut off from the real world. In AR, users' world views remain intact and virtual objects simply augment the reality, whereas, in VR, users' world views are totally altered, and they can no longer see their actual surroundings.

In this research, a VR application aims to address the first two challenges while two AR applications aim to address the last two challenges. The VR application assists users in visualizing and understanding our solar system by using a VR headset. Users can take an immersive, virtual tour of the solar system. This virtual simulation closely parallels the movements of the planets, as well as their form, scale, and location in relation to the Sun. Thus, this application enables users to view our solar system in an immersive environment, which could be helpful in visualizing and comprehending a system that is not easily observable. The Drinking Water AR application displays information on drinking water accessibility and the environmentally sustainable use of water bottles rather than plastic cups. The application can be used to locate drinking water related information by simply pointing the device camera towards a Point of Interest (POI). Also, it can be used to file and view water-related complaints. Thus, the application helps users to conveniently identify drinking water related information inside Auburn University (AU), thus providing easy access to clean drinking water. The Sun Path AR application helps users visualize Sun's path at a selected date and location. Students study the Sun's path in several areas, but they often fail to visualize and comprehend it. Architects often analyze the sun's path to evaluate the positioning of solar panels at a particular location. An effective solar panel placement helps optimize solar energy cost. Thus, the application could possibly assist the users in efficient solar panel placement.

Empirical studies on the effectiveness of adding mobile game-based augmented reality into basic education suggests that AR techniques can boost student learning [3]. Similarly, there is an AR application to hydrate dementia-affected older adults [4]. The application reminds, inspires, directs, and monitors hydration among those adults. Likewise, students were readily engulfed in AR and their ability to interact with the interface and control virtual objects helped them to understand more advanced concepts of Earth-Sun relationships [5]. All the above-mentioned works in the literature back up this study's argument that AR can help with customized learning, resource access, and visualizing abstract concepts.

In conclusion, the applications serve as a proof of concept for use of immersive technology in addressing engineering concerns. In addition, K-12 students were introduced to the concept and usability of applications at a camp held virtually due to Covid-19. Likert scales metric was used to assess the efficacy of application usage.

In Section II, the paper discusses previous work by other authors related to this research. The project architecture used in the research is then presented in Section III. In Section IV, the paper depicts the usability study of the research. In Section V, the result of the study is reported. Finally, in Section VI, the authors provide conclusions and future work briefings.

II. RELATED WORK

A. AR/VR Modes and Characteristics

Immersive technology blurs the line between the real and virtual worlds, allowing users to feel fully immersed in the experience [6]. Immersive technology leverages a 360 space to either create a new reality or to extend the reality into some degree of virtuality. Virtual environment often shuts down a user from his/her reality and absorbs them into a new, digital environment [7]. As a result, immersive technology immerses users in a simulated world, altering their mental state. Immersive technology can be broadly categorized into four categories: 360, VR, AR, and MR. Virtual reality and augmented reality are two main types of immersive technology. Virtual reality (VR) fully takes over one's vision, giving users the feeling of being transported from the physical world to a virtual one. On the other hand, augmented reality (AR) simply overlays virtual objects onto the user's view of the real world. Milgram's reality-virtuality continuum is a pictorial representation of the spectrum of immersive technologies. Figure 1 depicts the transition and chasm from a real environment to a virtual environment.

Based on the underlying implementation scheme, AR is classified into three different categories: Marker-less AR, Mark-based AR, and Location-based AR. In the same way, VR is classified in 3 Degrees of Freedom (DoF) and 6DoF based on user's degree of freedom.

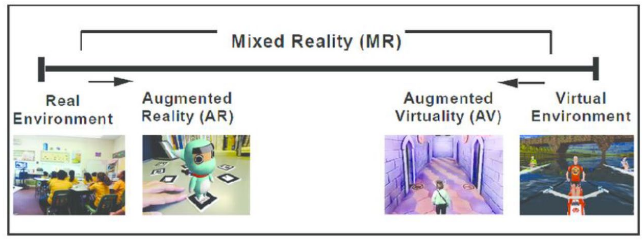

Figure 1. Milgram's reality-virtuality continuum.

Augmented Reality creates a composite view by adding virtual components to users' real view. AR is quite popular these days in various fields such as social media, learning, shopping and so forth. With the advent of Snapchat filters, AR became quite popular in social media. Soon after Facebook too integrated filter-based AR functionalities in many of its applications. Similarly, Ikea has AR features in its shopping application with the help of which customers can pick a product and place it at different points in their world view to see how the virtual product fits in their world view. Likewise, various apps such as Quiver, Blippar and Aurasma use AR to help student with learning [8]. There are basically 3 types of AR: Marker-based AR, Marker-less AR, and Location-based AR.

Marker-based AR uses pre-defined markers set by the developer of the application. When the markers are detected in the real world, virtual objects are augmented to the scene. Markers may be any form of 2D image, including black- and-white and color images. Figure 2 depicts AR content overlay over a pre-defined marker.

Figure 2. Marker based AR [9].

Marker-less AR is not bounded to a particular marker, but rather allows users to position objects anywhere they want within their real-world view. After placing an object, even if the device camera is removed from the line of sight, the application still remembers the position of the object using a method called Simultaneous Localization and Mapping (SLAM), and so when the device is brought back into line of sight the object is once again visible [9]. Figure 3 is an AR enabled retail application by Ikea. It is a marker-less AR app that allows users to place virtual products at desired position before buying them, thus assisting users with product selection and decision-making.

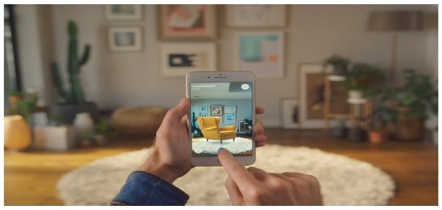

Figure 3. IKEA AR app example [10].

Location-based AR enables the ability to place virtual objects at various GPS coordinates. Location-based AR, in its simplest form, collects data from device components such as GPS, accelerometer and digital compass to identify the device location and position. The application then compares device data to POI information and adds virtual objects to the real environment accordingly [11]. An example of one of the most popular location-based AR apps is Pokémon Go. Figure 4 depicts another location-based AR application where different points of interest objects are overlaid as per their corresponding GPS coordinates.

Figure 4. Location based AR app [11].

VR is an immersive technology that allows users to interact with a virtual environment as if it were the reality. In virtual reality, Head-Mounted Displays (HMDs) are important for bringing the technology to life. An HMD is worn over the head, with the user's world view entirely obscured and only the screen displays visible in front of their eyes. The display supports a stream of data, images, and other such material. Currently, there are several powerful 3DoF and 6DoF HMDs available on the market. Google Cardboard is an example of a 3DoF headset and supports 3DoF (rotational movement around the x, y, and z axes). Similarly, Oculus Quest by Facebook, illustrated in Figure 5, is an example of a 6DoF headset and supports 6DoF (rotational movement around the x, y, and z axes, up, down forward, and backward).

6DoF tracking ensures a higher level of immersion than 3DoF as the user presence is more authentic. Figure 6 illustrates 3DoF and 6DoF tracking.

Figure 5. Oculus Quest headset [12].

B. *Applications in Academic Settings*

A survey study regarding use of augmented reality provided a scenario in which enabled mobile devices were used for learning and the associated pros and cons of the device usage was evaluated [3]. The questionnaire type survey is based on one single application – EduPARK – which analyzes mobile learning via students' opinion regarding the use of mobile devices for learning. The survey considers a total of 244 students at primary Portuguese Education System. The study participants consisted of students aged 10-16 years old among which 51.6 percent were girls and 48.4 percent were boys. The EduPARK application is designed for a specific urban park in Portugal.

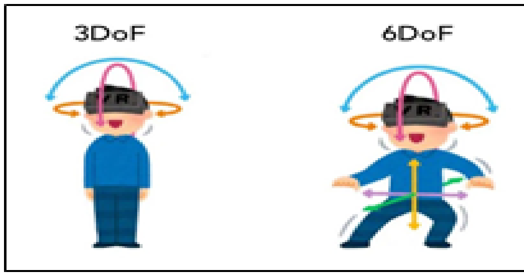

Figure 6. 3DoF and 6DoF [13].

The application uses Augmented Reality (AR) to provide various biological and historical references of the local park. The app was developed in Unity 5 using Vuforia framework and makes use of Vuforia's 2D marker-based technology. The marker-based technology allows the app to detect images/markers, pre-defined by the app creator, and overlay AR contents when the markers are detected by the device camera. As per the paper, the markers were manually installed in either tiles already existing in the park, or on plaques positioned for the purpose of sticking the markers onto them. The authors of the paper weigh in on students' perspective with the application usage. The findings of the paper suggest that the overall perspective remained positive with application usage amongst the students. The study also suggests that students believe that mobile devices, in general, are beneficial when they want to quickly find up-to- date information. However, students had their concerns with some of the external aspects of the application usage such as unstable, slow access to internet connectivity, restrictions forbidding them from carrying mobile devices to the classroom and ease of distraction by other applications inthe mobile device.

All in all, this paper suggests that use of AR mobile applications in learning can be beneficial. A study was done that proposed an AR app that helps cognitively impaired elderly people with hydration [4]. Even though a significant number of older adults are capable of drinking water/fluid by themselves, several cognitive deficits such as poor initiation, decreased motivation, amnesia, and premature decay of intention may hinder their capability [14]. Poor Initiation in older adults is observed when they fail to recall, and this deficit is common in elderly people with dementia [14]. Due to poor initiation, old adults fail to recall where and how to fetch water. Often, older adults have a degraded sense of taste and smell due to which drinking water might not be as quenching. Thickening of orbitofrontal cortex, a part of the brain that pleases and is activated after drinking water [15], when medically observed in older adults, results in lack of fulfillment and delight that follows water intake [15]. Premature decay of intention occurs when a certain activity takes longer than anticipated time to fulfil, or when an activity is thought of, but execution is hindered by some other distraction. Decay in intention is significantly higher in elderly people with cognitive defects [16]. The paper claims that the AR app proposed has advantages over existing water drinking reminder apps when it comes to helping cognitively impaired old adults to stay hydrated [4]. The app makes use of Vuforia marker- based technology and a game like activity to motivate users to meet/increase water intake. Furthermore, it also mentions carrying out a feasibility study of two versions of the app- basic and advanced - with elderly people (in assistance with their caregivers) to find out which of the two could be more suitable. It is, therefore, clear from the paper that the proposed AR game is beneficial for hydration amongst elderly people since it assists them to cope with their cognitive disabilities.

In the application-based paper, the authors use AR involving exercises designed to teach spatial concepts of rotation/revolution, solstice/equinox, and seasonal variation of light and temperature [5]. It utilizes ARToolkit to teach about Earth-Sun relationships to thirty undergraduate geography students. Users utilized a lightweight Cy-Visornf DH-440 head mounted display (HMD) with a Logitech QuickCam Pro 3000 video camera attached. The HMD and camera were connected to a laptop running Windows XP and ARToolkit version 2.52 software. The paper claims that students find it challenging to understand spatial concepts and phenomena that are complex, and the use of AR based application resulted in a significant improvement in student understandings along with reduction in misunderstandings. Often, teachers use 3D objects or props available in the classroom to explain complex concepts but both teacher and students struggle since the available objects often fail to mimic the actual concept. AR based applications usually come in handy at such scenario and eradicate the need for props. The research made use of pre- and post-assessment worksheets, and the analysis of the assessment resulted in some definitive statistics as follows:

- In general, conceptual, and factual understanding ofthe concepts improved in all cases.
- The most significant improvement was seen in those with lower pre-assessment scores.
- Most of the students resorted to pictorial descriptions to help illustrate their understanding on both pre and post assessment which further fortified the stance on use of pictures being more intuitive when it comes to understanding and explaining complex spatial concepts

The research also made some qualitative analyses and drew some definitive conclusions as stated below:

- Ability to interact with the interface and control over virtual objects helped students to understand more advanced concepts.
- In some cases, the students could no longer distinguish the difference between real and superimposed virtual objects. In no time, they felt like all virtual objects were assimilated in the real world.

The paper, thus, explores AR's potential to help student visualize complex spatial concepts, and puts forth a definitive conclusion that AR rightly assists students with their learning and understanding.

III. PROJECT ARCHITECTURE

A. *Approaches to Deployment*

The approach to deployment depends on the software development model and the wireframes of the applications. Waterfall development model was utilized to implement each stage of the application development and wireframes were utilized to easily identify the application requirements and deployment.

Waterfall development model: Waterfall model was used to develop all three applications discussed in this paper. The entire software development process is split into different phases, and each phase is carried out sequentially in this approach. For each of the applications the same fixed set of phases were defined as illustrated in Figure 7.

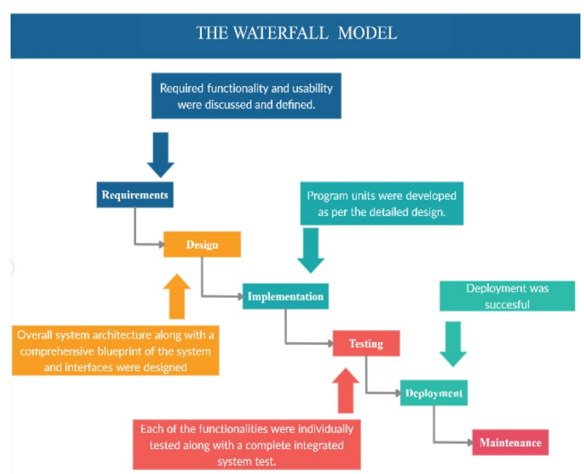

Figure 7. Waterfall Model.

Wireframes for Drinking Water AR Application: The welcome activity is a splash screen that shows the logo of the application and lets users know that the application is starting up. After the splash screen is successfully rendered, if it is the first time that the user is using the app then the app will ask the user for device camera and GPS permissions. When and if the user allows all required permissions, then the loading device location dialog is shown while device GPS is asynchronously being fetched by a background thread. After the location is fetched the app makes use of ARCoreLocation to fetch and position the water marker overlay on the device camera view. The main activity also has a view/file complaint button which can be used by general users to file complaint and admin users to view and resolve the complaints. The user authentication and data storage functionalities are achieved using Google's Firebase (a cloud database). The application wireframes are illustrated in Figure 8.

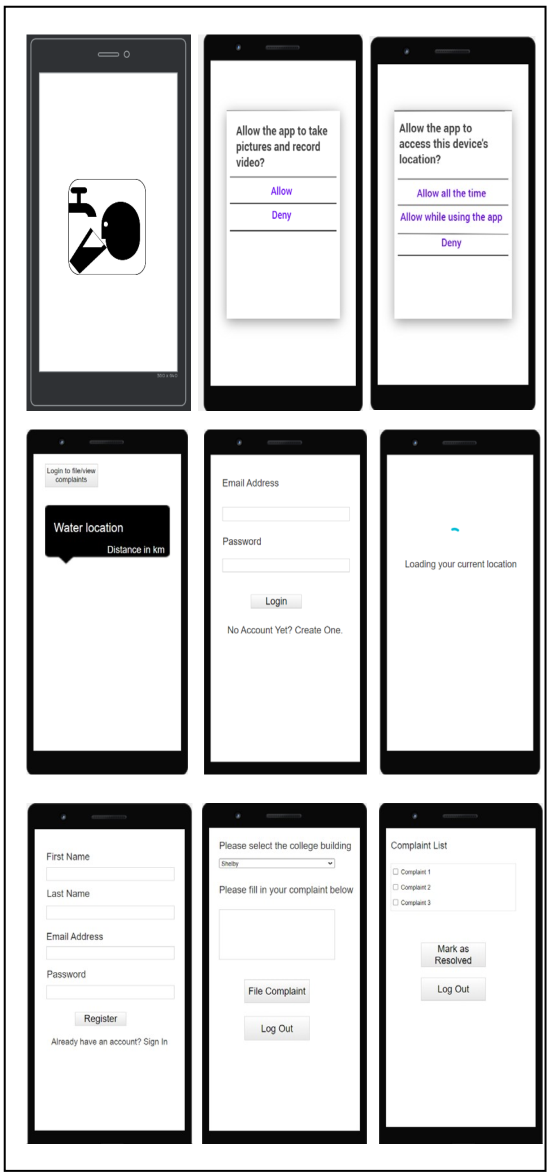

Figure 8. Drinking Water AR application wireframe.

Wireframes for Sun Path AR Application: The welcome activity is a splash screen that shows the logo of the application and lets the user know that the application is starting up. After the splash screen is successfully rendered, if it is the first time that the user is using the app then the app will ask the user for device camera permission. When and if the user allows camera access, the user is taken to the main activity of the application. All other functionalities of the application is found in the main screen of the app. The application wireframes are illustrated in Figure 9.

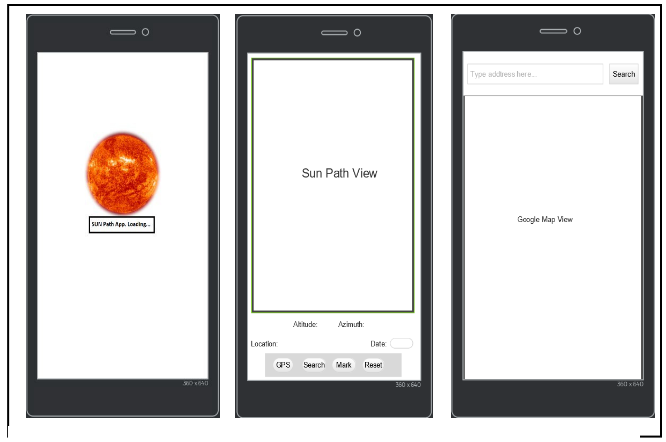

Figure 9. Sun Path AR application wireframe.

Wireframes for Solar System VR Application: The main screen is the world space view for the user. The view includes all eight planets and the Sun in the solar system. All planets are simulated to mimic their position, scale, and rotation relative to the Sun. Users can use the Oculus Quest controllers to teleport within the world view. To give users a more realistic feel, the controllers are disguised as human hands in the scene. Users can get closer to each planet and the Sun to have a better view of the objects and the text associated with the objects. The application wireframe is illustrated in Figure 10.

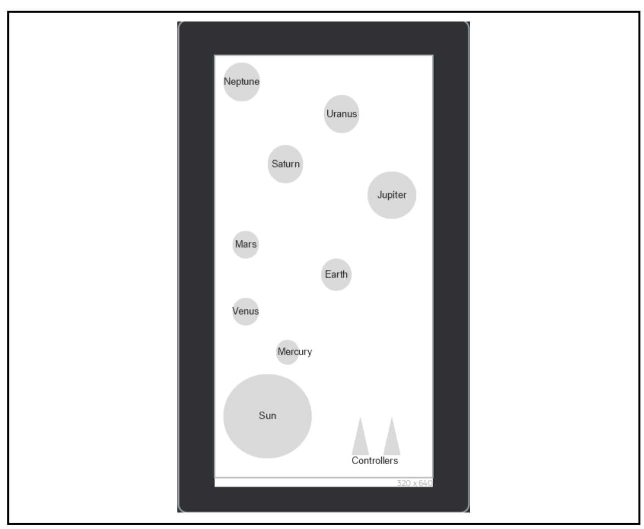

Figure 10. Solar System VR application wireframe.

B. Equipment Selection

Software & hardware requirements stay the same for AR applications and differ with the VR application.

AR applications software requirements:

- Minimum Android version: 7 (API level 24).
- Target Android version: 9 (API level 28)

AR applications hardware requirements:

- ARCore supported Android mobile devices.
- Target Android version: 9 (API 28)

VR application software requirements:

- Quest builds 20.0 release

VR application hardware requirements:

- Oculus Quest.

C. Drinking Water AR Application

The application began with the identification of the following functional requirements:

- Use Augmented Reality (AR) to show drinking water availability, consumption, and statistics on eco-friendly endeavor to reduce plastic cups in some of the buildings within Auburn University.
- Users of the application can see information overlay via their device camera when pointed to the respective buildings.
- Provision of two level of user authentication: General and Admin.
- General users can sign up and login to file complaints related to drinking water problems, if any.
- Admin users can sign up and login to view complaints and resolve them accordingly

The pictorial representation in Figure 11 is the flowchart that depicts the runtime flow of the water application. When the application is started it first checks to see whether the device is supported. If the device is supported, then the application seeks user permission to use device camera and GPS coordinates since both components are required for the application to run. Once the permissions are granted then the application initializes ARCore and ARCorelocation functionalities asynchronously. After the asynchronous methods return Future objects, the application renders the location markers.

The water AR application is developed in Android Studio using Java programming language, and libraries such as Google's ARCore, Google's FireBase and ARCoreLocation by APPoly. ARCore is Google's platform for building AR experiences. It assists a device to understand its real environment so that it can augment it. Two fundamental features of ArCore are as follows:

- Motion tracking: allows tracking position of the mobile device relative to the world.
- Understanding of the real world: Allows devices to understand vertical and horizontal surfaces and planes [17].

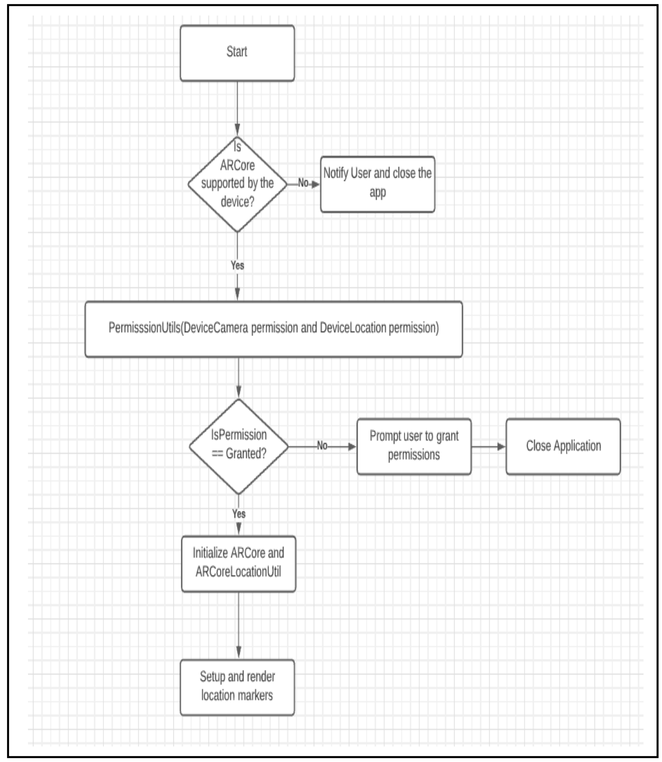

Figure 11. Flowchart of Drinking Water AR Application.

ARCore API which handles session lifecycle, access to device camera and pose is instantiated using ARCore session class. While this session is running ARCore holds exclusive access to device camera. Since this class consumes a significant amount of heap memory of the device, it is essential to call close method to release memory while not using the session. Failure to close may result in app crashing [18]. Similarly, ArSceneView is a SurfaceView which integrates with ARCore to render a scene [19].

Two of the methods from the ArSceneView class that have significant implementation in the application are getArFrame method which returns the most recent ARCore Frame, if available, and getSession method which returns the ARCore Session used by the view. Likewise, Frame class in ARCore captures the state and changes to the AR system by making a call to session object. It makes use of the getCamera method of the class to get the camera object [20]. Once the libraries are imported, to place a virtual object in a scene, anchor must be defined. Anchor class describes a fixed location and orientation in the real world [21].

Anchor in the application is obtained from the ArCoreLocation library by APPoly. APPoly is a software company based in the United Kingdom and contributes to the open-source community with various software packages. One such software package is ARCoreLocation. Since ARCore does not support use of real-world coordinates in its AR space [22], this application makes use of the ARCore Location library to realize the location-based functionality in the app.

The location library used to realize location- based AR is ARCore-Location: 1.2 [23]. ARCoreLocation allows the water app to position AR objects at real-world GPS coordinates. The real-world GPS coordinates (longitude and latitude) are provided to the application by making use of a JSON file.

The application data related to users and complaints is handled using Google's Firebase – a cloud service that is used to authenticate users and store data in Cloud Firestore. Cloud Firestore is a NoSQL, document-oriented database in which data is stored in documents and can be used to easily store, sync and query data for applications. These documents are organized into collections. There are no table or rows, unlike SQL databases. A series of key-value pairs is stored in each document. Subcollections and nested objects can be found in documents, all of which can include primitive fields such as strings or abstract objects such as lists. The relation between data, document and collection is summarized in Figure 12.

Figure 12. Collection in Cloud Firestore.

The application has two collections: complaint collection and user collection. Complaint collection holds the complaint documents that the users filed, and user collection holds the users registered in the system.

D. *Sun Path AR Application*

The application began with the identification of the following functional requirements:

- Use Augmented Reality (AR) to show Sun's path at a given date, time and location.
- Users of the application can see sun path related information overlay in their device camera while using the application.
- Users can search for any location coordinates provided by Google Maps.

The pictorial representation in Figure 10 is the flowchart that depicts the runtime flow of the sun path application. When the application is started, it seeks user permission to use device camera since the component is required for the application to run. Once the permission is granted then it initializes the default scene and overlays the sun path on top of the device camera view. The user then can select custom location, date and time and the application will update the scene accordingly. Figure 13 depicts the flowchart for the application.

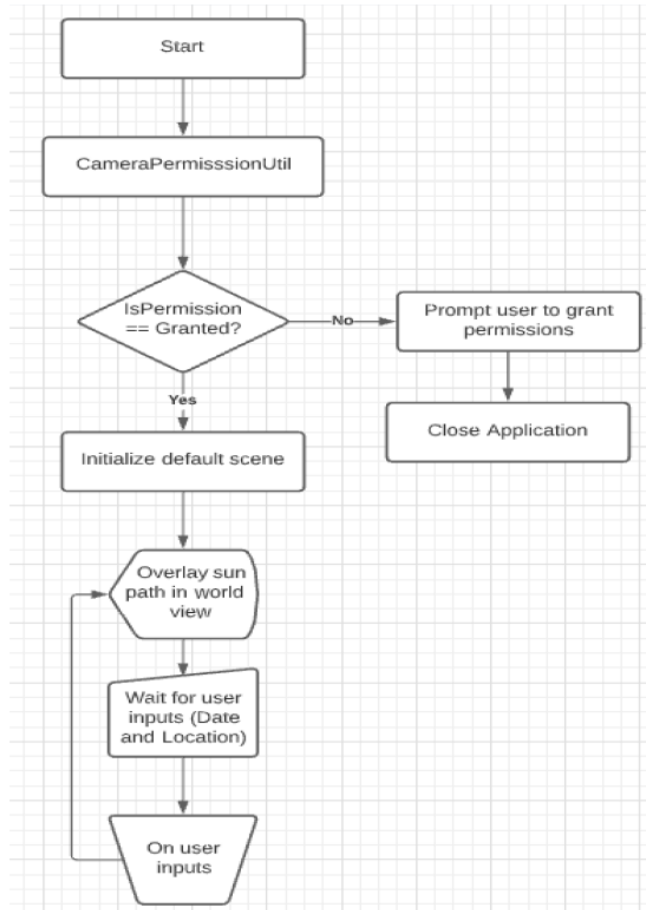

Figure 13. Flowchart of Sun Path AR Application.

The Sun path AR application is developed in visual studio using JavaScript programming language and React Native framework. React Native provides developers with a community of open-source modules that can be readily incorporated in app development. An overview of components is as illustrated in Figure 14.

Figure 14. React Native overview [24].

This application is realized into three main custom components: 1. Location Component 2. Display Component, and 3. Main Component. Each of these components make use of core components and community components and interact with one another. Location Component: This is the component where location-based logic and code is written. This component makes use of following community components:

- @react-native-community/geolocation
- react-native-google-places-autocomplete
- react-native-maps

Display Component: This is the main user interface component where UI logic and code is written. This component mainly comprises of core components such as View, Text and ScrollView. The community components used are:

- @react-native-community/datetimepicker
- react-native-vector-icons/MaterialCommunityIcons

Main Component: Is the engine of the application. All custom components are called here along with the following community components:

- react-native-WebView
- react-native-camera

Amongst various sun position calculation algorithms (such as Spencer, Pitmann and Vant-Hull, Walraven, PSA, and Michalsky), PSA has superior accuracy and performance [25]. Figure 15 illustrates PSA algorithm's performance in terms of accuracy in calculating zenith distance, azimuth, and sun vector deviation.

	Average	Standard deviation	Mean deviation	Range
Error in zenith distance	−0.001	0.114	0.091	[−0.398, 0.370]
Error in azimuth	0.002	0.190	0.138	[−1.568, 1.461]
Sun vector deviation	0.147	0.080	0.065	[0.000, 0.409]

Figure 15. PSA algorithm's performance.

User provided GPS coordinates, date and time is fed into the PSA algorithm function. The function returns Sun spherical coordinates and that is used in a projection matrix to visualize the sun path and overlay it on top of the world view. The integration of the algorithm in the application is shown in Figure 16.

Three.js library is used by the app to draw 3D objects on the device's camera view. Three.js is a 3D library that draws 3D using WebGL. Essentially, the 3D library is used to build objects and then link them. It simplifies the production and manipulation of scenes, lighting, shadows, materials, textures, and 3D math, among other items. The renderer is the most critical aspect of a Three.js app. A Renderer receives a Scene and a Camera and renders the scene. A Scene object, which resides in the renderer, includes other objects such as mesh objects, light objects, and Object3D.

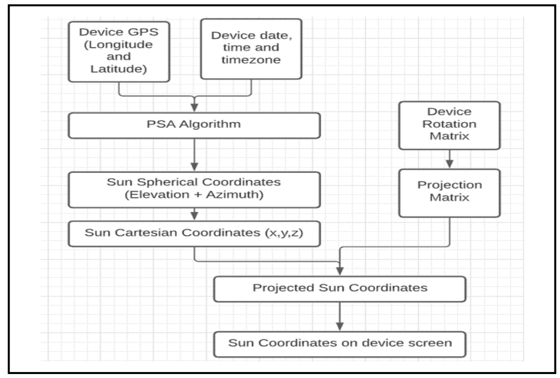

Figure 16. PSA algorithm integration in the application.

In three.js, a Mesh is the product of combining three things:

- A Geometry: It refers to the shape of the object.
- A Material: This refers to aspects like the geometry's color and texture.
- The object's location, direction, and scale in the scene in relation to its parent.

The application uses Amazon Simple Storage Service (Amazon S3) in Amazon Web Services (AWS) to load all of the front-end JavaScript files (such as Three.js), HTML and CSS. Amazon S3 utilizes REST API to efficiently store and retrieve data during runtime.

E. Solar System VR Application

The application began with the identification of the following functional requirements:

- Use Virtual Reality (VR) to create a 3D environment that simulates the solar system.
- Simulation will include planetary revolution and rotation.
- Users can teleport within the solar system to have a closer look at the Sun, planets and their moons.

Figure 17 shows the flowchart of the runtime flow of the Solar System VR application, developed in Unity using C# programming language. When the application is started, it first checks to see if the headset in which the application is being run is compatible. The application currently only supports Oculus Quest, and so trying to run it on other headset will cause the application to crash. After the initial validation is successful, the app will then initialize the camera component and the world space/scene of the application. Immediately after, the application will render all GameObjects of the scene and start the planetary rotation script (which is used to simulate planet revolution around the Sun). While in the world space of the application, the user can use controllers to teleport to different areas in the solar system and have a closer look at each of the planets. As illustrated in Figure 18, a scene in Unity can have objects that are called GameObjects. GameObjects serve as containers for components. Depending on the type of object desired, various combinations of components can be added to a GameObject. Developers can either use in-built components or create a custom component using Unity Scripting API [26].

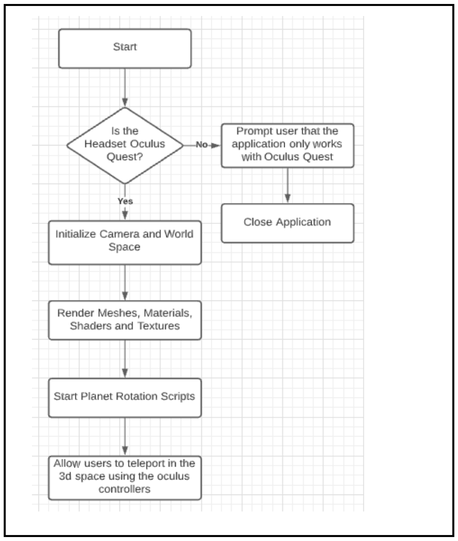

Figure 17. Flowchart of Solar System VR Application.

Transform component, which defines position and orientation of the object it is attached to, is the only indispensable component in a GameObject. All other components either default or custom can be attached or detached from a GameObject.

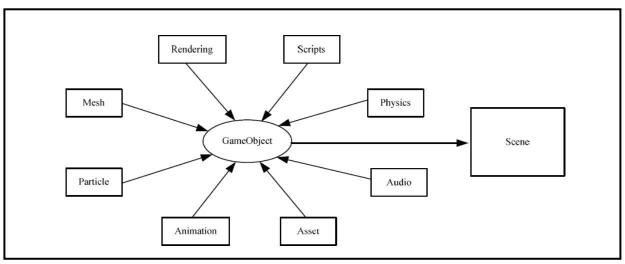

Figure 18. Unity3D GameObject Component Model.

IV. USABILITY STUDY

A. *Virtual Educational K12 Camp*

Research in the Formation of Engineers (RFE) computing virtual camp was conducted for K-12 students, in which, students from grade 9 to 11 participated. These students were instructed on important topics of AR/VR and were also asked to use the applications. The following observations were gathered from students' responses:

- All the students were unsure if they had used AR/VR applications before, as shown in Figure 18.
- Many students indicated that the use of AR/VR functionalities helped them in better understanding of subject topics.
- Students equivocally agreed that the apps were easier to use and that they were able to effortlessly determine drinking water sources and sun location.

Pre-survey and post-survey detail the discrepancies in subjects' comprehension before and after using the AR/VR applications developed for this research. Students developed a greater understanding of the technology by using the applications. According to the post-survey findings, as depicted in Figure 19, 50 percent of the students strongly agreed, and the other 50 percent agreed that using such technologies was interesting. The Drinking Water AR app made it easy to find drinking water places, according to 50 percent who agreed somewhat, 25 percent who agreed, and the remaining 25 percent who strongly agreed. Similarly, 50 percent strongly agreed, 25 percent agreed, and 25 percent slightly agreed that determining the sun's location using the Sun Path AR app was simpler.

B. *Pre-Survey*

According to the pre-survey findings, as shown in Figure 19, 100 percent of the students were unaware of the AR/VR technology prior to being introduced in this study.

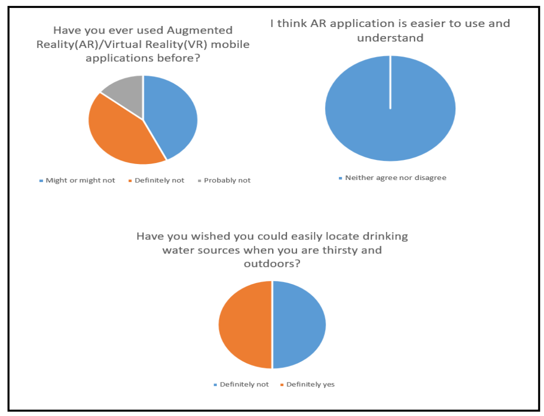

Figure 19. Pre-Survey results.

C. *Post Survey*

According to the Post Survey findings, as shown in Figure 20, 100 percent of the students agreed that using AR/VR technologies is interesting.

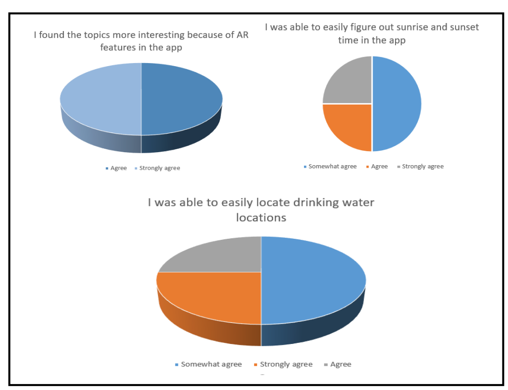

Figure 20. Post-Survey results.

V. RESULTS

A. *Drinking Water AR Application*

The application makes use of location-based AR to overlay virtual objects when the device is pointed towards the line of sight of POIs. Currently, Haley building, and Shelby Engineering buildings are the POIs for the application. Figure 21 shows the overlay when the app is brought to the line of sight of one of the coordinates. By pointing their phones towards the POIs, users can quickly identify drinking water sources and related information. In addition, the app also promotes civic engagement. Users can register/sign into the program and then file complaints about water supplies.

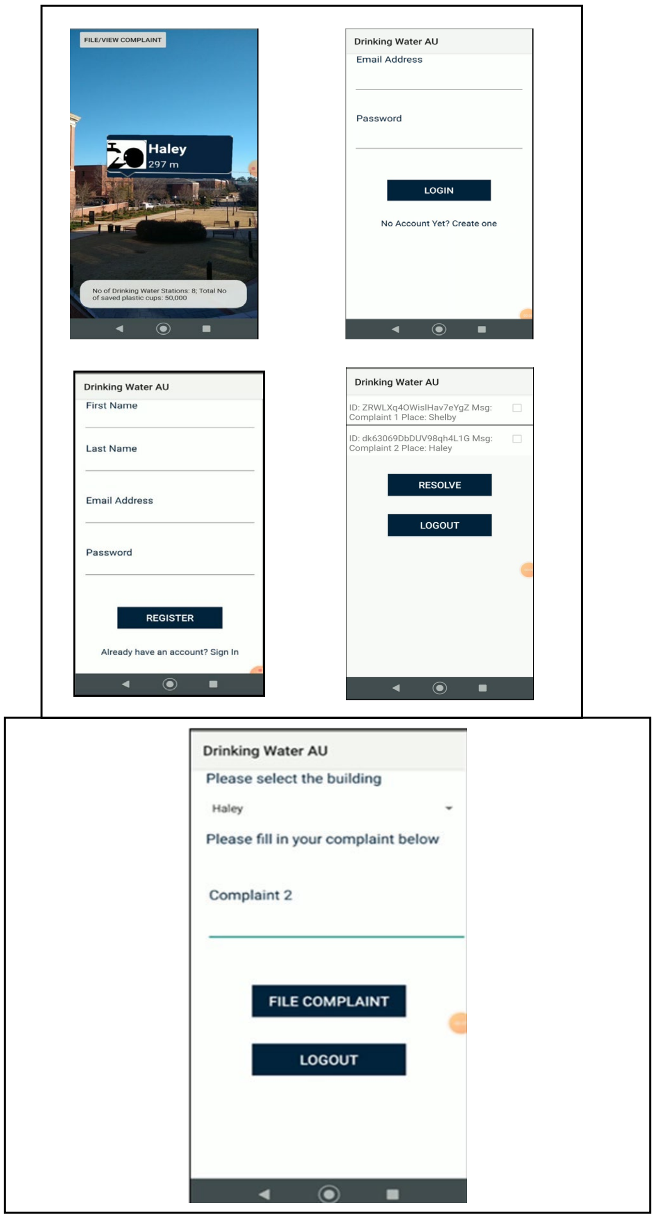

Figure 21. Drinking Water AR Application prototype.

Also, the application has provisions to add admin users. Admin users can look at the complaints and mark them resolved when accomplished. Currently, people on campus can use Google Maps to locate buildings but they do not have access to building related information. In the future, the application could be expanded to provide users with not only water information about the buildings, but also information about the buildings' internal mappings.

B. *Sun Path AR Application*

The application makes use of marker-less AR to overlay virtual objects in device's camera view. The main scene of the app displays Sun's path at a given date, time, and location, as illustrated in Figure 22. Sun is the major source of energy to our planet, and examining its path is essential for better harvesting its energy. Sun path diagrams provide a wealth of information on how the sun can affect a site and structure over the year. The solar azimuth and altitude for a given position can be determined using the diagram. A conventional way of examining its path is by manually plotting points/lines in the diagram to get solar azimuth and altitude. Accurate and timely analysis of Sun's path plays a significant role in multitude of sectors. This app eliminates the need to manually measure the position of the sun at aspecific date, time, and place.

Users can easily access sun related information such as sun position, sunrise time and sunset time. Users can use the search functionality in the app to visualize Sun's path in any coordinates searchable in Google Maps API, as demonstrated in Figure 22. Practical uses, such as estimating solar power and solar water capacity, as well as agricultural applications, are possible with this app.

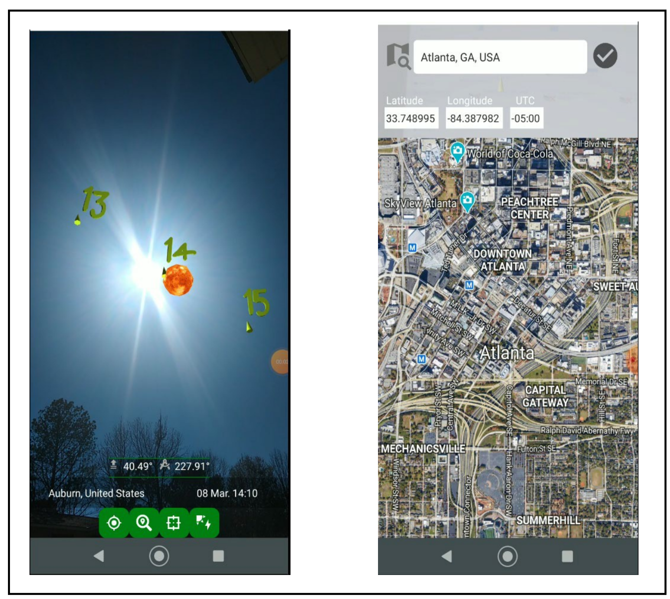

Figure 22. Sun Path AR Application prototype.

C. Solar System VR Application

The application makes use of VR to simulate our solar system. In the main scene, users can see the movements of the planets, as wells as their form, scale, and location in relation to the Sun. Users can use controllers as their hands to teleport within the app and have a better visual of the Sun and planets, as illustrated in Figure 23. This can be useful to K-12 education as it provides an immersive, interactive way to visualize and comprehend the solar system. This way of teaching using VR could be extended to other subjects.

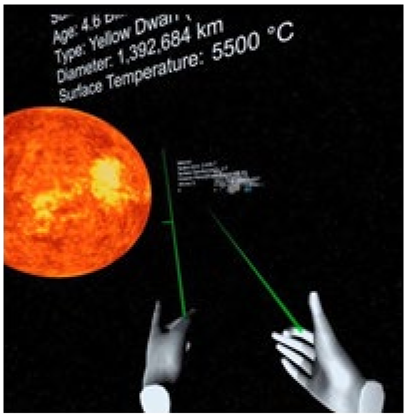

Figure 23. Solar System VR Application prototype.

VI. CONCLUSIONS AND FUTURE WORK

The Drinking Water AR app served as a prototype to resolve the issue of access to safe drinking water while also encouraging public participation by enabling users to file water-related complaints. By assisting users in visualizing sun path at a given time, date, and place, the Sun Path AR application served as a prototype to help users learn about sun path and its role in making solar energy affordable. It provides solar azimuth and altitude information to the user, eliminating the need to manually calculate the values usinga sun path diagram. The Solar System VR app acted as a model for enhancing virtual reality by creating an immersive and interactive solar system application. The app aided the user in visualizing a concept which is not readily apparent.

The effectiveness of apps was also evaluated among K-12 students using a Likert scale-based pre- and post-survey metric. The study included twelve students from various schools across the United States. Based on the user reviews, it is fair to say that the applications were effective in terms of interaction, functionality, usability, and user experience.

However, the implementations and evaluations had some limitations that could be addressed in the future. A virtual camp, conducted online due to Covid-19, was not quite effective to quantitatively evaluate the effectiveness of the work. In the future, the authors propose evaluating the application in an in-person camp with greater number of participants. Besides, following changes to the applications is proposed:

- Currently, the water application only supports two of the buildings inside Auburn University, and so scaling it to add more buildings is proposed.
- The mock data used for drinking water application could be replaced with actual data from the university.
- Both the sun path application and the water application are developed for android phones only. So, equivalent versions of the applications compatible to iPhone could be developed.
- Similarly, solar system VR application is only runnable in Oculus Quest Headset and could be built to support a greater number of headsets.

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