

# Exploring the Impact of Augmented Reality (AR) on STEM Education in Ghana

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## Abstract

Essential technologies such as augmented reality (AR) and virtual reality (VR) has shown to improve teaching and learning as compared to traditional teaching aids of textbooks. A much higher AR experience has been captured in many researches where users report higher satisfaction, having more fun, and eagerly wanting to repeat the experience. Remarkably, user motivation remains significantly higher for AR systems as compared to traditional alternatives even when the AR experience is deemed to be more challenging. Besides the numerous benefits replete of AR, its application especially in the area of education, remains much to be desired. The paper aims to develop an android AR application using Unity3D with additional Vuforia libraries to provide a rich learning experience and enhance the learning process of STEM students, particularly those studying biology (anatomy of the human skeletal structure) in Senior High School's (SHSs) in Ghana. The application used different image targets from the SHS Biology GAST (Graduate Association of Science Teachers) textbook as markers to display augmented educational content. When the application is pointed to the markers in the book, the animated 3-Dimensional models were displayed with links to anatomy videos and web articles. The study examined learning patterns that motivated students before and after using the AR mobile application, the results showed a significant increase in the learning motivation, comprehension and retention of educational content by the students. The results further showed that AR can be used to augment theoretical concepts taught in educational institutions and laboratories if explored.

**Keywords:** Vuforia, Unity3D, Augmented Reality, Virtual Reality

## 1 Introduction

Gagne (1977) classifies learning as an important process of cognitive and social changes over a lifetime. Assertions put forward by Holzinger *et al.* (2005), indicates that there is a paradigm shift in learning patterns which is mainly attributed to the evolution and integration of technology to support teaching and learning. It was further state that, technology induced teaching and learning help students to acquire information and reference materials as and when they need it, how they want it and in the right quantity. These technologies continue to prove their convenience as they stimulate the learning environment and promotes student motivation to learn. One such technology which has gained immense popularity in recent years to advance the study of Science, Technology, Engineering, and Mathematics (STEM), particularly, the study of the human skeletal structure is augmented reality (AR) and/or virtual reality (VR). STEM education is considered crucial to the development of every economy (Nugent *et al.*, 2015), but there seems to be decreasing readiness and motivation on the part of students to pursue STEM majors (Osborne and Dillon, 2008). Views from Talanquer (2014) indicate that one of the major challenges derailing the advancement of

STEM education is the lack of alternative learning platforms that will provide meaningful experiences to students. In Ghana, the West Africa Examination Council (WAEC) continue to express growing concern over the poor performance of most students in science and mathematics related subjects. To avert the challenges mentioned, this study leverages on the importance of embedding Augmented Reality (AR) into learning environments. In AR, virtual objects (i.e. anatomical models) superimpose a real time image of the real world with either two (2D) or three-dimensional (3D) Computer Generated (CG) objects, allowing users to interact with them (Azuma *et al.*, 2001). AR has offered a new medium of interaction between the physical and virtual worlds and enhanced user perceptions of the real world (Kesim and Ozarlan, 2012). AR allows users especially students to develop important learning patterns as it has become one of the key emerging technologies in education (Wu *et al.*, 2013), Once developed, AR models can be displayed on mobile and desktop devices, head-mounted devices (HMDs) as well as through stereoscopic projectors and screen-based AR systems for wider audiences. In this study, the AR technology known as BIOMATE is deployed using a handheld device as the mobile assistive learning

tool. BIOMATE is an open source AR application that brings anatomy and human skeletal diagrams contained in Senior High School Biology GAST (Graduate Association of Science Teachers) to life. The mobile-Augmented Reality (mAR) technology affords students the opportunity to gain improved and repeated access to the subject matter at all times as it mobilizes the learning environment irrespective of location and time, allowing for flexibility of learning, especially in higher education. The 2D or 3D computer generated objects are further augmented with anatomy videos with links to web articles thus to enrich the learning experience and enhance both teaching and learning. The integration of this technology will turn the popular Senior High School Biology GAST textbook into a highly interactive AR platform with easy maneuverability. Despite the numerous benefits replete with the AR technology, this paper seeks to achieve the following:

- i. Build an (AR) application to transform human skeletal images into 2D/3D interactive models that will support teaching and learning; and
- ii. Provide rich educational content in the form of videos and web links thus to facilitate learning and understanding using AR.

### **1.1 Study Materials Used by Science Students in Ghana**

Science students in Senior High Schools rely heavily on lecture materials from tutors and government approved textbooks, other teaching and learning materials (TLMs) as well as libraries and science laboratories for concept experimentations. The problem associated with the traditional learning platforms is further exacerbated by the fact that in most senior high schools, teaching notes are either dictated or handwritten on chalk boards for students to copy as is done in junior high schools. Students make unnecessary mistakes copying handwritten and dictated teaching materials because of illegible handwritings, unclear wordings and lack of clarity in dictations. Even though, some schools have laboratories for experiments, very few have the right specimen or instructional models to support effective teaching and learning. Other have the laboratories and specimen but lack qualified personnel who will manage and guide students to utilize the available infrastructure to enhance their understanding of lessons in class.

### **1.2 Justification of the Proposed Augmented Reality Application**

Pandemics such as the prevailing COVID-19 create an urgent demand for technologies that can provide surreal experience for students to easily assimilate educational content especially in STEM. Technology such as AR is the panacea. Equipment for setting up the base structure (a computer system, webcam and/or projector) is readily available and also in most mobile devices. This will eliminate the barrier to providing practical training to students in their home whiles enabling students to learn anytime at their convenience. AR affords users additional interactivity (i.e. users can manipulate the virtual content in different positions either by rotating or tilting, etc.) over traditional printed media.

### **1.3 Effects of using AR in Education**

- i. The main benefit of using AR technology is for students to easily assimilate the abstract concepts surrounding the study of the human anatomy structure using 3D object models. By working directly in 3D space, difficult spatial problems and spatial relationships may be understood better and faster than with traditional methods;
- ii. AR books can support immersive learning, advance the understanding of complex information and increase motivation and participation (McKenzies and Darnell, 2003);
- iii. AR helps tutors to plan the educational material to promote independent learning or to perform collaborative tasks;
- iv. AR offers a rich contextual platform for learning and developing skills, this fact calls to constructivist notions of education where students take control of their own learning;
- v. The AR technology makes available opportunities for more authentic learning and appeals to multiple learning styles, thus allowing each student to discover his/her own learning path;
- vi. It is perceived that the use of AR technology involves an added motivation for students because it inspires them to

learn by experiencing and interacting with virtual elements. Some studies mention that the learning curve is faster and students get more and better assimilation of the issues when virtual reality tools are used; and

- vii. Augmented Reality applied to different learning environments, provides the appropriate ways to develop professional skills as well as being a facilitator for the development of transversal skills. For educational institutions it must be pointed that AR is a cost-effective technology for providing students more attractive content than does paper, and even provide virtual equipment to laboratories for training, which otherwise is difficult. Therefore, it is of grave concern to extend its use to all educational levels and any subject. The schools can overcome shortcomings of equipment and physical machines with virtual 3D models to conduct training

## 2 Resources and Methods Used

### 2.1 Software Development Life-Cycle

The Software Development method employed is the “Code and Fix” method. The success of the research is heavily depended on the approach chosen. The “Code and fix” method is an anti-pattern, which is commonly used though it may be ineffective or counterproductive in practice. It is often the result of schedule pressure on the software developer(s). Testing often begins late in the cycle. Unavoidable bugs are then fixed before the product is released (McConnell, 1996).

The AR application is primarily composed of off-line and on-line processing. The off-line processing covers the selection and management of identical objects in advance, geometric model of objects in the virtual world, establishment of physical model, generation of behavior model and 3D scenes. This part is mainly finalized using Unity 3D. The on-line process includes identification of objects and produce the corresponding feedback in real time and real scene. The virtual object is added to reality and the human-computer interaction is realized. This process is mainly achieved by Vuforia Software Development Kit (SDK).

### 2.2 Feasibility Studies

The feasibility focused on the technical, schedule, economic, resource and operational aspects towards the success of developing the mobile application.

The focus aspects are discussed as follows:

- i. **Technical feasibility:** Technical resources required to develop and implement the system were available. The tools included a working camera, laptop/desktop computer to serve as the computational unit, display unit, internet connection and relevant software (Blender).
- ii. **Schedule feasibility:** The specified time to complete the project, i.e. twelve (12) weeks was enough to create the base and core functions of BIOMATE beta version;
- iii. **Economic feasibility:** The amount of money involved was marginal. The cost involved was mainly that of internet data, which was quite expensive in this part of the world;
- iv. **Resource feasibility:** Resources available for development was adequate. However, for testing of software for user experience, currently time resource available to the developer rendered it infeasible;
- v. **Operational feasibility:** The suggested solution has the potential to solve the problem stated, as far as improving understanding of abstract biological concepts is concerned.

#### 2.2.1 Functional Requirements

The functional requirements defined for this project are:

- i. User should be able to access 3D models and videos;
- ii. User should be able to directly access web articles within the system;
- iii. User should be able to toggle between 3D models, videos and web articles panels; and
- iv. The software should be hosted on the Android Play Store for easy accessibility.

#### 2.2.2 Non-functional requirements

These are requirements not related to the functional aspect of the software. The necessity of requirements is categorized logically as must have, should have, could have, and a wish list:

- i. Must have: Separate panels to easily switch between accessing a 3D model, video or web article;

- ii. Should have: control buttons such as “close”, “pause” and “resume”; and
- iii. Could have: A Quiz panel to test understanding after accessing all relevant materials.

### 2.2.3 User Interface requirements

To foster easy adaptation and usage by the target users, the software interface should be;

- i. Easily recognizable. i.e. it should have a similar form factor of other chat applications;
- ii. Quick in response; and
- iii. Should be simple yet consistent across pages.

## 2.3 Flowchart of BIOMATE

As depicted in Fig.1, when the application is directed to the GAST, the camera captures the real-world image and compares it with stored markers within the AR application leveraging on Vuforia library. If a match is found, appropriate 3D material, article or video will be displayed else it will revert to searching for the marker

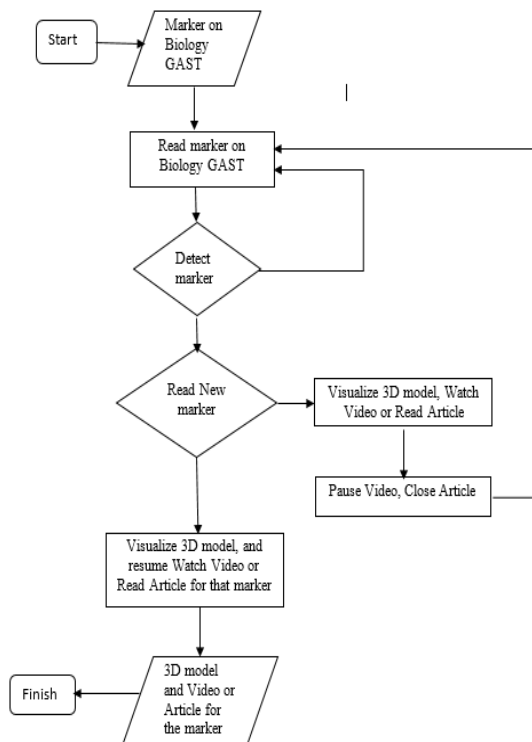


Figure 1 Flowchart of BIOMATE

### 2.3.1 Unity 3D

Unity 3D is a cross-platform integrated 3D game engine established by Unity Technologies Co. Ltd. It superposes the virtual reality and realizes human-computer communication with some AR development tools. Unity 3D was chosen for this project because it allows Vuforia SDK extension plug-ins to detect and track under the equivalent ports and creates AR applications and games. It provides ample development box functions to create games and other interactive 3D content. Unity 3D can append sunlight, fog, wind, sky box, water and other physical materials, ambient sound and animated video to the virtual scene. Meanwhile, you can browse, test and edit 3D application scenarios. Also, it is available to release to requisite platforms, such as Windows, iOS, Android and so on.

### 2.3.2. Vuforia SDK

Vuforia SDK is an augmented reality (AR) software development kit for mobile devices launched by Qualcomm. It utilizes computer vision technology to identify and capture planar images or 3D objects in real time and permits developers placing virtual objects through the viewfinder of the camera and adjusting the position of objects on the background of the camera. Vuforia SDK supports 2D and 3D objects including multiple target configurations, images with fewer symbol and frame labels. There is an added function in the SDK. It takes advantage of virtual buttons to detect localized constriction. Moreover, it can select and reconfigure the target image in real time and create a target set according to the scheme. Figure 2 depicts the data flow diagram of the Vuforia SDK.

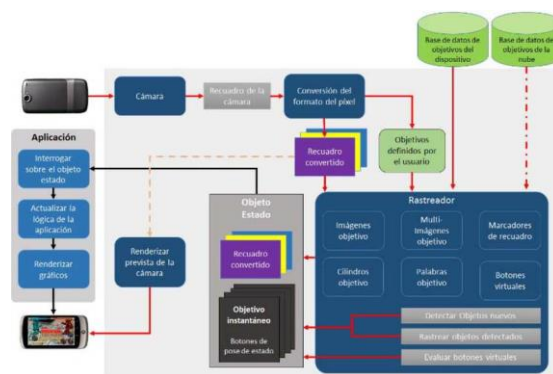


Figure 2 Data flow diagram of Vuforia SDK

Vuforia SDK’s data stream of is divided into four modules: inputting, database, tracking and matching and render output. Mobile phones can

take hold of images of each frame in the present real scene through the camera and then matched with identical objects in the database, according to the pixel format transformation. After that, preset virtual objects such as 3D model, animation or video are added to the real scenes. The SDK can also interact with virtual objects, render and output information at mobile terminals.

## 2.4 Environment Development and Production Process of Application

### 3.7.3 Establish of the Environment

- i. Unity 3D was downloaded and installed;
- ii. Vuforia development plug-ins were downloaded; and
- iii. Objects were created in Vuforia net for identification purposes.

1. Create license: Click Develop on the development home page of Qualcomm Vuforia and then Add License Key on License Manager. Select Development and name the App First. The object is generated.

2. Create Database: Click Add Database on Target Manager and name “anatomy”. Thus, the creation is completed.

3. Create Target: select the “anatomy” that has just been created. Establish the identification target. Elect Single Image and the picture path. Set the picture width and complete the creation.

4. As shown in the fig. 3, download and create a good identification target.

Vuforia website. Locate the established License Key.

- vi. Copy it to Unity and modify other parameter settings as depicted in fig. 4
- vii. Select the Image Target in Hierarchy to view the inspector window. Click database in Image Target Behavior and choose the Unity package file just imported. Click Image Target again and elect the target image contained in the import file as depicted in fig. 5.
- viii. Add the required 3D model to Hierarchy and drag the model into the Image Target to become a child object of the Image Target as depicted in fig. 6.
- ix. Add User Interface (UI) to allow the user to toggle between modes, i.e. 3D, Video and Web Article.
- x. Create C# script to manage UI and responsiveness to the application.

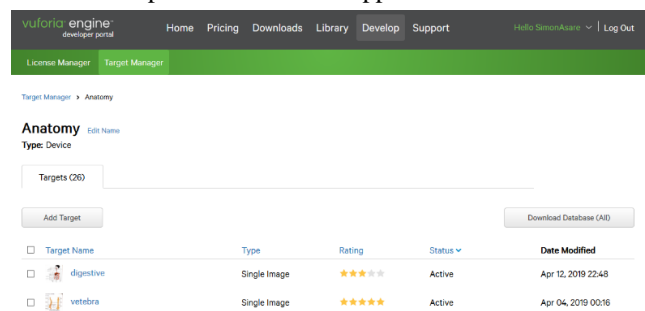


Figure 3 Vuforia Development Interface

### 2.4.1 Process of AR Application (BIOMATE) Generation

- i. Create a new 3D project in Unity.
- ii. Download Unity package plug-ins on Vuforia.
- iii. Import the Vuforia plug-ins in Unity and the downloaded Unity package file
- iv. Plugins folder and Vuforia will appear under the Asset directory after importing. Delete the Main Camera in Hierarchy and then drag the AR Camera and Image Target under the Vuforia /Prefabs directory to the scene.
- v. Select AR Camera in Hierarchy to view the Inspector window. Click Open Vuforia Configuration in Inspector window and fill in the App License Key. Enter the

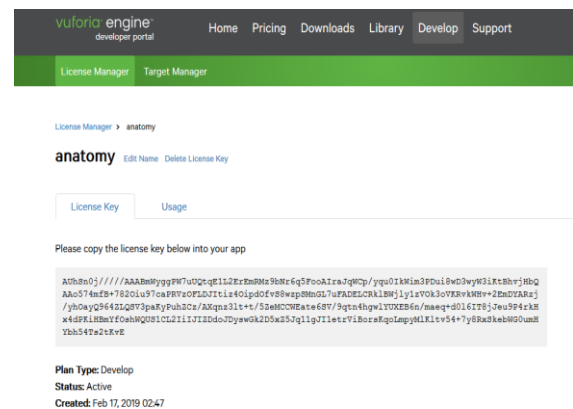


Figure 4 Creating of License in Vuforia

## Add Target

### Type:



### File:

Choose File

.jpg or .png (max file 2mb)

### Width:

Enter the width of your target in scene units. The size of the target should be on the same scale as your augmented virtual content. Vuforia uses meters as the default unit scale. The target's height will be calculated when you upload your image.

### Name:

Name must be unique to a database. When a target is detected in your application, this will be reported in the API.

Figure 5 Creating Targets in Vuforia

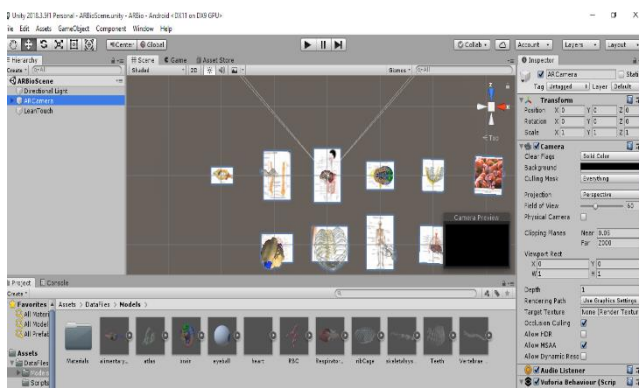


Figure 6 Development of AR Application in Unity 3D

## 3 Results and Discussions

### 3.1 Component Testing

System testing basically deals with the process of implementing the application with the stakeholders in order to evaluate the system's compliance with its specified requirements. Component testing was carried out on separate modules of BIOMATE application to identify possible bugs and performance issues. The system modules were

categorised as follows; 3D Models, Anatomy Videos and Web Article Panes.

The 3D pane was activated by touching the "3D button" on the User Interface of the device been used to interact with the application, this deactivates the video media. The mobile phone's camera then detects the image target and super imposes the 3D model on it. The Video pane was also activated by touching the "Video button" on the User Interface, this deactivates the 3D models pane and an anatomy video relating to the current image target. This is then super imposed on the target. Finally, the Web Article Pane was activated by touching the "Web button", this in turn deactivates both the 3D models and Video panes. With the aid of internet connection, the user is able to open the related article through an installed browser on the mobile phone. There is a control menu which allows you to pause and exit the BIOMATE Application.

### 3.2 Image Targets and their Corresponding 3D Models

BIOMATE has eleven (11) image targets with their corresponding 3D models successfully incorporated. The image targets were snapped from the Senior High School Biology GAST (Graduate Association of Science Teachers) then Blender studio was used to model the 3D versions. Fig. 7 shows the full human skeletal structure. The paper sought to augment different parts of the skeletal structure into very interactive model through the BIOMATE application.

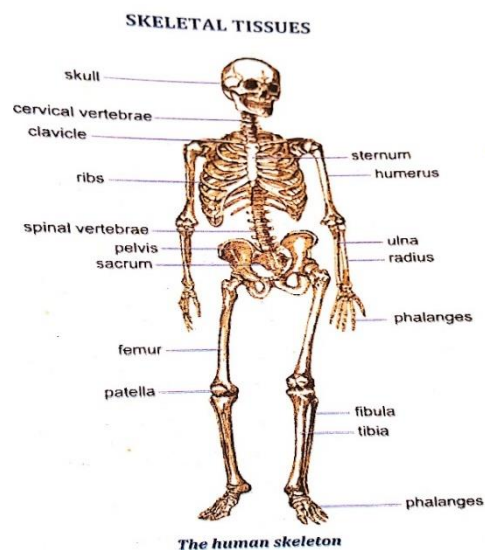


Figure 7 Human Skeletal Structure

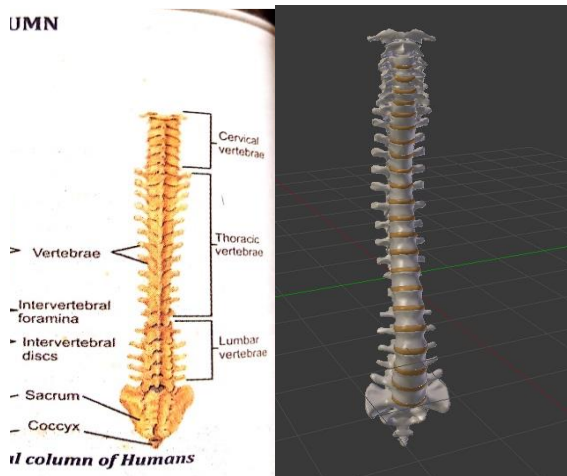
Fig. 8 depicts the interactive 3D augmented model of the human skeletal structure. In this form the BIOMATE environment allowed for a user to

interact with 3D model. The user was able to flip the image around, thus making it possible to view it at all angles.

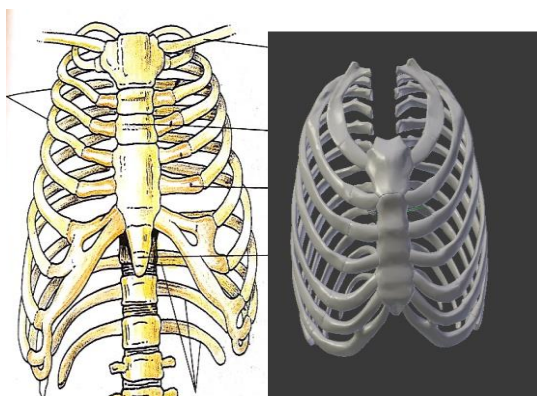


**Figure 8 3D Interactive Model**

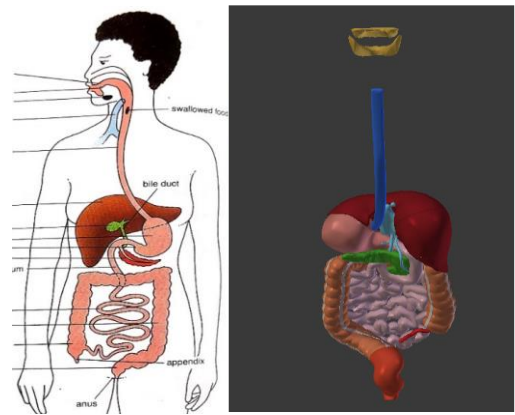
Fig. 9 shows the vertebral column target image before processing and the 3D interactive model after processing.



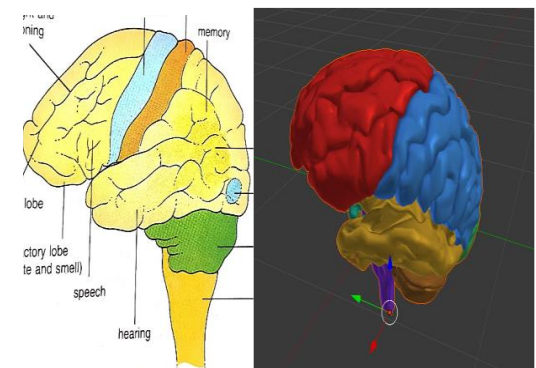
**Figure 9 Vertebral Column Image Target and Corresponding 3D interactive Model**



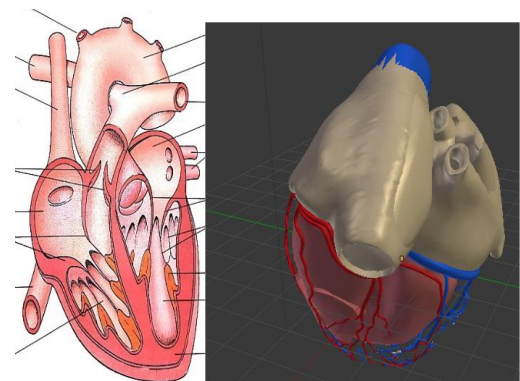
**Figure 10 Rip Cage Target Image and Corresponding 3D Interactive Model**



**Figure 11 Digestive System Target Image and Corresponding 3D Interactive Model**



**Figure 12 Human Brain Target Image and Corresponding 3D Interactive Model**



**Figure 13 Human Heart Target Image and Corresponding 3D Interactive Model**

### 3.3 Android View of the BIOMATE Application

BIOMATE was compiled into an android application file (.apk) with Unity 3D Engine, after several tests regarding the Vuforia's camera ability to detect the image targets within the database, the next tests were with regards to the alignment to the 3D models on targets. The orientation of the videos was optimised with regards to the resolution and width of the markers. The User Interface (UI) was designed, where the menus and buttons were created for easy interactivity. They were then optimised to be responsive on a mobile device before an event handle script was attached to it. The Event handler written in C# was to control the On-Click event for the Pause and Exit menu as well as switch from one pane to the other. Scripts were also added to allow a user the ability to translate, scale and rotate the 3D models through touch. The beta version of the application was compiled and installed on an android phone. Pictorial images are depicted as follows.

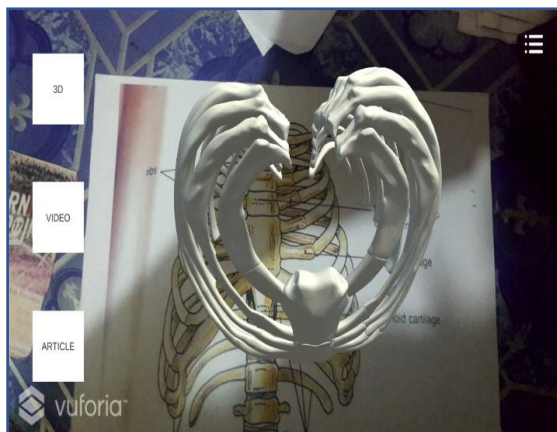


Figure 14 Rib Cage 3D Model Superimposed on Rib Cage Target Image

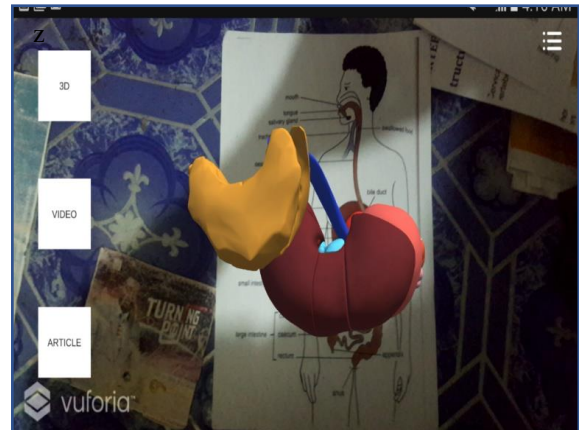


Figure 15 Digestive 3D model supper imposed on Digestive Image Target

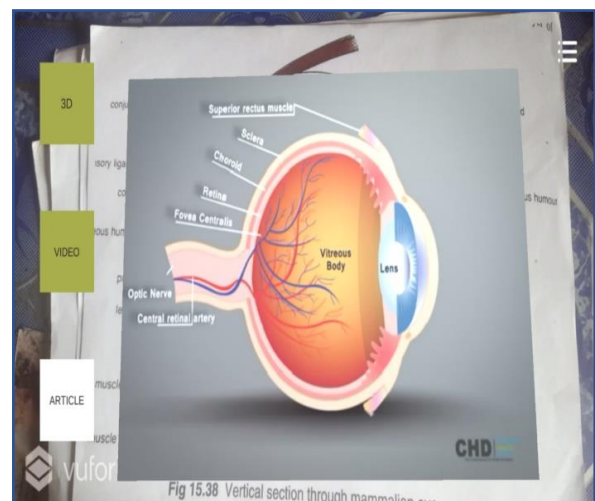


Figure 16 Video Media supper imposed on Image Target

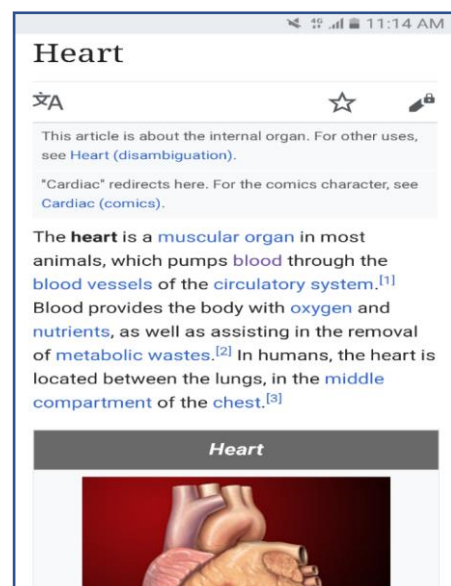


Figure 17 Web Article of the Heart Accessed Through BIOMATE



## 4 Conclusions and Recommendations

From the study, the following conclusions were drawn:

Even though, the Government through the Ministry of Education is investing massively to improve teaching and learning, there exist two fundamental challenges:

- i. Lack of motivation on the part of students to pursue STEM related careers; and
- ii. Inability of the teachers to adequately explain certain study areas

The challenges were attributed to three main issues:

- i. Over reliance on the traditional methods of teaching and learning;
- ii. Difficulty in adopting new technologies to improve lecture delivery; and
- iii. Financial constraints to deploy the right technology for the right job.

After the development, testing and usage of the application, users were fascinated about the system because it supported the understanding of complex phenomena by providing unique visual and interactive experiences that combined real and virtual information and helped to communicate abstract problems to learners. The application also enabled learners to interact with the 3D information, objects and events in a usual way. Results further showed that the educational experience offered by Augmented Reality is diverse for a number of motives:

- i. Supported seamless communication between real and virtual environments;
- ii. Use of tangible interface representation for object manipulation; and
- iii. Ability to changeover smoothly between reality and virtual reality.

Finally, it is concluded that, learning by doing helps students pursuing STEM programs to perform much better academically.

From the work that has been carried out, the following recommendation was made:

This project is limited to the android operating platform, moving forward iOS versions can be compiled as well as desktop version to increase the reach and especially make it easier to be used in classrooms.

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