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Mixed and Augmented Reality Tools in the Medical Anatomy Curriculum

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Abstract. The use of augmented reality (AR) in the medical field has grown since 2007-2013 and was first introduced in surgical departments. AR and mixed reality (MR) allow us to explore complex structures, observe phenomena that are difficult or impossible to see otherwise, and interact with the virtual structures they display. Recently, they are beginning to be adopted for education. This work examines whether new AR and MR technological tools, when used in the context of anatomical teaching, can allow for strengthening of teaching quality - for example by overcoming new or existing constraints such as the limited availability of dissection specimen. This work also considers how these technologies are to be applied efficiently and practically in teaching. An attempt is made to answer these questions in three stages: i) a non-systematic review of the literature ii) a review of augmented reality solutions for anatomy available on four different platforms iii) a 30-person study of the usability of augmented reality. The results show that there is potential for AR and MR to supplement anatomical teaching, but that traditional methods remain indispensable.

Keywords. augmented reality, mixed reality, anatomical teaching, e-learning, digital tools for supplementing medical teaching

1. Introduction

Anatomy is a fundamental branch of the medical curriculum. As the human body is the target of daily interventions and investigations, this discipline is a cornerstone of physicians' medical skills. Anatomical knowledge allows for safe and quality medical practice, through the understanding of decisions and actions taken and the fact that it contributes to effective communication between health professionals [1]. Given its importance, its teaching should be as effective as possible, in terms of accuracy of the acquired knowledge, and its resilience.

Since the Renaissance, the study of corpses and their dissection have been the main means of teaching anatomy [2]. Today, this discipline is traditionally taught in the preclinical years and provides basic knowledge in the four fields of macroscopic anatomy

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(including dissection), neuroanatomy, histology and embryology. Course material generally includes slideshows with verbal explanations, bodies for dissection, presentations of already dissected body parts and books with two-dimensional images [3].

Since its inception, the field of anatomical teaching faces several practical constraints. These include the time allocated within the medical curriculum, the practicality of using human bodies and the ethical and emotional dimension surrounding the handling of corpses by students. Some of those constraints are relatively new, or are currently increasing in severity. The evolution of the constraints which apply to the field of anatomical teaching, raises the question of whether the tried and true methods are still optimal. In addition, technological advances make previously unavailable medias and modalities possible. This raises the questions of how modern technologies could be used to supplement the teaching of this discipline, whether applying these tools would lead to improved efficiency in practice, and what additional challenges technologically augmented anatomical teaching might present. Previous work [3] shows that anatomy learning is most effective when the desired structures can be examined from all angles and at any time. Recent technological advances in the field of virtual, mixed and augmented reality have led to the emergence of widely available consumer software, academic or commercial, which focus on anatomy learning.

One aspect of this work consisted in evaluating the already-available tools and solutions in the academic and commercial field, through a literature review and application inventory. In a second stage, two of the most promising mixed-reality applications were selected in order to conduct a usability study, with the participation of medical students. This usability study focused on the hands-on evaluation of two applications available on Microsoft's mixed reality headset, "Hololens". The results collected throughout this study are evaluated in order to extract recommendations in proposing an evolution in the teaching of this discipline.

2. Methodology

2.1. Nonsystematic Literature Review

A literature search was conducted on the following search engines and knowledge bases: PubMed , Google scholar , Embase/Elsevier/ScienceDirect , Wiley Online Library , Web of science, and more. The inclusion criteria for literature was: The article must discuss the topic of AR/MR in the general field of medicine OR the article must discuss the topic of AR/MR in the teaching of anatomy.

2.2. Study of Available Solutions

Presently, the most widely used AR devices are consumer smartphones and tablets [4]. In the pursuit of studying available AR and MR solutions, the three most promising AR and MR platforms were identified, and software available on those platforms was tested and evaluated. Selection criteria: Software was selected for evaluation according to the following criteria: i) the software must focus on human anatomy ii) the software must present significant AR or MR capabilities. iii) the software must be available for use on the Hololens, Apple device, or Google Play device platforms. Of the selected software, a

sub-selection was made based on available user-review ratings. Finally, a small portion of the selected software was excluded due to practical limitations. Each remaining software solution was tested in-person, and evaluated according to a consistent evaluation scheme. The evaluation scheme was formed to include as much potentially relevant information as possible for anatomical teaching providers.

2.3. Usability Study

The usability study conducted in the course of this work can be modeled in three parts. The experiment set-up: the target demographic for the study was medical students, in the 2nd to 5th year. 1st and 6th year students were not targeted due to a lack of complete ongoing anatomical curriculum. 30 medical students signed-up for and participated in the study. The hands-on experiment: two solutions were selected based on their ease-of-use, relevance and completeness: "Dynamic Anatomy" and "Holoanatomy", both MR applications intended for and tested on the Hololens. Hands-on experimentation: during 30 minutes, participants were to interact with both selected MR solutions, in a semi-supervised manner. Structure was given, but not imposed in the participants' interaction with each application. Assistance was available and given on request. Then a usability questionnaire, developed based on the standard set by [5], was filled in by participants after they had completed all other tasks. The questionnaire contained 4 sections: 1) **statements** concerning their experience with MR, 2) perceived **positive and negative** aspects, 3) a **multiple-choice** question regarding their preferred mode of anatomy teaching, and 4) **arguments** supporting their choice on the multiple-choice question.

3. Results

3.1. Nonsystematic Literature Review

Using the criteria outlined in Subsection 2.1, 27 existing articles were selected for review. 8 of the reviewed articles relate to describing evolution in the topic of AR in anatomical teaching. 19 of the reviewed articles concern tools presently available to apply AR and MR technologies.

Work by [6] describes the evolution of AR use in medical scenarios, and identifies a rise in activity for these topics in the years 2007-2013. The terms MR and AR are used inconsistently in the literature. As a result, tracing back the evolution for MR specifically is challenging. Technical limitations have contributed to hindering the introduction of AR to the medical field [7] Despite this, research projects involving the use of AR in medical scenarios, and specifically in anatomical teaching were identified. Previous works look at the use of AR in surgery [6], neurosurgery [8], and oto-rhino-laringology [9] Research towards the use of AR for anatomical teaching dates back at least as far as 1997 [10]. Since then, several works [11] have focused on applying AR in medical teaching.

3.2. Available AR and MR Solutions

52 applications were selected, 26 of those available on the Apple ecosystem, 16 on the Google Play ecosystem, and 10 on the Hololens. Of those, 35 applications (respectively 17, 8, and 10 for Apple, Google Play, and Hololens) could be tested in person.

Table 1.: Open-ended 3-positive-3-negative-aspects questionnaire results

Hololens for anatomy teaching				MR for anatomy teaching			
Positive	%	Negative	%	Positive	%	Negative	%
Ease of use	26%	Discomfort	35%	3D Visualization	22%	Discomfort	30%
Adjustability	10%	Field of view	22%	Practicality	18%	Missing touch	17%
Convenience	9%	Price	19%	Super-real		Space required	17%
Comfort	9%	Software bugs	10%	visualization	15%	Little benefit	
Low weight	9%	Availability	7%	Stimulating	12%	compared to PC	10%
Interactivity	9%	Non-trivial		Interactivity	10%	Lack of realism	8%
Portability	7%	learning curve	7%	Increased		No social aspect	8%
Intuitiveness	7%			understanding	9%	Lack of real body	5%
Image quality	7%			Innovative	8%	Non-mature tech.	5%
Voice, gesture				Add, remove, and			
recognition	7%			isolate structures	6%		

The overall resulting impression is as follows: At the time of this study, MR/AR applications exist which could be used as tools to supplement anatomy teaching. However commercial solutions do not yet exist for every body part, or are not suited for all specific teaching modalities. A knowledge base of these evaluations was compiled and is made freely available (www.dugas.ch/public/realite-mixte-app-evaluation-data). Based on these evaluations, the Hololens platform was selected for the usability study described in Subsection 2.3.

3.3. Usability Study

The usability questionnaire contained 4 sections. The results obtained for each section are as follows:

The **statements** supplied in the questionnaire were graded on a scale from 1 (worse) to 7 (best). The mean score by category was 5.03 for the usefulness, 5.42 for ease of use, 6.2 for ease of learning and 5.63 for satisfaction. The overall grade was 5.47. Full results are available on request.

Responses to the open-ended **3-positive-3-negative-aspects** questionnaire were grouped into conceptual categories, semantics aside. Those categories, and the frequency at which participant responses fell into the relevant category are shown in Table 1.

As shown in Table 2, in the concluding **multiple-choice** poll, following hands-on testing of MR tools and existing software, an overwhelming majority of students expressed a desire for both classical methods and technological tools to be used in the teaching of anatomy in the medical curriculum.

In the open-ended supporting **arguments** question, participants were asked to motivate their choice. Responses to this open-ended question were grouped based on conceptual similarity. Arguments for using MR in anatomical teaching fell into the following categories: i) Access to specimens, and in particular the ability for home-work, which is difficult with real specimens. ii) Access to otherwise-impossible (referred to as *super-real* in this work) visualizations, such as dynamical properties, hidden structures, etc. Arguments for traditional methods fell into the following categories: i) realism, and the ability to show details which digital media can not practically capture ii) the psychological impact of real bodies on professional maturity iii) the importance of all senses in anatomy learning.

Table 2.: Preferred modality to be used in anatomical courses

Proposed general statement	selected %
Only MR methods, with Hololens	3%
Only currently used, traditional methods	11%
A combination of traditional and MR methods	86%

4. Conclusion

It has been shown that practical factors such as a high number of students, passive participation, difficult concepts [12], and a large quantity of material to be learned, can lead to sub-optimal or superficial learning for students in medical anatomy. Proper spacing of study sessions is important for optimal long-term memorization [13]. Use or AR and MR anatomical teaching could pose several advantages, such as the possibility of increasing the frequency of leaning instances, interaction with models and specimens which are rare in practice, and super-real visualizations. This work shows that medical students are open to the introduction of technological tools to supplement, though not replace, traditional anatomy teaching. Potential future work involves extending the scope of the present study, and conducting a feasibility study from the perspective of anatomy teachers.

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