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MOBILE AUGMENTED REALITY APPLICATION IN MEDICAL EDUCATION IN THE 2010s

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ABSTRACT

In the recent years, medical education is facing various difficulties. Students are struggling to visualize the internal organs and bones, it is insufficient cadaver for dissection demonstration, there are lack of equipment for training, and not enough opportunity for hands-on training. Technologies have been utilized to supplement teaching in medical education to overcome the mentioned difficulties. Augmented Reality in particular mobile Augmented Reality has shown a rise in the application of medical education in this decade. This paper aims to do a narrative review to study the overall progress and development of mobile Augmented Reality application in medical education from year 2010 to 2020. From the review done, we found that the application of mobile Augmented Reality in medical education is feasible, it is well accepted by medical students. We also identified current research gaps and potential future development of mobile Augmented Reality in medical education. It was found that there is lack of research done to study long term effect on the users. Interaction between virtual object and real-world object was lacking in some applications. More refinement and update are needed on flow, media and design of Augmented Reality application. There is also essential to study the influence of marker size or surface material.

Keywords: mobile augmented reality, medical education, mobile learning simulation.

INTRODUCTION

Currently, medical education is facing a lot of challenges. Firstly, most medical subjects are perceived as a dull and labor-intensive subject. This is due to medical knowledge is learnt with textbook traditionally. Current teaching methods of anatomy are restricted to either traditional 2D form of learning, like textbook, or 3D form like dissection, it is unlikely to see the virtual 3D models.

Anatomists face the challenge of the changing modes of medical education and assessment, such as fewer contact hours and limited resources. Moreover, students are from diverse groups with different sets of prior scientific literary levels, cultural backgrounds, and experiences (Singh et al. 2019). Since students are dispersed in many sites, anatomy teaching delivery becomes more challenging (Allsop et al. 2020).

Besides, there are some problems faced by medical school in hands-on training. When learning the skill, students observe instructor’s demonstration or video, students might not be able to see clearly the internal structures and anatomical landmarks, thus might affect the performance (Aebersold et al. 2018).

These situations will cause problem in medical personnel training in the coming generation. To overcome the problems, many interventions have been proposed which include proposing Active and Engaging Learning Strategy (Singh et al. 2019), using videoconferencing (Allsop et al. 2020), and the use of virtual 3D model to deliver anatomy teaching (Lo et al. 2020). Many students and teaching faculty proposed that anatomy should be taught in combination with clinical subjects in a vertically integrated manner (Gulnaz et al. 2018).

The medical education is experiencing changes to adapt to new generation students. New technologies are used to enhance the teaching of medical students. Among all, Virtual Reality (VR) and Augmented Reality (AR) have been used in preclinical teaching, and training in surgery (Pantelidis et al. 2018). AR is different from VR, in which VR application intended to replace the whole real world with a virtual world created digitally. The users will immerse into an artificial world without interaction with the real physical world. Both technologies have their own strength. One of the advantages of AR over VR is the lower risk of social isolation and social communication among users. Besides, the use of VR can cause several adverse effects such as dizziness, motion sickness, eyes fatigue and headache (Park and Lee 2020).

AR has many applications and its potential is huge. Dey et al. (2018) reviewed AR usability studies in various areas, such as education, entertainment, gaming, industrial, medicine, tourism, navigation, etc. The review also found that there is an increase in application using handheld displayed; mobile device. According to Pantelidis et al. (2018), despite AR has many possible clinical applications in medicine, its implementation in medical education is not extensive yet. Kiryakova et al. (2018) also agree that AR has emerged as a complementary education tools. Eckert et al. conducted a review which focused on application in medicine, it showed that there is an increasing trend of AR application in medicine, but its usage is still in the early stage (Eckert, Volmerg, and Friedrich 2019). This paper stated that the application is applied more to treatment than training. Another integrative review (Gerup, Soerensen, and Dieckmann 2020) notice that anatomy and anesthesia are the most frequently studies subject with AR and MR application. However, it suggests that more studies should be done on research design and instructional objectives achievable by AR and MR-based application. On the other hand, a narrative review was done to study the outcomes of application of AR in anatomical education (Chytas et al. 2020). It concludes that despite study of AR application in anatomical education is limited, the potential of AR in teaching is promising. From these reviews, we noticed that there is no review has been done on a more narrowed aspect, i.e. the application of Mobile AR in medical education. Since this is a niche area, we conducted a narrative review to study the overall progress and development of Mobile AR application in medical education. We focus on the research from year 2010 to 2020 when mobile devices started to be more common to public.

INTRODUCTION TO AUGMENTED REALITY

AR overlaid virtual images onto real world objects, users still feel their own existence in real world. AR is a medium where information is superimposed to the physical world in registration with the world. It gives the user ability to interact with the information or virtual object. In a nutshell, there are three characteristics that define AR (Azuma 1997), which are, it combines real and virtual world, it is interactive in real time, and it is registered in 3D.

AR identifying scene through two major methods, vision-based or location-based (Peddie 2017). Vision- based AR can be marker-based and markerless. When the application uses the device camera to recognize markers, it is marker-based. If the application can recognize real world object such as photographs, labels etc, it is known as markerless. Location-based AR applications use the device's GPS to determine the position of the device, then use related database to retrieve information about objects at the location, commonly building name, street name and so on.

MOBILE AUGMENTED REALITY APPLICATION IN MEDICAL EDUCATION

Mobile AR is AR application that users can take with them. Examples are smartphones and smart tablets. The advantages of mobile AR are the AR application can be experienced at the location that makes the most sense. People can bring the technology with them. Besides, mobile AR is often low in cost compared with other hardware. In contrast, mobile AR does has some limitations such as the usage restrictions on the mobile device and an internet connection in some locations (Garrett, Anthony, and Jackson 2018).

According to Nincarean et al. (2013) the emergence and widespread ownership of mobile devices has led to an increased interest to integrate the benefits of mobile learning and AR applications. Mobile AR based systems are portable, individualistic, and enable social interactivity.

A mobile device is a convenient device compared to AR headsets because it is portable. In line with the increasing popularity of mobile devices globally, AR is used extensively on mobile devices such as smartphones and tablets. Its potential in education become more important in the recent years (Nincarean et al. 2013). The number of applications seems to show an increase since 2016 after the successful story of Video game Pokemon Go.

In the 2010s, mobile AR has been used in medical education as early as 2012, where mARble® was developed (Von Jan et al. 2012). mARble® is an AR powered learning environment for mobile phones. Its content management is based on an easily adaptable and comprehensive XML scheme. Database for different medical specialties can be built easily. More researches were done by different groups to develop mobile AR application in medical education in the following years.

In anatomy teaching, a group of researchers (Jamali et al. 2015) developed a mobile prototype learning environment that utilizes mobile-Augmented Reality (mAR). The prototype is called the Human Anatomy in Mobile Augmented Reality or HuMAR. HuMAR aims to aid students to learn anatomy of the human skeletal structure, and with the hope that it could potentially enhance their learning process. In the pilot test that engaged science's students from three different universities, results concluded that students were satisfied with HuMAR in terms of its usability and features.

A study conducted at the University of British Columbia, Canada provided nursing, occupational therapy and physical therapy students with a geopositioned AR experience (Garrett, Anthony, and Jackson 2018). Students could access to AR resources using mobile devices during their supervised labs and during unsupervised practice sessions. They were encouraged to make conceptual links from multimedia resources to physical equipment. Result shows that new technologies can motivate and enhance student learning. However, technical issues such as scanning problems, slow Internet response times, and incompatible smartphones made students frustrated, possibly affecting their learning negatively.

Other than this, the Floating Euphoria Framework was combined with the SQLite database to develop an AR anatomy system of the human body (Kurniawan et al. 2018). The system can interactively display the whole body or parts of the human body. The usefulness of the application was evaluated with recruiting high school students and medical students in Indonesia for learning the anatomy of the human body. The results show that the application helps students to learn human anatomy.

MATERIALS AND METHODS

From the outcome of previous researches, using mobile AR as a tool for enhancing medical education is a potential method. Our study aims to review the progress and development in mobile AR in the area of medical education.

A literature search was conducted using search engines and database of Google Scholar, ScienceDirect, Scopus and IEEE XPLORE. The inclusion criteria for literature was: The articles conducted study of mobile AR in medical education during the period of 2011 to 2020.

After filtering, a total of 18 research papers related to mobile AR in medical education in the 2010s were reviewed. Some observations were extracted in the following sections to show a clear picture of the progress of mobile AR in medical education over the 10 years.

DATA EXTRACTION

TYPE OF STUDY

Out of the 18 studies reviewed, 15 studies did user evaluation. From these 15 studies, two were pilot test, one with 10 participants (Von Jan et al. 2012) and one with 4 participants (Quqandi et al. 2019), another study conducted pilot test and final test in the same paper with same number of participant, i.e. 30 science students from three different universities (Jamali et al. 2015). On the other hand, two studies by Soeiro et al. (2015) and Christ et al. (2018) did not do user evaluation, only technical description of the application were given. One study validated the application by technical measurement (Jain et al. 2017).

Almost all studies (11 studies) adopted experiment with laboratory design. Other 4 are quasi-experiment studies where participants used the tool out of laboratory setting, i.e. one case where participants were free to move navigate equipment in university building (Garrett, Anthony, and Jackson 2018). 3 cases in their own living place or campus; in the study of Carlson & Gagnon (2016), healthcare representative consists of simulation technicians, specialists, deans, and faculty (participants) were invited to try the prototype at the own campuses; whereas in Birt et al. (2017) and Ferrer-Torregrosa et al. (2016) studies, distance education students were given the apps to practice prior to the test.

All studies used between-subject study design, the participants were randomly assigned to either control group or experiment group. Except one study allowed participants to freely choose the tools (Birt et al. 2018). Only one study by Noll et al. (2017) did follow-up test after 14 days of the experiment to study if participants had retained more knowledge.

MEASUREMENTS MADE

Fourteen studies measured the user experience of participants, included educational and emotional effect on learning (Von Jan et al. 2012), perceived usability (Noll et al. 2017), perceived enjoyment (Quqandi et al. 2019), perception of the education value of AR tools (Garrett, Anthony, and Jackson 2018), users' satisfaction about the apps (Aebersold et al. 2018), cognitive load scale (Küçük, Kapakin, and Göktaş 2016) and user interface or interactive function (Kurniawan et al. 2018), etc. Only one study did functionality test (Jamali et al. 2015). Jain et al. (2017) did technical measurement to prove that the virtual rendering in the AR application has dimensional similarities to its physical counterpart.

Five studies measured on the improvement in knowledge and 3 studies measured one the improvement in hands-on skill learned. To measure the knowledge learnt, pre-test and post-test were given to participants, (Küçük, Kapakin, and Göktaş 2016)(Moro et al. 2017)(Henssen et al. 2020). To measure the hands-on skill learned, Birt et al. (2017) measured four key performance indicators across the two selected airways skills. Aebersold et al. (2018) measured the participants skills in managing the nasogastric tube based on the checklist item. Ebner et al. (2019) measured the quality of kidney measurement and the time to complete kidney measurement.

TABLE 1. Summary of measurement

Reference	Measurement	No of Participant
Von Jan et al., 2012	Educational & Emotional effect on learning.	10
Jamali et al., 2015	Changes in knowledge, behaviors and attitude Functionality test.	30
Soeiro et al., 2015	No user study evaluation conducted.	NA
Ferrer-Torregrosa et al., 2016	The time spent, the acquired learnings, the metacognitive perception, and the prospects of the use of AR for study. Test score	171
Carlson & Gagnon, 2016	Overall experience.	32
Küçük et al., 2016	Academic achievement test and cognitive load scale.	70
Moro et al., 2017	Health effects of VR, perceived engagement, acquired knowledge. Test score.	59
Jain et al., 2017	Technical accuracy: Virtual rendering in the AR tool has dimensional similarities to its physical counterpart.	NA
Noll et al., 2017	Baseline emotion status, perceived usability.	44
Birt et al., 2017	Learned hands-on skills.	85
Kurniawan et al., 2018	Perception of teaching materials, user interface, multimedia features, interactive function, practicability.	30
Garrett et al., 2018	Perceptions of the education value of AR tools.	253

Birt et al., 2018	Knowledge and learner perception Learned skill.	46
Christ et al., 2018	No user study evaluation conducted.	NA
Aebersold et. Al., 2018	Skill competency evaluation (hands-on skill learned). Users' satisfaction & perception about the application.	69
Ebner et al., 2019	Quality of kidney measurement (hands-on skill learned). Usefulness of the application.	66
Quqandi et al., 2019	Perceived enjoyment, perceived usefulness, users' satisfaction and students' perceived self-regulation.	4
Henssen et al., 2020	Test score Cognitive load, motivation	No detail given

TYPE OF SPECIALITY

Thirteen out of 18 existing mobile applications were developed by their own. Three out of them were developed by other company (Aebersold et al. 2018) (Ferrer-Torregrosa et al. 2016) (Küçük, Kapakin, and Göktaş 2016). One of them was developed by using an open source platform, name ARISE (Carlson and Gagnon 2016) and another one does not provide information about the developer (Ebner et al. 2019).

The AR teaching tools have been applied in many specialities in medicine. It was most commonly applied in anatomy. Where one was used in teaching bones of lower appendicular skeleton, one was used for teaching in extrinsic muscle of foot, six on neuroanatomy and brain teaching, and two were used in general anatomy.

The second common applied specialities was nursing. Related to nursing, two applications were developed for theory-based teaching while another two for hands-on skill-based training. Besides, one AR training tool was also applied in paramedic. One application was developed for sonography hands-on training. On the other hands, mobile AR has been used in forensic pathology education once. Finally, one application was used in dermatology.

TABLE 2. Summary of speciality

Reference	Specialty	Type
Von Jan et al., 2012	Forensics pathology	Scenario Simulation
Jamali et al., 2015	Anatomy (bones of the lower appendicular skeleton)	Theory
Soeiro et al., 2015	Brain anatomy	Theory
Ferrer-Torregrosa et al., 2016	Anatomy (extrinsic muscles of the foot)	Theory
Carlson & Gagnon, 2016	Healthcare simulation education (scenarios for nursing, medical assistant, emergency medical technician)	Scenarios Simulation
Küçük et al., 2016	Neuroanatomy (Medulla spinals)	Theory
Moro et al., 2017	Skull anatomy	Theory
Jain et al., 2017	Human anatomy	Theory
Noll et al., 2017	Dermatology	Theory

Birt et al., 2017	Laryngoscopy (airways management training in Paramedic)	Hands-on
Kurniawan et al., 2018	Human anatomy (internal organ, external organ)	Theory
Garrett et al., 2018	Nursing, occupational therapy and physical therapy (equipment in the clinical skills laboratories)	Theory
Birt et al., 2018	Brain, brainstem, spinal cord	Theory
Christ et al., 2018	Neuroanatomy	Theory
Aebersold et. Al., 2018	Clinical psychomotor skills for Nursing education (placement of NGT)	Hands-on
Ebner et al., 2019	Sonography motor skills training (time to complete kidney measurement)	Hands-on
Quqandi et al., 2019	Nursing clinical lab training, introduces new ways of interacting with manikins, and allows students to view patient scenarios instead of relying on teacher explanations.	Scenarios Simulation
Henssen et al., 2020	Neuroanatomy (human brain)	Theory

OUTCOMES OF USER EVALUATION

For hands-on training, all studies showed better performance of the participants who used the AR application for training. For non-hands-on application, majority studies reported mobile AR enhanced the understanding of the subject, increase students' motivation in learning and improve the student's learning performance. Anyway, one study found that there were only small variations regarding emotional involvement, and learning experiences. Where both the control group and AR group rated the application similar in its stimulating effect (Noll et al. 2017). However, in the follow-up test after 14 days, mobile AR group had retained more knowledge.

Despite the majority positive result, certain studies reported negative result. One study found that textbook group performs better. However, the difference is statistically insignificant (Von Jan et al. 2012). Another study reported that students who used cross-sections of the brain to learn neuroanatomy showed significant more improvement on test scores than students who learn with AR mobile device (Henssen et al. 2020). But further analysis hypothesized that the difference was caused by the fact that the study material in cross-sections groups was more in line with the test. One study reported that students found Oculus Rift VR was superior than mobile AR (Birt et al. 2018), but it was hypothesized that the preference was due to bias. In another study, it was found that there was no significant difference in test score and user experience observed among treatments (Moro et al. 2017).

For interview session, most participants perceived the application was useful, it was able to enhance independent learning. Generally, participants response that the prototypes were a good start and they are looking forward to the new scenarios. However, participants also feedback that the AR application was not a replacement of simulation but best utilized adjunctive to laboratory (Carlson and Gagnon 2016). At the same time, students also expressed concerns about replacing direct instructor-led demonstrations (Garrett, Anthony, and Jackson 2018).

ANALYSIS AND DISCUSSION

LIMITATION OF EVALUATION DESIGN

There were some limitations in the evaluation design of the reviewed papers. When designing experiment, attention needs to be given to the internal validity and reliability of the tests, especially on the difference in content of teaching materials, since some teaching material in one group might be more advantageous or bias toward some test (Henssen et al. 2020). In study which involve longer period learning using the AR application out of laboratory setting, interaction between groups might happen (Ebner et al. 2019).

Some studies might have recruitment bias, due to some participants might have prior exposure to particular tool before. For example participants in the study of Birt et al. (2018) had utilized Oculus Rift VR as a regular component of their study, they might show preference over this tool. Some students have experiences, skills and knowledge in that hands-on skill, thus they will show better performance (Aebersold et al. 2018). The background of participants needs to be known before recruitment. For example, participants might have better motor skills with their mobile device due to their gaming habits (Ebner et al. 2019).

Most evaluations were done on one institute only, these limit the validity of the treatment. Besides, only one research studied whether there is a long term effect, such as better retention of the knowledge (Noll et al. 2017). The rest of the evaluations study only the effect immediately after the treatment.

SYSTEM LIMITATION

For the application, there are some limitations in term of technical aspect. Some technical issues were faced by participants when using the application, such as slow internet and scanning problem (Garrett, Anthony, and Jackson 2018) or inadequate features of their smart phones (Küçük, Kapakin, and Göktaş 2016). More refinement and update are needed on flow, media and design (Carlson and Gagnon 2016).

Marker size plays a crucial role in the application. If there are too many markers used, the marker placement process is time-consuming and might reduce visibility. Similarly, if the marker was too big, it might reduce visibility too. However, if the marker is too small, it caused problem in tracking (Birt, Moore, and Cowling 2017). Attention needs to be paid on the material of the marker, if the marker has reflection surface, it could obscure sections of each marker.

For simulation application, the non-stereoscopic image depicted on the device's screen could lead to a slight dissonance in regards to the learners' sense of depth (Birt, Moore, and Cowling 2017). Interaction between virtual object and real world object was lacking in some applications. Quqandi et al. (2019) suggested more interaction between manikin, monitor and scenario in their application.

POTENTIAL FUTURE DEVELOPMENT

From previous section, it can be observed that there are some research gaps. We would like to make some suggestions for future research. In term of user evaluation, it is suggested to recruit participants from various institute for validation purpose (Aebersold et al. 2018). A longitudinal study could be carried out to study the long-term effect of the new teaching tool, to see if it could help in longer term memory retention. Functional test and heuristic evaluation could be carried out to improve the application. Future study should pay more attention when recruiting participant, their background should be taken care of to ensure better internal validity and reliability.

In term of technical aspects of the application, we would suggest to add more interaction between virtual object and real-world object. We also see the needs to add more interactivity in the application especially between instructor and students. In some studies, students feedback their concerns about replacing direct instructor-led demonstrations (Garrett, Anthony, and Jackson 2018). If instructor can communicate with students with the application, the students can enjoy the benefits of both in-person guidance and technology aids.

Besides, students expect to see more multimedia such as video, animation and images to be added. More user-friendly interface shall be designed. Better guidance or tutorial should also be provided for beginner users.

On the other hand, for simulation training, the effect of marker's placement, size, and the amount could be studied further. Currently, the majority of the research was done for anatomy. By viewing the positive feedback in the speciality of anatomy, we would suggest that the same approach can be applied to other speciality such as physiology teaching.

CONCLUSION

In this paper, we conducted a narrative review on application of mobile AR in medical education. We focus on reviewing studies done within 2010 to 2020. Eighteen studies have been reviewed and analyzed. We can conclude that, mobile AR has great potential in medical education. All studies have shown its feasibility. User evaluation also shown that its acceptability among users, in particular young universities students, has been well received. Some research gaps have been identified. Thus, some potential future developments have been suggested.

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