



7th World Conference on Educational Sciences, (WCES-2015), 05-07 February 2015, Novotel Athens Convention Center, Athens, Greece

Utilising Mobile-Augmented Reality for Learning Human Anatomy

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Abstract

Augmented Reality (AR) is a technology that augments reality with either two or three dimensional computer generated imagery (CGI), objects and/or information, and allows users to interact with them. AR on mobile devices are evolving and offer a great deal of potential in terms of learning and training. This paper discusses the development process of a mobile prototype learning environment that utilises mobile-Augmented Reality (mAR). The prototype is called the Human Anatomy in Mobile Augmented Reality or HuMAR, and the selected learning topic is the anatomy of the human skeletal structure. The main objective of HuMAR is to aid students and it could potentially enhance their learning process. There has been a report stating that there is a decline in retaining and generating long lasting information longer when learning the abovementioned topic. This paper describes the theory, concept, prototype development and results of HuMAR taken from a pilot test. The pilot test used the experimental method with science's students from three different universities. The objectives of the pilot test were to consolidate users' experience from a didactic and technical point of view. Based on the results of the pilot test, it is concluded that students were satisfied with HuMAR in terms of its usability and features; which in turn could have a positive impact in their learning process.

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Peer-review under responsibility of Academic World Education and Research Center.

Keywords: Learning environment; mobile-Augmented Reality; motivation; prototype; system requirements.

1. Introduction

Learning is an important process of cognitive and social changes over a lifetime (Gagne, 1977). Nowadays the

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organization of learning is shifting (Holzinger et al., 2005), for instance, with the introduction of technology in learning in secondary schools and universities (Holzinger et al., 2005). Also, (Holzinger et al., 2005) adding the technology is believed to help students in acquiring information and reference material when they require it. With the convenience of most technologies, it stimulates the learning environment and promotes student motivation, which are important factors in learning (Holzinger et al., 2005).

This study highlights a technology called Augmented Reality (AR) designed to be embedded in a learning environment in higher education. AR is a technology that augments or superimposes 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 technology can be viewed using various devices, such as a see-through Head Mounted Display (HMD), a desktop or laptop computer, or a mobile device equipped with at least one back camera.

In this study, AR technology is presented using a handheld tablet device as the mobile assistive learning tool designed to increase interest and engagement in the learning process (Balog & Pribeanu, 2010). The mobile-Augmented Reality (mAR) technology gives the student the opportunity to gain improved access to the subject. It mobilizes the learning environment irrespective of location and time, allowing for flexibility of learning, especially in higher education.

In addition, with mAR technology features, it supports students in learning complex subjects, in particular, the subject of anatomy. This subject involves learning anatomy in the practical dissection laboratory, where there is exposure to the structure of the human body, animals and internal organs (Farlex, 2014). The practical session, facilitates students to learn more complex parts of the body structure. Nevertheless, after the practical sessions in the learning curriculum, most students have difficulty in recalling the subject matter. In relation to this problem, this case refers to a study conducted by (Ganguly, 2010). Reference by (Ganguly, 2010) states, human anatomy didactic lectures followed by practical dissections could not generate long lasting understanding of the subject. In addition, further observations of the anatomy students showed they were experiencing problems with retaining information (Ganguly, 2010).

Learning is often associated with two conditions; 1) location; and 2) time (Holzinger et al., 2005). Based on these two conditions, a number of important problems have been raised; namely, difficulty of access to relevant references from the laboratory due to limited opening hours, and limited physical materials, such as framing materials to borrow for revision. This could be a barrier to long-lasting understanding of the subject matter. However, these problems could be solved by introducing alternative teaching resources such as mobile learning tools (Holzinger et al., 2005). Mobile learning is especially significant to the user. With mobile devices, information is always with the user (Norman et al., 2012) because the he/she has easy access to information through a mobile device. Whilst, a traditional learning material, for instance using a textbook, has limited access and lack of visual understanding of the subject matter. This is especially so in learning anatomy. Hence, the mobile learning facility provides the benefit of mobility, and enhances the learning environment. Mobile learning is known as ubiquitous learning, and the term ubiquitous refers to providing learning using handheld devices such as mobile phones and tablets as the assistive learning tools.

In solving the above mentioned learning problems, revising the subject matter more often by using Augmented Reality (AR) technology (Chehimi et al., 2007; Norman et al., 2012) is one possible method of learning that could alleviate the problem. Moreover, (Bergman et al., 2013) assert, in keeping longer information, repetition of knowledge must be practised (Bergman et al., 2013). With mAR technology, the student can access the learning information regularly. The facilitation of time and location can affect the motivation of learners, and with better facilitation could result in improvements in the learning outcomes of students (Markwell, 2003).

Furthermore, according to (Markwell, 2003), many factors control the quality of learning. These include the aptitude and motivation of an individual student to learn at his/her own pace. In addition, (Markwell, 2003) remarks, the quality and diversity of learning also depend on; 1) The presence of the student body of which they are involved with; 2) The syllabus in which they study; 3) The strategies of teaching them; 4) The technique of the assessment process and feedback; 5) The availability of learning resources, e.g., libraries, laboratories, and ICT, and; 6) The scope for learning in the classroom, including in-house and extra-curricular settings, and the wider institutional and social context. Based on these factors, the design of quality teaching and learning is important, and the enrichment of teaching and learning resources should be a major focus. Therefore, any kind of educational application and domain specific technology must be considered. This enrichment leads to an improvement in learning methods and

fosters student motivation and also increases the quality of the learning outcomes (Balog & Pribeanu, 2010; Di Serio et al., 2013; Markwell, 2003).

This paper focuses on the development of a prototype educational tablet application called Human Anatomy in Mobile-Augmented Reality (HuMAR) utilizing AR technology. This HuMAR application is currently implemented as a learning tool, designed to enhance learning and foster student motivation and to increase the learning outcomes in skeletal anatomy. Here we describe the theory, concept, and the development of the HuMAR prototype. The software and hardware specifications, the learning materials used as well as the development process involved in developing this prototype application are also outlined.

2. Prototype HuMAR Application: Concept and System Overview

The prototype HuMAR application runs on an Android tablet with a multimodal interface function that can facilitate better interaction in terms of understanding of the subject using 3D objects. The selected focus for the implementation of HuMAR was the bones of the lower appendicular skeleton; this included the pelvis, femur, tibia, fibula, tarsus (x7), metatarsals (x5), and phalanges (x14).

The prototype HuMAR application runs in a similar way to a courseware-based application. In education, courseware means educational software that is designed for learning and teaching material in the classroom. Normally, a courseware application has a number of features, for instance, navigation buttons, information about the subject matter and hyperlinks. These features were added into HuMAR, to create interactivity with the system and to enhance the learning of any of the selected bones.

In order to view the augmented or superimposed object, the HuMAR uses the tablet's screen. The flow of interaction starts with a marker, which can be specified as an image on any surface, where the tablet's camera will work as an image scanner. In HuMAR, image is detected as a marker, and is measured by the width of the desired dimensions. Subsequently, the tablet's camera detects and recognizes an assigned marker. Once a marker has been recognized, an application installed on the tablet will display and superimpose the respective CG 3D object onto the screen. In this prototype, each bone image from the unit laboratory manual has been assigned with a specific marker in the prototype application. The dimensions of the marker in terms of height and width will be set during development. The marker size is very important, as the pose information will be detected within the same scale, which has been set earlier. For example, if the target marker is 20 units wide, moving the camera from the left border to the right border of the target marker changes, the image is still in the position of 20 units along the x, y-axis (Siltanen, 2012). The process involved in running the HuMAR application consists of; *the user; the mobile device / tablet; and the marker used to project augmented object*. To enable HuMAR, the user has to click on the application from the tablet. The application begins with the actual environment by using the camera of the tablet device aimed at a marker in the unit laboratory manual. Once the marker has been recognized, the respective augmented 3D model is displayed and superimposed onto the device screen, so the user can see the augmented object. A user can view an augmented 3D model of part/s of a bone when the user moves the camera of the tablet device into the area of the marker.

3. Prototype HuMAR Application Development Phases

A System Development Life Cycle (SDLC) in project management must be carefully planned to make sure all tasks are manageable. The SDLC model describes what the application is and how it should be developed (Ragunath et al., 2010). Fundamentally, it is comprised of various parts and phases, from planning to testing and deploying the application.

To determine the success of the development cycle, the *Waterfall Model* SDLC methodology was introduced. The *Waterfall Model* is a process or phase that is carried out in sequence (Ragunath et al., 2010). The performance of the HuMAR prototype development within the *Waterfall Model*. The progress of HuMAR development flows from the beginning, steadily downwards, to the final output.

The development of the prototype which consisted of five phases: 1) identifying the functional requirements; 2) identifying the technical requirements; 3) prototype development; 4) pilot testing; and 5) final prototype application.

Development begins with general requirements, such as functional and technical specifications, followed by duration of development, and cost which are then carefully considered and/or designed.

3.1. Functional Requirements of the prototype HuMAR application

The functional requirements are a series of interactive applications that allow the user to view input actions and program response actions, in terms of application capabilities. During Phase I, the conceptual features of the prototype HuMAR application were identified in order to enhance the efficiency of learning and hence offer a longer retention of information. A comparative analysis from (Jamali et al., 2013) has been taken through a few interfaces from other mAR technology applied in various industries; for instance education, advertising, entertainment, and tourism. As a result, based on the high success rate of selling product efficiently (Institute, 2004) in advertising using a multimodal interface this concept has received a very positive response from users. This could be due to the mobility and easy access of the product information (Chehimi et al., 2007). By carrying out this concept in prototype HuMAR application, the student's desire to learn is increased as he/she engages with the mAR technology. Simultaneously, they are motivated to understand and memorize without being forced to obtain the information from other limited resources.

The HuMAR offers 3D bone images with 360° angles that project the subject matter more efficiently onto the visual plane to facilitate understanding. In HuMAR, hand movements, for example finger interactions, are required. User interactions, which encompass body or hand gestures with the mobile device are a common characteristic of the kinesthetic style of learning. This learning style provides a more exciting learning environment and serves to motivate students (Siltanen, 2012).

Furthermore, the interaction of the prototype HuMAR application is based on a non-linear navigation concept (Ragunath et al., 2010). Non-linear navigation allows the user to navigate freely through the application content without the requirement to follow predetermined paths (Ragunath et al., 2010). In HuMAR, students can click on any part of the bone. The HuMAR is equipped with a control panel, comprised of two buttons for each bone. These are the *Help*, and *Info* buttons. The control panel is located at the upper right corner of the screen. The *Help* button within the control panel that describes how the user can interact with the HuMAR prototype application. The built-in *Help* also describes how a user can use the control panel for object selection, movement, rotation, scaling and screen freeze.

Moreover, there is an *Info* button that provides details of the skeletal system description. Each bone will be briefly explained and displayed in the description box whenever a student clicks on the label. A medical dictionary link is available to provide the student with additional information relating to the bony feature in question. This HuMAR prototype provides additional assistance for students in the form of a virtual experience of human anatomy. Students can initiate their learning anytime and anywhere, without relying on fixed university lab opening hours each time they need to study and access resources (i.e. the actual physical bones themselves).

3.2. Technical Requirements

Technical requirements are a set of specifications that must be met to allow a hardware product to be fully operable. These specifications are required to optimize the performance of this specific prototype HuMAR application. At the least, compatible technical requirements must be met to ensure the efficiency and effectiveness of the application.

To project an AR object, we have selected handheld devices, for instance, tablets, as display devices. The mAR application connects to the mobile Android operating system (OS), and the minimum requirement to operate it is version 2.3. The android platform includes a set of managed application programming interfaces (API) applicable to the Android device. For smooth and seamless operation, the mAR application must run with a Central Processor Unit (CPU) with at least a 1.6 GHz frequency and a display screen resolution of 1024 x 600.

To effectively deploy the mAR application, an android device must have a back camera, to track specific markers. Tracking is a method of registering what is being captured by the camera and merges the virtual image generated by the computer. The most common tracking methods used are position and orientation. Tracking the position initiates the graphic system to render views from the user's position. The back camera is used to capture the

real world surroundings and the front panel display screen is used to view the augmentations, such as the information, which has been set earlier by a particular marker.

3.2.1 Prototype HuMAR Application Architecture

The data flow of the system architecture prototype HuMAR application system begins with mAR running on the Android device. The first interaction is to point the tablet's camera onto the target or marker position. The prototype HuMAR application architecture starts with a new database, created from the Vuforia AR toolkit online database (Q. C. E. Incorporated, 2014), to set the target marker for each bone. A single target-based image is selected with a customized width and dimension, according to the preference. The image has to be uploaded in order to add a target to the database. This allows the activation of the authoring part in the Unity3D (Technologies, 2014) software to be explained in detail later in the Prototype Development, Phase III, Integration of Content and Mobile Device. The augmented object is displayed on the tablet screen for user interaction with the mAR application.

3.3. Prototype Development

In the prototype HuMAR application development, there are two stages: the creation of the content itself and then its integration with the tablet device. In this section, we explain the details of the development workflow.

3.3.1 Content

The contents of the prototype HuMAR application began with bone descriptions, bone joint locations, bone part labels, and reference links which were gathered following advice from discussions with anatomists. These features were built-in for students studying a Forensic Anatomy and Anthropology unit at Murdoch University, to improve their learning environment by using the mAR prototype as a learning tool for identifying the osteological features of the lower appendicular skeleton (bony features of the pelvic limb). The content of the prototype HuMAR application covered a Laboratory designed to study the Pelvic Limb. Bones of the pelvic limb include the pelvis, femur, tibia, fibula, tarsus, metatarsals and phalanges. In acquiring images of the lower limb skeletal elements, articulated and non-articulated bones were provided for photography. The photography session was undertaken at the Anatomy Museum in the Primate Room associated with the Veterinary & Life Science School, Murdoch University, South Street Campus. This session was organized for the development of the 3D modelling.

3.3.2 Integration of Content and Mobile Device

The integration of content involved two phases using two authoring tools: 1) 3D Modelling, and 2) Software Development Kit – AR.

3.3.2.1 3D Modelling Authoring Tool

For the final part of developing the 3D bone models, the lower limb skeletal features were transformed in 3D Studio Max, version 2013 (A. Incorporated, 2014). This software is used as a modelling tool for 3D objects. With anatomical assistance, each part of the bone was deconstructed within 3D Studio Max into several components according to the skeletal system. This facilitated a more detailed user understanding. Bone textures were mapped onto every bone to produce realistic bones in 3D form. During this bone identification session, all bones were then accurately positioned based on skeletal anatomy within 3D Studio Max (A. Incorporated, 2014).

3.3.2.2 Software Development Kit – (SDK)- Authoring Tool

To produce an augmented environment, an AR extension is required. For the HuMAR prototype, an extension called Vuforia (Q. C. E. Incorporated, 2014) was used. Vuforia is a software platform, designed for high quantity

operation of AR on mobile devices. Moreover, Vuforia provides the tools to create all categories of AR experience. The current implementation of this SDK is widely used for various types of product delivery in commercials, education, sports, (Q. C. E. Incorporated, 2014) and in other fields. For this prototype development, a mobile educational courseware application approach was employed. Educational courseware is educational material, loaded with information about the subject matter in digital form for teaching, training, and learning purposes (Schitai, 1998).

During the prototype HuMAR application development difficulties became apparent when the Vuforia extension was integrated into 3D Studio Max. This resulted in limitations in supporting this extension for rendering and tracking AR. Consequently, Unity3D software, version 4.3.4f1 (Technologies, 2014) was used to work with Vuforia (Q. C. E. Incorporated, 2014) AR extension in the mAR prototype development. All 3D bone objects converted into the FBX (.fbx) file format, were exported to Unity3D software and incorporated with Vuforia (Q. C. E. Incorporated, 2014) for AR tasks. The FBX is an acronym for the "FiLMBOX" product name. It is used to provide interoperability between digital content creation applications. This file format preserves the entire functionality of the original file and can be manipulated by diverse programs.

In Unity3D (Technologies, 2014), all bones were precisely labelled and described to provide relevant information for learning human anatomy specifically in human osteology, narrowed down to lower limb bones. Throughout this process, all functions such as control panel, bone placements onto marker, and finger interactions with the prototype HuMAR application were designed in Unity3D.

3.4 Pilot Testing

User pilot testing was conducted for measuring the reliability of the prototype HuMAR application. This involved 30 students, equipped with prototype HuMAR application using tablets. This testing session was executed according to HuMAR data collection procedures. First, a brief student training session of the HuMAR functions was conducted. The students were exposed to and familiarized with the prototype for 40 minutes, having already learned about the bones for their learning activity during a one hour tutorial. After this we distributed a questionnaire to students to capture their responses to the prototype HuMAR application functionality. The functional testing was gauged using eight (8) features, namely; 1) *The realism of the 3-Dimensional images*; 2) *The smooth changes of images*; 3) *Precision of 3-Dimensional images*; 4) *Learning improvement*; 5) *View angle for for stimulating interest and motivating learning*; 6) *Object manipulation*; 7) *Enhancement of understanding*; and 8) *Labelling assist memorization*. Table 1 consists of definitions of each feature in the user reliability testing results.

Table 1. Definition of prototype features.

Feature	Definition
The realism of the 3-Dimensional images	The realism of the three-dimensional (3-D) images in this application is useful in learning. The 3D characteristics provide a realistic environment which can increase an individual's motivation to learn. This is due to the ability of an object in 3D to hold interest and attention in the learning process.
Image smoothness	The smooth changes of images in this application are of great value. It assists in the performance of object transition and also during scaling, rotating and moving objects. The transition performance refers to the efficiency and velocity of object responsiveness.
Precision of 3-Dimensional images	The realism of the 3-D images in this application helps to enhance the student's understanding. The accuracy of the object helps the learner remember the real object in terms of object placements, indentations and textures.
Learning improvement	The ability to vary the perspective position of the 3-D objects in this application permits the student to discover better. The 360° angles (x, y, z axis) enable the student to learn about an object with more precision, especially in identifying the exact position of the subject matter.
View angle for stimulating interest and motivating learning	The ability to change the view position of the 3-D objects in this application makes for more motivated and interesting learning. The level of motivation and the enhanced learning experience influences the ability of individuals to achieve learning objectives in their subject areas. This can lead to a stronger self-centred learning concept.
Object manipulation	The power to control the objects (e.g.: rotate, scale, and move) within the augmented reality environment encourages learning and makes it more exciting. It provides the ability to manipulate the object and to see the subject in detail. This manipulation signifies the capability of interaction which is a main feature of the prototype.
Enhancement of understanding	The ability to manipulate the objects in real time along with the use of the description panel provided, enhances the student's understanding and will facilitate the student in acquiring more information about

Labelling assists memorization	the subject. This prototype has the potential to offer greater understanding of the subject being studied. The ability to learn through the labelling of each object can improve student's memory. This label feature was built into the application to help the student retain what he/she has learned for a longer period. Providing this feature for each bone helps the student to work out the character and position of the bone accurately.
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This testing session was prepared according to the procedure of HuMAR data collection. First, we conducted a brief training for the students to learn the HuMAR functions. The students were exposed and familiarized with prototype HuMAR for about 40 minutes, having learned about the bones for their learning activity during one (1) hour pre-lab. Afterward, we distributed a questionnaire survey to the students in regards to responding to HuMAR's functionality. Through this functionality testing, with a Likert scale from 1 (strongly disagree) until 5 (strongly agree), the values are presented for each feature of HuMAR, in Table 2 as follow:

Table 2. Usability testing result.

HuMAR Features	N	Minimum	Maximum	Mean	Std. Deviation
The realism of the 3-Dimensional images	30	4	5	4.27	.450
Image smoothness	30	4	5	4.27	.450
Precision of 3-Dimensional images	30	4	5	4.43	.504
Learning improvement	30	4	5	4.43	.504
View angle for stimulating interest and motivating learning	30	4	5	4.47	.507
Object manipulation	30	4	5	4.40	.498
Enhancement of understanding	30	4	5	4.27	.450
Labelling assist memorization	30	4	5	4.47	.507
Valid N (listwise)	30				

Table 2 depicts, the usability testing result from HuMAR features. The features consist of the ability of; *The realism of the three-dimensional(3-D)*; *Image Smoothness*; *Precision of 3-Dimensional images*; *Learning Improvement*; *View Angle for stimulating interest and motivating learning*; *Object manipulation*; *Enhancement of Understanding*; and *Labeling assist memorization*.

The descriptive analysis was carried out on that result. Regarding task performing, it can be generalized that, the students were satisfied with the HuMAR usability test. For HuMAR usability testing, it showed some students selected the highest and the slightly lower scores for satisfaction in maximum column of each feature from the scale 1 until 5.

These higher mean values indicate to the gratification of the users to these provided functions. These features provide the satisfactory outcomes to the users in this prototype. It could be observed that the mean value and the highest value of Standard Deviation (SD) displayed in the features of *View Angle for stimulating interest and motivating learning*; and *Labeling assist memorization*. These results suggested that: 1) Most of the students have commonly agreed that these two functions are needed to assist their learning environment; 2) By using HuMAR, the ability to change the angle view of the subject matter is inviting and possible to spur their interest and wanting to learn; 3) With labels provided, it showed, it will improve their memory to retain the information longer and have a better understanding of the subject learnt.

Following to the relative consistency of second highest value of the $SD > 0.5$, features on the *Precision of 3-Dimensional images*; and *Learning Improvement*. It could be inferred that, in the experiments, all students experienced an enhancement in their learning substance. Most of the students possessed the chance to improve their study by controlling their interest in getting the info precisely about the bone parts through 360° angles. Regarding to conditions on a scale from 4 (Agree) to 5 (Strongly Agree), most of the students selected scale 5 on the Object Manipulation, which led the HuMAR has a substantial capacity to convey info and make learning interactively. This situation was considered as one of the important factors in their learning atmosphere. Furthermore, the agreement

continues within the *The realism of the three-dimensional (3-D); Image Smoothness; and Enhancement of Understanding*; the results indicate gratification on these features.

In summary, most of the students indicated interest in applying the prototype HuMAR application. With 30 cooperative students performed in this pilot testing, it could be deduced from the outcomes of the dependability of the prototype HuMAR application was achieved.

4. Final Prototype Testing and Preliminary Result

Initially, in our study of user testing reliability, we attempted to identify a significant difference in learning improvement between the non-technology and mAR-technology interventions. We conducted pre-test and post-test evaluations for a preliminary result. These tests were carried out to measure changes in knowledge, behaviors and attitudes of the participants (Newton, 1999). There were 30 students in this session. In a ten minute pre-test organized in the first week, students were given a question to answer without access to any information material or reference books. Next, they were given the questionnaire related to the current learning method.

The post-test was conducted in the following week. During this post-test, the participants were split into two groups. The first group was a control group (non-technology). This group was able to use the human skeleton as a resource for their learning activity. In this learning activity the students were taught for 40 minutes and were required to complete the post-test questions at the end of the session.

The second group was exposed to mAR-technology in their learning activity. The students were given training in the use of the prototype HuMAR application prior to commencement of the learning activity. Similar procedures were used with the control group. The learning activity lasted 40 minutes, after which, the post-test questions were distributed to students for completion. The results of the preliminary result are shown in Table 3.

Table 3. Paired differences of T-Test

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	score_pre - Post_CLM	-8.067	7.216	1.317	-10.761	-5.372	-6.123	29	.000
Pair 2	score_pre - Post HuMAR	-14.933	9.479	1.731	-18.473	-11.394	-8.629	29	.000

As supported by the pre/post-tests score, results proved that both learning techniques have increased from pre-test to post-test sessions. However, there are significant differences in terms of variation in growth in the post test sessions between the control group (CLM) and treatment group (HumAR) methods. The results explained, there is a mean growth rate of -8.067 in traditional learning. Meanwhile, performance scores using HumAR showed a nearly double increment of mean -14.933. In summary, with a remainder of 6.866 boosts between control and treatment group, the effects from pre/post-tests clearly demonstrate, with the assistance of technology mAR, it can enhance the understanding onto the subject, increase their motivation in the learning process and improve the student's learning performance to a larger extent than the common learning

5. Discussion and Conclusion

Ubiquitous learning is now becoming a trend (Lee et al., 2012). There are many people from various fields speaking about opportunities for learning via ubiquitous means; in the workplace, in education, and in the home (Lee et al., 2012). The simplicity and mobility of the mobile device allows for more effective learning and retention of knowledge (Balog & Pribeanu, 2010). With use of the prototype HuMAR application features, students should be able to enhance their learning environments and improve their ability to retain information. To determine the significance of mAR technology, pre/post-usage-tests were conducted. Both pre and post groups were evaluated using the same test. Although the number of students in this preliminary study was small, nevertheless,

there was a substantial difference in values between the two groups.

It appears that the mAR technology learning experience has been effectively delivered to students. Using current technology, many higher institutions are changing their teaching methods. They are moving from instructed-learning to a self-centred learning method. Although there have been a variety of technological interventions in education, there has been a lack of adoption of mAR technology (Azuma et al., 2011). In addition, many of the previous studies (Chu et al., 2010; Tsai et al., 2012) state that mAR technology has been ignored in the learning environment in general, and particularly at the university level. Based on these studies, the role of mAR as part of the teaching and learning process has not been sufficiently investigated (Hwang et al., 2008). According to (Billinghurst, 2002), this technology is still underutilized because there are not enough experts available who are able to develop the content of the subject. They do not have the required level of skill needed to develop 3D modelling, programming knowledge and a detailed understanding of the subject for content development (Dunser et al., 2012).

In general, researchers in educational technology are in agreement that more motivation studies of mAR as a learning method are needed (Lee, 2012; Margetis et al., 2012; Rogers, 2012; Tarng & Ou, 2012; Ternier & Vries, 2011). The students' intrinsic and extrinsic motivations should also be taken into account. The use of this technology could be very effective in motivating students' learning and nurturing their ability to become passionately involved in their own learning process. This prototype HuMAR application will assist them in learning human anatomy using enhanced materials which stimulate their interest and help them to retain information longer. Based on the significant results obtained in the pre/post-tests, encouraging higher education institutions to adopt and implement the HuMAR application prototype as a teaching and learning tool is considered imperative in enabling effective and positive learning for the future.

Acknowledgements

I would like to express my gratitude to Professor Dr. Fauziah Othman, Head of Human Anatomy Department, a deeper appreciation to both lecturers, Dr. Siti Ramona Rosli and Dr. Suryati Mohd Thani, Faculty of Medicine & Health Sciences, University Putra Malaysia (UPM), 43400 UPM Serdang, Malaysia, for granting permission to run the pilot test in the class.

A thankfulness to Mr. Shamsul Bahrin Gulam Ali, Lecturer, School of Biology, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Malaysia, for allowing us to conduct a pilot test in the class and the great cooperation has been rendered during the pre/post-test sessions.

Last but not least, a deepest appreciation to Associate Professor Dr. Sharifah Fauziah Hanim Syed Zain, Director, Centre for Foundation, Languages and General Studies and Co-curriculum, Cyberjaya University College of Medical Sciences (CUCMS), Jalan Teknokrat 3, Cyber 4, 63000 Cyberjaya, Selangor, Malaysia, for giving us an opportunity to carry a research on Foundation in Science students at the respective university. A gratefulness also, to all supportive lecturers involved, Mr. Tang Cher Hing, Ms. Noor Azizah Suliman, Mrs. Norhafiza Abdul Ghani, Dr. Nor Azah and Mr. Mahathir Azahari, for letting us to collect a related information for the benefit of this research.

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