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Review

Augmented Reality, Virtual Reality, and Game Technologies in Ophthalmology Training

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Abstract: Ophthalmology is a medical profession with a tradition in teaching that has developed throughout history. Although ophthalmologists are generally considered to only prescribe contact lenses, and they handle more than half of eye-related enhancements, diagnoses, and treatments. The training of qualified ophthalmologists is generally carried out under the traditional settings, where there is a supervisor and a student, and training is based on the use of animal eyes or artificial eye models. These models have significant disadvantages, as they are not immersive and are extremely expensive and difficult to acquire. Therefore, technologies related to Augmented Reality (AR) and Virtual Reality (VR) are rapidly and prominently positioning themselves in the medical sector, and the field of ophthalmology is growing exponentially both in terms of the training of professionals and in the assistance and recovery of patients. At the same time, it is necessary to highlight and analyze the developments that have made use of game technologies for the teaching of ophthalmology and the results that have been obtained. This systematic review aims to investigate software and hardware applications developed exclusively for educational environments related to ophthalmology and provide an analysis of other related tools. In addition, the advantages and disadvantages, limitations, and challenges involved in the use of virtual reality, augmented reality, and game technologies in this field are also presented.

Keywords: augmented reality; gamification; virtual reality; skill acquisition; computer simulation; optical sciences

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1. Introduction

In the last decade, a wide variety of Augmented Reality (AR) and Virtual Reality (VR) applications have been developed, which have attracted great interest in different fields related to education [1]. Many professionals are up to date with this knowledge, which allows them to develop hardware and software applications related to the educational environments of medical training [2].

Recent research shows that the use of AR and VR in medical instruction has resulted in the progress and advancement of clinical skills. Therefore, a growing body of literature related to the different uses of AR and VR can be found in the development of skills in medical specialists in different areas, and the use of AR and VR in the treatment of patients with any pathology.

However, there is a gap in the literature regarding systematic reviews that summarize the research conducted on the use of AR and VR within an educational context in ophthalmology training. To fill this gap in the literature, this paper aims to analyze the current state of the use of AR and VR in educational environments related to ophthalmology, thus demonstrating the significant advantages, disadvantages, challenges, and limitations faced in this area. Furthermore, the results of this systematic review can be used by other researchers to identify potential research directions in the field.

A gradual interest in the use of instruments and simulators with technologies related to AR and VR started in the 90s, with the first surgical simulations using these AR and VR technologies, with the main objective of generating an action plan during the operation. This allowed the participants to improve their skills by developing them prior to entering an operating room, thus ensuring a higher level of success. The rapid development of these technologies is due to the miniaturization of the associated devices, which has provided an accelerated increase in their implementation, while the low cost of the components allows for the development of mobile platforms with increased portability for use in any space [3].

The emergence of simulators allows surgical procedures to be evaluated through training. Simulation in VR can be divided into several levels of complexity: simplified VR that is limited to user interaction with the computer, advanced VR when the user makes use of additional interface elements, and surgical simulation that makes use of feedback advanced systems and virtual immersion requiring sensory inputs and outputs [4,5].

Surgical training using simulators has been used in many medical specialties to provide adequate training in a controlled environment that can guide an objective assessment of each of the skills and responsibly monitor their progress. The need for these surgical simulators in education—and especially in ophthalmology—is driven by many forces, including the vision of optimizing surgical training with a reduced time frame for trainees. In the United States, the Accreditation Council for Graduate Medical Education (ACGME) remains responsible for the process of managing and monitoring the development of surgical competencies in the training of residents in surgical specialties and objective evaluation tools are of vital importance in this process [6]. On the other hand, the use of AR is increasingly present in guided surgery processes, where surgeons rely on imaging technologies to make decisions at the time of their surgical procedure; this facilitates greater control of the surgical procedure for doctors, with optimized use of available operating rooms [7].

VR and AR are present in a variety of important hardware and software in medicine, though three main characteristics are shared: immersion, presence, and interaction. The term used for these interaction paradigms with these characteristics that bring together the three concepts is extended reality (XR). The affordance of XR technologies is to create environments that would not otherwise be possible in the real world and has very important applications as well as practical implications in medical disciplines. In ophthalmology, virtual reality simulators have become increasingly important as tools for surgical education. More recent developments have also explored diagnostic and therapeutic uses in ophthalmology [8].

In this paper, the different technologies used in the training of ophthalmologists are presented, including an analysis of the experiences found in AR, VR, and gamification in the teaching of optical sciences. Throughout the search process of related research, the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is considered [9]. All 71 selected articles ([3–8,10–73]) were read, analyzed, and fully evaluated, including screening for bibliographical references that could be of interest to obtain a sufficient base of articles to support this research.

To analyze how augmented reality technologies and "gamification/serious games" can be used for the training of ophthalmologists, four research questions were defined:

RQ1. What are the advantages, disadvantages, limitations, and challenges of AR and VR technologies in ophthalmology training?

RQ2. What hardware and software tools have been developed for teaching ophthalmology?

RQ3. What are the AR and VR tools, or frameworks used for developing applications in the field of ophthalmology?

RQ4. What are the advantages, disadvantages, limitations, and challenges of game technologies in ophthalmology training?

RQ5. Can Games Technologies be used to support teaching processes in ophthalmology?

Section 2 describes the search methodology followed to develop this study. In Section 3, research questions are answered. Finally, in Section 4, the discussion of findings, results, and conclusions are presented.

2. Search Methodology

In this section, the inclusion criteria, search strategy, and exclusion criteria are explained.

2.1. Inclusion Criteria

The search criteria were based on articles from the field of optical sciences, which have used AR, VR, or game technologies for the training of professionals in ophthalmology, and the rehabilitation and treatment of patients. Therefore, journal articles were included, all articles were evaluated without limitation to a specific publication time, and articles in English, Portuguese, and German were analyzed.

2.2. Search Strategy

The search terms used are based on "game-based-learning, serious, games, gamification, augmented reality, virtual reality, ophthalmology, optometrist, training, and learning" limited to the area of computing, medicine, and engineering. These search terms were connected using the Boolean operators "AND" and "OR" to capture all relevant article suggestions.

An additional search method was added as a validation strategy in the Web of Science and Scopus databases. The Tree of Science (ToS) tool is a web tool that uses the structure of the citation network to identify relevant literature [10]. ToS shows the information in the form of a tree, where the classic articles are in the roots, the structural articles form the trunk, and the most recent articles are the leaves; with this search methodology, it was possible to observe the most relevant authors for the subject and more easily analyze articles.

All articles linked to the use of technologies related to AR, VR, and gaming technologies in the development of skills related to the optical sciences were included, which were found to range from 1995 to the year 2021. The categories range from the use of technologies for teaching, the use of simulators to improve operational skills, and the use of serious games to enhance the learning of basic concepts under the strategy of learning by playing.

To identify previous studies carried out in our field of interest and ensure that our research is useful to the scientific community, we conducted a search in different databases (Scopus, Web of Science, PubMed, and Google Scholar) using the search syntax shown in Table 1. In the search string, the asterisk (*) is a wildcard that can be used to retrieve terms that have multiple spelling variations. For instance, using the word "learn" with the wildcard at the end would retrieve results that contains the variations learn, learner, learning, learnt, learned, etc.

Table 1. Search String.

Database	Search String
Scopus	Title-abs-key (((game and based and learning) or (serious and Games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*)) and (limit-to (doctype, "ar") or limit-to (doctype, "cp")) and (limit-to (subjarea, "comp") or limit-to (subjarea, "medi") or limit-to (subjarea, "engi"))
Web of Science	ts = (((game and based and learning) or (serious and games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*)) or ti = (((game and based and learning) or (serious and games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*))
PubMed	(((game and based and learning) or (serious and games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*)) or ts = (((game and based and learning) or (serious and games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*))
Google Scholar	(((game and based and learning) or (serious and games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*)) or ts = (((game and based and learning) or (serious and games) or (gamification) or (augmented and reality) or (virtual and reality)) and (ophthalmology* or optometrist*) and (training* or learn*))

2.3. Exclusion Criteria

Throughout the search process, 509 articles were found among all the databases listed above. After removing duplicate articles in the different databases, 449 articles were considered for the next step. The title and abstract of these 449 articles were analyzed to determine whether they met the inclusion criteria. Articles related to the treatment of diseases and recovery procedures in patients were excluded, and only those scientific articles that referred to the use and application of AR and VR technologies related to the training of professionals in the optical sciences were included, prioritizing those technologies that were designed or created for this purpose. This entire classification process is detailed in Figure 1. In addition, the references included in these 65 articles were reviewed, and 6 more articles were found that were then also included in this work.

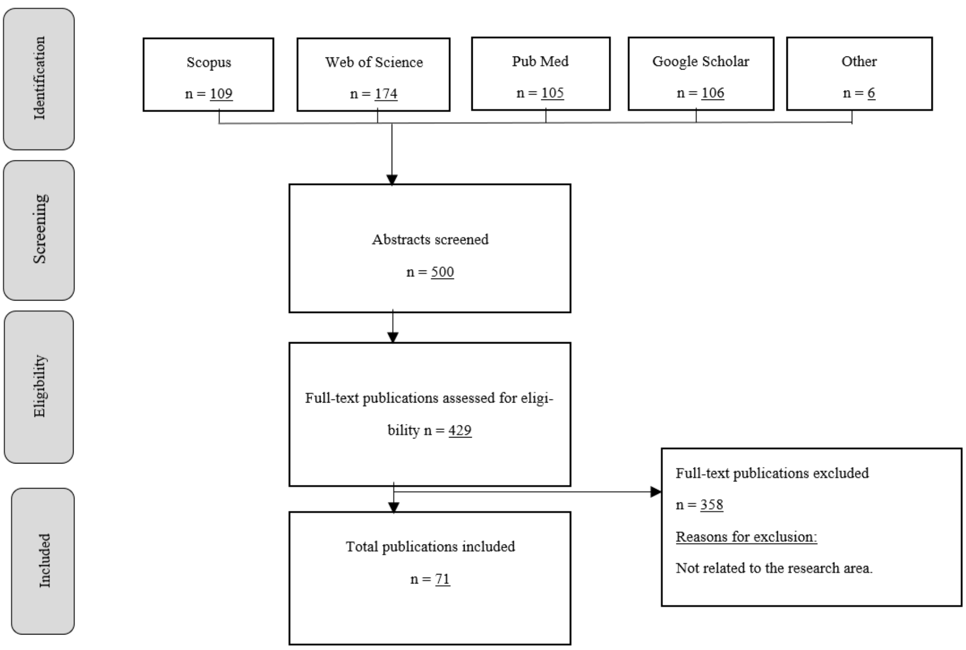

Figure 1. Classification process.

3. Review Studies Available on the Topics Related to AR in Optical Sciences Training

We found two systematic reviews in the field (Table 2), but neither allowed us to answer the research questions addressed in this paper. Consequently, the systematic review reported in this article was thus necessary to identify the current state of research on the use of AR, VR, and game technologies in the field of ophthalmology training.

Table 2. Recent review studies.

Study (Papers Reviewed)	Summary of Findings	Analysis
131	A total of 131 studies were included in this review, with 93 different simulators described. Of these 131, 53 were virtual reality studies, 47 were wet laboratory models, 26 were dry laboratory models, and 5 were on electronic learning. Of all the analyses carried out, only two of the studies provided any evidence. The models with the greatest validity evidence were Eyesi Surgical, Eyesi Direct Ophthalmoscope, and Eye Surgical Skills Assessment Test [11].	A wide range of models have been described, but only the Eyesi has undergone comprehensive investigation.
73	The authors introduce an analytical model to evaluate AR applications for teaching in medical education. Moreover, there is an increasing interest in the use of AR for medical education [12].	There is a lack of research on medical training with AR and, therefore, there is insufficient evidence for recommending adoption in the curriculum.

Although Lee et al. [11] analyzed 93 different simulators in great detail, in all the explained cases, only the Eyesi simulator was considered, whereas Tang et al. [12] revised other related technologies that were not designed for the study of ophthalmology. Finally, we can mention that none of these surveys analyzed the use of game technologies.

4. Results

From the analysis of the 71 selected articles, the previously proposed research questions could now be answered.

4.1. RQ1: What Are the Advantages, Disadvantages, Limitations, and Challenges of AR and VR Technologies in Ophthalmology Training?

To answer this question, the related articles have been analyzed and each advantage and disadvantage has been pointed out as the first set and each limitation and challenge in a second set.

4.1.1. Advantages

The presence of teaching–learning methodologies through AR and VR has a long tradition of multiple applications within medicine. These types of methodologies range from treating patients with disabilities, training models for people, and teaching aids for teachers, among others. AR and VR have been present in the world of medical sciences for more than a decade, and their importance as an element of collaboration in virtual educational environments is increasingly important in the development of professionals in the optical sciences [13,14].

Hence, to achieve more effective training of medical residents through the better and faster development of skills, efforts have been focused on generating a variety of training and research methodologies in AR and VR, with the aim of developing tools of AR and VR to provide more complete, systematic, and effective training to improve the learning techniques of specialists and thus improve preoperative planning and the living conditions of patients [15].

The use of AR and VR has gained increasing interest for acquiring ophthalmic surgical skills outside the operating room and, therefore, increasing patient safety. Although training in real life with real patients will continue to be necessary for the ophthalmologist, the use of augmented reality ophthalmoscopy (ARO) for beginners and medical students in indirect ophthalmoscopy offers many advantages: it is not necessary to dilate the pupils of the student or the patient, there is no light toxicity due to prolonged exposure during training, and there is no need for a slow search for suitable patients with specific findings for the educational program [11,16].

Simulation has been widely discussed in the field of ophthalmology, and many authors indicate that it can be used both to improve and measure the performance of professionals in training. One of its main advantages, apparent throughout this analysis, is the opportunity to repeat specialized surgical procedures since VR practices are always available for ophthalmic residents to perform difficult procedures. In addition, some studies have planned for the use of VR simulators in shortening residency programs, since the resident assimilates knowledge and practices faster as well as there being a clear reduction in educational costs [3,17].

The potential benefits of using VR or AR and integrating them into conventional treatment processes are many: Multiple repetitions of low simplicity tasks in clinical practice can be performed in a safe environment without the need for constant supervision by the instructor or training staff nor the provision of medical assistance, which could dramatically reduce the costs associated with physical training facilities and trained medical personnel [11]. For patients with physical difficulties in mobility, virtual reality glasses that could be used in a safe environment, e.g., from the safety of their homes, could reduce the need for hospital visits. VR and AR experiences can be designed to be increasingly engaging and user-friendly, reducing patient attrition rates and providing a more enjoyable environment [18]. VR and AR can facilitate investigation through secure data collection to monitor progress. The use of VR in surgical training could, according to studies, reduce the possibility of surgical errors, which would lead to a great improvement in patient safety [19].

4.1.2. Disadvantages and Limitations

There are numerous advantages of using AR and VR technologies, which allows many possibilities for development in the teaching–learning process, all of which are related to the improvement of competencies to develop knowhow in medicine and other areas of health science.

However, the total substitution of practical subjects, in which direct interactions with the patient, clinical rotation, and medical–surgical training is necessary, cannot completely disappear from the educational scene because they are directly linked to the development of abilities and skills, so the presence of teachers is necessary. Therefore, the teacher–student relationship in common training areas, such as schools, hospitals, and university clinics, cannot be eliminated from the teaching–learning process [20].

Other disadvantages are the high development and maintenance costs as well as high investment costs in hardware and software, which generally requires fast devices with good processing capacity to facilitate procedures [3].

Virtual reality is still a dispersed and fragmented market. The different technologies that were analyzed during this study are still in an adaptation phase, and the compatibility between platforms is not yet so clearly defined, so its use cannot be replicated with each piece of created hardware. A characteristic that can have a negative impact on the operator's performance is the hardware configuration itself, and an error in the adjustment and calibration of the device can result in the user not having the best experience in using and seeing the content clearly. Thus, any time spent on adjustments by the operator can be wasted if a satisfactory experience is not ultimately obtained [21].

Effort and eye fatigue is one of the main disadvantages of using VR devices, because looking directly at the screen can cause eye fatigue. When using these types of devices, users tend to blink less frequently, and this causes the surface of the eye to dry out, which results in visual exhaustion and tiredness. Another problem that has been related to the use of these technologies is motion sickness, as the brain receives the same signals regardless of whether the observation is based on an image that involves a movement or on a real movement, so the use of virtual reality devices can cause dizziness [22].

Users suffering from eye diseases such as amblyopia or other conditions that impose focus or those related to poor depth perception may not perceive 3D effects. It should also be considered that the excessive use of these technologies can cause fatigue or exhaustion in the neck region due to the weight of the device or due to remaining in one position for an extended period [23].

Although clinical research in virtual reality seems a promising terrain for the development of medical skills, important theoretical and practical challenges persist, and the lack of defined and clear technical standards may not allow for determination of its economic feasibility. Further studies that compare the VR and AR experience are required to clearly define its benefits. VR and AR systems are not always easy for patients to use. Additionally, eye and neck fatigue issues and access to the cyberspace remain practical barriers for wider use [24].

4.1.3. Challenges

Despite the obvious advantages of using these technologies and their constant improvements, different studies and simulations in risk reduction have shown that further improvement is needed. There is also a lack of research on designing a curriculum that uses these advantages in ophthalmology [25]. The goal of all surgical training programs is to produce physicians with excellent medical judgment and surgical skills. With the ever-increasing complexity of eye surgery and the zero tolerance for surgical misadventure, the challenge of training future eye surgeons is rapidly increasing [3,14].

Despite the enormous progress made in the last 20 years in the field of surgical VR simulation, there are still many obstacles to overcome [3]. We summarize what we consider to be the challenges in Table 3.

Table 3. Challenges.

Challenges	Description
Interaction with virtual world	The development of new technologies will help to replicate images with greater clarity and reality.
Need to generate more studies	There are very few published studies on VR and AR, so more studies should be generated to demonstrate their efficiency in ophthalmological surgery.
Lack of metrics	The research community has not established a standard metric, and the search for a realistic and inexpensive VR method has led to experimentation with various technologies.

All the studies analyzed above distinguish innate surgical ability from surgical skills. Skills are learned during specialized training but require underlying fundamental skills, such as strength, manual dexterity, eye–hand coordination, psychomotor skills, perceptual ability, and visuospatial ability, which were recognized by various authors as being important for surgical training [26].

Moreover, in the literature, we did not find studies that consider adaptive mechanisms in personalizing the students' learning experience. The use of adaptive mechanisms based on machine learning techniques might help to personalize the learning experience so that the AR and VR simulators can adjust to the students' learning needs, preferences, interests, and motivations. In that regard, a future research direction could be the design and evaluation of smart learning environment for ophthalmology training [27].

One of the most important challenges is visual perception since computer science currently experiences applications of the graphic world to be an important challenge since they are extraordinarily complex and try to achieve a perfection in involving all the senses.

Although all graphical algorithms have rapidly developed, the development of new and agile techniques is still needed to ensure a satisfactory result for what we call user perception. This component is a new challenge, given that all applications try to immerse the user in the reality of the application. For all this to be possible, an analysis of the computer/human interfaces is needed to really help in defining the needs of the user and the perception mechanisms for implementing increasingly efficient devices [28].

All this must be analyzed in new lines of study from the analysis of interfaces to their perspective from the human vision, including the analysis of touch and tactile sensation, auditory sense, sense of taste, sense of smell, and from the perspective of psychological biofeedback [29].

By analyzing all the advantages, disadvantages, and challenges of these technologies, we have realized that although these technologies are important for student training, they are not yet part of a comprehensive curriculum developed in conjunction with the adaptation process. In most universities, however there are already complementary efforts to support training in some classes, but it is still an experimental theory.

Much needs to be done for this type of technology to be integrated as an integral part of educational curricula, however, there have been great advances in the introduction of these technologies in the world of professional training in ophthalmology.

4.2. RQ2: What Hardware and Software Tools Have Been Developed for Teaching Ophthalmology?

To answer this question, different hardware and software models for ophthalmoscopy simulation have been described, but very few studies evaluate the efficacy of each individual model. Many more studies are still required to effectively compare and determine the best results that are oriented toward medical education and the improvement of skills through simulation models, applied to both medical students and young ophthalmologists in training.

Although many XR ophthalmic applications were identified during the search, we mainly focused on the following domains: education and diagnostics. In education, simulators have proven effective in improving ophthalmoscopic and surgical skills.

In the medical area, the influence of AR is the most prevalent. VR platforms have been basically designed to teach fundamental concepts and subjects and appear, very rarely, in the training of surgical skills in surgeons. Google Glass (Available online: https://www.google.com/glass/start/, accessed on 19 April 2022) (Google Inc., Mountain View, CA, USA) or Microsoft HoloLens (Microsoft Inc., Redmond, WA, USA) are used in AR to visualize diagnostic images and complex surgical procedures, thus increasing the possibility of success [30].

Likewise, ophthalmology has seen the increasing influence of XR. Medical training in the postgraduate area in ophthalmology continues to increase as the use of virtual eye surgery simulators becomes increasingly present, from 23% in 2010 to 73% in 2018. AR and VR technologies are increasingly present in antiviral therapy of ophthalmic diseases, such as amblyopia and visual field defects. Although it is a very innovative technique for the treatment of these diseases, ophthalmologists must continuously analyze the advantages and disadvantages of the use of technologies, which will allow them to make decisions about the correct application of technology in these treatments [8].

4.2.1. HoloLens

A vascular localization system based on the use of HoloLens (Available online: https://www.microsoft.com/es-es/hololens, accessed on 18 April 2022) technology can be used to precisely locate the area to be drilled and represents invaluable support to the surgeon when performing a surgical procedure. This system meets precision in different clinical trials, and error reduction will have to remain a very important topic for research. Some studies show that hardware limitations could also be a source of error, which is why many criticize the feasibility of the system. According to the studies, the sources of error could be generated from the beginning of the process precisely in the acquisition of tomography data, MRI (magnetic resonance imaging) until the end of the surgical procedure, including image error, registration error, tracking error, and error human [31].

4.2.2. Google Glass

Appearing for the first time as the Google Glass Explorer Edition in 2013, Google Glass is a device that is placed on the head and uses a wireless interface, which is designed to provide users with an interesting VR or AR experience and very good comfort. Google Glass uses the Android operating system, and the user can see information on a small screen to the right of the user's right eye. Google Glass offers has an interesting gateway to access instant information. In its Explorer Edition, the capabilities of voice activation and data transmission and the built-in camera have attracted the interest of commercial industries and professional operations, including those in healthcare. One of the most attractive aspects for the field of surgery is the multitasking capabilities of Google Glass and its enormous responsiveness to commands that involve movement, and its voice commands allowing hands-free use has made it particularly attractive for the surgical field. These attractive advantages provide surgeons with the opportunity to improve the workflow in an environment where maintaining sterile conditions in the operating room and continually monitoring patients during surgery is crucial [32].

4.2.3. VES: Virtual Eye Surgery

Virtual Eye Surgery simulation training in graduate medical education (GME) in ophthalmology has been shown to improve surgical skills in training cataract surgery operating processes and reduce the learning curve for the surgical process. Information from different studies shows that current VES educational practices would provide an interesting framework for ophthalmic GME programs that are considering adding VES simulation to their training programs [33].

4.2.4. THELMA: The Human Eye Learning Model Assistant

THELMA consists of a polystyrene mannequin human head that uses retinal images to simulate the device. The advantages of this model in its first version are the improved simulation of the doctor–patient relationship. This provides a sense of correct position, although the intense reflection of light was still a problem, which was especially due to the quality of the paper in the printed photographs [34].

4.2.5. The EYE Exam Simulator

The EYE Exam Simulator (Available online: https://www.kyotokagaku.com/en/products_data/m82m82a/, accessed on 18 April 2022) developed by Kyoto Kagaku Co., Kyoto (Japan) and Eye Retinopathy Trainer® developed by Adam, Rouilly Co., Sittingbourne (UK) are life-size mannequin human heads with a manually adjustable pupil that allows access to a high-quality, engineered 35 mm wider retina through a handheld ophthalmoscope. Because this system is so much more complex, novice examiners can have problems if there is not an experienced staff member there to support them in its use [11].

4.2.6. iExaminer

To face the challenges in the study of the eye and the precise mastery of the fundus examination, online websites have been developed with multimedia content that allow for the observation of a healthy eye or an eye with pathologies so that the user can differentiate between normal eyes of the sick.

Recent developments also include a fundus simulator developed by Kyoto Kagaku Co., Ltd., which enables the lesson developer to closely monitor what practitioners are focusing on and assess whether movements and points of interest correspond to the possible simulated states of the patients based on interchangeable images. The iExaminer (Available online: https://www.welchallyn.com/en/microsites/iexaminer.html, accessed on 18 April 2022) system is a device created to facilitate eye examination by aligning the ophthalmoscope's optical axis with the visual axis using only the Apple iPhone 4 or 4s, and this device allows one to capture and store high-quality images for definition of the fundus and of the retinal nerve for further evaluation [35].

4.3. RQ3: What Are the AR and VR Tools, or Frameworks Used for Developing Applications in the Field of Ophthalmology?

To answer this question, a search has been made for technologies designed and developed specifically for the teaching of optical sciences. The following sections list these technologies and discuss the features, benefits, and options that they offer.

4.3.1. Eyesi® Surgical Simulator

Eyesi is an advanced augmented reality simulator for indirect binocular ophthalmoscopy training (Available online: https://medical-simulator.com/cirugia-oftalmologica/4206-eyesi-surgical.html, accessed on 18 April 2022). This simulator has an extensive database of clinically relevant pathologies, Eyesi significantly expands the range of diagnostic training for all residents available in all ophthalmology and optometry programs [36].

The Eyesi® simulator (Vrmagic, Mannheim, Germany) is explained in Rai et al. [37], Roohipoor et al. [26], Saleh et al. [38], and Lee et al. [11]. All these authors inform us that most of the users who used this technology obtained a significant decrease in stress and significantly improved their skills in the exploration processes and in the different surgical processes. Eyesi® is an advanced binocular ophthalmology training system. It has an extensive user-administrable database for the analysis of clinically important pathologies. This team provides a spectrum of training to generate diagnoses for ophthalmology and optometry students [8,39].

This simulator provides a model of the patient's head with a cataract that can be operated in a frontal or lateral position, and residents see the intraocular surgical field through a microscope; the vision is stereoscopic and offers a realistic depth of field. It has an online training portal (vrmnet) with the option of connecting the simulators in a network and allows all up-to-date training and user data to be stored in a central server to be accessed safely through a computer or mobile device 24 h a day. This allows instructors to view the training history of their residents online and compare the results with the training data of their peers [40,41].

At the time of testing the Eyesi surgical simulator, highly experienced surgeons were able to verify their greater ability in the different tasks in the operating room and as the hours of experience increased, obtaining a significant improvement in all aspects and thus improving their scores within the simulator. Compared with novice surgeons, the skilled intraocular surgeons performed operations significantly faster and more accurately and successfully completed the different tasks with far fewer attempts. After several attempts, the novice surgeons demonstrated clear improvements with regard to the time to successful task completion. The main improvements occurred after the first two iterations, indicating a rapid familiarization and training effect [42].

The simulator offers an immersive and realistic environment without risk for the patient and integrates all aspects of a real surgical scene, suitable for training in hospitals and universities. It is important to mention that the evaluations in the conducted study reveal significant enough participants to generate favorable statistics for improvement through the use of these technologies [39,43].

A series of studies mention the experiences in the use of Eyesi® and refer to the training developed with the Eyesi® tools, the benefits of using a surgical simulator, and the direct reduction of intraoperative problems [44].

The most recent studies that referred to the use of the Eyesi® simulator with all its learning modules show the methodology to be acceptable, thus demonstrating its validity; this is important when evaluating teaching–learning models with new tools, i.e., guaranteeing that the desired result is actually being achieved [36].

All studies encourage the shift toward modern medical training for medical schools and in postgraduate training. Although it is true that the acquisition of these technologies is a challenge due to their acquisition costs, it is important to adopt this type of technology since time savings are produced and greater security in the effective treatment of the patient is provided. Although the validation methodology is acceptable and the data indicate reliability, the number of participants was not sufficient in any of the cases to establish an adequate level of representation to guarantee its reliability [45,46].

The results indicate that the simulator can accelerate progression in the early stage of learning and provide tangible data to instructors and program managers. On the other hand, the simulator is also conditioned by the inability to practice scleral depression. Therefore, it cannot substitute for experience with an actual patient. However, it will allow for a comfortable experience for the patient if the other parts of the exam are performed competently [37,47].

4.3.2. Microvistouch

The Microvistouch (Available online: https://www.immersivetouch.com/, accessed on 18 April 2022) simulates the capsulorhexis, clear corneal incision, and phacoemulsification steps of cataract surgery. The Microvistouch does not come with a set of tangible instruments. In VR immersion, the handpiece turns into a keratome, hook, or forceps as required by the simulated procedure.

The different experiences with the Microvistouch simulator are analyzed in [6], in which the author analyzes the use of these tools during surgery and the use of a surgical simulator as an evaluation tool to teach important concepts along with training in the operating room to accelerate the teaching of ophthalmic surgery. In turn, it is concluded that using this type of simulator should be an integral part of the study plan to evaluate a user's knowledge and skills.

4.3.3. Eyesi® Surgical Simulator versus Microvistouch

An important difference between the Microvistouch and the Eyesi® is that while the Microvistouch has a head model like the Eyesi®, the ophthalmic practitioner does not interact with it in the same way. The mannequin is positioned such that the student can practice proper hand placement on the forehead and cheek of the patient as part of the surgeon's posture in real life [48].

In Microvistouch, students do not touch a physical model of a patient as in Eyesi®. However, immersive touch creates an experience of haptic feedback, and this is new in VR cataract surgery simulators [6,49].

The evaluation methodology was based on four variables: circularity, precision, fluency, and general punctuation. The sample obtained in the different studies varies from 45–90 participants, and it was concluded that the use of this type of surgical simulator as a tool for evaluating surgical concepts together with training in the operating room can speed up the teaching of ophthalmic surgery. Therefore, it is recommended that these simulators be used as part of the specific curriculum that evaluates the knowledge and skills of the users [50,51].

As a result, it has been possible to hypothesize that the residents' performance in the simulator would indicate how they performed in the operating room; the validation of Microvistouch provides a clear reference of the skills and knowledge of the resident [52].

4.3.4. PixEyes

Ophthalmic Simulator (SimEdge SA, Loos, France) is a VR tutoring system and an ophthalmological disease simulator. The objective of this simulator is training in real conditions for the diagnosis and laser treatment of diseases such as diabetic retinopathy, age-related macular degeneration, retinal vascular diseases, and glaucoma. PixEye (Available online: https://www.toshbromedicals.com/, accessed on 18 April 2022) is designed primarily for the treatment of retinal disorders [53].

In the results, an improvement in skills is observed thanks to PixEye, where a significant improvement was achieved in the medical student's ability to perform laser trabeculoplasty [54].

4.3.5. Robotic Surgical Simulator (RoSSTM)

The RoSS (Available online: http://simulatedsurgicals.com/, accessed on 18 April 2022) (Simulated Surgical Systems LLC., San Jose, CA, USA) is a portable and self-contained system. This system has 52 unique exercises properly categorized for the better understanding of the user: It has modules of orientation, motor skills, basic surgical skills, intermediate surgical skills, and practical surgical training [55].

4.3.6. Mimic dV-Trainer (dV-Trainer)

The dV-Trainer (Available online: https://medical-simulator.com/box-trainers/4713-winco-pro.html?search_query=dV-Trainer+&results=1, accessed on 18 April 2022) (Mimic Technologies, Seattle, WA, USA) is a portable and independent device with movable pedals. It is very practical and should be placed on a table. The simulator appeared in 2007, has a relatively high cost of around USD 100,000 and contains 65 unique exercises. The dV-Trainer hardware has manual controls, which use three leads to measure hand movements rather than the more precise arms found in the RoSS and the true da Vinci Surgical System.

4.3.7. da Vinci Skills Simulator (dVSS)

The dVSS (Available online: https://mimicsimulation.com/da-vinci-skills-simulator/, accessed on 18 April 2022) (Intuitive Surgical, Sunnyvale, CA, USA) prototype first appeared in 2011, costs about USD 85,000, and includes at least 40 well-categorized exercises. The simulator cannot function independently and requires a da Vinci Surgical System console and has the disadvantage that it cannot be used for training purposes.

4.3.8. SimSurgery Educational Platform (SEP)

SimSurgery (SEP) (Available online: https://tracxn.com/d/companies/simsurgery.com, accessed on 18 April 2022) (SimSurgery, Oslo, Norway) is an autonomous robot developed in the Netherlands. It is one of the most economical compared to the same of its generation, it costs between USD 40,000 and 45,000 and only has 21 tasks to develop. It has a two-dimensional monitor that fulfills the eyepiece function satisfactorily. The operator's manual controls are mounted on a dashboard and are versatile and comfortable.

4.3.9. Other Related Technologies

Many companies are focusing on the development of surgical teaching interfaces using virtual reality headsets. Osso VR (Available online: https://www.ossovr.com/, accessed on 18 April 2022) has developed a platform with collaborative training solutions and has collaborated with orthopedic residency programs. In another experience, they have collaborated with Johnson & Johnson to present this technology to surgeons in the United States, and the Fundamental VR company has built some RA subassemblies with haptic feedback integration that allow it to transmit operative sensations [56].

The combination of smart devices generates options that combine the use of AR and VR together with a desktop screen and mobile devices (tablets and smartphones) to develop an innovative system that facilitates the education and training process in anatomy topics in a student-centered manner. The use and combination of these devices provides a friendly interaction surface on a common table, where a global view of an anatomical model is provided. This global view is available to all users, both instructor and students, and they can interact with the model using the touch-sensitive desktop screen surface.

In addition to all these advantages, each of the students has access to the model through a mobile device that is synchronized with the global view and provides each student with an individualized view, which facilitates training in virtual ocular anatomy [35].

The growing importance of simulation training in ophthalmology is clearly seen in the number and variety of models critically reviewed in this paper. Eyesi Surgical is the only model that has been subjected to different types of tests that can generate clear and specific evaluation criteria. Microvistouch has very few studies that allow clear criteria for comparison with other technologies, and the results obtained from the different analyzes are too limited to obtain conclusive data, so future work is necessary to make clear comparative models that analyze the advantages of each tool. PixEyes, RoSSTM, dV-Trainer, dVSS and SimSurgery are tools for the practice and diagnosis of different diseases with their respective training modules.

4.4. RQ4: What Are the Advantages, Disadvantages, Limitations, and Challenges of Game Technologies in Ophthalmology Training?

This section mentions the different advances and potentialities of each of the gaming technologies and how they have been included in different educational or training tools.

Augmented reality game-based learning (ARGBL) is an advantageous approach for the development and enhancement of the teaching and learning process, but in the search carried out, no articles were found in which ARGBL was considered.

In the systematic review, only two experiences were observed in which game technologies were applied to the teaching of ophthalmology. Therefore, there are not enough studies to verify its advantages, disadvantages, limitations, or challenges.

Eyeclinic is the first VR gamification application analyzed at the ophthalmological level. It was born to enhance training through gamification. This application simulates an ophthalmology clinic where participants can attend to their patients in real time. The aim is for specialists to update their knowledge, especially in the retina and glaucoma fields. To expand the clinic and exceed the levels, users must solve medical cases created by expert ophthalmic professionals and based on their own experience [57].

Available in both operating systems (iOS and Android), it can be downloaded directly from the site (Available online: www.eyeclinic.es, accessed on 18 April 2022) and once professionals confirm their data, they will be able to test a total of 200 clinical cases to reinforce the latest techniques in ophthalmic treatments [58].

The second gamification application is analyzed in Wilson et al. [59], and the evaluation showed that the application could successfully simulate the processes involved in performing eye exams. The app was highly rated for all elements of perceived usefulness, ease of use, and usability. Medical students stated that they would like to learn other medical skills in this way in the future.

In the app, the person performs a series of tasks during their learning process, and a series of virtual rewards help guide and report on their progress. For example, suppose the specialist completes each of the tasks successfully within a level. In that case, he will receive a reward with a virtual badge that will remain within his statistics in the program. In the questionnaire section, the user will be presented with eight questions and is given a certain amount of time to answer them. Depending on the number of correct answers, the user receives a virtual badge within the application, which varies between gold, silver, or bronze [60].

The interest in using gaming technologies is reflected in many areas of knowledge, especially some AR and VR applications are already seen in the environment, which allows ophthalmologists to have a training process based on these technological tools, but there are not enough studies with these that can determine sufficient enough points of comparison as well as determine their advantages or disadvantages. What is true is that it is expected that this type of technology will increase every time when seeing the results in the training of new professionals in ophthalmology and in optometry.

4.5. RQ5: Can Games Technologies Be Used to Support Teaching Processes in Ophthalmology?

The analyzed studies established positive responses to game technologies as part of the training process for apprentices and experts in the training of surgical skills in ophthalmology. Furthermore, most of the articles identified in this systematic review, which were published in the last decade, underscore consumers' growing relevance and interest in applying AR simulation and game technologies in ophthalmology teaching [61].

Through this research, we identified a number of laparoscopic simulators, such as ProMIS, ImmersiveTouch, and AR glasses (Google Glass © and Microsoft Hololens ©, among others), so it can be concluded that there is a great diversity of tools for the surgical training in all areas of medicine supported, and, in turn, by articles that were intended to demonstrate the different experiences that led to its validity [62].

Throughout the analysis of the articles, the significant progression of technological advances that have made the simulation of Virtual Reality a viable element for training surgical skills can be observed; however, there are other skills necessary for good performance in a ward of surgery that must be complementary to the technical ability that is intended to be achieved with this type of training.

Therefore, we can point out that game technologies can be used to provide adequate support to improve learning in ophthalmology. In all related studies, it was evidenced that the use of these technologies significantly improved student scores.

Each of the studies demonstrates interesting initiatives to bridge the gaps in the teaching and learning processes. In general, it is determined that the procedure used to carry out the different evaluations is traceable, and its methodology is fully verifiable; however, the sample size of all the analyzed studies is not significant enough to demonstrate the impact of the research.

Several very interesting technologies that are not specifically designed for medical uses were also analyzed. However, since comparisons have not been conducted in other studies, they are difficult to evaluate, so establishing their validity has been a limitation [18,63].

The projects identified in this systematic review are the only ones that allowed us to evaluate their preparation as an educational tool based on a comparison of their characteristics, which allow us to evaluate their key elements and validate their strengths and weaknesses [64].

When analyzing these two experiences, we must ask ourselves the following question: Are serious games and these gaming technologies useful for improving medical skills? The truth is that the answer is very likely yes, although there are very few important studies and reflections to prove this, their continued use in medicine can be taken as supportive evidence, due to the seriousness with which this profession has historically treated the making of decisions and the knowledge upon which they are based, given that the result could be a person's death [65].

The importance of serious games is that elements can be incorporated into professional and educational practice that make it much less tedious, monotonous, and repetitive, allowing its users to have a more engaging experience and, in the process, become better doctors. The objective of using game technologies is not to detract from the seriousness of the profession but to improve the technique of learning and have fun during the process while the users do what they like to the most [66].

5. Limitations

According to the development of the research, the following limitations were found.

1. Methodological limitations include the lack of available data or sufficient research. There is very little research at the time in which we conducted this systematic review about ophthalmology related to new trends in teaching and learning with immersive technologies;
2. Most of the analyzed articles have an adequate research method, though their samples are too small for robust data analysis;
3. There are very few systematic reviews on related topics, so there are very few data that can be seen as providing a clear or consistent answer;
4. Some developed VR and AR tools might not have been reported in the analyzed articles because those tools were developed by companies for commercial purposes;

5. The lack of studies related to the use of gaming technologies in the field of ophthalmology is one of the most important limitations that we found.

6. Conclusions

The simulators that make use of AR and VR technologies are co-categorized as effective tools that allow shortening of the gap for users to improve their skill level in the different surgical processes. They also allow taking advantage of the best experiences and techniques of experts in the field, which are replicated through these training methods.

There is a promising future for surgical simulators with numerous possibilities in different educational areas. Innumerable performances in these studies show that the acquisition of simulators is useful and necessary to investigate their possibilities [8].

Simulation in ophthalmology is a novel process that has proven to be effective and promises to be part of the future of ophthalmologist training programs worldwide. It should always go hand in hand with personalized patient care, which is irreplaceable. Simulation is a cost-effective tool in the training of specialized doctors, which seeks, similarly to all else in a doctor's training, to be of the greatest possible benefit for the patient [67].

The development of ophthalmology training applications using AR and game technologies generates more confidence in students as they subsequently practice these skills on real patients. The evaluations showed that the applications analyzed in this systematic review were found to be easy to use and users indicated their confidence in using them again in the future [63,68].

Training on the analyzed Eyesi, Microvistouch, and PixEye simulators increased the self-efficacy of ophthalmology residents toward cataract surgery in real life. It is also concluded that motivation toward simulators was stable over time and was not influenced by the performance of each student. The relationship between the total amount of tasks the student had to pass, as an indicator of simulator performance, and higher perceived self-efficacy, was remarkable. All of the analyses developed in this systematic review can provide key information to further improve the cataract formation curriculum.

The use of AR and VR simulators by resident physicians in developing their professional practice is proven to be highly beneficial in improving learning in the development of cataract surgery [69].

The short-term future is somewhat uncertain, and we can identify pending challenges in the use of AR and VR in providing a complete experience in the surgical training process. New research should help extend medical technologies to their highest level and focus efforts on areas that need improvement.

It should be understood that in analyzing the use of these technologies related to VR and AR, the intention was not to advocate for a total replacement of conventional forms of teaching but, rather, to demonstrate that they are an important reinforcement and accompaniment for improvement of those limitations that occur in traditional forms. Future studies should be much more ambitious in seeking new horizons [70].

The use of a surgical simulator as an essential tool in the process of evaluating surgical skills and concepts along with assisted training in the operating room can greatly expedite the teaching of ophthalmic surgery. Ideally, the use of a simulator should be part of a specific curriculum that assesses the knowledge and skill of the user and is tailored to the individual learner [6,71].

AR and VR are concepts that have the possibility of enhancing real life. There are several elements that need to be clearly observed, including usability, privacy, and security, and only the future will tell if the legal complications are those that slow down the interest in these innovative technologies. However, as the costs become simplified and the use of this technology increases, those of us who analyze this type of technology must expect an increase in the interest of users to use them and learn more about them [72].

AR and VR, as versatile technologies, have the potential to make profound transformations in how the education of health professionals is carried out. The different studies in this systematic review show that the use of VR and AR can improve knowledge and skills in short periods of time and with much greater efficiency than digital education, online or offline. These technologies have greater interactivity, and the results show that knowledge and skills are consolidated with higher quality to generate greater confidence before an intervention [73].

Although Google Glass and HoloLens have enormous advantages and show enormous potential and impact in the surgical field, healthcare providers are unsure as to which tasks might benefit the most from their intervention. Future studies might focus on defining the limitations associated with their use and to what extent they can be used to support patients [32].

The introduction of lower cost VR and AR technologies (e.g., Oculus Rift, Samsung Gear VR, Google Cardboard) makes VR and AR an increasingly interesting and popular option for use in learning and entertainment. However, unsupervised use of these entertainment technologies has been creating difficulties and concerns along with their introduction in recent years. Although these interesting discoveries should be updated in additional studies on this topic, the implications in the use of these technologies show that VR and AR are technologies that, when unsupervised and based on entertainment, may not be appropriate for all children. It is a latent concern, and regarding the fusion of these technologies with gaming technologies, the concerns include promotion of a sedentary lifestyle, cyberaddiction, violence, social isolation, and desensitization in addition to safety issues [74].

In the education of future specialists in the field of ophthalmology, VR and AR could one day play an integral role in training new surgical skills. These technologies have the potential to provide solid expertise in developing new surgical skills while reducing operating room costs and minimizing risks to patients.

A very important point to consider is that when new procedures are introduced, it takes time for doctors to feel confident enough to teach these techniques to residents, which creates a delay in the transfer of knowledge. The use of the technology seen in this work can shorten the procedures for updating new surgical techniques.

A future research direction might be to conduct further studies with longitudinal educational interventions with AR or VR tools when training ophthalmologists to analyze the real impact and affordances of these technologies in this field. Another avenue of research in this field is to identify the effect of these technologies on the students' cognitive load during training. Moreover, further research can be conducted on the development of smart learning environments with immersive and games technologies for training ophthalmologists. Since the topic is still under development and adoption of these technologies is in its early stages, there are still many open issues that deserve further research.

Finally, due to the lack of articles related to training in diagnostic imaging in ophthalmology, another possible future work would be related to the creation of a training course that, making use of Augmented Reality, Virtual Reality and game technology, reinforces this competence in students.

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