

Augmented Reality in Healthcare Education for Human Anatomy

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ABSTRACT

The study of structures in the human body is known as human anatomy. Medical students face a lot of difficulties while understanding the core concepts of Human Anatomy. To learn anatomy, Augmented Reality (AR) offers an interactive learning experience by visually constructing 3D objects in the user's world. AR has transformed healthcare education by supporting interactive learning in a way that helps the students and other learners develop new skills by understanding different concepts in a fun and an interactive way rather than the old traditional methods. Various studies show how Augmented Reality has helped different sectors such as Healthcare, Education, Gaming Industry etc. in improving their overall standards by providing a holistic view about different topics. To acknowledge the positive impact of AR in healthcare education in Human Anatomy, a Systematic Literature Review (SLR) is presented in this article. For this article, 34 papers were chosen through a comprehensive procedure. As per our best knowledge, no SLR is available that gives us an extensive review in this field of study. In this paper, we have presented different AR Systems and MAR applications to understand human anatomy in an interactive manner. A taxonomy diagram of the used AR techniques to learn human anatomy has also been presented. Different human organs and body parts taught through AR to help healthcare professionals and students have also been identified in this paper.

KEYWORDS

Augmented Reality, Healthcare, Healthcare Education, Human Anatomy, MAR Applications, AR Systems

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1. INTRODUCTION

Augmented Reality gives an interactive experience of a real-time environment in which real world objects are visually represented via computer generated perceptual information. Augmented Reality is basically a superimposition of images, sounds over real-life scenes [1]. The majority of disease related research is focused on image based diagnosis [41] [42] [43]. Nowadays, Augmented Reality is being used in various fields such as medicine and healthcare, gaming, navigation, tourism, school education etc. Augmented Reality's impact on the world is quite significant and is already on the rise. The use of AR has gained a lot of popularity, especially in healthcare education.

To promote learning in an interactive way such that the learner is able to develop new skills and enhance his/her critical thinking has a great importance in today's world. Augmented Reality can support interactive learning with the ability of displaying virtual object in the user's world using smartphones, head-mounted gears etc. and this has helped the field of healthcare education in an immense manner. AR applications (ARAs) have been used by students and helped them immensely in learning. However, these applications have not been accepted as much [2] [40].

Recently, Augmented Reality has opened its ways in developing in the surgical medical training. Augmented Reality provides a detailed and influential learning experience. Doctors can now internally examine the patient without going through lengthy procedures. As there are unlimited benefits attached with AR in healthcare education, there is a need for further studies and advancements in this discipline. The traditional teaching methods used in Human Anatomy

are not interactive. Over the years, AR systems and applications have introduced a new fun way of learning anatomy and many studies have been conducted in this regard. The results of an integrative review [7] conducted to study the current Augmented and Mixed Reality based healthcare applications included twenty-six studies and all of them showed various benefits while significantly outperforming traditional teaching techniques in 11 studies in the healthcare education sector. A Systematic Literature Review [44] identified studies related to the use of AR in learning about the human nervous system.

This paper's primary objective is to identify different AR systems and MAR applications that have helped healthcare professionals and medical students to interactively understand the concepts of human anatomy. As per our best knowledge, there is no SLR available that gives us an extensive review in this field of study. A taxonomy diagram of the used AR techniques to promote interactive pedagogy and aid students in learning human anatomy has also been presented. This article also identifies various human organs and body components taught using AR to assist medical practitioners and students.

The remaining article is structured accordingly: Section 2 presents a research methodology by defining a set of research questions, the criteria for including and excluding different studies, and a search string to extract and collect relevant studies. Section 3 summarizes the results gathered from the systematic mapping study. Section 4 identifies the challenges faced by students while using AR techniques for learning. Section 5 highlights the validity threats to this paper. Section 6 discusses the conclusion.

2. RESEARCH METHODOLOGY

Over the years, healthcare education in the field of Human Anatomy has seen various changes when it comes to teaching professionals or students using technologies such as Augmented Reality. Most of the studies conducted in this regard have shown positive results in terms of providing an efficient way of learning healthcare concepts. The research methodology chosen for this paper is a Systematic Literature Review and its objective is to review how AR has played its part in healthcare education in the field of Human Anatomy. The methodology adopted for this review was proposed by Keele [3] and is shown in Figure 1.

A. Research Objectives

The following are the primary objectives of this research:

- **RO1:** Recognizing the interactive learning experience provided by Augmented Reality to learn Human Anatomy.
- **RO2:** Highlighting developed MAR applications in different studies to study human anatomy.
- **RO3:** Identification of major human organs and body parts taught via AR in different studies.
- **RO4:** Proposing a taxonomy to show which AR techniques are used to learn human anatomy.

B. Research Questions:

The first and foremost step is to define the research questions for this systematic study. As defined in Table I, this SLR focuses on three questions.

TABLE I: Research Questions

No.	Research Question	Motivation
RQ1	How AR learning methods in Healthcare education have been used to promote interactive pedagogy in the field of Human Anatomy?	To identify new learning methods in Human Anatomy
RQ2	How MAR applications have helped healthcare education in the field of Human Anatomy?	To identify the MAR applications in Human Anatomy
RQ3	Which human body parts or organs have been interactively taught through AR in healthcare education in the field of human anatomy?	To identify the body parts or organs being taught through AR in human anatomy?

C. Search String:

The next step is to define the search string to identify and collect relevant studies which can help us analyze the research questions. A pilot search comprising of specific keywords was conducted to draw out relevant papers. In our search string, we focused on keywords such as Augmented Reality, Healthcare, Education, Systems etc. Our selected databases were IEEE Xplore, Google Scholar, Elsevier, Science Direct, ACM, PubMed and Springer. Table II shows the search string used for this SLR.

TABLE II: Search String

Source	Proposed Search String	Perspective
IEEE Xplore Google Scholar Elsevier Science Direct PubMed Springer	("Augmented Reality" OR "AR") AND ("Healthcare*" OR "Education" OR "Learning" OR "*Anatomy") AND ("MAR applications" OR "Systems" OR "Tools")	Healthcare

D. Screening of Relevant Papers:

Not all of the publications found during the examination process were accurately related to the research questions presented in the SLR, so they had to be discarded. For screening of relevant studies, we followed a process given in a study [4]. The first phase of screening included studies based on their titles. Studies that were unrelated to the targeted field of study were omitted. The second phase of screening included the reading of the abstract of all the articles which cleared the first screening phase.

1) INCLUSION CRITERIA:

Inclusion criteria consisted of the following parameters:

- Papers presenting AR techniques to learn human anatomy.
- Papers reviewing the use of AR in human anatomy

2) EXCLUSION CRITERIA:

The following types of papers were excluded based on the given parameters of the exclusion criteria:

- Papers irrelevant to the search string.
- Papers written in any language other than English.
- Articles that failed to present new and effective ideas.
- Papers that aren't published in journals, conferences, patents and technical reports.

E. Quality Assessment

Quality assessment is done to analyze the quality of selected studies. The Quality Assessment of this SLR is performed using the following criteria:

- (a) The study contributes towards AR in healthcare education in the field of human anatomy. For this question, there were two possible responses:
 - Yes (+1) if the study contributed.
 - No (0) if the study didn't contribute.
- (b) The paper solves the interactive pedagogy problem. For this question, there were three possible responses:
 - Yes (+1) if the study presented a solution to the problem.
 - Partially (+0.5) if the study partially presented a solution
 - No (0) if the study didn't offer any solution.
- (c) The selected article empirically validates the results. The possible answers for this question were:
 - Yes (+1) if the study empirically validated the results.
 - No (0) if the study didn't provide any empirical validation.

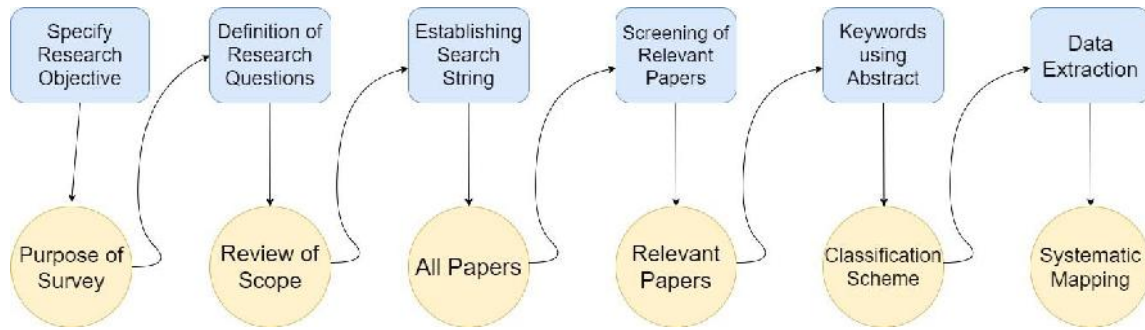


Fig. 1: Research Methodology

- (d) The selected papers were published in a conference or a journal. The possible answers for this question are given in Table III.

TABLE III: Quality Assessment Criteria

Publication Source	Rank	Points
Journal Publication	Q1	2
	Q2	1.5
	Q3 or Q4	1
	None	0.5
Conference Publication	CORE A	2
	CORE B	1.5
	CORE C	1
	None	0.5

F. Data Extraction

The data extraction methodology consisted of possible answers to research questions.

RQ1. To address this question, papers published related to the research question should be selected and interactive learning techniques from those papers should be listed.

RQ2. To answer this question, papers published on MAR applications in learning human anatomy should be selected.

RQ3. To answer this question, different human organs or body parts on which the relevant studies are focusing on should be selected.

3. ANALYSIS

This section includes detailed assessments of the research questions from the selected studies.

A. Classification of Studies

The papers selected for this SLR are presented in Table IV. The major focus of these papers is also briefly described. Figure 3 presents the selected studies published per year. The publication channel wise distribution of the selected

papers is presented in Figure 4.

B. Taxonomy

A taxonomy diagram has also been presented which shows available techniques of AR to learn human anatomy. The figure 2 shows the proposed taxonomy.

RQ1. How AR learning methods in Healthcare education have been used to promote interactive pedagogy in the field of Human Anatomy?

Augmented Reality learning methods and systems have introduced different simulations and applications that can enrich the human anatomic structure by integrating three dimensional objects in a learner's physical world. This way the learner can see three dimensional representations of human organs such as Heart, Brain, Neck etc.

AR has significantly improved the learning curve for professionals in Anatomy. Various researches have been conducted in this regard.

A study [8] reviewed seven papers that included the use of Augmented Reality in Anatomy. These papers were extracted from several databases including PubMed and Scopus. Comparative and non-comparative studies were carried out. The results concluded that Augmented Reality in teaching anatomy had promising results.

In a study [9], the role of AR in nursing was observed. 69 candidates took part in the process of inserting a Nasogastric tube in a mannequin. The students were split into two lots. First lot used video as well as didactic training and the other lot used the AR simulation training module. This module was prepared by utilizing a hybrid approach that combined footage with 3D computer graphics. This allowed the participants to visualize the whole process by keeping an eye on key anatomical compositions. To lay strong emphasis on critical learning objectives for each subtask, interactive virtual simulation exercises were included that also highlighted the safety measures to avoid complications.

The students using the Augmented Reality module gave a very satisfied feedback and showed much more competence at nasogastric tube placement in relation to the ones using video and didactic training. Tobias [10] presented an AR magic mirror system to teach human anatomy.

TABLE IV: Classification Table

Classification					Quality Assessments				
Reference	Publication channel	P. year	Research Type	Major focus	(a)	(b)	(c)	(d)	Scores
[2]	Journal	2016	Survey	Surveyed the use of Augmented Reality in healthcare education including human anatomy	1	0	0	1	2
[5]	Journal	2019	Survey	Discussed the use of AR in surgical education	1	0	0	1	2
[6]	Journal	2015	Proposed Solution	Proposed a web application which used AR to assist in anatomy learning	1	1	1	0.5	3.5
[7]	Journal	2020	Integrative Review	Conducted an integrative review to study the current AR and MR based healthcare applications	1	0	1	1.5	3.5
[8]	Journal	2020	Literature Review	Reviewed seven papers from databases of several databases to study the benefit of AR in teaching anatomy	1	0.5	1	1.5	3.5
[9]	Journal	2018	Evaluation Research	Evaluated the AR simulation training module among Nursing students to place a Nasogastric tube in a mannequin	1	0.5	1	2	4
[10]	Conference	2018	Proposed Solution	Proposed a AR magic system to learn human anatomy	1	1	0	0.5	2.5
[11]	Conference	2014	Proposed Solution	Proposed an AR edutainment system in the form of a puzzle game to learn bone anatomy	1	1	0	2	4
[12]	Journal	2017	Evaluation Research	Evaluated the effectiveness of AR or VR as a mode to learn structural anatomy	1	0.5	1	2	4.5
[13]	Journal	2010	Proposed Solution	Proposed a tool named BARETA to aid student learning in anatomy.	1	1	0	2	4
[14]	Conference	2019	Proposed Solution	Developed an AR system to learn anatomy for a big group of users	1	1	1	0.5	3.5
[15]	Conference	2013	Proposed Solution	Proposed an accurate learning environment to learn human anatomy using Augmented Reality	1	1	1	2	5
[16]	Conference	2013	Proposed Solution	Developed an AR SARP application for a system to explore teaching anatomical structures on a user	1	1	1	2	5
[17]	Journal	2020	Evaluation Research	Conducted a comparative study between AR and VR applications among 82 participants for anatomy training	1	0	1	2	4
[18]	Conference	2017	Evaluation Research	Focused on the perceptual difference between NRMM and RMM design for the objective of learning anatomy.	1	0.5	1	2	4.5
[19]	Conference	2018	Evaluation Research	Evaluated learning resources developed using augmented reality technology in anatomy	1	0	1	0.5	2.5

Classification					Quality Assessments				
Reference	Publication channel	P. year	Research Type	Major focus	(a)	(b)	(c)	(d)	Scores
[20]	Conference	2018	Proposed Solution	This paper presented an AR environment for training of neurosurgery.	1	1	0	2	4
[21]	Journal	2015	Proposed Solution	Developed and evaluated an AR tool for learning human anatomy	1	1	1	2	5
[22]	Journal	2016	Proposed Solution	Developed an AR magic system to learn human anatomy	1	1	1	1.5	4.5
[23]	Journal	2021	Proposed Solution	Developed and evaluated a new AR tool to learn about cardiac anatomy	1	1	1	1	4
[24]	Journal	2020	Evaluation Research	Evaluated the use of AR in learning neuroanatomy	1	0	1	2	4
[25]	Journal	2021	Evaluation Research	Used AR and CT for teaching head and neck anatomy to students	1	0	1	2	4
[26]	Journal	2019	Evaluation Research	Assessed the advantages of using AR to teach integrated radiology in anatomy	1	0	1	2	4
[27]	Journal	2019	Proposed Solution	Presented a learning environment using AR to aid students in learning anatomy	1	1	1	2	5
[28]	Conference	2020	Proposed Solution	Developed a MAR application to learn knee as well as foot anatomy	1	1	1	0.5	3.5
[29]	Conference	2019	Proposed Solution	Developed a MAR application to learn nerve anatomy	1	1	1	0.5	3.5
[30]	Conference	2015	Proposed Solution	Developed a mobile application based on AR to learn about hand anatomy	1	1	1	0.5	3.5
[31]	Journal	2018	Proposed Solution	Developed a MAR application that could help in learning human anatomy and its complexities with the help of AR	1	1	1	0.5	3.5
[32]	Journal	2020	Proposed Solution	Developed a mobile application that could help in learning heart anatomy and its complexities with the help of AR	1	1	1	1.5	4.5
[33]	Journal	2019	Proposed Solution	Developed a MAR application to learn about the heart's anatomical structure and blood flow	1	1	1	0.5	3.5
[34]	Journal	2020	Evaluation Research	Evaluated 41 MAR applications that had the potential of playing a vital role of helping students in learning human anatomy.	1	0.5	0	2	3.5
[35]	Journal	2015	Proposed Solution	Presented an educational prototype using MAR to learn about human anatomy.	1	1	1	0.5	3.5
[36]	Conference	2019	Proposed Solution	Developed an AR mobile application to aid student learning in learning brain anatomy	1	1	1	1	4
[37]	Journal	2019	Evaluation Research	Evaluated an AR ultrasound trainer application which helps in learning about human kidney	1	0.5	1	0.5	3

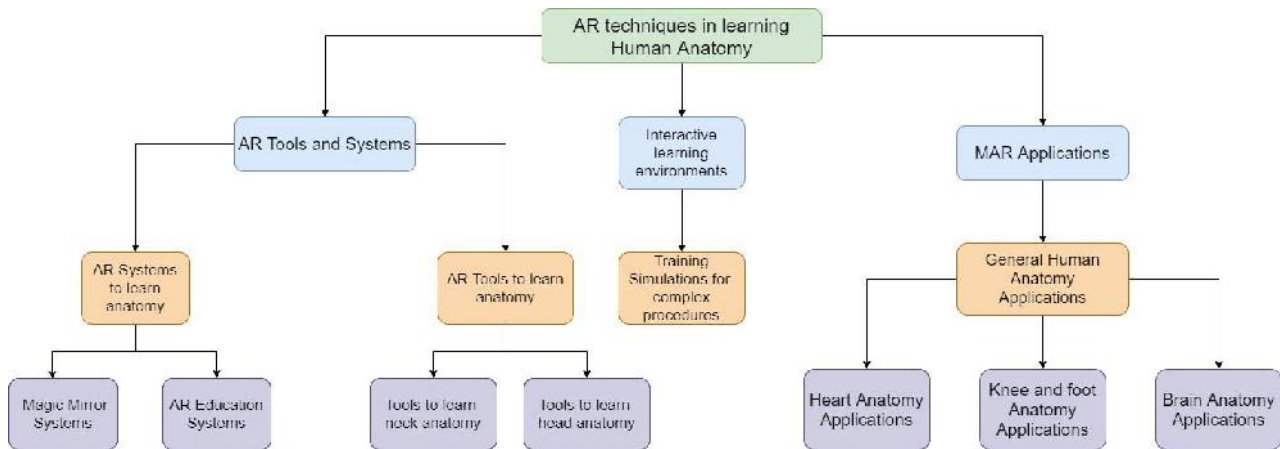


Fig. 2: Taxonomy Diagram

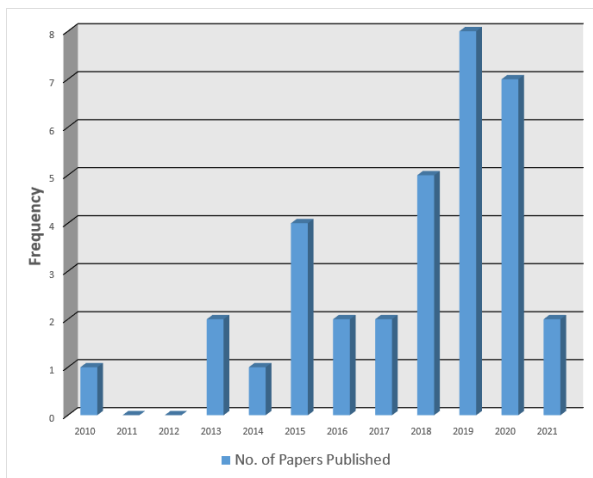


Fig. 3: Selected studies published per year

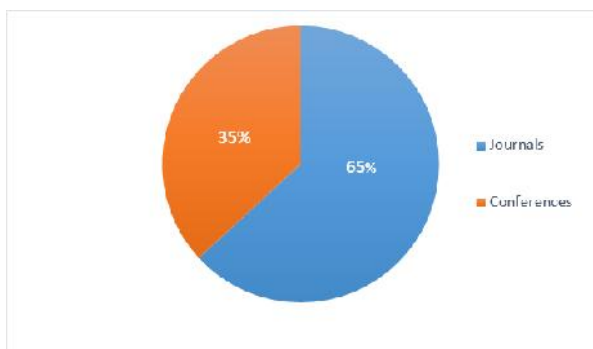


Fig. 4: Publication channel wise distribution of selected studies

The system, with the help of a depth camera, could identify an individual’s posture. It could also create a human body’s illusion by augmenting a volumetric display of a CT dataset onto the body. The system was also smart enough to display 3D representations of different organs and information and

images related to human anatomy.

To learn about bone anatomy, Phillip [11] came up with an edutainment system based on Augmented Reality, This system was named AR bone puzzle. It used human body as frame of the puzzle. The virtual bones were used as puzzle pieces. The user could learn about bone anatomy via a puzzle game. This paper’s target audience was medical students and young children.

A study [12] assessed the effectiveness of AR or VR as amode to learn structural anatomy. 59 participants randomly used AR, VR and Tablet Based applications to learn skull anatomy. Afterwards, a knowledge assessment was carried out. The results of the assessment proved that AR and VR were effective tools to supplement anatomical learning.

Normally, Anatomy is taught via dissecting cadavers. A study [13] presented a tool named BARETA to aid student learning in anatomy. BARETA combined Rapid Prototyping with Augmented Reality to provide stimulation for touch and sight to teach anatomy. The primary objective of BARETA was to introduce an interactive interface based on touch and sight rather than just using a mouse and a keyboard.

The presented AR systems in different studies providean opportunity to the students to learn human anatomy interactively. These systems make Anatomy easy to learn by providing 3D representations of different body parts and organs. However, the cost of these AR systems in these studies have not been discussed. Also, their practical implementation in different universities to teach medical students or hospitals to train medical staff is still limited.

RQ2. How MAR applications have helped healthcare education in the field of Human Anatomy?

A study [28] came up with a mobile application to learn knee and foot anatomy using Augmented Reality. Unity 3D and Vuforia was used to develop this application. The application helped the students learn about complexities regarding knee as well as foot. A research [31] aimed to come up with an application that could learn anatomy and

its complexities with the help of AR. The procedure applied in this process was an AR marker on a cell computing platform. After that, a photo was taken of the marker. The photo was then divided into several pieces. The sample was then compared to the database's preserved images. Floating Euphoria framework combined with SQLite Database was used in this system. The tool's usefulness was tested with the candidates of medical and high school for acquiring knowledge about the human anatomy and the outcomes easily went in favor of interactive AR visualization's effectiveness in helping candidates learn. A questionnaire was also designed to determine the user's satisfaction level in using this application. Five categories were a part of this survey. Each category consisted of three questions. Results showed that this application proved to be useful in learning human anatomy.

Cuneyd Celik [32] conducted a study regarding the execution of MAR applications into the Biology laboratory to understand more about heart and its anatomy. This study aimed to come up with a MAR application that would explain the anatomy of heart, making it easier for pre-service Science instructors to comprehend for their laboratory purposes. The results of this study concluded that MAR application assisted the Science teachers in understanding about heart and its anatomy in a better way as they achieved a great learning experience.

Sumitra Nuanmeesri [33] showed how AR was used to teach heart anatomy and flow of blood using an Android device showed better results. The study aimed to increase the interest of students towards learning about heart anatomy and blood flow. To analyze the development of Augmented Reality in this perspective, pre-test and post-test meeting the standards of Content Validity Index (CVI) were developed to gather the learning results. The collected information about the human heart was used to construct an AR model.

The assessment of the post-test results indicated that students who used AR instead of videos and hardcopy media to gain an insight about the human heart had better results to offer.

Another study [34] was conducted regarding the potential of MAR applications in learning human anatomy. Initially, 41 apps were evaluated in the first phase. After filtering, the study evaluated seven mobile applications which met rigorous selection criteria for a detailed analysis. An evaluation framework was created with a set of 19 points from three major areas which included the performance of the app, the information architecture it had and the educational value it could offer. The apps selected were available on iOS App Store. Those apps that had in-app purchases or were not free in any way were discarded from this study. The study showed that despite some limitations, AR solutions had the potential to attract students' attention and increase their motivation to learn more about Human Anatomy.

Jamali [35] presented an educational prototype using MAR technology to aid student learning in human anatomy. The study used a pilot test to discuss the process of development and findings. Moreover, the test also utilized an experimental method which included students of different

educational institutions. This test was carried out to gain an insight on user experience from a technical perspective and to measure the prototype's reliability. The primary objective of this prototype was to increase students' learning process.

Juanes [38] presented a tool to study Human Anatomy. The study aimed to come up with a mobile application to teach the concepts of human anatomy. The technological tool was developed by capturing particular fixed anatomical images available in an anatomy atlas. The fixed images could then be visualized as three dimensional (3D) models with a mobile app. The application was developed using Unity 3D, Maya and Vuforia i.e an augmented reality library which can be easily imported into Unity 3D. The mobile application had the capacity to detect an anatomical image from an atlas and show a corresponding 3D model of that image.

Augmented Reality has also aided students and medical staff in learning about brain anatomy in a fun and interactive way as compared to the traditional teaching method. Wahyudi [36] came up with an AR mobile application to aid student learning in which students could hold and analyze the human brain as a 3D Digital object. Holding and observing a 3D digital human brain introduced a new interactive user experience. The study showed that the method proposed could help to promote interactive learning activities.

The strengths of these MAR applications are that they can offer flexible learning. Students can learn about anatomy from anywhere around the globe. Moreover, these applications provide a 3D representation of different human organs to aid interactive learning in anatomy. However, the performance of these MAR applications are usually device dependent. In case of a device with low processing power, the application might not run smoothly.

RQ3. Which human body parts or organs have been interactively taught through AR in Healthcare education in the field of Human Anatomy?

Different studies have covered different aspects of human anatomy. Some studies [32] [33] have presented AR Applications that cover details about human heart. Moreover, some studies have introduced systems and conceptual models that cover different organs of the human body such as brain, heart, lungs etc. in a single study. There are also studies [37] which focus on learning about the human kidney. There are AR educational systems [11] which can teach about the bone anatomy through a puzzle game. A study [28] also proposed an AR system to learn about the knee and foot anatomy. The body parts and human organs interactively taught through AR Systems and applications are presented in Table V.

4. CHALLENGES

Although AR has introduced interactive modes and techniques to aid student learning, however, medical students face challenges associated with implementation of AR applications and systems. These challenges are described below:

TABLE V: Identification of human organs and body parts

Reference	Human Organ/ Body Part Covered	Major focus
[32] [33]	Heart	Presented MAR Applications to understand the complexities of the human heart.
[37]	Kidney	Evaluated an AR trainer app for the ultrasound of a kidney.
[11]	Bone	Developed an AR puzzle game to learn bone anatomy.
[28]	Knee and Foot	Proposed and AR system to interactively learn Knee and Foot anatomy.
[36]	Human Brain	Developed an AR mobile app to aid students in learning brain anatomy.

A. Unstable projected image

A study [39] reported that medical students using AR smartglasses experienced the projected image to be unstable. To get a stable projected image, they had to keep their head still.

B. Unavailability of tactile feedback

At times, AR systems are unable to give tactile feedback. A study [24] reported unavailability of tactile feedback from an AR system used to learn neuroanatomy.

C. Signs of fatigue

While using AR System as an interactive tool for learning, students have experienced signs of discomfort. A study [12] reported that medical students using head-mounted gears reported signs of headaches and eye fatigue. Henssen's study [24] also pointed out that students who had to hold smart tablets used to implement an AR system experienced fatigue and tiredness.

D. Detection of AR markers

Students learning anatomy face issues in the detection of AR markers via AR applications making it difficult to detect anatomical images.

5. VALIDITY THREATS

The following validity threats are presented in this section:

A. Internal Validity

It deals with data extraction and its analysis. Classification of selected papers, extraction of data and final results were evaluated by the authors of this paper.

B. External Validity

It deals with this article's generalization. The outcomes have been plotted in relation to the Healthcare field. The validity of the provided outcomes in this study focuses on AR in human anatomy. Classification of studies discussed may help in future work in this domain.

C. Conclusion Validity

In this SLR, the threat of conclusion validity is referred to incomplete or irrelevant extraction of data. To encounter this, the techniques used to extract data and select studies have been clearly stated in the data extraction section.

6. CONCLUSION

A Systematic Literature Review has been conducted in this paper that gives an extensive review on the AR techniques used in healthcare education in the field of human anatomy. A total of 34 papers were carefully identified and selected to carry out this study. This SLR focuses on AR systems and MAR applications used to promote interactive pedagogy in the field of human anatomy. A taxonomy diagram of the different AR techniques used to aid student learning has also been displayed. Moreover, different human body parts and organs taught through AR have been identified in this study. This SLR can contribute in future work in this domain by providing a holistic view of interactive AR techniques in learning human anatomy.

REFERENCES

- [1] B. M. Garrett, J. Anthony, and C. Jackson, "Using mobile augmented reality to enhance health professional practice education", *Current Issues in Emerging eLearning*, vol. 4, no. 1, pp. 10, 2018.
- [2] J. Herron, "Augmented reality in medical education and training", *Journal of Electronic Resources in Medical Libraries*, vol. 13, no. 2, pp. 51-55, 2016.
- [3] S. Keele, "Guidelines for performing systematic literature reviews in software engineering", Technical report, Citeseer, vol. 5, 2007.
- [4] T. Dybå and T. Dingsøy, "Empirical studies of agile software development: A systematic review", *Information and software technology*, vol. 50, no. 9-10, pp. 833-859, 2008.
- [5] S. Sheik-Ali, H. Edgcombe, and C. Paton, "Next-generation virtual and augmented reality in surgical education: a narrative review", *Surgical technology international*, vol. 33, 2019.
- [6] M. Kiourexidou, K. Natsis, P. Bamidis, N. Antonopoulos, E. Papathanasiou, M. Sgantzios, and A. Veglis, "Augmented reality for the study of human heart anatomy", *International Journal of Electronics Communication and Computer Engineering*, vol. 6, no. 6, pp. 658, 2015.
- [7] J. Gerup, C. B. Soerensen, and P. Dieckmann, "Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review", *International journal of medical education*, vol. 11, pp. 1, 2020.
- [8] D. Chytas, E. O. Johnson, M. Piagkou, A. Mazarakis, G. C. Babis, E. Chronopoulos, V. S. Nikolaou, N. Lazaridis, and K. Natsis, "The role of augmented reality in anatomical education: An overview", *Annals of Anatomy-Anatomischer Anzeiger*, vol. 229, pp. 151463, 2020.
- [9] M. Aebbersold, T. Voepel-Lewis, L. Cherara, M. Weber, C. Khouri, R. Levine, and A. R. Tait, "Interactive anatomy-augmented virtual simulation training", *Clinical simulation in nursing*, vol. 15, pp. 34-41, 2018.
- [10] T. Blum, V. Kleeberger, C. Bichlmeier, and N. Navab, "miracle: An augmented reality magic mirror system for anatomy education", in *2012 IEEE Virtual Reality Workshops (VRW)*, 2012, pp. 115-116.

- [11] P. Stefan, P. Wucherer, Y. Oyamada, M. Ma, A. Schoch, M. Kanegae, N. Shimizu, T. Kodera, S. Cahier, M. Weigl, M. Sugimoto, P. Fallavollita, H. Saito, and N. Navab, "An ar edutainment system supporting bone anatomy learning", in *2014 IEEE Virtual Reality (VR)*, 2014, pp. 113–114.
- [12] C. Moro, Z. Štromberga, A. Raikos, and A. Stirling, "The effectiveness of virtual and augmented reality in health sciences and medical anatomy", *Anatomical sciences education*, vol. 10, no. 6, pp. 549-559, 2017.
- [13] R. G. Thomas, N. W. John, and J. M. Delieu, "Augmented reality for anatomical education", *Journal of visual communication in medicine*, vol. 33, no. 1, pp. 6-15, 2010.
- [14] F. Bork, A. Lehner, D. Kugelmann, U. Eck, J. Waschke, and N. Navab, "Vesarlius: An augmented reality system for large-group co-located anatomy learning", in *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, 2019, pp. 122–123.
- [15] M. Meng, P. Fallavollita, T. Blum, U. Eck, C. Sandor, S. Weidert, J. Waschke, and N. Navab, "Kinect for interactive AR anatomy learning", in *2013 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 2013, pp. 277-278.
- [16] A. S. Johnson and Y. Sun, "Exploration of spatial augmented reality on person", in *2013 IEEE Virtual Reality (VR)*, 2013, pp. 59-60.
- [17] R. S. Vergel, P. M. Tena, S. C. Yrurzum, and C. Cruz-Neira, "A comparative evaluation of a virtual reality table and a hololens-based augmented reality system for anatomy training", *IEEE Transactions on Human-Machine Systems*, vol. 50, no. 4, pp. 337-348, 2020.
- [18] F. Bork, R. Barmaki, U. Eck, K. Yu, C. Sandor, and N. Navab, "Empirical study of non-reversing magic mirrors for augmented reality anatomy learning", in *2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 2017, pp. 169-176.
- [19] L. F. G. Arias, N. D. D. Méndez, and C. D. Flores, "Augmented reality learning resources in anatomy" in *2018 XIII Latin American Conference on Learning Technologies (LACLO)*, 2018, pp. 476-483.
- [20] W. Si, X. Liao, Q. Wang, and P. Heng, "Augmented reality-based personalized virtual operative anatomy for neuro-surgical guidance and training", in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 2018, pp. 683-684.
- [21] J. Ferrer-Torregrosa, J. Torralba, M. A. Jimenez, S. García, and J. M. Barcia, "Arbook: Development and assessment of a tool based on augmented reality for anatomy", *Journal of Science Education and Technology*, vol. 24, no. 1, pp. 119-124, 2015.
- [22] M. Ma, P. Fallavollita, I. Seelbach, A. M. V. D. Heide, E. Euler, J. Waschke, and N. Navab, "Personalized augmented reality for anatomy education", *Clinical Anatomy*, vol. 29, no. 4, pp. 446-453, 2016.
- [23] W. B. Little, C. Dezdrobotu, A. Conan, and E. Artemiou, "Is augmented reality the new way for teaching and learning veterinary cardiac anatomy?", *Medical Science Educator*, vol. 31, no. 2, pp. 723-732, 2021.
- [24] D. J. H. A. Henssen, L. V. D. Heuvel, G. D. Jong, M. A. T. M. Vorstenbosch, A. V. C. V. Walsum, M. M. V. D. Hurk, J. G. M. Kooloos, and R. H. M. A. Bartels, "Neuroanatomy learning: Augmented reality vs. cross-sections", *Anatomical sciences education*, vol. 13, no. 3, pp. 353-365, 2020.
- [25] J. K. Weeks, J. Pakpoor, B. J. Park, N. J. Robinson, N. A. Rubinstein, S. M. Prouty, and A. C. Nachiappan, "Harnessing augmented reality and ct to teach first-year medical students head and neck anatomy", *Academic radiology*, vol. 28, no. 6, pp. 871-876, 2021.
- [26] F. Bork, L. Stratmann, S. Enssle, U. Eck, N. Navab, J. Waschke, and D. Kugelmann, "The benefits of an augmented reality magic mirror system for integrated radiology teaching in gross anatomy", *Anatomical sciences education*, vol. 12, no. 6, pp. 585-598, 2019.
- [27] R. Barmaki, K. Yu, R. Pearlman, R. Shingles, F. Bork, G. M. Osgood, and N. Navab, "Enhancement of anatomical education using augmented reality: An empirical study of body painting", *Anatomical sciences education*, vol. 12, no. 6, pp. 599-609, 2019.
- [28] L. S. Lee, S. A. Z. S. Aluwee, G. C. Meng, P. Palanisamy, and R. Subramaniam, "Interactive tool using augmented reality (ar) for learning knee and foot anatomy based on ct images 3d reconstruction", in *2020 International Conference on Computational Intelligence (ICCI)*, 2020, pp. 281-286.
- [29] M. Cook, A. Payne, J. H. Seo, M. Pine, and T. McLaughlin, "Innervate ar: dynamic interaction system for motor nerve anatomy education in augmented reality", in *International Conference on Human-Computer Interaction*, Springer, 2019, pp. 359-365.
- [30] C. Rodriguez-Pardo, S. Hernandez, M. A. Patricio, A. Berlanga, and J. M. Molina, "An augmented reality application for learning anatomy", in *International Work-Conference on the Interplay Between Natural and Artificial Computation*, Springer, 2015, pp. 359-368.
- [31] M. H. Kurniawan, G. Witjaksono, "Human anatomy learning systems using augmented reality on mobile application", *Procedia Computer Science*, vol. 135, pp. 80-88, 2018.
- [32] C. Celik, G. Guven, and N. K. Cakir, "Integration of mobile augmented reality (mar) applications into biology laboratory: Anatomic structure of the heart", *Research in Learning Technology*, vol. 28, 2020.
- [33] S. Nuanmeesri, P. Kadmateekarun, and L. Poomhiran, "Augmented reality to teach human heart anatomy and blood flow", *Turkish Online Journal of Educational Technology-TOJET*, vol. 18, no. 1, pp. 15-24, 2019.
- [34] S. Dreimane and L. Daniela, "Educational potential of augmented reality mobile applications for learning the anatomy of the human body", *Technology, Knowledge and Learning*, pp. 1-26, 2020.
- [35] S. S. Jamali, M. F. Shiratuddin, K. W. Wong, and C. L. Oskam, "Utilizing mobile-augmented reality for learning human anatomy", *Procedia-Social and Behavioral Sciences*, vol. 197, pp. 659-668, 2015.
- [36] A. K. Wahyudi, J. Y. Mambu, A. V. Lengkong, Z. Ardian, "Implementing augmented reality as a digital props of brain anatomy using 3d cuboid tracker", in *2019 1st International Conference on Cybernetics and Intelligent System (ICORIS)*, 2019, vol. 1, pp. 151-155.
- [37] F. Ebner, A. D. Gregorio, F. Schochter, I. Bekes, W. Janni, and K. Lato, "Effect of an augmented reality ultrasound trainer app on the motor skills needed for a kidney ultrasound: prospective trial", *JMIR serious games*, vol. 7, no. 2, pp. 12713, 2019.
- [38] J. A. Juanes, D. Hernández, P. Ruisoto, E. García, G. Villarrubia, and A. Prats, "Augmented reality techniques, using mobile devices, for learning human anatomy", in *Proceedings of the Second International Conference on Technological Ecosystems for Enhancing Multiculturality*, 2014, pp. 7-11.
- [39] K. Bogomolova, I. J. M. van der Ham, M. E. W. Dankbaar, W. W. van den Broek, S. E. R. Hovius, J. A. van der Hage, and B. P. Hierck, "The effect of stereoscopic augmented reality visualization on learning anatomy and the modifying effect of visual-spatial abilities: a double-center randomized controlled trial", *Anatomical sciences education*, vol. 13, no. 5, pp. 558-567, 2020.
- [40] Ahmad Naeem, M. S. Farooq, Adel Khelifi, Adnan Abid: "Malignant Melanoma Classification Using Deep Learning: Datasets, Performance Measurements, Challenges and Opportunities", *IEEE Access* 8 (2020): 110575-110597.
- [41] Hassan Malik, M. S. Farooq, Adnan Abid, Junaid Nasir Qureshi, Muzammil Husain: "A Comparison of Transfer Learning Performance versus Health Experts in Disease Diagnosis from Medical Imaging", *IEEE Access* 8 (2020): 139367-139386
- [42] Khalid, H., Hussain, M., Al Ghamdi, M.A., Khalid, T., Khalid, K., Khan, M.A., Fatima, K., Masood, K., Almotiri, S.H., Farooq, M.S. and Ahmed, A., A Comparative Systematic Literature Review on Knee Bone Reports from MRI, X-rays and CT Scans Using Deep Learning and Machine Learning Methodologies. *Diagnostics*, 10(8), p.518 (2020).
- [43] Ali, Yasir, Amjad Farooq, Talha Mahboob Alam, Muhammad

- Shoib Farooq, Mazhar Javed Awan, and Talha Imtiaz Baig. .
"Detection of Schistosomiasis Factors using Association Rule Mining." IEEE Access 7 (2019): 186108-186114.
- [44] Wirza, Rahmita & Nazir, Shah & Khan, Habib & G. Magarino, Ivan & Amin, Rohul, "Augmented Reality Interface for Complex Anatomy Learning in the Central Nervous System: A Systematic Review", Journal of Healthcare Engineering, vol. 1155, no. 10, 2020.