

Bio-WTiP: Biology lesson in handheld augmented reality application using tangible interaction

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Abstract. Augmented Reality (AR) is a combination of objects of both real and virtual that partially merged into a single environment. In the education field, the process of teaching and learning can be more interesting with the engagement of AR as aided learning tools during classes. However, the remaining problems are, Biology was one of the subjects that hard for students to easily understand such as learning water transport in the plant. The use of touchscreen in handheld interaction is limited due to screen size for user to use in handheld AR interaction for 3D object manipulation. Therefore, this project aims to develop a Biology lesson handheld AR application using tangible interaction (Bio-WTiP AR). There are three phases that have been carried out, which are AR feature-based tracking, integrate Biology application with tangible interaction in handheld AR and evaluation. The testing and evaluation have been performed based on usability and user acceptance. The results show the application has been accepted by the users as the users found it is interesting to learn the process of water transport in the plant on hand. Based on the results, this project has successfully produced a Bio-WTiP application that can enhance the users learning process at once gave users experience in AR.

1. Introduction

Augmented Reality (AR) is an upgrade version of reality where life directly or indirectly reads of physical actual-world surroundings are jumbled with layered computer-generated images over user view of the actual-world [1]. Nowadays, teachers either in primary or secondary school prefer to use digital technology as a medium for them to deliver their lessons such as slide notes, videos, or three-dimensional (3D) graphical multimedia. Hence, AR is one of the newest technologies that enable seamless connection in combining physical and virtual worlds that have applied to education.

This paper presents the development of Biology lesson handheld AR application using tangible interaction, namely Bio-WTiP. It is for science stream student in secondary school with the implementation of AR technology in it. Instead of learning just by using textbook which is too ordinary, this application will provide better learning concept, and 3D graphic as students also can enjoy and experience the new growing technologies in the application. Since we are living in the era that encountering a fast penetration of smartphones, portable devices, and mobile application, it makes sense for the student to start learning using these gadgets instead of books as now all information just one touch away.

The Bio-WTiP application allows the student to manipulate with the displayed 3D graphics using tangible interaction. By using tangible interaction, the student can take control of the model display by adding water molecule to the plant as this project focuses on water transport in the plant. They need to



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hover the mobile phone's camera to the marker, which is the plant marker provided for the app to displays the 3D graphics and student can interact with it. Therefore, this paper describes the literature review, development process and the Bio-WTiP application. It ends with the conclusion after discussing the findings.

2. Literature Review

2.1. Augmented Reality

AR is a system that seamlessly permitted users to see the actual-world environment with the virtual objects overlaid upon it. There are three major facets in the AR system that fuses real and virtual objects in the actual-world environment. Which are, real-time, runs interactively, and roster real and virtual objects with each other [2]. The definition of Milgram's Reality-Virtuality Continuum was discovered by Paul Milgram and Fumio Kishino. It is an interval between the actual-world environment and the virtual environment, in between as a continuum that, where AR is closer to the actual world and Augmented Virtuality (AV) is close to a real virtual environment. AR also relies on the registration, such as alignment of the digital content, which is "augmentation" on the physical surrounding (digital registered marker) [3].

2.2. Feature-Based Tracking

Nowadays, most people prefer to use feature-based in their AR application instead of a marker-based system. To registering virtual objects into the actual-world environment, software development kit (SDK) like Vuforia is needed as a platform for AR applications. Vuforia, developed by Qualcomm, allows different AR applications to be produced and helps to recognise and monitor planar images and 3D objects in real time [4]. By this platform, it would roster and tracks the objects of the actual world and matches them with objects of the virtual world. Then the 3D model is controlled through Rajawali [5]. The key features in Vuforia incorporate the capability of the software to recognize and track images, objects, text, markers and modernize environments [6]. According to [4], there are no repeated patterns present in the image goal to achieve a better image recognition efficiency, and they must have high local contrast, uniform distribution of features and high density of features. This SDK supports the build-in Android, iOS and Universal Windows Platform (UWP) applications for mobile applications.

2.3. Tangible User Interface (TUI)

Handheld Augmented Reality (HAR) applications allow interaction with the physical environment of the user through tablets or smartphones on top of the real world with virtual content [7]. In general, handheld interaction device are widely understood as illusion lenses as users could use a camera on the opposite side of the screen to see the real world with simulated content through a monitor on the devices [8]. To manipulate the virtual objects in HAR applications, there are many interaction techniques that have been used by the user. AR handheld interaction has been categorized into two technique which is tangible interaction and intangible interaction [9] [10].

According to [11], the goal of TUI is to transform real objects into computer interface input and output devices. Originally, Ishii and Ullmer introduced TUI to describe novel human-computer interaction (HCI) types focused on the physical manipulation of everyday objects [12]. In term of interface, handheld AR interface can be advanced to Mixed Reality (MR) interface where user can use MR apparatuses to work with simulation in more immersive [13]. The tangible approach allowed intuitive interfaces to be developed, promoting collaborative activities, two-handed interactions, and providing a robust sense of straightness to users. [12] aforesaid that it is believed that contact with tangible interfaces is more normal or familiar than with other forms of interfaces and could be more available to young children, people with learning disabilities or novices, minimising the brink of participation. According to [14], tangible interaction provides various DOF for the user to interact with the immersive environment.

Paddle-based interaction is one of the tangible techniques that is relevant and efficient for use in education which has been studied by [15] and supported by [11]. Paddle-based interaction provides a choice on how to use a TUI in AR for virtual object scene assembly as it enables virtual objects to be

controlled between a scene. The paddle is the key instrument for interaction device and is intended to be used by either hand to create static and dynamic behaviours. [15] also believed that it is very natural to conduct these forms of interaction with a real paddle. Thus, the user can easily use this method to apply tangible interaction in AR environment as its able user assemble a difficult arrangement of virtual objects in the AR applications.

Touch-based is one of the techniques in handheld AR for object manipulation [16]. The most common used touch-based input is via a touchscreen device. There are several issues regarding the use of touch-based as input to the AR application. Yusof et al. [17] has stated part of the issues regarding to AR experiences due a natural intuitive interaction technique instead of simply pointing and clicking, and manipulating 3D content from the 2D gesture. In addition, Bai et al. [18] supported the statement from [19], it is due to small size device the interaction area and display is limited which caused the limitation in occlusion of the finger on the screen content. This issue caused the user to feel uncomfortable to play around with the application freely. Thus, the use touchscreen in handheld interaction is too usual for the user thus tangible interaction is used in handheld AR interaction [20] and [21] stated that current interaction method mainly finite to clicking and 2D touch.

Besides that, hand gesture interaction also is one of the inputs that allow users to interact in more naturally and intuitively [22]. Gesture-based interaction interprets the user's, actions separated from the device [23]. Usually, to allow a real-time hand gesture interaction, an external device is needed to combine the gesture in the context of AR environment with the physical world such as Leap Motion Controller. The device used infrared (IR) to determine the position of the objects in a limited real time-space [22]. The use of an external device like Leap Motion Controller required a lot of budgets and it is unsuitable to be practiced with a tablet as Leap Motion required to connect via USB to a computer [24].

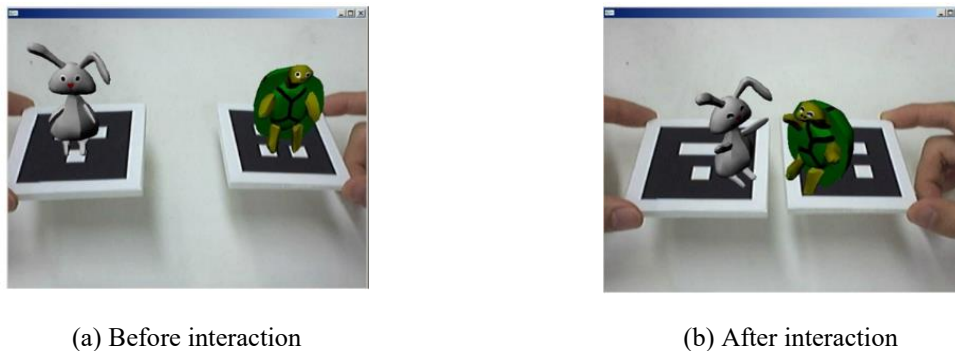
There are drawbacks for TUI, however, as it can be vital to modify certain physical properties, making it difficult to inform by observing what the state of the digital data associated with that object is at a physical object. Therefore, the limitations can be overcome through the employment of AR. Besides using a handheld device, the tangible interaction also can be extended into using bare hands to interact [22].

2.4. AR in Education

There are multiple user learning environments discussed in [25] that, through the adaptation of Virtual Reality (VR), AR and MR, can create an immersive educational experience. By implying mobile AR application in education, it can enhance the students' learning understanding capacities [26]. The learning process of certain subjects also can be more interesting by using AR [7]. Usually, in educational institutions, lecture notes are famous teaching materials. However, educators are always looking for a new way to teach students and exploring new technologies that can give advantages to students in learning efficiently. Thus, it leads to found that AR is one of the latest technologies that considered as having a potential for pedagogical applications [27]. Furthermore, [28] has claimed that AR has a great potential to give out the valuable context for education as it allows learning method with experiences that can connect the information from the real world.

3. Related Works

Immersive authoring of tangible AR application is a system that suggested new approached for authoring tangible AR proposed by [29] that been called immersive authoring. Tangible AR approached which mixed interface of tangible user input methods with the output of AR display. This approach was suggested for virtual content in AR interface so it can be employed using a physical object. The main purposed of this approach also to created intuitive AR interface. It depended on precise tracking of the real object while using tangible AR interface and to achieve this requirement, ARToolKit computer vision tracking library was used. This is because the direction and orientation of the camera relative to square fiducial markers could be determined by ARToolKit, making it easier to create a tangible AR application [29]. Figure 1 below shows the prototype that was developed by [29] where it shows the virtual objects before interacted with each other (Figure 1 (a)) and when both markers interacted to one another (Figure 1 (b)).



(a) Before interaction

(b) After interaction

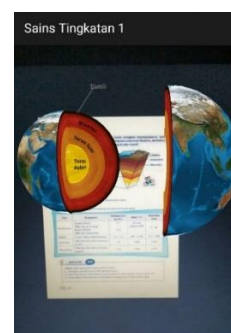
Figure 1. An interactive Tangible AR application [17].

SHARED SPACE Space-Multiplexed Interaction in AR was one of prototype example developed by [30]. The application applied the idea of tangible AR, which was used to develop a simple but powerful spaced-multiplex AR interface for several users. As it was designed to build a multiplayer AR game that does not involve user training, it offered users to play the AR application with another user. Furthermore, SHARED SPACE Space-Multiplexed Interaction needed the user to wear an Olympus HMDs with the camera attached to it as a medium for users to view the 3D graphics in the virtual world. It also provides users with multiple cards to select and look at the models from any angle. It is a game for users to find the matched object. When both objects are matched, the animation was triggered. While this is only a basic application, it has given a great test of the utility of a tangible interface for virtual object manipulation [30].

Students usually have a hard time to understand terms in science or a process that involve in certain subtopics during classes. Some schools did not provide a projector in their classroom for teachers to show a video during teaching. This is because an AR Buku Teks application was developed by Xentral Methods in 2016 to easier the teaching process in class as it required a mobile phone for display. This AR application developed especially for Malaysian textbooks for primary and secondary schools. The application has covered syllabus for science Form 1 and 2 only. The application is to assisted students in better understanding the subject in hand via 3D modelling, videos, and audio. Users needed to scan the image target which is images from the textbook itself for displaying the 3D model as shown in Figure 2 which consisted of cell structure function (Figure 2 (a)) and earth's layers (Figure 2(b)).



(a) Cell structure function



(b) Earth's layers

Figure 2. AR buku teks content.

4. Proposed Bio-WTiP AR Application

This section explains the system overview of the Water Transport in Plant for Biology lesson in handheld AR application using tangible interaction or in short, we named as Bio-WTiP AR application. The following subsection includes the 3D object modelling, 3D object animation and the project interface.

4.1. Tracking and Bio-WTiP Workspace

Tracking process implemented to display the virtual object on the top of the real world, and the use of Vuforia SDK in this project is to track the target images and allowing them to interact with space in the real world. In Vuforia, the way to track the target manager image was by using Vuforia target manager. Vuforia Target Manager is one of Vuforia library that has a web-based tool that enables developers to create and manage target databases online. The virtual object was displayed on the screen right after the camera recognized the features of the image target that has been registered in the Vuforia database. Figure 3 below shows the tracking process and user workspace.

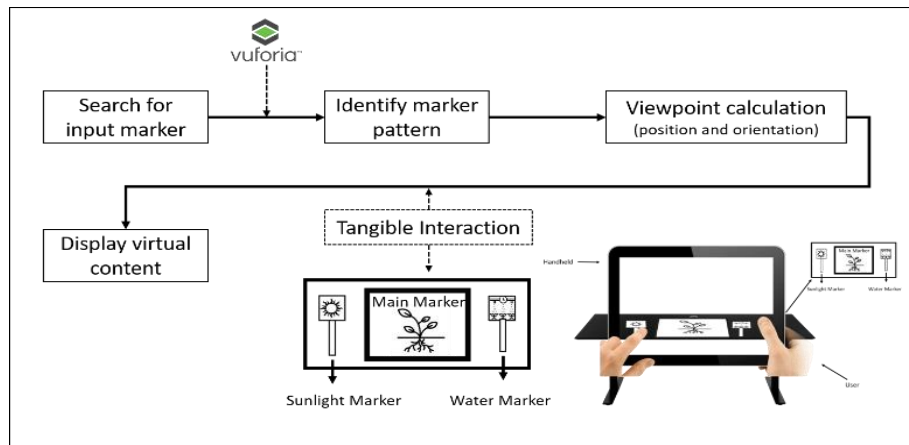


Figure 3. Tracking and AR workplace.

The tracking process that takes place when the user was required to test the project were displayed in Figure 3. At first, the AR camera searched for the input marker. This occurred when the user hovers the handheld's camera to the printed marker, which is the Plant marker. Then, the input marker must match with the pattern of the marker that has been uploaded in the Vuforia database. The viewpoint calculation allowed the process of recognition of the marker and allowed the virtual object appears on the top of the marker. Tangible interaction happens between one marker (Sunlight Marker) with another marker (Water Marker) that takes place until the display of the virtual content has appeared on the screen.

4.2. Tangible Markers

Tangible AR interface mixed the augment display potential of AR with intuitive interaction and manipulation of a physical object. It also supports the interaction between actual and virtual worlds as it provided with natural interaction range. This project utilized the used of tangible interaction between multiple markers to control the manipulation of the virtual content in the application and the use of virtual buttons to give out input to the user for better understanding. Figure 4 below shows all the marker used in this project, and each marker holds different virtual content and purposes.

The plant marker (Figure 4 (a)) allows the display of a 3D AR plant model in the scene while the sunlight marker (Figure 4 (b)) holds the sunlight constraint. The water marker (Figure 4 (c)) allowed the display of 3D AR water molecules in the scene between the stem of the plant, and lastly, the virtual buttons marker (Figure 4 (d)) holds multiple virtual buttons where users interacted with it to give out more information about the learning process. Three processes occurred when the markers interact with each other. The 3D model plant needed to be presented throughout the process for users to manipulate the virtual content displayed.

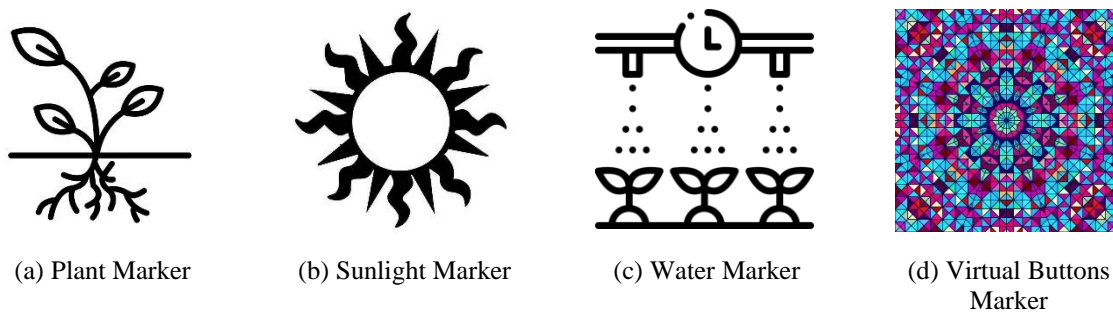


Figure 4. List of markers.

The expected number of markers used in this project was four in total. First is the main marker, the other two is the elements or constraints to the AR environment which is, water molecule and presence of sunlight, and lastly is a virtual buttons marker that contained five buttons elements.

4.3. Simulation Data

The data of 3D models in the project are modelled using Blender 2.8 as it was easier the process to shape the primitive shape such as cylinder to the Bezier curve for the body of the plant. When all the shapes were joined to create a plant, the materials for the model is set. Then the 3D model will be exported into FilmBox (FBX) file format. The FBX file format is a well-known 3D data interchange format utilized between 3D editor and game engines. As the 3D model need to be imported into the Unity, FBX offers the right choice as it can support a lot of combined data as the 3D model need to keep the 3D bones models and the colour materials of the model. All the process mentioned illustrated in Figure 5 below.

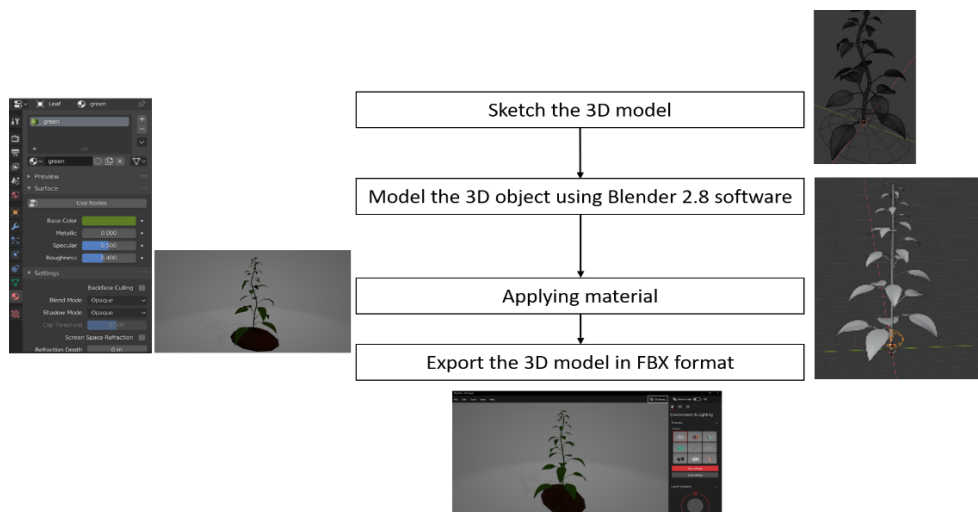


Figure 5. 3D Modelling process for 3D object.

The 3D plant model that has been designed and used in this application is shown in Figure 6. Figure 6 (a) shows the basic plant model without the adding of materials to the surface of the 3D model plant, and Figure 6 (b) shows the plant model with adding of material. There are three parts needed to be ready in creating the plant model, which are the base of the plant which represent the ground with soil, the stem of the plant and the leaf of the plant. These three parts have been created separately and joined at the end of the process. Curve modifier was added at the stem and leaf of the plant in Blender 2.8 to give a curve shape to the plant model. It is to make the plant looked real in user views instead of a basic solid straight plant model. To avoid a holographic viewing on the plant's stem when the plant was sliced, select the faces of the plant's stem in Blender edit mode, then click *Shift+N* to add a normal line to the surface of the plant model

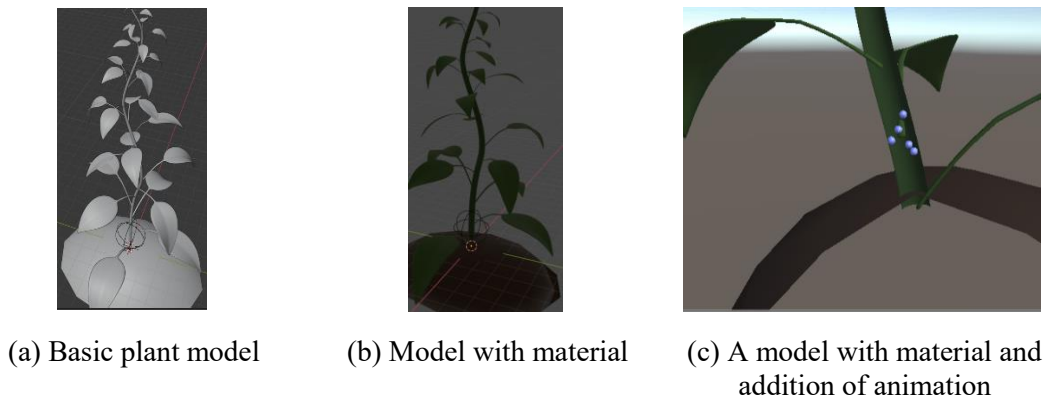


Figure 6. Plant Model.

The animation was created by adding a new Animator Controller than the animation clip was recorded by controlled and placed the position of x, y, and z of the model by the keyframes in the timeline. It easier as the position flow of the water molecule can be controlled to the exact position in between the plant’s stem model. Figure 6 (c) shows the animation of the water molecule in between the stem of the plant run in Unity 3D. There are several water molecules has been added into the plant’s stem where the molecules animated once it has spawned into the environment.

5. Implementing Tangible Interaction in Bio-WTiP

As presented in Figure 7, the flowchart to demonstrate the object manipulation using tangible interaction in handheld AR. The user starts with the opening the camera, followed by scanning the targeted marker. After that, a virtual object which in this case is a plant augmented onto the marker through this application, and the user can also manipulate the water flow in the plant by adding another marker to the AR space. Besides, the user also can see an animation flow of water molecule transport from root until the leaf of the plant by click one of the virtual buttons displayed. When the user adding the water, there will be an audio of information and process flow regarding the current condition of the plant. User can play with the process of water transport in the plant by adding a water molecule once at a time and increase or decrease the intensity of the sunlight into the AR environment.

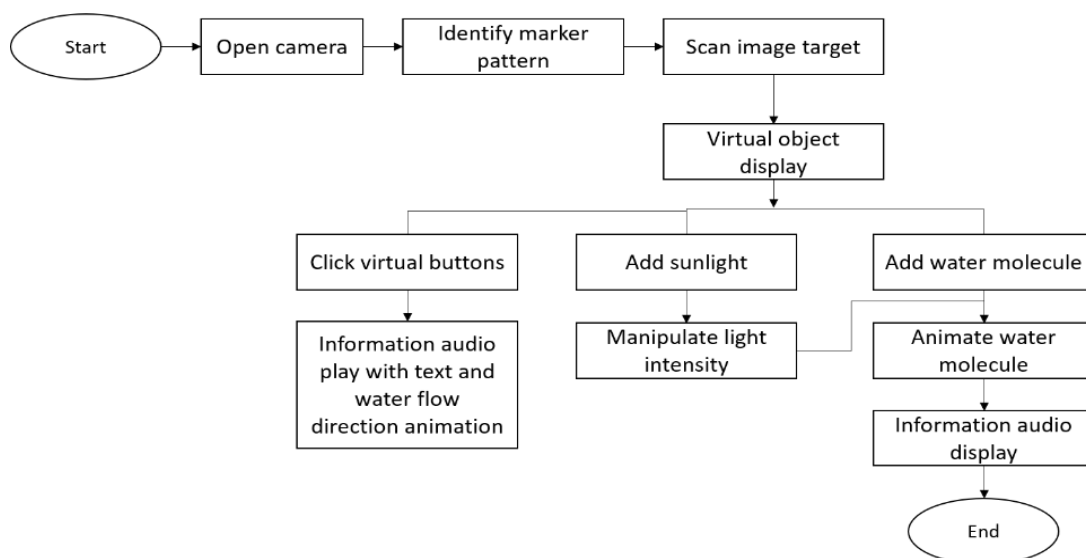


Figure 7. Tangible Interaction Flowchart.

Tangible interaction began as a user needed to add water molecules to the environment of the sliced plant model. The process of adding water molecules to the AR environment began when the camera detected the water marker. The water molecule spawned in between the plant's stem on the plant marker. The animation of water flows from the bottom of the plant until the leaf occurred. User can freely add the amount of water molecule to the plant, and each time the camera detects the water marker, a water molecule spawned to the environment.

Furthermore, the user can control the light intensity in the environment to see the change of the water molecule flow's speed. The light intensity of the environment can be control by using sunlight marker. The nearer the sunlight marker to the plant marker, the higher the value of light intensity which reflected the increasing of the water molecule flow's speed. Each marker used in this application held different object or purpose to it. Plant marker holds the 3D model of the plant. Water marker holds water molecule, an attached of note, and the trigger event to spawn the water molecule to the plant environment. The sunlight marker holds the sunlight of the environment and the trigger event to calculate the distance of markers to control the light intensity value.

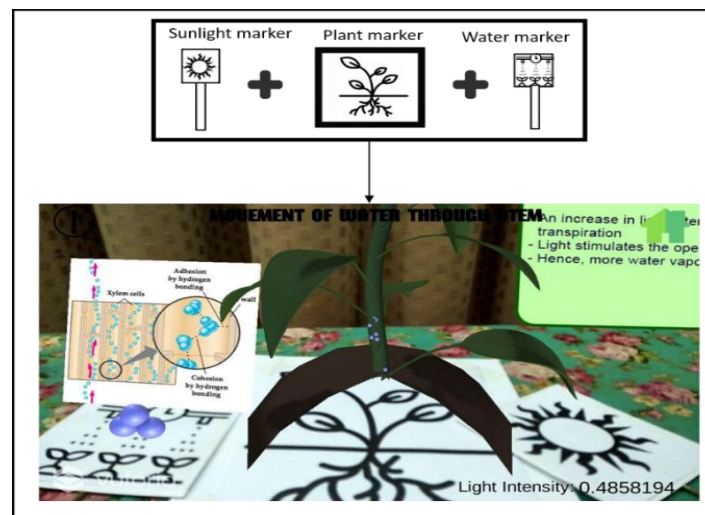


Figure 8. Tangible Interaction between markers.

Based on Figure 8, it shows the interaction that occurs when a water marker and sunlight marker detected by the camera. The water marker caused the spawning of the water molecule to the plant, and the sunlight marker increased the light intensity in the environment. Along with three of these markers, there are virtual buttons marker that user could use during the learning process. The virtual buttons marker consisted of five virtual buttons in totals, and all the buttons held different audio and text to it for the user to listen and read the information.

The virtual buttons are shown in Figure 9 (a) below. For “Info 4” button in Figure 9 (b), there is an animation occurred in the AR plant environment where there is an arrow indication showed the user the direction flow of the water transport from the root to the leaf, and the result is as shown in Figure 9.



Figure 9. Virtual buttons with animation of water flow.

6. Evaluation

This phase was tested and evaluated the AR Biology lesson for mobile application using tangible interaction. It also focused more on user testing the prototype development and, the feedback from the test was collected to make further improvement if required. The test was conducted by Form 4 and Form 5 students who enrol in science courses as the application focused on Biology lessons.

The evaluation from the user testing process explained based on the bar charts. There are seven female and three male respondents to this application. Seven on the respondents did not have any experience in encountering AR technologies and three from the respondents have experienced AR technologies. The questions measured in a scale from range 1 (negative attributes) to range 5 (positive attributes) asked about respondents experienced and satisfaction in using the application. Figure 11 shows the evaluation results for Biology-Water Transport in Plant Augmented Reality (Bio-WTiP AR) application.

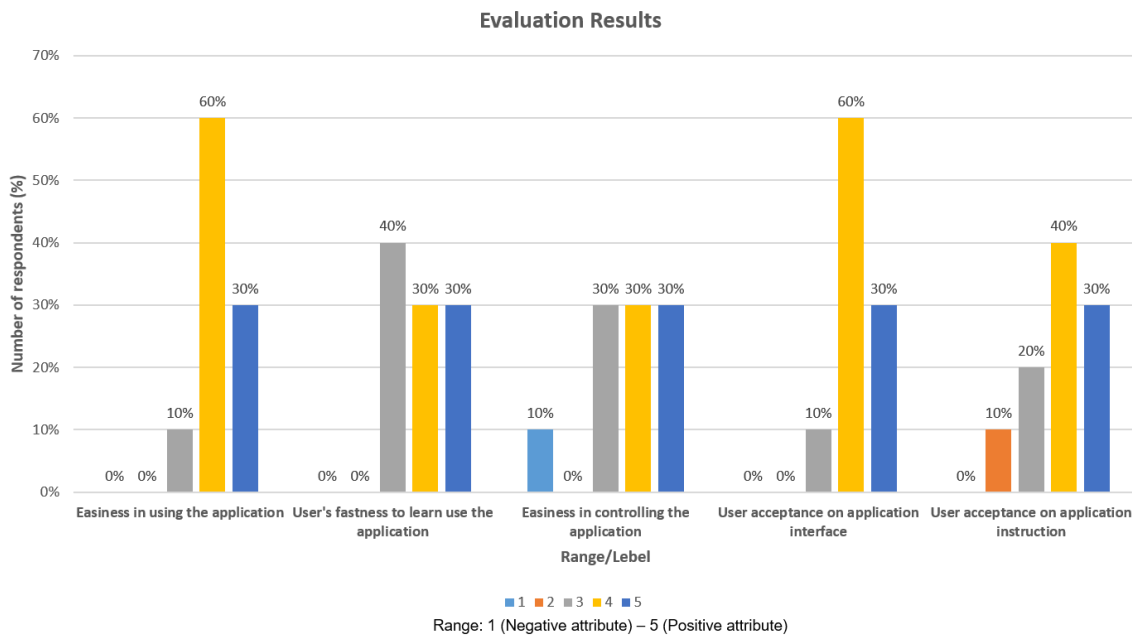


Figure 10. Usability Testing Results.

Figure 10 shows the results in bar charts of users respond to usability testing. For respondent's easiness in using the Bio-WTiP AR application, it clearly shows that most of the respondents found it

quite easy to use the application with a percentage of 60% in total that agreed and 30% strongly agreed that the application is easy to use and understandable. Only one respondent which hold 10% of the results ranged the application on the third level which is not too hard and not too easy to use.

Next, respondent's fastness learned to use the Bio-WTiP AR application. Majority of the respondents found the application was fast to learn as 30% of the respondents range their level at the fourth, which represented as fast. Another 30% of the respondents range their level at the fifth, which represented as very fast. 40% of the respondents found the application was not too fast and not too slow to be learned, and none of the respondents is slow in pace to learn how to use the application.

Third, is the level of easiness for the respondents to control the Bio-WTiP AR application during the testing process. There are three levels that have the same number of respondents where it is range from in the middle of easy and hard, easy, and very easy. All these three levels held the percentage of 30% each of respondents and only 10% of the respondent found that the application is very difficult to be controlled during the testing process with none of the respondents ranged at the very hard and hard level.

Then, for respondent acceptance on the Bio-WTiP AR application interface, the graph shows that more than half of the respondents agreed that the interface design of the application was well designed. 60% and 30% of the respondent agreed and strongly agreed that the interface design was accepted to use. 10% of the percentage with represent of one respondent rated the design interface of the application at 3/5. Interface design is essential as it attracted the respondents to feel excited when interacting with the application and this shows that the design interface of the application was well accepted.

The fifth is the respondent acceptance on the clearer of the instruction in the Bio-WTiP AR application that given to the respondents. Based on the result, there are various answers to the question where 70% of the respondents' rate the application provide clear instruction to its users as they agreed (4/5) and strongly agreed (5/5) to the question given. 20% of the respondents rated 3/5 for the level as they found it is not too easy to understand the instruction given in the application and 10% of the respondents rated it is hard (2/5) for them to grasp the instruction provided.

Overall, all of the respondents were satisfied with the Bio-WTiP AR application as 50% of respondents rated 4/5 that they are satisfied enough on the Bio-WTiP AR application and the rest is strongly satisfied with the application with percentage of 50% in total. The high satisfaction of the application came from the easiness of the application to use, the easiness to control the application and interaction in the application, how clear the instruction is given to use the application and how well the design of the application interface.

7. Conclusion

From the result, this project developed to easier students in remembering and understanding on how the process of water transport in plant's stem occur. The topic was picked because the student had a hard time to visualize the process that occurs in a plant as it is visible towards naked eyes and they tend to have a misconception towards water transport in plant process.

The project is limited to one external condition that affects the rate of transpiration which is the presence of the sunlight in the environment. The target markers used was already being fixed as it has stored in the Vuforia database cloud. The build of the Bio-WTiP AR application also is limited to Android users only as the application was built in android package kit (APK) file format. The interaction that been applied in the application is tangible interaction where user needs to interact with another target marker to interaction with the virtual object. Furthermore, the interaction was limited to adding of the water molecule in the plant, manipulation of light intensity and play of voice information from virtual buttons only.

For the future works, to have a better understanding of the lesson, the system should have a more external condition that affects the rate of transpiration which are temperature, humidity, and air movement. Based on the usability testing, the respondents have recommended improving the application in the dual language, in English and Malay. It can give the users a better understanding to align with their syllabus in school. Multi-user interaction is another suggestion for future work, where a collaborative interface can be leveraged across learning environment.

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