Use of Augmented Reality (AR) and Virtual Reality (VR) to address four of the "National Academy of Engineering Grand Challenges for Engineering in the 21st Century".

by

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Abstract

Engineering is the shrewd application of science to the exploitation and transformation of natural resources for the benefit of humanity. Humankind has always resorted to engineering in order to overcome limitations, overpower challenges and improve life in the planet. In recent years, immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) have gained a lot of popularity. The rapid development of AR/VR technology has the potential to help a broad range of sectors, with education, healthcare, manufacturing and retail among the most obvious beneficiaries. In this thesis, the authors discuss developing of applications using immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) and their significance in addressing some of the engineering challenges identified by National Academy of Engineering. The aim of this study is to develop two augmented reality (AR) and one virtual reality (VR) applications, as well as to assess their effectiveness in terms of interaction, functionality, usability, and user experience. These apps can be used to construct an immersive learning environment, locate and compare drinking water supplies in Auburn University (AU) buildings, visualize the Sun's position and direction at a given time and place, and take a virtual tour of our solar system.

Acknowledgments

I'd like to express my gratitude to my advisor, Dr. Daniela Marghitu, for providing me with so many wonderful opportunities and for being such a great mentor. Likewise, I'd like to express my appreciation and gratitude to my other advisor, Dr. Xiao Qin, and to my committee member, Dr. Bo Liu, for reviewing my work and providing valuable feedback. Last but not the least, I would like to express my gratitude to my family and friends for all of their support over the years.

Table of Contents

List of Figures

List of Abbreviations

AR	Augmented Reality
VR	Virtual Reality
AU	Auburn University
POI	Point of Interest
AWS	Amazon Web Services
JSON	JavaScript Object Notation
REST	Representational State Transfer
API	Application Programming Interface
HTML	Hypertext Markup Language
CSS	Cascading Style Sheets
HMD	Head Mounted Display

CHAPTER 1. INTRODUCTION

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 in order to help people and the planet prosper. The grand challenges of engineering were announced in 2008 by a committee of leading technological thinkers. 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 (*Grand Challenges - 14 Grand Challenges for Engineering*, n.d.). This research makes use of immersive technologies to addresses four of such challenges: 1. Enhance virtual reality, 2. Advance personalized learning, 3. Provide access to clean water, and 4. Make solar energy affordable.

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 are able to 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 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 a number of 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.

Literature by Pombo & Marques (2019) provides empirical data on the efficacy of incorporating mobile game-based augmented reality approaches into basic education to improve student learning. Similarly, literature by Lehman et al. (2018) highlights use of an AR application to hydrate dementia-affected older adults. The application reminds, inspires, directs, and monitors hydration among those adults. Likewise, literature by Shelton & Hedley (2002) states that 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. All of the above-mentioned literatures 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.

CHAPTER 2: LITERATURE REVIEW

The objective of this literature review can be classified into three main categories:

1. Define and explain Immersive Technology.
2. Define and explain Augmented Reality (AR) and Virtual Reality (VR).
3. Review of previous research materials in favor of this study.

2.1 Immersive Technology

Immersive technology blurs the line between the real and virtual worlds, allowing users to feel fully immersed in the experience (Lee et al., 2013). 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 (Covarrubias, n.d.). 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.

2.1.1. 360

360 technology is the most basic form of immersive technology. This technology equips users with a spherical view and the ability to look in all directions within the view.

2.1.2 VR

VR often creates a totally immersive constraints such that users are completely cut off from the reality and are surrounded by contents in a virtual environment. Using head-mounted displays such as Google Cardboard, Oculus Quest, HTC Vive, and so on, users can swap real environments with virtual environments.

2.1.3 AR

AR extends the user's reality rather than replacing it entirely. This technology creates a composite view for the user by combining real and virtual objects within the real environment. One of the most popular implementation of AR is the use of filters in Snapchat. Snapchat users can augment their reality by using various snapchat filters.

2.1.4 MR

MR is a combination of both AR and VR. MR, like VR, uses a head-mounted display, but instead of shutting off reality, it augments it with virtual objects. Users can experience MR by making use of head mounted displays such as Microsoft HoloLens and Magic Leap.

Milgram's reality-virtuality continuum is a pictorial representation of the spectrum of immersive technologies. Figure 2.1 depicts the transition and chasm from a real environment to a virtual environment.

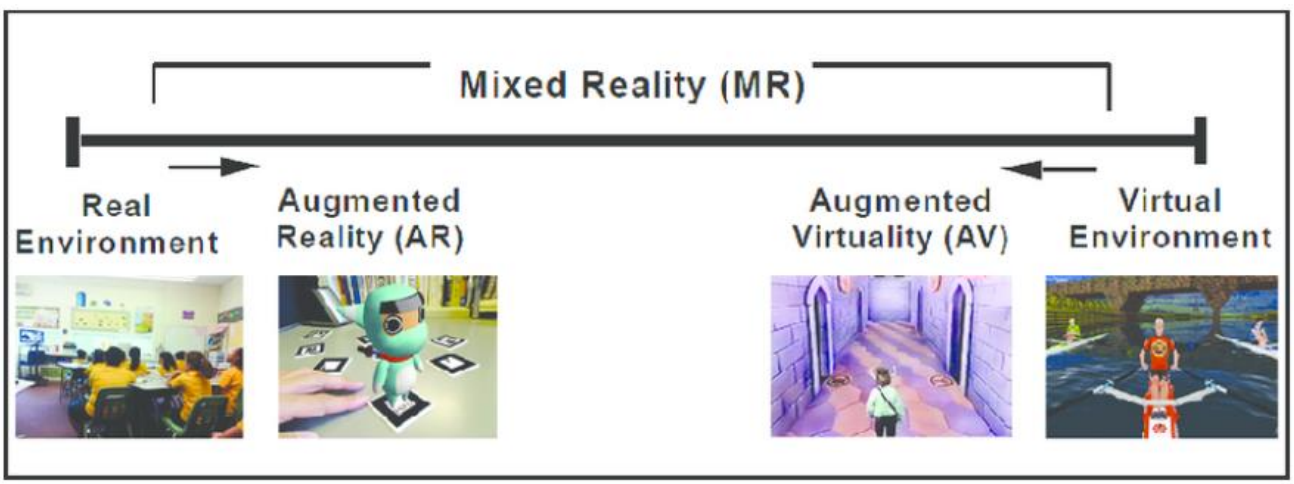


Figure 2.1: Milgram's reality-virtuality continuum. (Source: Segovia et al., 2015)

2.2 Augmented Reality and Virtual Reality

Virtual reality and augmented reality are two different types of immersive technology. Virtual reality (VR) fully takes over one's vision, giving the user 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. On the basis of 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 3DoF and 6DoF on the basis of user's degree of freedom.

2.2.1 Augmented Reality

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 (*6 Exciting AR Apps for Student Learning*, n.d.). There are basically 3 types of AR: Marker-based AR, Marker less AR and Location-based AR.

2.2.1.1 Marker-based AR

This type of AR uses predefined 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 2.2 depicts AR content overlay over a pre-defined marker.

Figure 2.2: Marker based AR. (Source: El Filali & Salah-ddine, 2019)

2.2.1.2 Marker-less AR

This type of 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 SLAM (Simultaneous Localization and Mapping), and so when the device is brought back into line of sight the object is once again visible (Ahir, 2019). Figure 2.3 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.

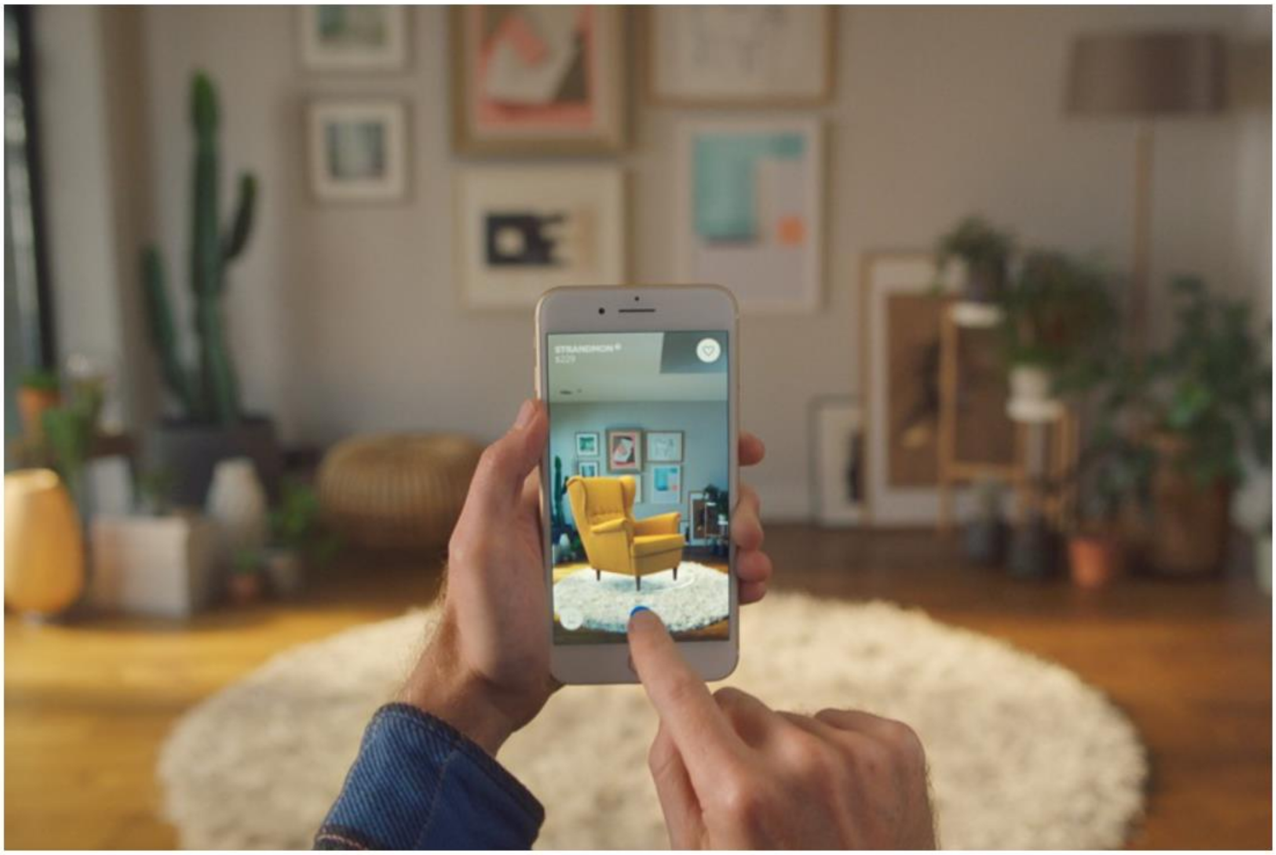


Figure 2.3: IKEA AR app example. (Source: Ayoubi, 2017)

2.2.1.3 Location-based AR

This type of 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 point of interest (POI) information, and adds virtual objects to the real environment accordingly (H., 2018). An example of one of the most popular location-based AR apps is Pokémon Go. Figure 2.4 depicts another location-based AR application where different point of interest objects are overlaid as per their corresponding GPS coordinates.

Figure 2.4: Location based AR app. (Source: Locatify, n.d.)

2.2.2 Virtual Reality

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. A head-mounted display (HMD) is worn over the head, with the user's world view entirely obscured and only the screen display visible in front of their eyes. The display supports a stream of data, images and other such material. Currently, there are a number of powerful 3DoF and 6DoF HMDs available in the market. Google Cardboard is an example of a 3DoF headset and supports three degrees of freedom (rotational movement around the x, y, and z axes). Similarly, Oculus Quest by Facebook, illustrated in Figure 2.5, is an example of a 6DoF headset and supports six degrees of freedom (rotational movement around the x, y, and z axes, up, down forward, and backward).

Figure 2.5: Oculus Quest headset. (Source: Oculus Headsets, n.d.)

6DoF tracking ensures a higher level of immersion than 3DoF as the user presence is more authentic. Figure 2.6 illustrates 3DoF and 6DoF tracking.

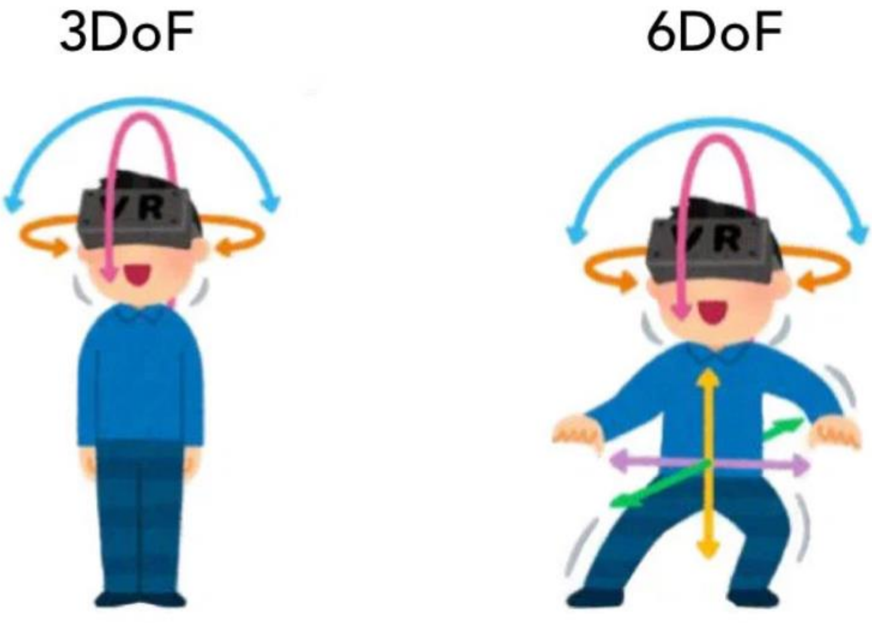


Figure 2.6: 3DoF and 6DoF. (Source: Heaney, 2019)

2.3 AR and Student Learning

The literature by Pombo & Marques (2019) presents a survey study regarding use of augmented reality which enabled mobile devices for learning and the associated pros and cons of the device usage. The questionnaire type survey, in particular, is based on one single application – EduPARK – which analyzes mobile learning via students' opinion regarding the use of mobile devices for learning. The survey takes into account a total of 244 students at primary Portuguese Education System. These students comprised 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.

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, predefined 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 it.

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 in the mobile device. All in all, this paper suggests that use of AR mobile applications in learning can be beneficial.

2.4 AR and Drinking Water

The literature by Lehman et al. (2018) proposes an AR app that helps cognitively impaired elderly people with hydration. Even though a significant number of older adults are capable of drinking water/fluid by themselves, a number of cognitive deficits such as poor initiation, decreased motivation, amnesia, and premature decay of intention may hinder their capability (Mentes, 2006). Poor Initiation in older adults is observed when they fail to recall, and this deficit is common in elderly people with dementia (Ishii, 1966). 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 (de Araujo et al., 2003), when medically observed in older adults results in lack of fulfillment and delight that follows water intake (Pacheco et al., 2015). 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 (Radvansky et al., 2010).

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 (Lehman et al., 2018). 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.

2.5 AR and Geosciences Education

In the application-based paper by Shelton & Hedley (2002), the authors use AR involving exercises designed to teach spatial concepts of rotation/revolution, solstice/equinox, and seasonal variation of light and temperature. 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:

1. In general, conceptual and factual understanding of the concepts improved in all cases.
2. Most significant improvement was seen in those with lower pre-assessment scores.
3. 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:

1. Ability to interact with the interface and control over virtual objects helped students to understand more advanced concepts.
2. 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.

2.6 Unity3D Game Engine

UNITY3D Game Engine, as stated by Xie (2012) is the core of game control. It provides an essential framework and common functions for developing games. There are several variations in the internal implementation strategies in game engines, but their overall aim is to increase the performance of developing games. Unity3D has unique advantages in the basic programming of a unit. One feature of Unity3D is that it is possible to import or export game resources and objects in the form of a package that can easily share development work with various projects. Unity3D utilizes component model programming architecture which is highly scalable. Each unit in a scene is called a GameObject. A GameObject can be thought of as a container that holds many different components at any given instance. A script is a component, for instance, and its function is to provide a logical operation on a GameObject. A script is a game behavior control class that should inherit a base class called MonoBehaviour.

MonoBehaviour describes typical methods of event triggering. The Awake() method is only executed once when the script is called in the life cycle of an instance of the script, and can be used to initialize variables when a game starts. Much like the Awake() process, the Start() method is performed only once, and it can also be used to initialize variables. After executing the Awake() and Start() methods, it is possible to recycle other event methods to trigger a game's life cycle. Figure 3 lists the important event methods in Unity3D and their execution order relationships. Furthermore, Unity provides physics engine implementation package that helps objects to respond to various physics related forces such as collisions, acceleration, gravity, and so forth (Unity Technologies, n.d.). A GameObject visualization is as depicted in Figure 2.7.

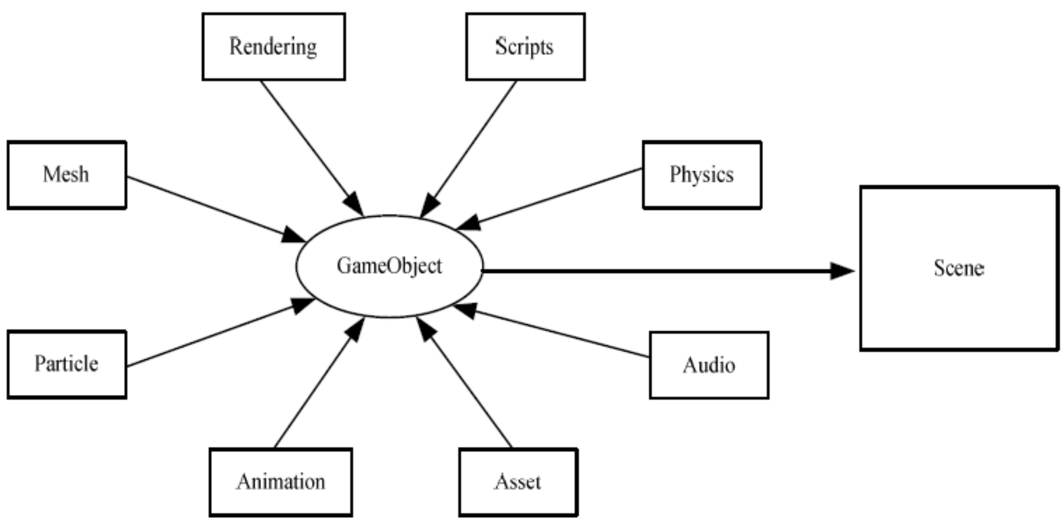


Figure 2.7: Unity3D GameObject Component Model. Source: (Xie, 2012)

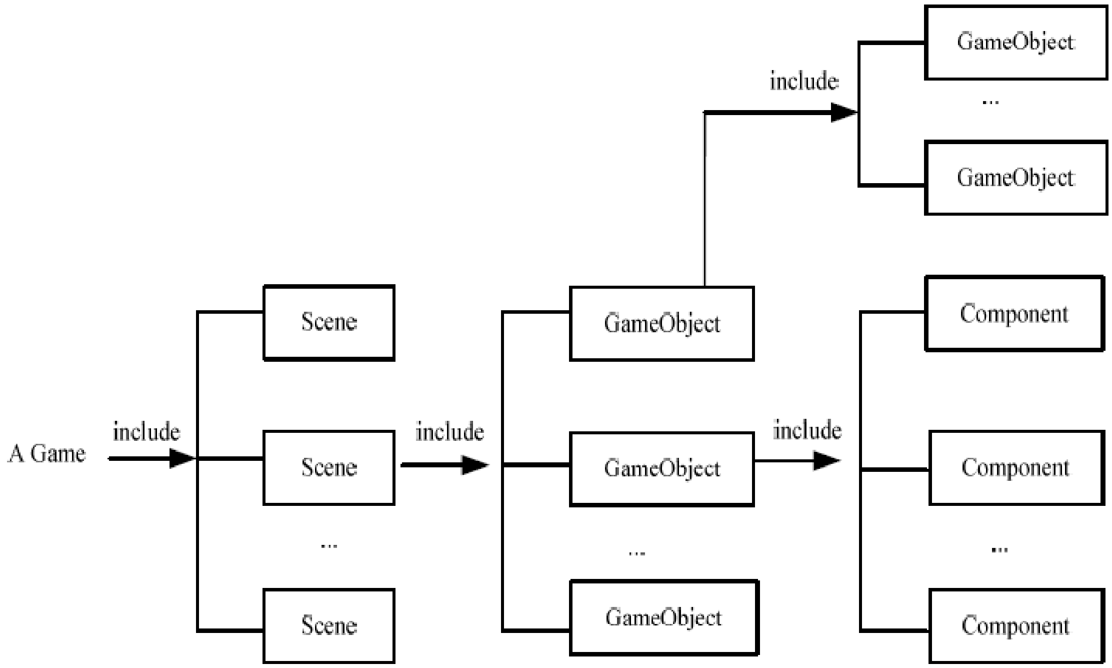


Figure 2.8: Unity3D game project hierarchy; Source: (Xie, 2012)

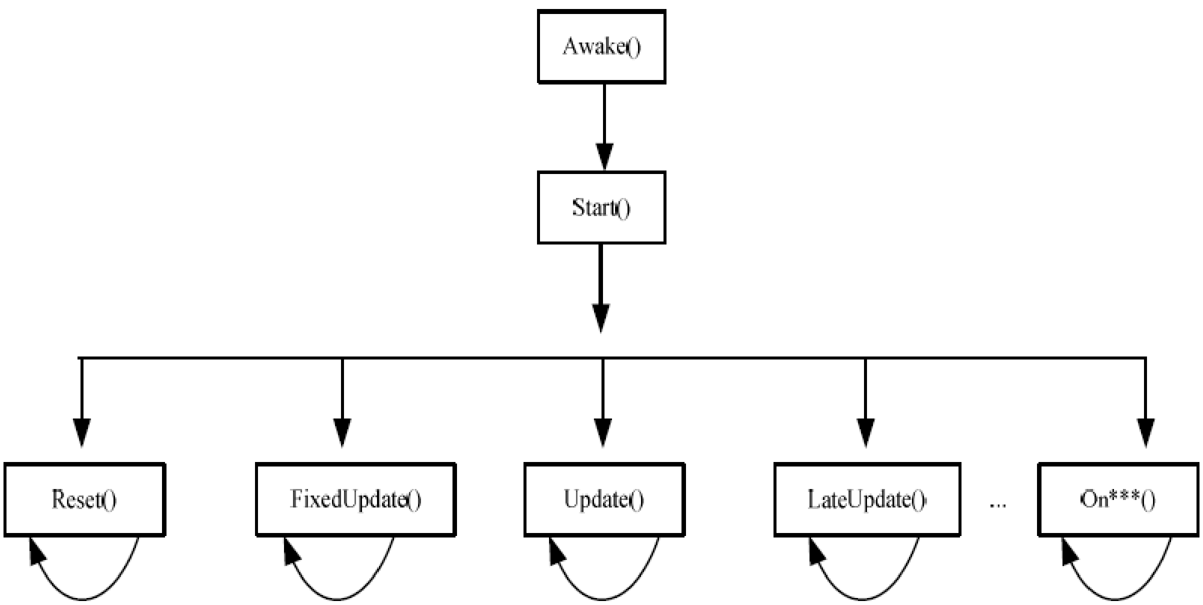


Figure 2.9: Event-driven model; Source: (Xie, 2012)

CHAPTER 3. METHOD

This chapter introduces the research problem, the hypotheses, and the conceptual model of the study.

3.1 Study of the Problem

The purpose of this study is to develop AR/VR applications to address four out of the fourteen engineering challenges. This research makes use of Augmented Reality (AR) and Virtual Reality (VR) to address four of such challenges: 1. Enhance virtual reality, 2. Advance personalized learning 3. Provide access to clean water, and 4. Make solar energy affordable.

3.2 Hypotheses

The two AR applications and one VR applications discussed in this thesis will serve as a proof of concept for using AR/VR technologies towards four engineering challenges: enhance virtual reality, advance personalized learning, provide access to clean water, make solar energy affordable. Furthermore, a survey is carried out to understand knowledge and usability of immersive technologies among K-12 students who participated in a virtual camp held by Auburn University.

3.3 Specification

The Specification depends on the Wireframe and the Software & Hardware requirements.

3.3.1 Wireframe

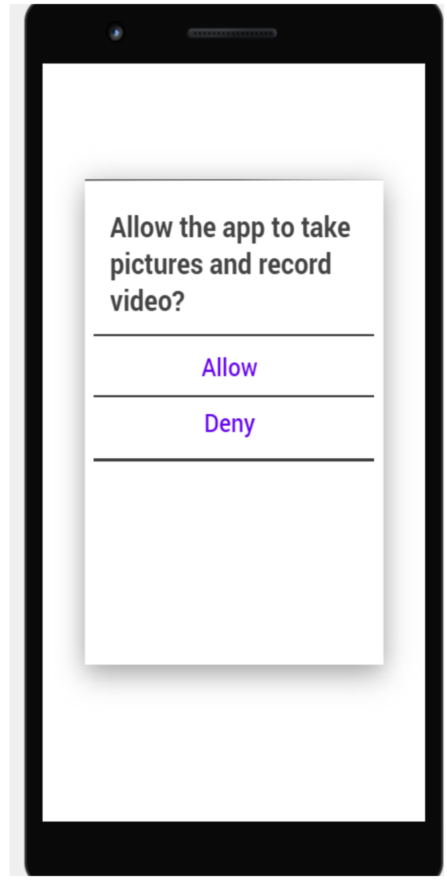
The wireframe was built to navigate through the application quickly.

3.3.1.1 Drinking Water AR Application

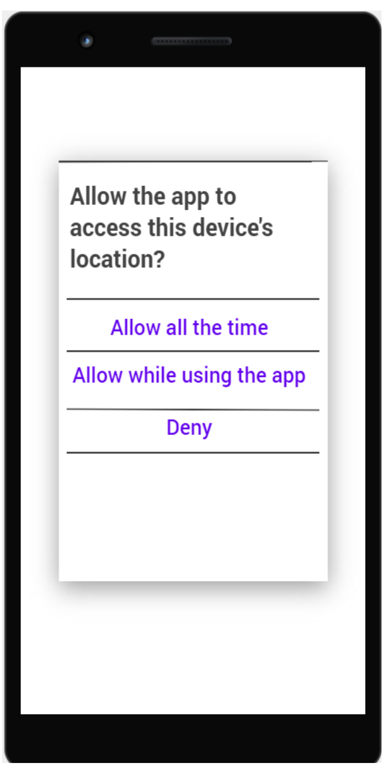
The welcome activity is a splash screen that shows the logo of the application and lets the user know that the application is starting up. After the splash screen is successfully rendered, if it is the first time that the user is using the app then the app will ask the user for device camera and GPS 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 functionality is achieved using Google's Firebase (a cloud database). The application wireframes are illustrated in Figure 3.1.


360 x 640

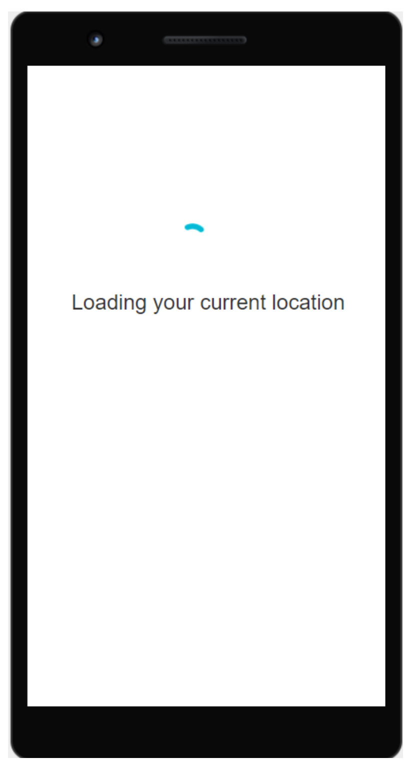
a


Allow the app to take pictures and record video?
Allow
Deny

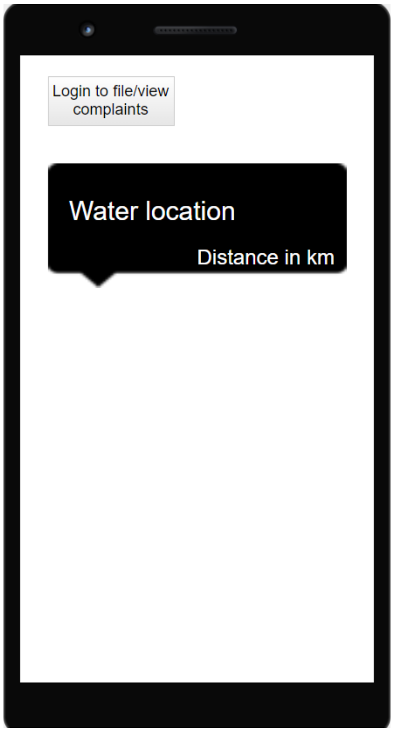
b


Allow the app to access this device's location?
Allow all the time
Allow while using the app
Deny

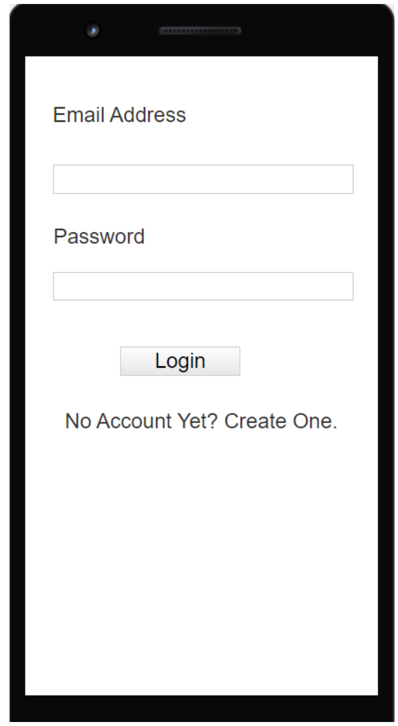
c


Loading your current location

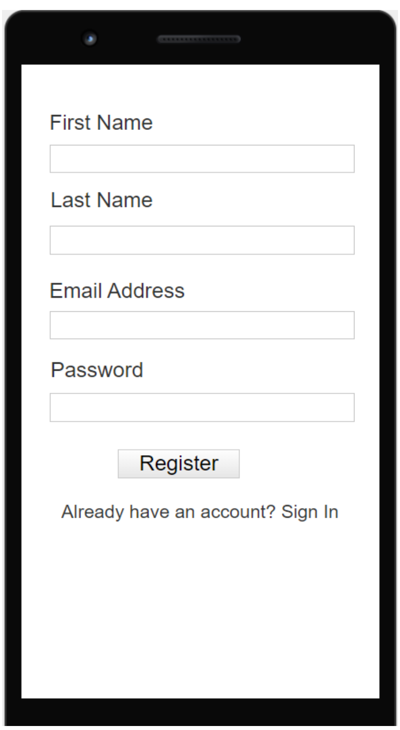
d


Login to file/view complaints
Water location
Distance in km

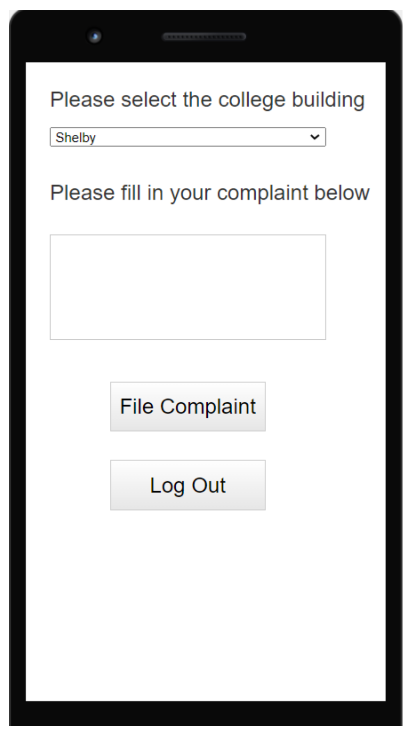
e


Email Address
Password
Login
No Account Yet? Create One.

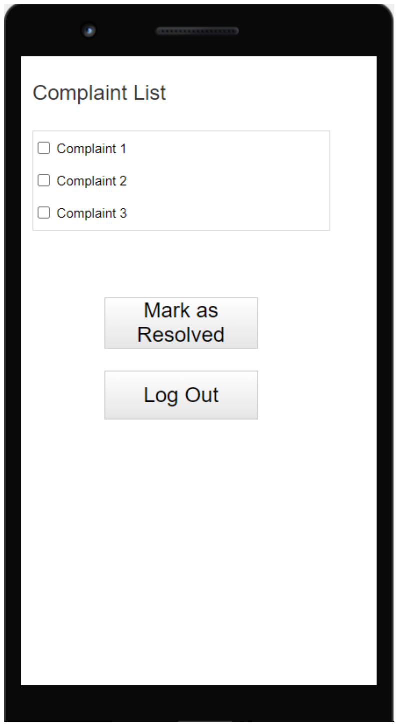
f


First Name
Last Name
Email Address
Password
Register
Already have an account? Sign In

g


Please select the college building
Shelby
Please fill in your complaint below
File Complaint
Log Out

h



i

Figure 3.1: Drinking Water AR application wireframe (a – i)

3.3.1.2 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 are found in the main screen of the app. The application wireframes are illustrated in Figure 3.2.


SUN Path App. Loading...
360 x 640

a


Sun Path View
Altitude:
Azimuth:
Location:
Date:
GPS
Search
Mark
Reset
360 x 640

b

c

Figure 3.2: Sun Path AR application wireframe (a - c)

3.3.1.3 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. In an effort 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 in order to have a better view of the objects and the text associated with the objects. The application wireframe is illustrated in Figure 3.3.

Figure 3.3: Solar system VR application wireframe

3.3.2 Software & Hardware Requirements

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

AR applications software requirements:

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

AR applications hardware requirements:

1. ARCore supported Android mobile devices. A complete list of supported devices can be found here: https://developers.google.com/ar/discover/supported-devices
2. Target Android version: 9 (API level 28)

VR application software requirements:

1. Quest build 20.0 release

VR application hardware requirements:

1. Oculus Quest.

3.4 Conceptual Model

The Conceptual Model specifies the flow chart for the applications, software development process, and functional requirements.

3.4.1 Flowchart

This section describes the runtime sequence of all the applications.

3.4.1.1 Drinking Water AR application

The pictorial representation in Figure 3.4 is the flowchart that depicts the runtime flow of the water application. When the application is started it first checks to see whether or not 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. Figure 3.4 depicts the flowchart for the application.

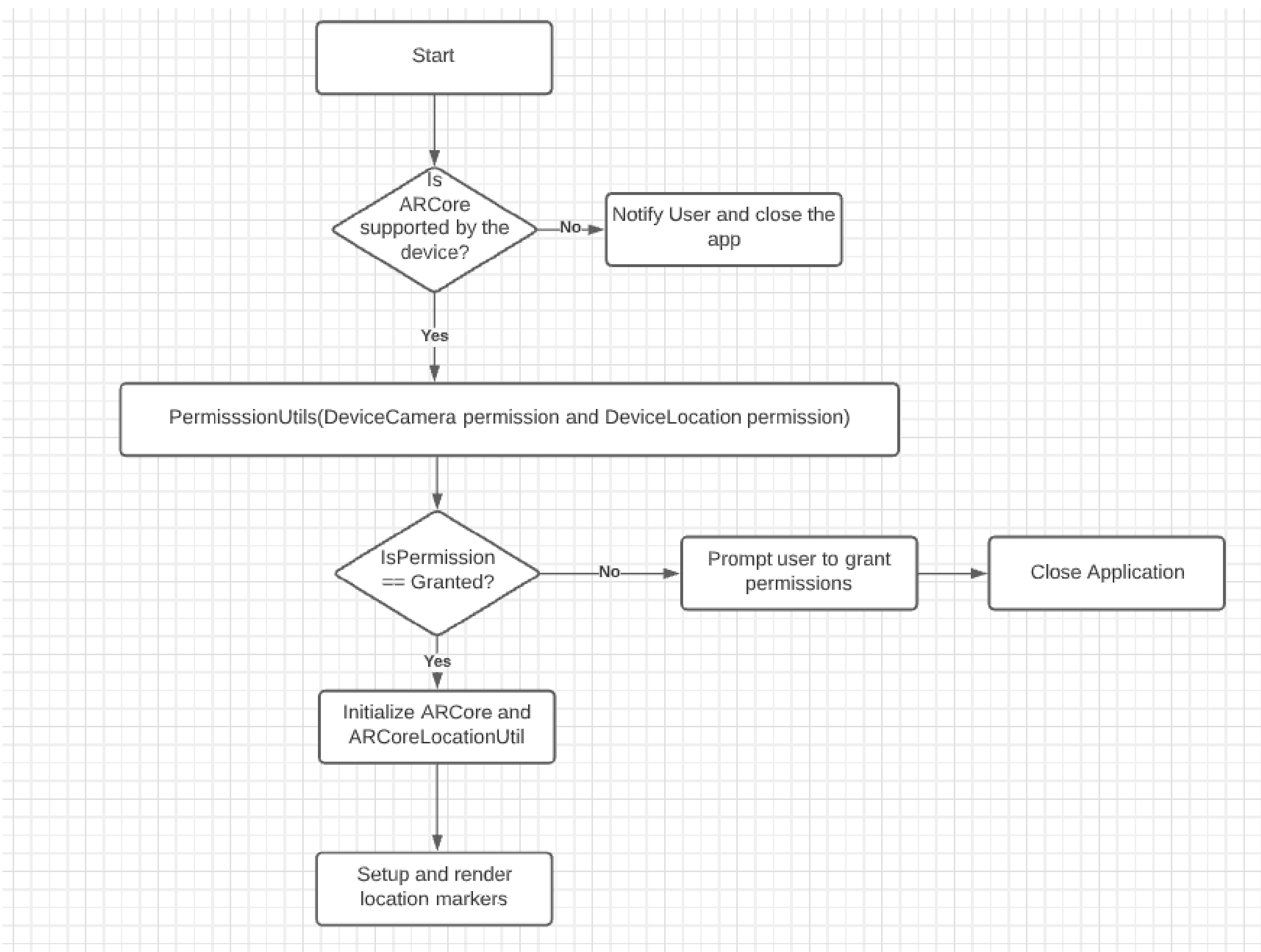


Figure 3.4: Flowchart of Drinking Water AR application

3.4.1.2 Sun Path AR application

The pictorial representation in Figure 3.5 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 has the ability to select custom location, date and time and the application will update the scene accordingly. Figure 3.5 depicts the flowchart for the application.

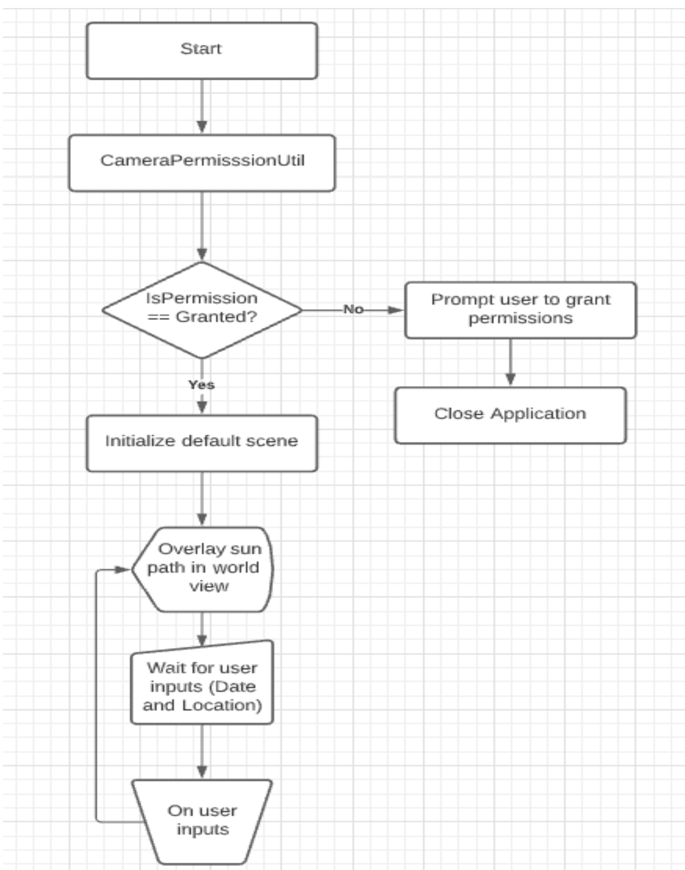


Figure 3.5: Flowchart of Sun Path AR application

3.4.1.3 Solar System VR application

The pictorial representation in Figure 3.6 is the flowchart that depicts the runtime flow of the Solar System VR application. 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. Figure 3.6 depicts the flowchart for the application.

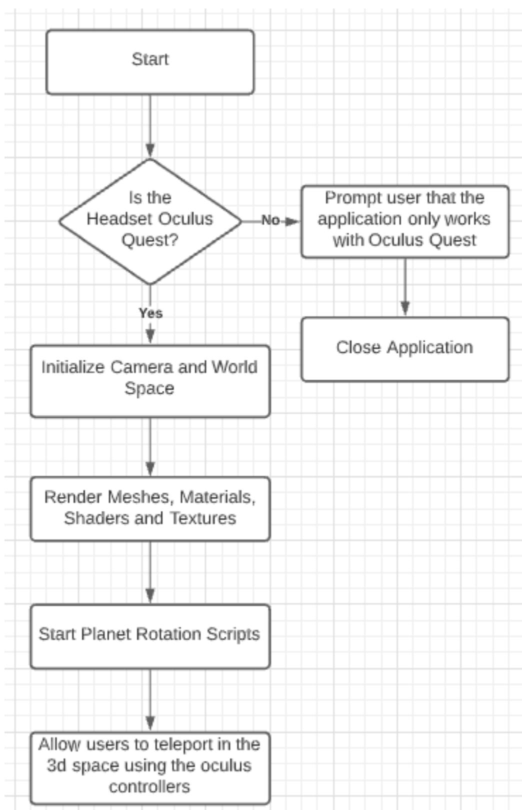


Figure 3.6: Flowchart of Solar System VR application

3.4.2 Software Development Process

Waterfall model was used to develop all three software. 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 3.7.

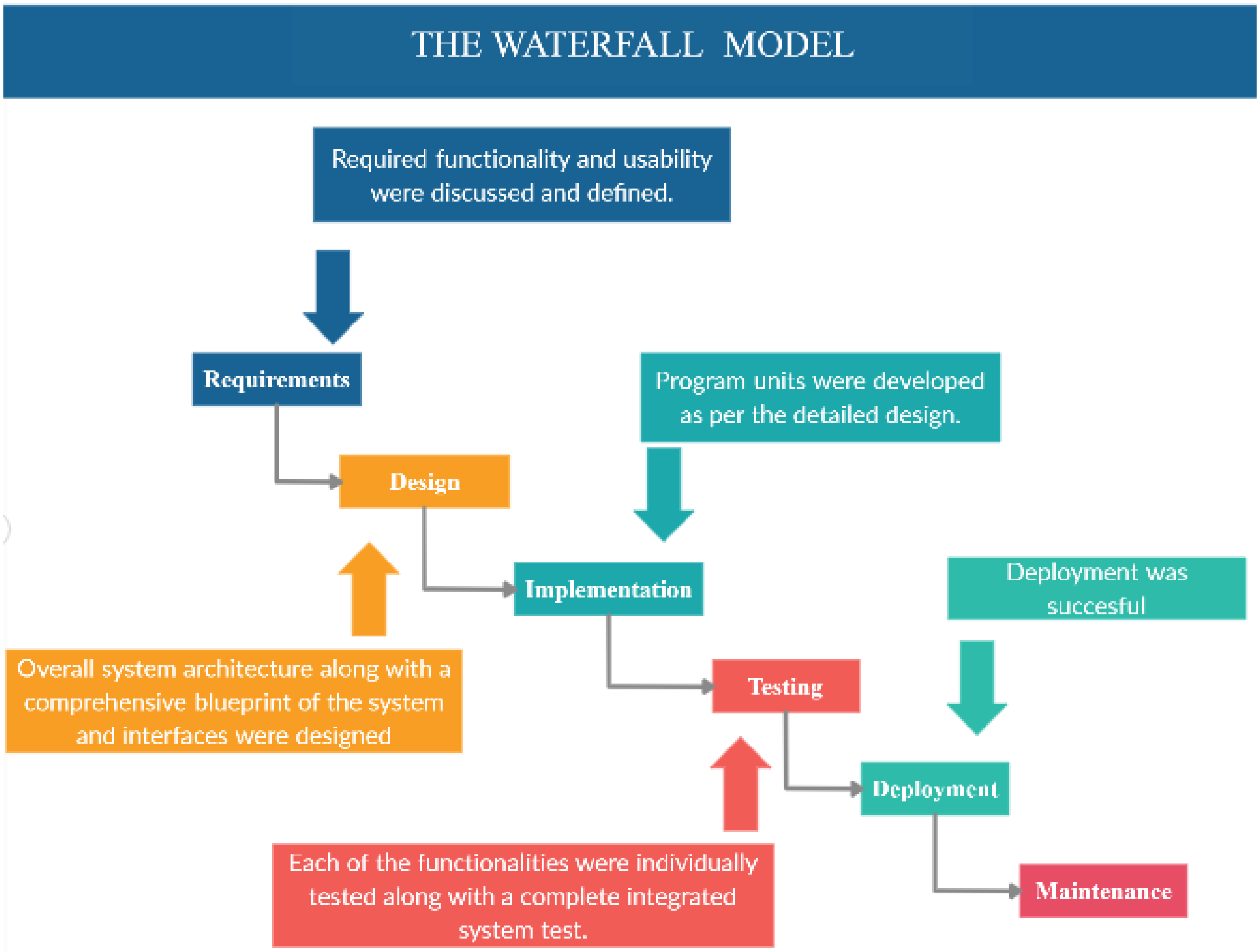


Figure 3.7: Waterfall model

On a successful completion of each implementation all functional requirements are verified for completion. The development process lasted for roughly six months.

3.4.2.1 Drinking Water AR Application:

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:

1. Motion tracking: allows tracking position of the mobile device relative to the world.
2. Understanding of the real world: Allows devices to understand vertical and horizontal surfaces and planes (*ARCore*, n.d.).

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 (*Session | ARCore*, n.d.). Similarly, ArSceneView is a SurfaceView which integrates with ARCore to render a scene (*ArSceneView | Sceneform (1.15.0)*, n.d.).

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 (*Frame | ARCore*, n.d.). 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 (*Anchor |*

ARCore, n.d.). 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 (Appoly, 2018), 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 (Appoly, 2018/2021). 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 database that can be used to easily store, sync and query data for applications. A top level view of how firebase interfaces between data access layer and the application layer is as shown in Figure 3.8.

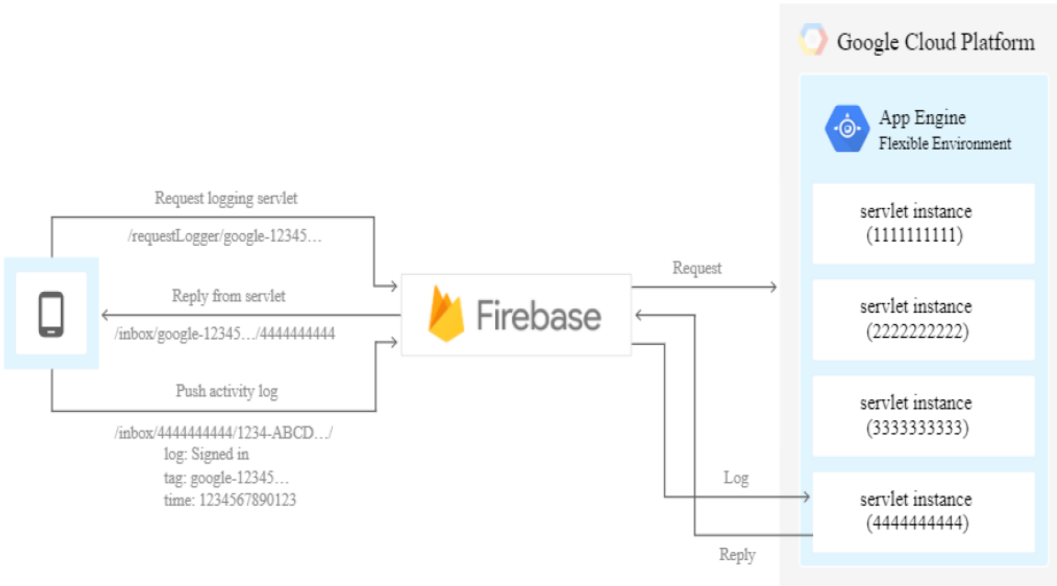


Figure 3.8: Firebase top level implementation view. (Source: *Build an Android App Using Firebase and the App Engine Flexible Environment,* n.d.)

Firebase provides with a number of authentication techniques:

1. Multiple Providers – These sign-in methods are provided email/password, email link, phone authentication, Google, Facebook, Twitter and GitHub.
2. One-tap sign-up and automatic sign-in – These methods provide automatic integration with One-tap sign-up for fast cross-device sign-in.

The application makes use of email/password sign-in method. The flow chart in Figure 3.9 depicts the login and signup functionalities in the application:

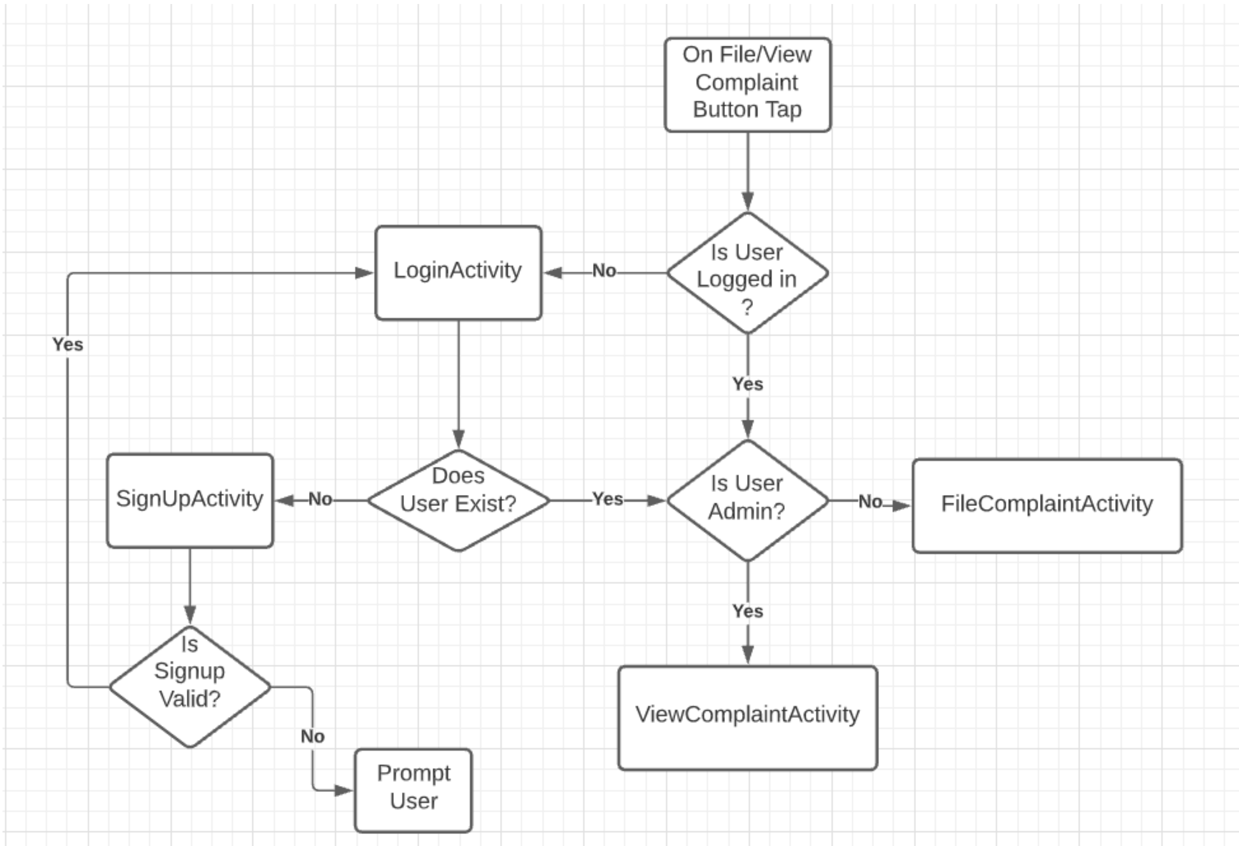


Figure 3.9: Login activity

1. ViewComplaintActivity: This is the activity where an admin user of the application is able to view complaints filed by users and then resolve them. The admin user will be redirected to this activity if the log in is successful.
2. LoginActivity: This activity is where the users are able to login and after successful login, the user is either transferred to ViewComplaintActivity or FileComplaintActivity depending on the user role. It contains two EditText for taking email and password from the user. There are two buttons for Login and Signup (signup button will transfer the user to the SignupActivity).
3. SignupActivity: This activity is used to register the user for the application and pass the user to LoginActivtiy after successful registration. It contains four EditText for taking

first name, last name, email and password from the user for registration. Two buttons for Signup and Login (login button will transfer the user to the LoginActivity).

Firebase provides two client-accessible, cloud-based database solutions that allow syncing of real-time data (*Choose a Database*, n.d.):

1. Realtime Database: This is Firebase's legacy, original database. It's an effective, low-latency mobile app solution that needs real-time synchronized states across clients.
2. Cloud Firestore: This is a newer database for mobile app development. It uses a modern, more intuitive data model to expand on the accomplishments of the Realtime Database. Cloud Firestore also offers richer, faster queries and scales better.

Database for the app is implemented using Firebase’s Cloud Firestore. Cloud Firestore is a NoSQL, document-oriented database in which data is stored in documents. 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 3.10. Complaints collection and Users collection in the app is as depicted in Figure 3.11 and 3.12 respectively.

Figure 3.10: Data model in Cloud Firestore (Source: *Cloud Firestore Data Model*, n.d.)

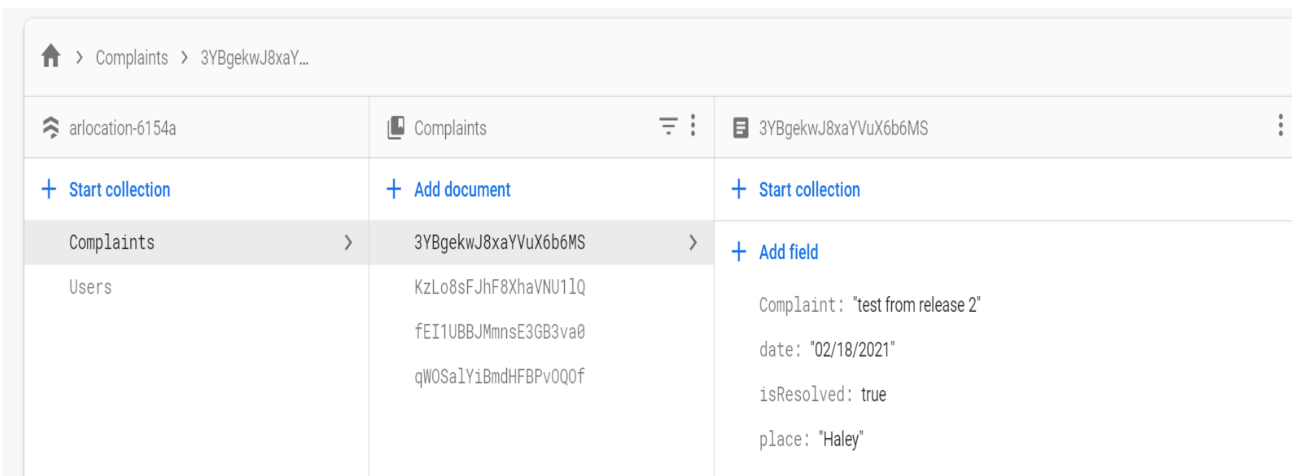


Figure 3.11: Complaints Collection and its documents.

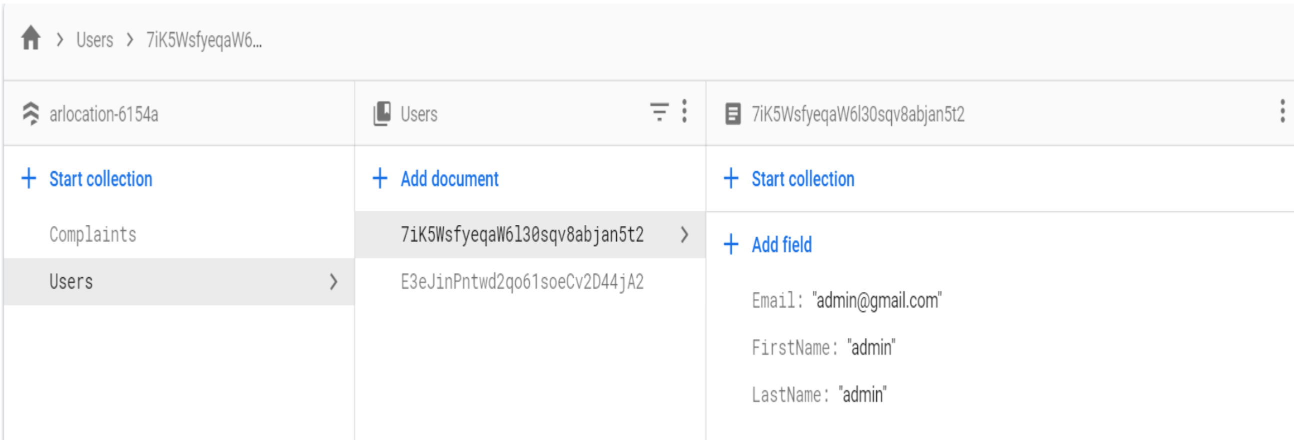


Figure 3.12: Users Collection and its documents.

3.4.2.2 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 3.13.

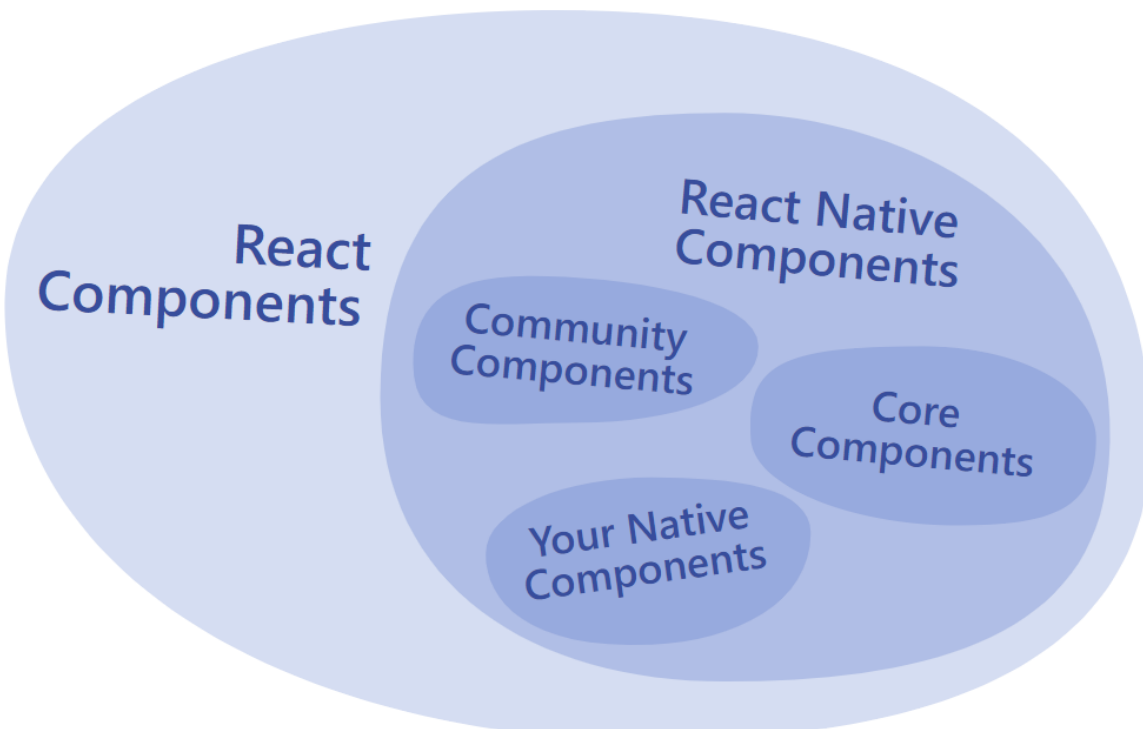


Figure 3.13: React Native overview (Source: *Core Components and Native Components · React Native*, n.d.)

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.

1. Location Component: This is the component where location based logic and code is written. This component makes use of following community components:
    a. @react-native-community/geolocation
    b. react-native-google-places-autocomplete
    c. react-native-maps
2. 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:
    a. @react-native-community/datetimepicker
    b. react-native-vector-icons/MaterialCommunityIcons
3. Main Component: This is the main component and the engine of the application. All custom components are called here along with the following community components:
    a. react-native-webview
    b. 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 (Blanco-Muriel et al., 2001). Figure 3.14 illustrates PSA algorithm's performance in terms of accuracy in calculating zenith distance, azimuth and sun vector deviation. Figure 3.15 illustrates performance analysis of all of the other algorithms. It is conspicuous from the figures that PSA has a superior performance in calculating Sun's position.

	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 3.14: PSA Performance (Source: Blanco-Muriel et al., 2001)

	Average	Standard deviation	Mean deviation	Range
Error in Zenith Distance				
Spencer	−0.657	13.895	11.34	[−45.568, 40.918]
Pitman and Vant-Hull	−0.119	0.235	0.186	[−1.036, 0.649]
Walraven	−0.119	0.196	0.155	[−0.798, 0.486]
Michalsky	−0.121	0.139	0.110	[−0.666, 0.345]
Error in Azimuth				
Spencer	0.059	15.377	12.378	[−53.516, 42.066]
Pitman and Vant-Hull	−0.068	0.376	0.270	[−2.875, 2.287]
Walraven	−0.176	0.253	0.187	[−2.465, 0.894]
Michalsky	−0.042	0.214	0.155	[−1.917, 1.532]
Sun Vector Deviation				
Spencer	15.966	9.203	7.588	[0.055, 46.460]
Pitman and Vant-Hull	0.322	0.175	0.140	[0.000, 1.097]
Walraven	0.271	0.139	0.112	[0.000, 0.798]
Michalsky	0.207	0.107	0.085	[0.000, 0.667]

Figure 3.15: Performance of other algorithms (Source: Blanco-Muriel et al., 2001)

The integration of the algorithm in the application is shown in Figure 3.16.

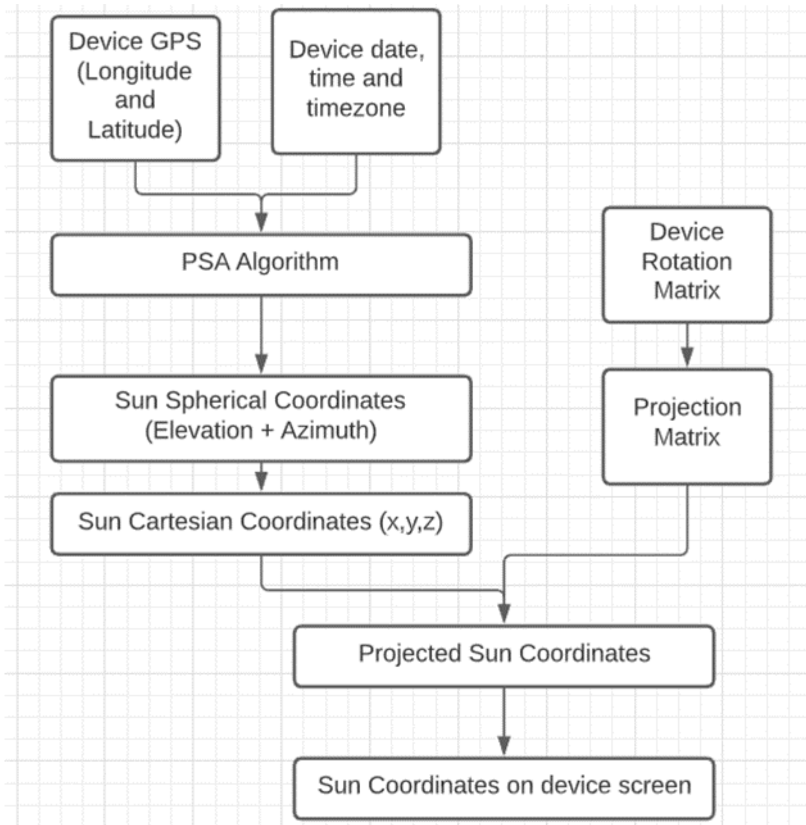


Figure 3.16: PSA algorithm integration

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.

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. Three.js sample structure is depicted in Figure 3.17.

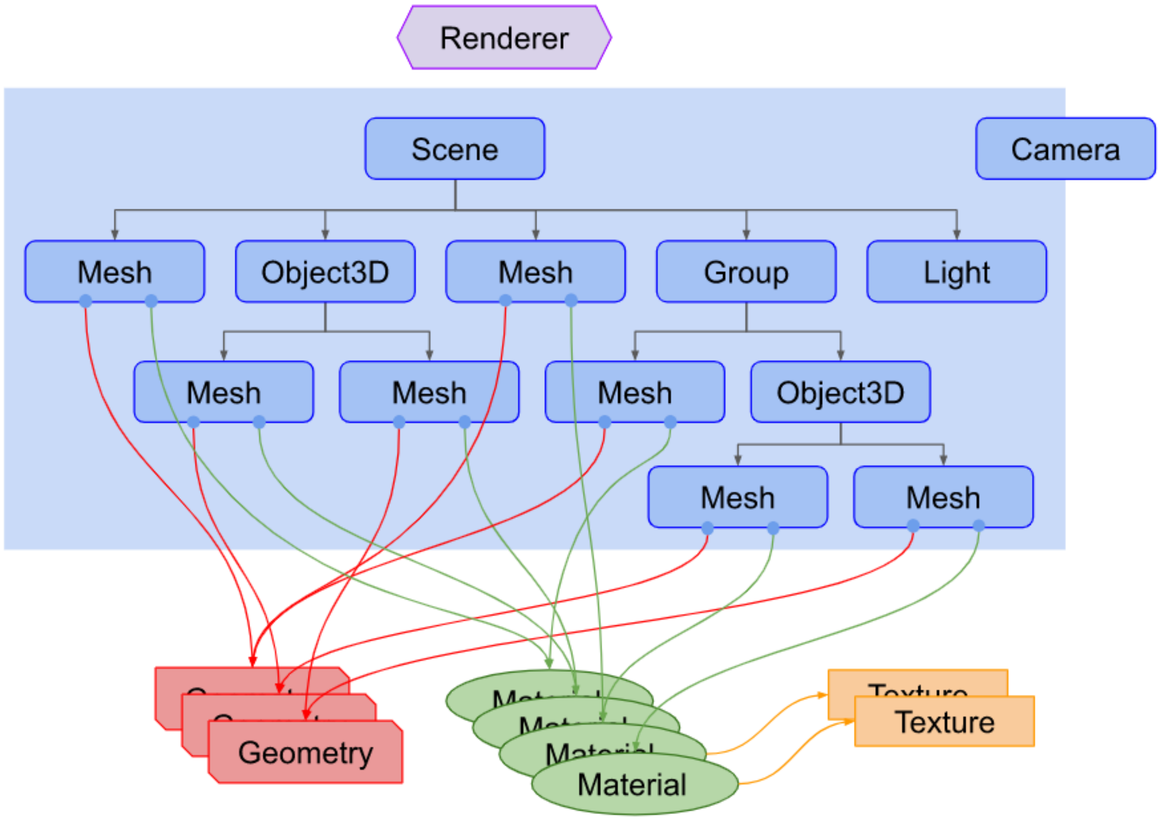


Figure 3.17: Three.js sample structure (Source: *Three.Js Fundamentals*, n.d.)

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.

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

1. A Geometry: It refers to the shape of the object.
2. A Material: This refers to aspects like the geometry's color and texture.
3. 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.

3.4.2.3 Solar System VR Application:

The Solar System VR application is developed in Unity using C# programming language.

As illustrated in Figure 2.7 in the literature review, 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 (*Unity - Manual: GameObjects*, n.d.). 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.

3.4.3 Functional Requirements:

3.4.3.1 Drinking Water AR Application

The project began with the following functional requirements:

1. 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.
2. Users of the application are able to see information overlay via their device camera when pointed to the respective buildings.
3. Provision of two level of user authentication: General and Admin.
4. General users are able to sign up and login to file complaints related to drinking water problems, if any.
5. Admin users are able to sign up and login to view complaints and resolve them accordingly.

3.4.3.2 Sun Path AR Application

The project began with following functional requirements:

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

3.4.3.3 Solar System VR Application

The project began with following functional requirements:

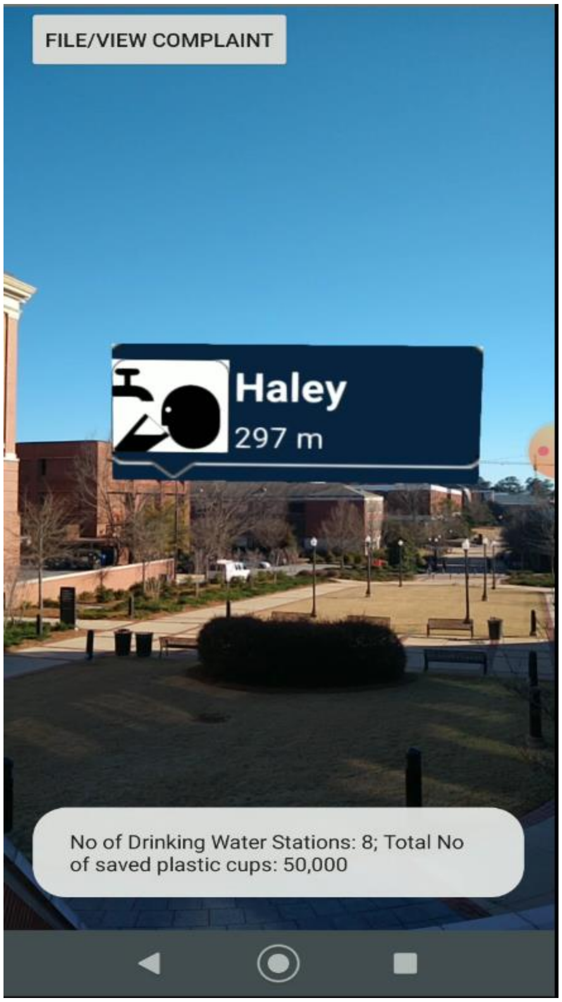
1. Use Virtual Reality (VR) to create a 3D environment that simulates the solar system.
2. Simulation will include planetary revolution and rotation.
3. Users are able to teleport within the solar system to have a closer look at the Sun, planets and their moons.

CHAPTER 4. RESULTS AND EVALUATIONS

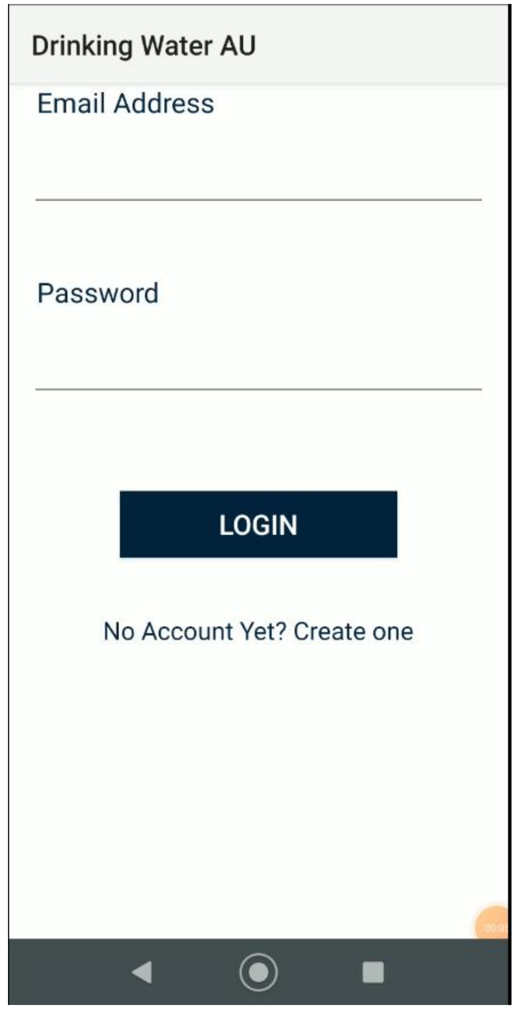
This section presents results and evaluation of each of the applications developed by the authors. Each application's prototype is produced according to the specifications, and the quantitative test results are discussed.

4.1 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 4.1.a 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 are able to register/sign in to the program (as shown in Figure 4.1.b and Figure 4.1.c and then file complaints about water supplies (as shown in Figure 4.1.e. Also, the application has provisions to add admin users. Admin users are able to look at the complaints and mark them resolved when accomplished, as illustrated in Figure 4.1.d. 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.


FILE/VIEW COMPLAINT
Haley
297 m
No of Drinking Water Stations: 8; Total No of saved plastic cups: 50,000

a


Drinking Water AU
Email Address
Password
LOGIN
No Account Yet? Create one

b

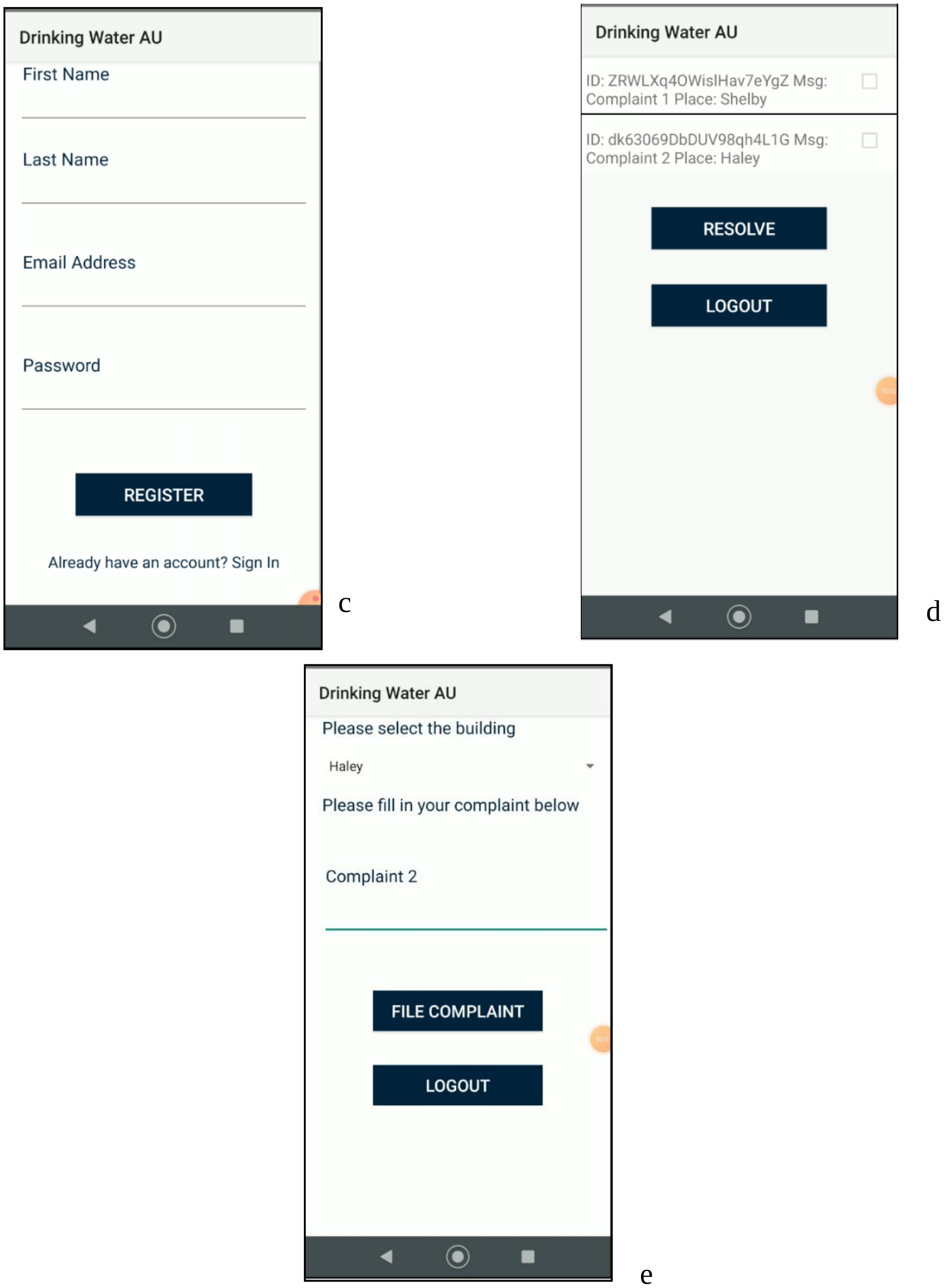


Figure 4.1: Water application prototype (a -e)

4.2 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 4.2. 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. This process is mostly tedious. 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 a specific date, time, and place.

Users can easily access sun related information such as sun position, sunrise time and sunset time. Users are able to use the search functionality in the app to visualize Sun's path in any coordinates searchable in Google Maps API, as demonstrated in Figure 4.3. Practical uses such as estimating solar power and solar water capacity, as well as agricultural applications, are possible with this app.


13
14
15
40.49°
227.91°
Auburn, United States
08 Mar. 14:10

Figure 4.2: Solar app prototype

4.3 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 4.4. 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.

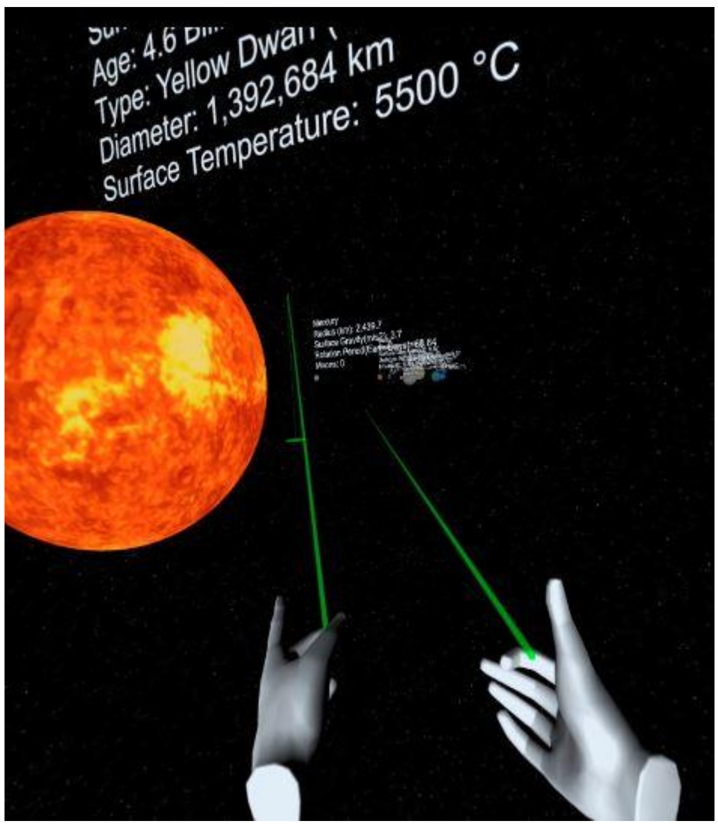


Figure 4.3: Solar system VR app prototype

4.4 Quantitative Evaluation

An 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:

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

4.4.1 Usability Testing

The following sections – 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, 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.

4.4.1.1 Pre-Survey

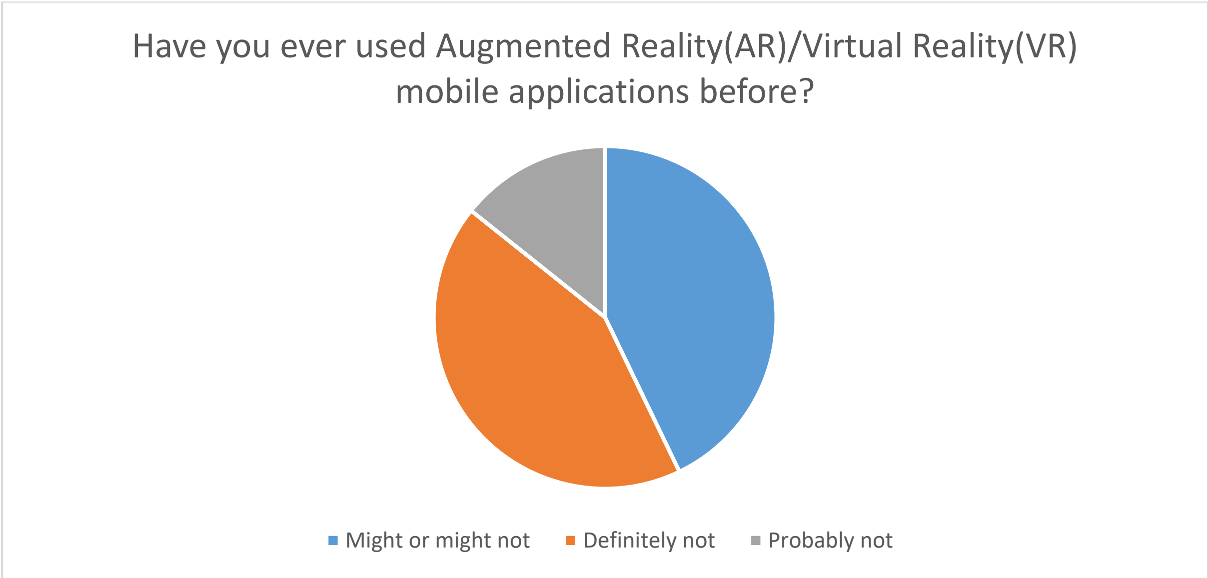


Figure 4.4: AR/VR usage

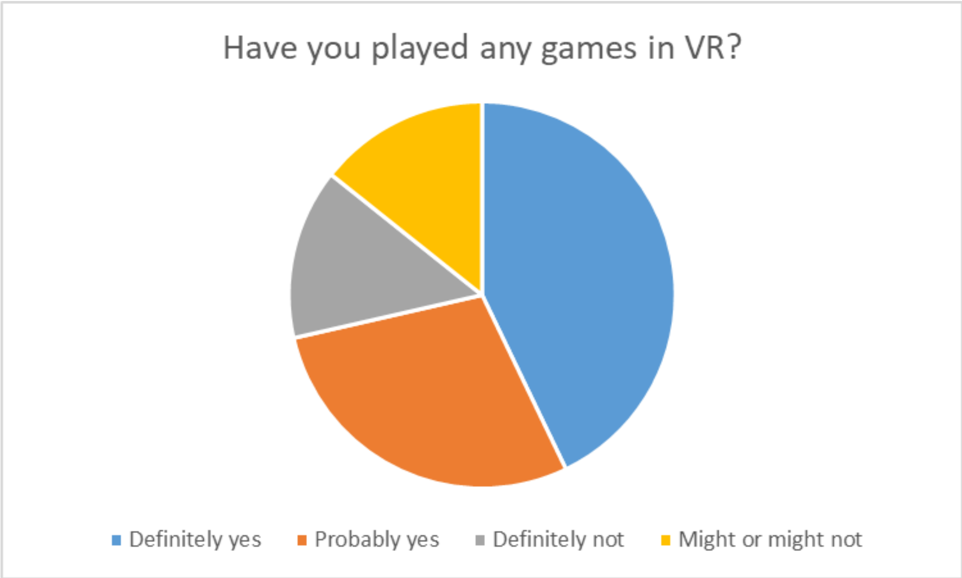


Figure 4.5: VR games popularity

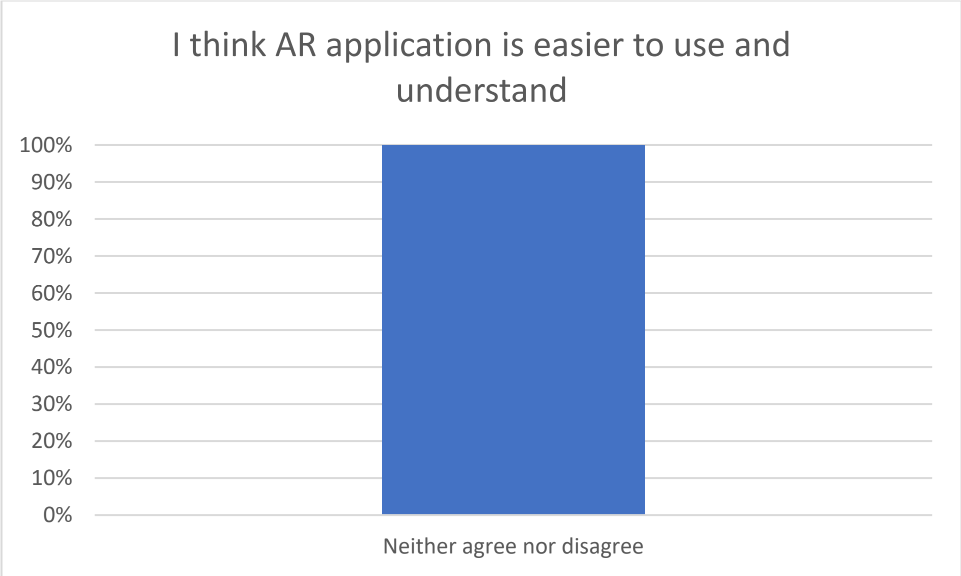


Figure 4.6: AR usage and ease

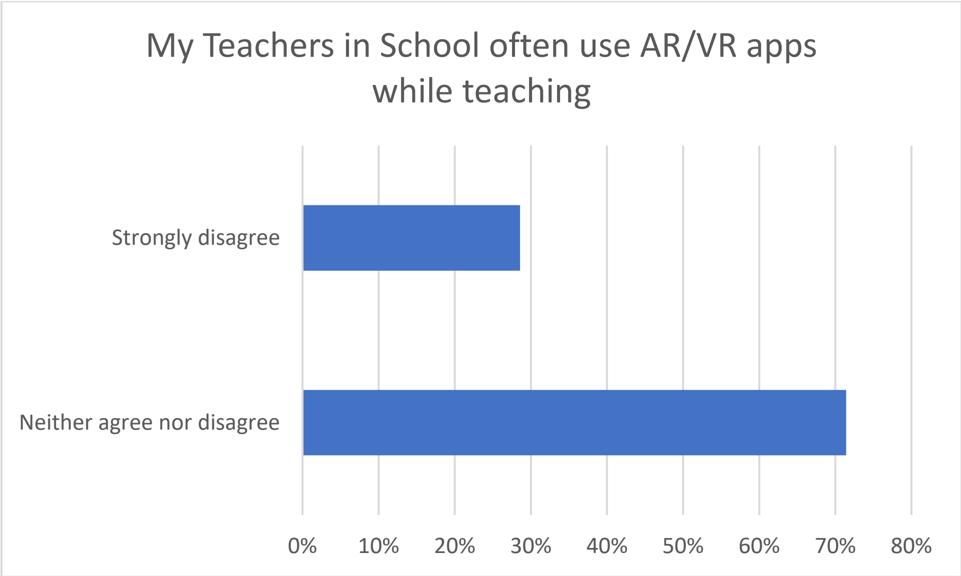


Figure 4.7: AR/VR in classroom

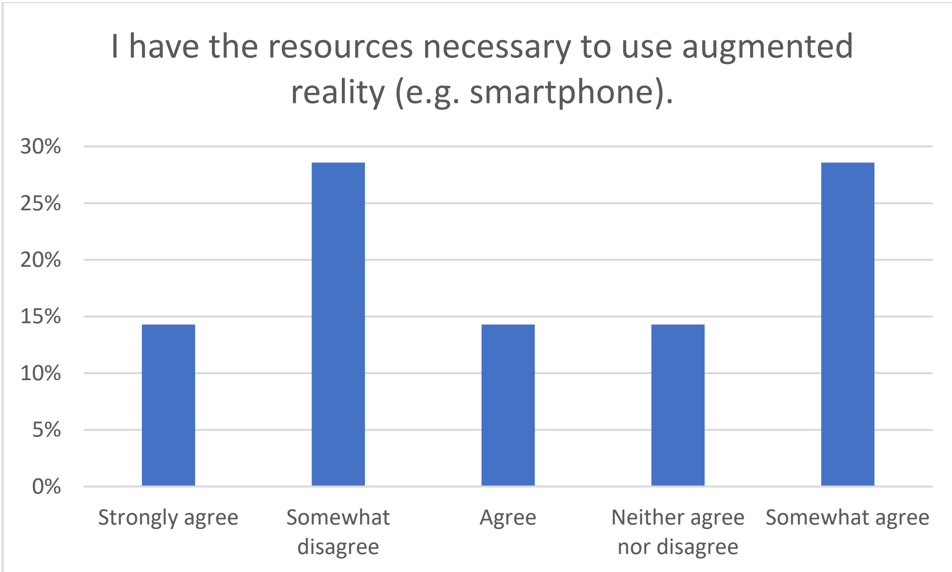


Figure 4.8: AR resource availability

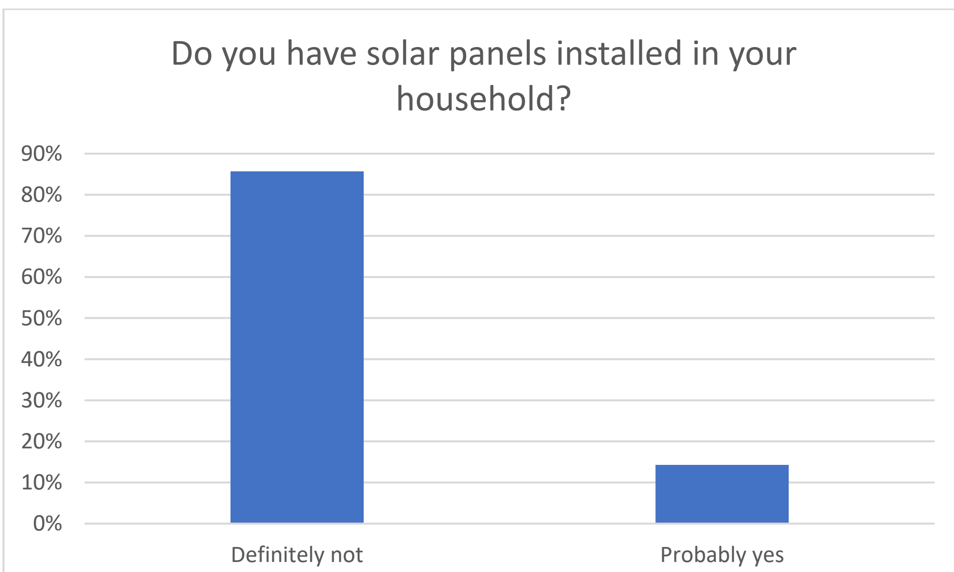


Figure 4.9: Solar panels in home

4.4.1.2 Post-Survey

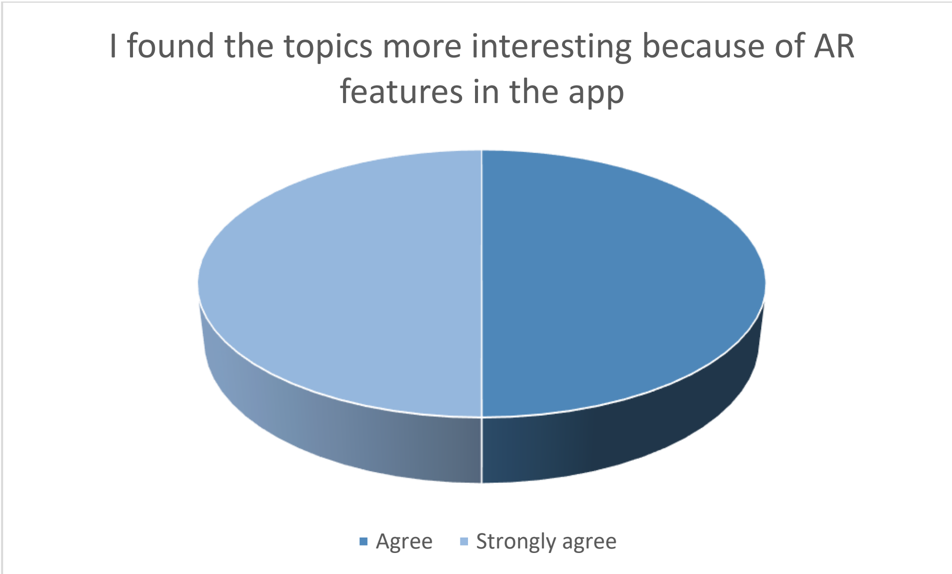


Figure 4.10: AR increasing interest on educational topics

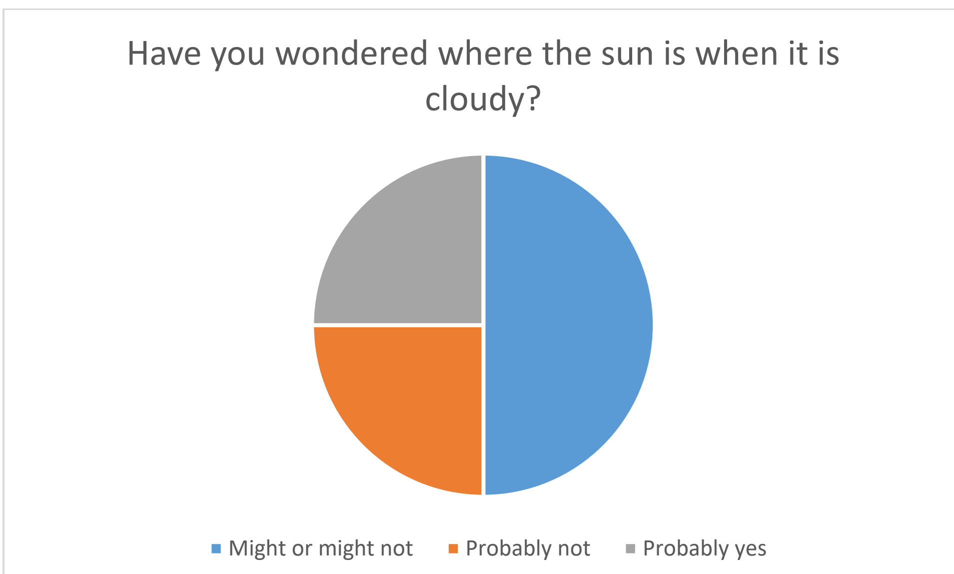


Figure 4.11: Curiosity about Sun's position

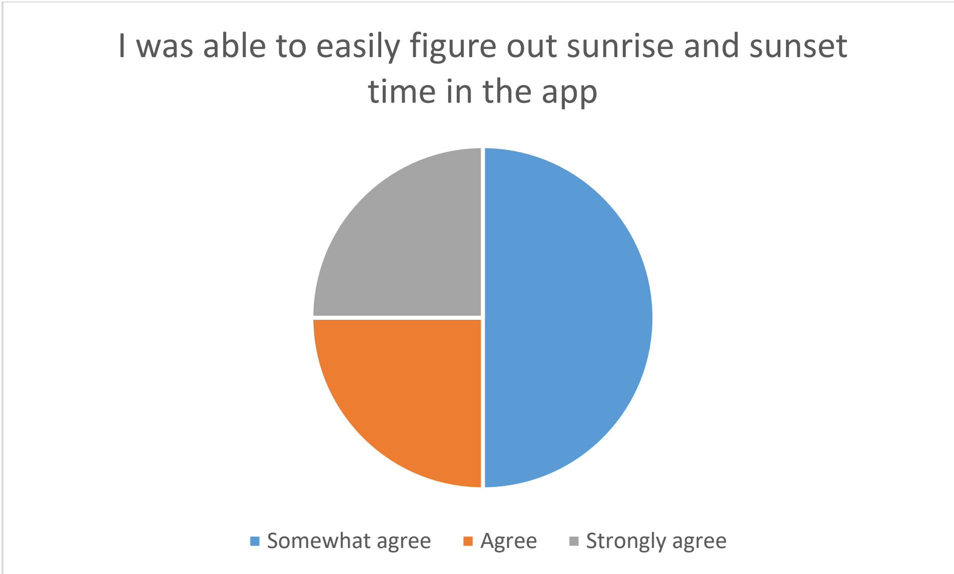


Figure 4.12: Applicability of Sun path AR app

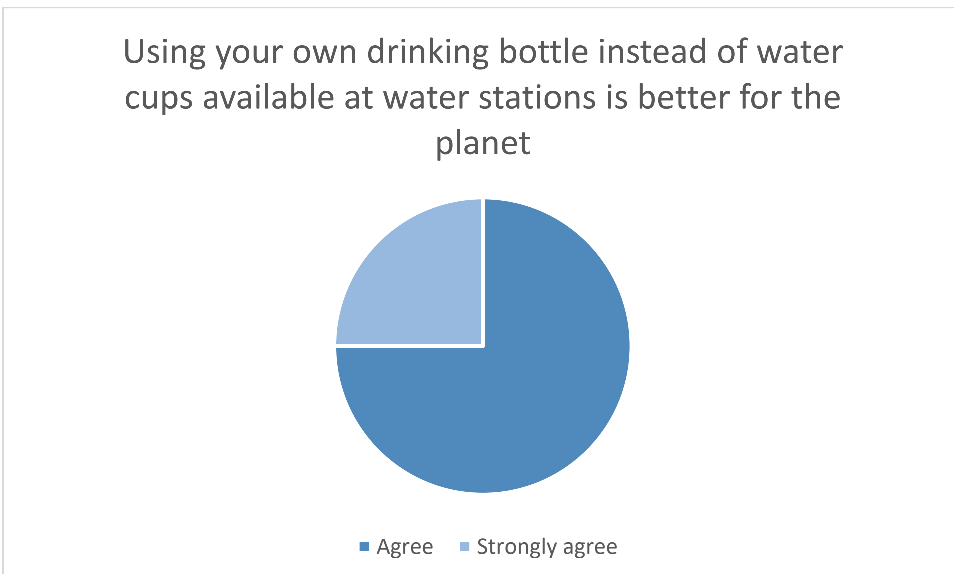


Figure 4.13: Ecofriendly awareness among K-12 students

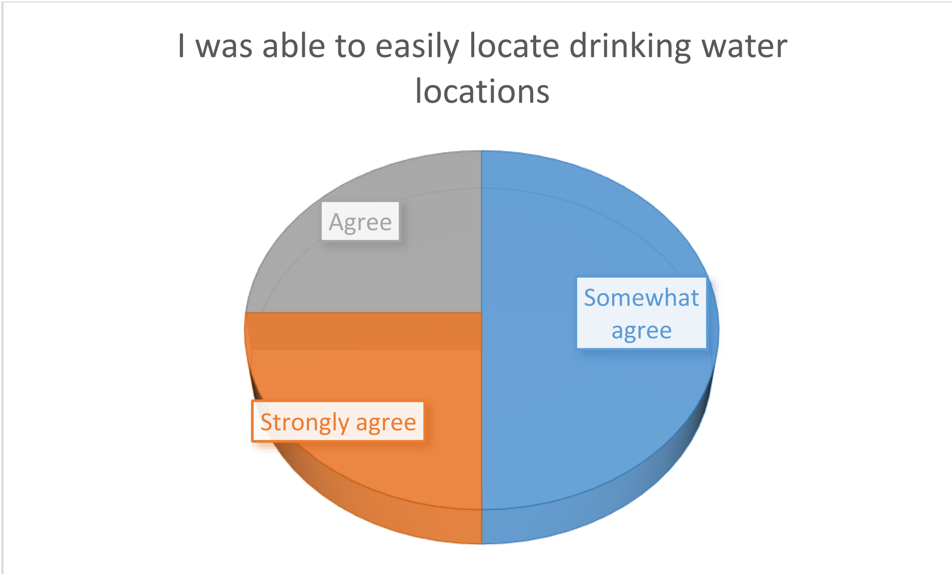


Figure 4.14: Applicability of Drinking Water AR app

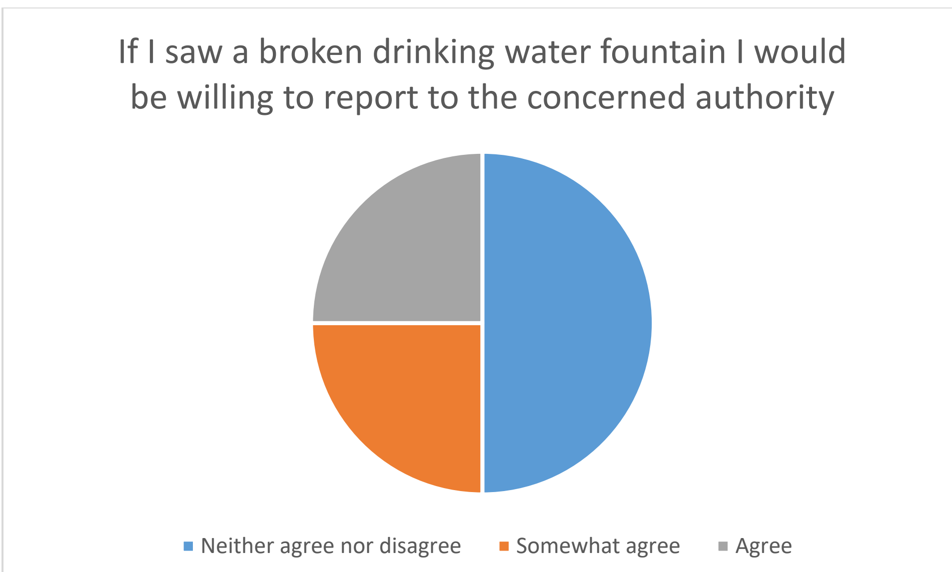


Figure 4.15: Civic engagement among students

CHAPTER 5. CONCLUSION

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 using a 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. 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, wasn't 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:

1. Currently, the water application only supports two of the buildings inside Auburn University, and so scaling it to add more buildings is proposed.
2. The mock data used for drinking water application could be replaced with actual data from the university.

3. 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.
4. Similarly, solar system VR application is only runnable in Oculus Quest Headset, and could be built to support more number of headsets.

REFERENCES

6 Exciting AR Apps for Student Learning. (n.d.). Edutopia. Retrieved March 10, 2021, from https://www.edutopia.org/blog/ar-apps-for-student-learning-monica-burns

Ahir, K. (2019, September 3). *What is the difference between Marker based and Markerless AR?* Medium. https://kumar-ahir.medium.com/what-is-the-difference-between-marker-based-and-markerless-ar-192fb9fa09c5

Anchor | ARCore. (n.d.). Google Developers. Retrieved March 10, 2021, from https://developers.google.com/ar/reference/java/com/google/ar/core/Anchor

Appoly. (2018, March 28). ARCore Location—Android Studio—Appoly News & Opinions. *Appoly*. https://www.appoly.co.uk/2018/03/28/arcore-location/

Appoly. (2021). *Appoly/ARCore-Location* [Java]. Appoly. https://github.com/appoly/ARCore-Location (Original work published 2018)

ARCore. (n.d.). Google AR & VR. Retrieved March 10, 2021, from https://arvr.google.com/arcore/

ArSceneView | Sceneform (1.15.0). (n.d.). Google Developers. Retrieved March 10, 2021, from https://developers.google.com/sceneform/reference/com/google/ar/sceneform/ArSceneView

Ayoubi, A. (2017, September 21). *IKEA Launches Augmented Reality Application*. Architect. https://www.architectmagazine.com/technology/ikea-launches-augmented-reality-application_o

Blanco-Muriel, M., Alarcón-Padilla, D. C., López-Moratalla, T., & Lara-Coira, M. (2001). Computing the solar vector. *Solar Energy*, *70*(5), 431–441. https://doi.org/10.1016/S0038-092X(00)00156-0

Build an Android App Using Firebase and the App Engine Flexible Environment. (n.d.). Google Cloud. Retrieved March 10, 2021, from https://cloud.google.com/solutions/mobile/mobile-firebase-app-engine-flexible

Choose a database: Cloud Firestore or Realtime Database. (n.d.). Firebase. Retrieved March 10, 2021, from https://firebase.google.com/docs/firestore/rtdb-vs-firestore

Cloud Firestore Data model. (n.d.). Firebase. Retrieved March 10, 2021, from https://firebase.google.com/docs/firestore/data-model

Core Components and Native Components · React Native. (n.d.). Retrieved March 10, 2021, from https://reactnative.dev/docs/intro-react-native-components

Covarrubias, C. (n.d.). *Immersive Technology: What is it and How can we Use it Today?* Advrtas. Retrieved March 10, 2021, from https://advrtas.com/immersive-technology/

de Araujo, I. E. T., Kringelbach, M. L., Rolls, E. T., & McGlone, F. (2003). Human cortical responses to water in the mouth, and the effects of thirst. *Journal of Neurophysiology*, *90*(3), 1865–1876. https://doi.org/10.1152/jn.00297.2003

El Filali, Y., & Salah-ddine, K. (2019). *AUGMENTED REALITY TYPES AND POPULAR USE CASES*. *8*, 91–97.

Frame | ARCore. (n.d.). Google Developers. Retrieved March 10, 2021, from https://developers.google.com/ar/reference/java/com/google/ar/core/Frame

Grand Challenges—14 Grand Challenges for Engineering. (n.d.). Retrieved January 24, 2021, from http://www.engineeringchallenges.org/challenges.aspx

H., L. (2018, July 17). *Location-Based AR Apps: Best Examples and Guide on How To Build*. Cleveroad Inc. - Web and App Development Company. https://www.cleveroad.com/blog/location-based-ar-apps-best-examples-and-guide-on-how-to-build

Heaney, D. (2019, May 5). How virtual reality positional tracking works. *VentureBeat*. https://uploadvr.com/how-vr-tracking-works/

Ishii, T. (1966). Distribution of Alzheimer's neurofibrillary changes in the brain stem and hypothalamus of senile dementia. *Acta Neuropathologica*, *6*(2), 181–187. https://doi.org/10.1007/BF00686763

Lee, H.-G., Chung, S., & Lee, W.-H. (2013). Presence in virtual golf simulators: The effects of presence on perceived enjoyment, perceived value, and behavioral intention. *New Media & Society*, *15*(6), 930–946. https://doi.org/10.1177/1461444812464033

Lehman, S., Graves, J., Mcaleer, C., Giovannetti, T., & Tan, C. C. (2018). A Mobile Augmented Reality Game to Encourage Hydration in the Elderly. In S. Yamamoto & H. Mori (Eds.), *Human Interface and the Management of Information. Information in Applications and Services* (Vol. 10905, pp. 98–107). Springer International Publishing. https://doi.org/10.1007/978-3-319-92046-7_9

Locatify. (n.d.). Location Based Augmented Reality Apps (AR & RTLS). *Locatify*. Retrieved March 10, 2021, from https://locatify.com/blog/location-based-augmented-reality-apps-2017-rtls-ar/

Mentes, J. C. (2006). A typology of oral hydration problems exhibited by frail nursing home residents. *Journal of Gerontological Nursing*, *32*(1), 13–19; quiz 20–21. https://doi.org/10.3928/0098-9134-20060101-09

Oculus Headsets: The Original Quest is Back | Oculus. (n.d.). Retrieved March 10, 2021, from https://www.oculus.com/quest/

Pacheco, J., Goh, J. O., Kraut, M. A., Ferrucci, L., & Resnick, S. M. (2015). Greater cortical thinning in normal older adults predicts later cognitive impairment. *Neurobiology of Aging*, *36*(2), 903–908. https://doi.org/10.1016/j.neurobiolaging.2014.08.031

Pombo, L., & Marques, M. M. (2019). Improving students' learning with a mobile augmented reality approach – the EduPARK game. *Interactive Technology and Smart Education*, *16*(4), 392–406. https://doi.org/10.1108/ITSE-06-2019-0032

Radvansky, G. A., Tamplin, A. K., & Krawietz, S. A. (2010). Walking through doorways causes forgetting: Environmental integration. *Psychonomic Bulletin & Review*, *17*(6), 900–904. https://doi.org/10.3758/PBR.17.6.900

Segovia, D., Mendoza, M., Mendoza, E., & González, E. (2015). Augmented Reality as a Tool for Production and Quality Monitoring. *Procedia Computer Science*, *75*, 291–300. https://doi.org/10.1016/j.procs.2015.12.250

Session | ARCore. (n.d.). Google Developers. Retrieved March 10, 2021, from https://developers.google.com/ar/reference/java/com/google/ar/core/Session

Shelton, B. E., & Hedley, N. R. (2002). Using augmented reality for teaching Earth-Sun relationships to undergraduate geography students. *The First IEEE International Workshop Agumented Reality Toolkit*, 8 pp.-. https://doi.org/10.1109/ART.2002.1106948

Three.js Fundamentals. (n.d.). Retrieved March 10, 2021, from https://threejsfundamentals.org/threejs/lessons/threejs-fundamentals.html

Unity Technologies. (n.d.). *Unity - Manual: Physics*. Retrieved March 10, 2021, from https://docs.unity3d.com/Manual/PhysicsSection.html

Unity—Manual: GameObjects. (n.d.). Retrieved March 10, 2021, from https://docs.unity3d.com/Manual/GameObjects.html

Xie, J. (2012). Research on key technologies base Unity3D game engine. *2012 7th International Conference on Computer Science Education (ICCSE)*, 695–699. https://doi.org/10.1109/ICCSE.2012.6295169

Yamamoto, S., & Mori, H. (2018). *Human Interface and the Management of Information. Information in Applications and Services: 20th International Conference, HIMI 2018, Held As Part of HCI International 2018, Las Vegas, NV, USA, July 15-20, 2018, Proceedings, Part II : 20th Inter*... Springer International Publishing AG. http://ebookcentral.proquest.com/lib/auburn/detail.action?docID=6242206