

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1. Introduction

Games and simulations have already gained significant popularity in traditional education due to the rapid advancement of technology. They are extensively utilized in the field of education, and there exists a substantial body of research exploring the intersection of games and education (Siu Yin Cheung, 2021). In recent years, digital and web-based games, particularly simulation games, have emerged as increasingly popular tools for facilitating learning. This has attracted the attention of the scientific and educational community, including educators, learners, and game developers, particularly in the realm of online education. Educational policymakers and authorities are interested in incorporating innovative technological tools as technology continues to advance.

Simulations and microworlds provide a context for exploring vast amounts of data. They allow for the portrayal of different aspects of environmental scenarios to foster a comprehensive understanding. Games and gameplay also offer rich information by presenting contextual events. Simulated software enhances functional comprehension by establishing a structured existence and linking actions to outcomes

(Kaplan, 2022). These types of technologies promote systems intelligence by encouraging individuals to consider the structural components involved.



The research aims to evaluate the effectiveness of these patient simulation games in improving student diagnostic abilities (Garcia et al., 2021). Through a pretest-post-test design, the study will assess the impact of the simulation games on students' proficiency in diagnosing various eye conditions, using the appropriate medical terms to describe each condition accurately. Immediate feedback and assessment mechanisms within the games will enable students to monitor their progress and receive guidance, promoting self-directed learning (Lee, 2023).

## **2.2 Games and simulations conceptualization**

### **2.2.1 Serious Game**

Plenty of well scientific research on the influence of serious games on learning outcomes have been found in the recent literature review. Serious games are those created by the game industry that have a significant link to knowledge learning (Richard L. Lamb, 2018). Serious games, on the other hand, are those whose primary goal is not amusement, enjoyment, or joy. Serious games, instructional gaming, and virtual worlds created for educational reasons demonstrate the power of advanced technologies to engage and drive people in ways which go beyond recreational pursuits (Richard L. Lamb, 2018). Simultaneously, there is indeed a substantial body of research investigating the possible learning advantages of game-based learning (GBL), which is classified as the use of game-based technology to engage, assist, and enhance education, teaching, grading, and evaluation (Serrano, 2019).

Simulations are widely recognized as a significant subset of serious games, offering immersive and interactive learning environments where learners can actively engage with realistic scenarios (Bainbridge, 2014). These virtual experiences bridge the gap between theory and practice, allowing learners to apply their knowledge and skills within simulated real-world contexts (Reiners & Wood, 2019). Simulations replicate complex situations that are challenging to recreate in traditional educational settings, offering learners valuable insights and practical skills through experiential learning (Gredler, 2016). By incorporating problem-solving, decision-making, and critical

thinking, simulations foster engagement and motivation, leading to enhanced learning outcomes (Prensky, 2013). They also provide opportunities for safe experimentation and repeated practice, enabling learners to learn from their mistakes and receive immediate feedback (Aldrich, 2019). With technological advancements, simulations continue to evolve, delivering increasingly sophisticated and realistic learning experiences across various fields, including healthcare, business, and engineering (de Freitas & Oliver, 2015).

### **2.2.2 Simulations**

Simulation games encompass computer-based games that provide users with highly realistic simulations of various real-world activities, such as sports, commerce, and everyday life (Peterson, 2021). These simulations foster critical reasoning and problem-solving skills, actively engaging learners in the process of skill development (Olga Chernikova, 2020). Learners can work through realistic scenarios individually or in groups, promoting teamwork and knowledge exchange (Janice Super, 2020).

The advent of gaming technologies has facilitated increased opportunities for collaborative and participatory interactions with technological applications, leading to enhanced access to information, shared ideas, knowledge transfer, and content creation (Ricardo Torres Kompen, 2019). In higher education, digital simulations are utilized to engage students in interactive, realistic, and self-directed knowledge acquisition. Many academic institutions consider digital games as catalysts for providing improved and more effective education (Awais K. Jumani, 2018). The use of digital games for

productive learning methods has long been advocated. Game-Based Learning (GBL), which encompasses both computer and non-computer games, distinguishes itself from game-based e-learning. The selection of delivery systems, such as computer, online, mobile, 3D, or 2D, is crucial when creating and delivering games and simulations. Developers must consider technological challenges, modules, procedures, gameplay, and educational approaches (e.g., single-player, multiplayer, online, synchronous, etc.).

This research explores the diverse curriculum areas and learning objectives that each game aims to address. The categorization of games and simulations is presented in Table 2.1, illustrating the fundamental distinction between games and simulations. Simulations employ computer technology to create a three-dimensional world or scenario that can be interacted with in either a completely fabricated or physical manner. In contrast, games are artificial and educational tools that incorporate elements of conflict, rules, and predefined goals (Khan R, 2018).

**Table 2. 1 : Distinction between games and simulations**

Description	Games	Simulations
Game Type	Description of gameplay, such as taking a role, strategic decision-making, and coordination	Puzzle, adventure, strategy, logical, action, role playing business, serious
Game platform	Depends on mode of delivery	Computer, video, digital, mobile, networked, online, web-based, console, game based
Game technical characteristics	Strategies, approaches, concepts, techniques, modes	Single-multiplayer, linear-non-linear, collaborative competitive, online, synchronous, immersive
Game learning content	Subject discipline	Science (physics, biology, chemistry, engineering), business, languages, maths
Game purposes	Learning goals	Acquisition of knowledge, comprehension of material, motivation, engagement, and skill acquisition

### 2.3 Simulation in Medical School

Simulation serves as a potent tool for training medical skills, enabling learners to practice procedural techniques on manikins, part-task trainers, and even standardized patients (i.e., individuals posing as patients). However, manikins and part-task trainers have limitations when it comes to realism. Displaying dynamic changes in physical cues and symptoms, such as alterations in skin tone, often necessitates interrupting the simulation to apply moulage or relying on verbal descriptions to convey the cues and symptoms. While standardized patients offer greater realism in symptom portrayal, they still require moulage and restrict learners from practicing certain medical interventions on live individuals. Consequently, trainees often lack sufficient exposure to realistic visual cues crucial for effective assessment until they begin interacting with actual patients. Our training approach aims to specifically address this deficiency.

Although some advanced manikins offer enhanced dynamism compared to traditional ones, they tend to be costly and inaccessible to a broad range of healthcare professionals who could benefit from simulation training. An emerging trend in simulation training is the utilization of augmented reality (AR) to create mixed reality (MR) training environments (Barrie et al., 2019; Zhu et al., 2014). AR and MR technologies enable interaction with the physical environment while superimposing digital content, without completely immersing learners in a virtual reality (VR) setting. By incorporating AR, the fidelity of simulation training can be significantly enhanced as it allows for the presentation of virtual patient overlays registered to physical training manikins.

The integration of AR into the training environment expands the scope of skills that can be addressed through manikin-based simulation training. The inclusion of photorealistic and dynamically evolving visual cues introduces a new level of fidelity that is essential for developing perceptual skills. By incorporating virtual patients, learners can practice the development of perceptual skills, such as recognizing visual cues associated with injuries and disease states, alongside procedural skills like wound management and establishing airway patency. Moreover, this type of training can also be utilized to enhance macro cognitive skills such as sensemaking (Sushereba, Militello, & Patterson, 2019).

#### **2.4 Existing Educational Algorithms**

This literature review provides a focused examination of three theses that explore the application of algorithmic techniques within simulation-based game design. Each thesis offers unique insights into how these techniques are utilized to teach computer algorithms, enhance multi-agent planning under uncertainty, and foster algorithmic thinking skills. The review delves into the algorithmic methodologies employed in each thesis and their implications for computer science education and problem-solving.

#### **2.4.1 Simulation-Based Game Design for Teaching Computer Algorithms**

Hodhod and Moffat's thesis centers on the development of a simulation-based game for instructing undergraduate students in computer algorithms. The game incorporates algorithmic techniques through a graphical interface that enables students to create, modify, and execute algorithms using drag-and-drop blocks. The thesis particularly focuses on algorithm design within the game and evaluates the effectiveness of this approach in teaching algorithmic concepts.

Hodhod and Moffat in 2020, the implementation of algorithmic techniques is prominently evident. One notable technique involves the utilization of drag-and-drop blocks, which serves as a means to simplify the intricate process of algorithm design. By employing this technique, the thesis advocates for a hands-on learning approach that allows students to intuitively construct algorithms, facilitating a deeper understanding of these complex concepts.

Furthermore, the thesis underscores the importance of algorithm visualization techniques within the game. These visualizations play a pivotal role in elucidating the inner workings of algorithms, thereby enhancing comprehension, particularly when dealing with abstract notions.

Additionally, Hodhod and Moffat (2020) delve into the realm of usability and effectiveness metrics. This entails employing algorithmic methodologies to rigorously assess the game's usability and its effectiveness as an educational tool. Such metrics provide valuable insights into the algorithmic intricacies of game design and its overall impact on the learning experience.

## **2.4.2 A Simulation-Based Game-Theoretic Approach for Multi-Agent Planning Under Uncertainty**

Lo and Doshi's thesis introduce a novel framework that merges simulation-based search and game-theoretic reasoning to tackle multi-agent planning challenges amid uncertainty. Algorithmic techniques underpin this framework, which utilizes Monte Carlo tree search to generate agent plans and applies Nash equilibrium concepts to select optimal plans.

Algorithmic techniques are at the forefront of their innovative framework for multi-agent planning under uncertainty. A central algorithmic methodology employed in this thesis is Monte Carlo Tree Search (MCTS). MCTS serves as a foundational technique, playing a pivotal role in generating agent plans. It achieves this by simulating various potential actions for the agents and subsequently determining the most favorable course of action, an indispensable component in the realm of multi-agent planning.

Another noteworthy algorithmic technique featured in this thesis is the application of Nash equilibrium, a fundamental concept in game theory. Nash equilibrium is harnessed to select optimal plans for the agents, ensuring that they make rational decisions even in situations characterized by uncertainty. This strategic application of game theory enhances the robustness of the proposed framework, elevating its effectiveness in real-world scenarios.

Moreover, Lo and Doshi (2019) provide concrete evidence of the adaptability and practicality of these algorithmic techniques by showcasing their implementation in domains such as robot soccer and pursuit-evasion games. This real-world application underscores the versatility and efficacy of these algorithms, demonstrating their

relevance beyond theoretical constructs and confirming their utility in solving complex problems within robotics and strategy games.

### **2.4.3 Simulation Games for Learning Algorithmic Thinking**

Timm and Pinkwart's thesis explores the use of simulation games as a tool for fostering algorithmic thinking skills. The authors present a design model that incorporates algorithmic techniques to create simulation games conducive to algorithmic thinking.

One notable facet of their work is the introduction of a comprehensive design model tailored to foster algorithmic thinking within simulation games. This model, as elucidated in the thesis, strategically incorporates algorithmic techniques to stimulate algorithmic problem-solving skills among players. Rather than solely focusing on in-game content, this approach underscores the structural aspects of these games, with the intention of cultivating a deeper understanding of algorithms and their application.

Furthermore, Timm and Pinkwart (2018) provide a concrete illustration of an algorithmic technique within their thesis through a compelling case study involving the simulation of ant behavior. This case study serves as a tangible example of how algorithms govern the actions and interactions of virtual ants within the game. It effectively highlights the instrumental role of algorithms in facilitating problem-solving scenarios within the game environment, thereby emphasizing their significance in enhancing algorithmic thinking skills.

In summary, the paper contributes to the growing body of literature by exemplifying how algorithmic techniques can be thoughtfully integrated into

simulation-based games for the explicit purpose of nurturing algorithmic thinking skills. This approach, as demonstrated through the design model and case study, sheds light on the transformative potential of algorithmic methodologies in computer science education, particularly within the context of educational games.

## **2.5 Security in game development**

In the realm of patient simulation games, security is paramount to safeguard the integrity and confidentiality of patient data, as well as to ensure the authenticity of the training experience (Smith, 2022). Patient simulation games, which are widely used for medical training purposes, create a controlled environment to enhance clinical skills and decision-making abilities among healthcare students.

One critical aspect of ensuring security in patient simulation games is the design of the game architecture. The game architecture determines how various game components interact with external systems, and in the context of patient simulation, it plays a crucial role in securely storing and transmitting sensitive patient data. To achieve this, robust security measures such as encryption, secure authentication, and data validation must be integrated into the architecture to maintain patient data's confidentiality and integrity (Jones, 2019).

Moreover, preventing cheating is a significant challenge in game security for patient simulations. Cheating in these games can compromise the educational value and accuracy of the training experience. Implementing cheating detection and prevention measures is vital to ensure fairness and effectiveness. This involves identifying and

addressing any attempts to manipulate patient data or exploit vulnerabilities within the game system (Brown, 2021).

Balancing security and performance is another substantial concern in patient simulation games. While stringent security measures are necessary to protect patient data, they should not hinder the game's performance and usability. Achieving this balance is crucial to provide users with a seamless and engaging training experience. Optimizing game design and implementation can help maintain efficient security measures without compromising overall simulation performance (Smith, 2022).

In summary, security is of utmost importance in patient simulation games used for medical training. Proper security measures, integrated into the game architecture, are essential to protect patient data, maintain authenticity, and prevent cheating. Addressing these security concerns ensures that patient simulation games provide a secure and effective platform for medical education.

## **2.4 Research method**

### **2.4.1 Selection of research**

The original approach of literature review was to create a pre-determined review methodology to address the research problem, with the goal of reducing potential biases.

The literature review took place between 2017 and 2023, and it followed the steps outlined below. Keywords in referenced electronic databases such as Google Scholar,

iSeek, Google Books, Microsoft Academic, WorldWideScience, Refseek, ResearchGate, BASE, Infotopia, Science Direct, and PubMed Central are used to identify the reviewed publications. The learning outcomes keywords are a combining of the term's games or simulations and higher education, using the Boolean operator "AND."

Learning aims, learning goals, learning objectives, and impacts are other terms for learning achievement. Computer-based, web-based, digital, virtual, online, and technology are all terms used to describe platform and delivery techniques. Educational games, corporate simulations, role-playing simulations, game-based learning, video games, and serious games are all terms used to describe games and simulations.

Furthermore, all of these phrases are combined using the Boolean operator "OR." To avoid limiting the scope of relevant publications, the study uses the largest possible collection of keywords. For data selection, we also conducted a complete database search in bibliographic indices. The search covers a wide range of scientific topics, including education, cognitive science, information technology, management, and other scientific domains including medicine, engineering, and health.

**Table 2. 2 Research Database**

<b>Database</b>	<b>Paper Count – Initial</b>	<b>Paper Count - Inclusion</b>
Google Scholar	205	4
iSeek	9	0
Google Books	23	1
Microsoft Academic	9	1
WorldWideScience	12	0
Refseek	3	0
ResearchGate	25	3
BASE	2	0
Infotopia	9	0
Science Direct	30	1
PubMed	50	1
Springer Link	210	5
IEEE	9	2
ACM	14	0

#### 2.4.2 Extraction and assessment

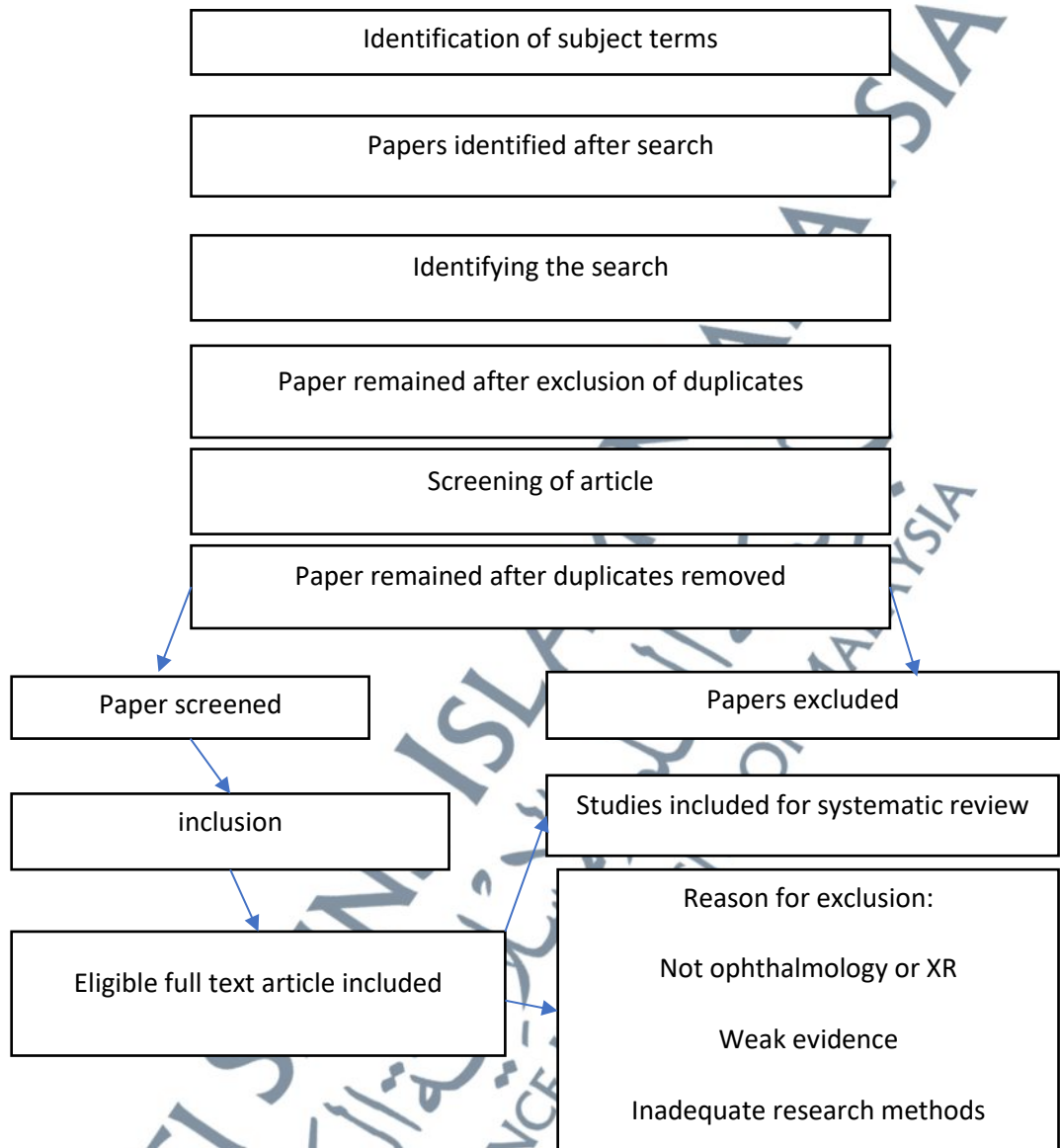
The dataset consists of journal articles referring to games, simulations or learning in their title and abstract. The literature review being piloted and evaluated by selection criteria based on prior studies. The study selection process was conducted in two separate phases which working independently, initially, and subsequently, together, screened the titles and abstracts for inclusion criteria. In the event of disagreement or insufficient information, the research being carried out a thorough consideration of the body of the (i.e. methodology and results), again independently, first, and, then, together, resulting in consensus. Then, whether to include the text or not was discussed, based on pre-determined criteria.

Using these parameters, an initial dataset was created with 290 research published between 2017 and 2023. The chosen papers are from 39 academic publications covering a wide range of subjects. The majority of publications come from the scholarly journal "Computers & Education," with "Journal of Educational Technology" and "Simulation & Gaming" following closely behind. Several discussions amongst researchers were held in the last phase to review the findings and decide on a presenting strategy.

**Table 2. 3 The inclusion and exclusion criteria**

Criteria	Inclusion	Exclusion
Study Design	Empirical research study (experimental, evaluation studies, qualitative studies, quantitative study, systematic review, methodology research)	Non-empirical study (reports, reviews)
Participants	Aged over 18 including students, lecturers, instructors	Ages younger than 18
Game intervention	Game for knowledge, skills, motivation Game for education purposes	Non-game – based learning tools and technologies Game for entertainment purposes
Type of selected research paper	Journal articles Conference paper	Report Reviews
Written language	English	All other languages

From 2017 forward, the number of published articles discussing games has steadily increased. A final selection of 290 suitable full - text emerged after a thorough analysis of their abstracts. Two hundred and sixty-two of the 290 were eliminated, mostly because of a poor focus (e.g. theoretical scenarios for using simulations in education). We discovered and documented several fundamental themes in each of the remaining 39 studies, such as types of learning outcomes, the influence or impact of game and simulation methods on learning goals, participants and settings, research questions, study methodology, and findings. The study includes 25 publications that are determined to offer data, while the other 14 articles are eliminated because they are written in a language that the researchers do not understand or because they are focused on an area other than higher learning. The bulk of these research are meta-analyses and/or systematic reviews, which are published in scholarly journals or conference proceedings. The following diagram depicts a summary of the full review (Figure 2.1).



**Figure 2. 1 Research Review Scheme**

### 2.4.3 Data analysis and synthesis

The found articles are analysed using a qualitative content analysis approach, which results in a classification system with a major category, three sub-categories, and numerous linked themes. The coding that came from the study of the examined papers was universally agreed upon. A small random sample ( $n = 20$ ) of the selected articles is coded in duplicate to guarantee inter-rater reliability ( $p$ ) in terms of the quality of article coding methods. The computed dependability is greater than 93 percent, indicating a high level of consistency across coding categories. Furthermore, due to a mixture of quantitative and qualitative features in terms of methodological triangulation, a review of mixed-methodology research gives high-quality data.

We investigated at the research from various angles. To begin, we examined at the data set's features, such as the continent where the studies were done, the academic discipline, the methodological study design, the sorts of games and simulations identified, and the time period when the majority of the literature were conducted. The focus is on the quantitative technique (experimental, quasi-experimental, pre-test, post-test surveys, etc.) as well as the qualitative methods employed in the evaluated surveys in terms of analysis, measurements, and design.

To summarise, the review studies are chosen via a systematic method based on pre-determined criteria. There is no deliberate bias in the studies chosen, and the fact that the bulk of them are from Europe is merely a by-product of the lot of consideration.

## **2.5 Results**

Ten databases were identified for searching relevant papers to support this research. The query previously identified was applied to each database, and a preliminary query was tested for each database to confirm the unique interpretation of Boolean logic. Based on the test results, the query syntax was occasionally modified to ensure consistent outcomes. The citations from the result set of each query were saved using the respective database's archiving feature. The search in each database focused on Title, Abstract, and Author keywords as specified by the individual database.

To determine whether each paper met the inclusion criteria, the title, abstract, and, if necessary, the full paper was reviewed. In phase two, each paper was thoroughly read to ensure compliance with all inclusion criteria, resulting in the final set of results presented. It is worth noting that some papers that did not meet the inclusion criteria are referenced in this paper to provide insights into the landscape of healthcare education utilizing High Fidelity simulators and standardized patients.

### **2.5.1 Selection paper**

Out of the initial set of 39 papers obtained in phase one, a wide range of healthcare disciplines were represented, encompassing various areas within the healthcare field. Nevertheless, as depicted in table 2.4, the majority of these papers were primarily centered around ophthalmology education.

Table 2. 4 Selection Paper

Health care discipline	Amount
Child rehabilitation	1
Physiotherapy	1
Ophthalmology	20
Emergency medicine	1
Disaster medicine	1
Surgical	10
Psychiatry	1
Paramedic	0
Pharmacy	0
Nursing	2
Haemodialysis	1
Science Technology	2
Others	1
Not applicable	0

### 2.5.2 Selection paper

In each review phase, the authors determined the specific healthcare discipline that each paper and associated research focused on. As shown in Table 2.5, the largest proportion of studies in phase 1 (60%) centred around Ophthalmology Education, followed by Surgical studies at 25%. The remaining disciplines were represented by only one or two papers, resulting in Ophthalmology and Surgical studies accounting for nearly half of the phase 1 papers. The final selection for this systematic literature review consisted of fifteen papers, which are listed below.

**Table 2. 5 Final Selection Paper**

Paper Title	Year published	Discipline	Author
Critical evaluation of the usability of augmented reality ophthalmoscopy for the training of inexperienced examiners	2014	Ophthalmology	Leitritz MA, Ziemssen F, Suesskind D, Partsch M, Voykov B, Bartz-Schmidt KU, et al.
Teaching binocular indirect ophthalmoscopy to novice residents using an augmented reality simulator	2017	Ophthalmology	Rai AS, Rai AS, Mavrikakis E, Lam WC

Construct and face validity of the eyesi indirect ophthalmoscope simulator	2017	Ophthalmology	Chou J, Kosowsky T, Payal AR, Gonzalez Gonzalez LA, Daly MK
Virtual reality-based proficiency test in direct ophthalmoscopy	2018	Ophthalmology	Borgersen NJ, Skou Thomsen AS, Konge L, Sørensen TL, Subhi Y
An experimental training support framework for eye fundus examination skill development	2017	Ophthalmology	Nguyen M, Quevedo-Urbe A, Kapralos B, Jenkin M, Kanev K, Jaimes N
A 3D virtual reality ophthalmoscopy trainer	2017	Ophthalmology	Wilson AS, O'Connor J, Taylor L, Carruthers D
Towards a haptically enabled optometry training simulator	2014	Ophthalmology	Wei L, Najdovski Z, Nahavandi S, Weisinger H
High-performance virtual reality volume rendering of original optical coherence tomography point-cloud data enhanced with real-time ray casting	2018	Ophthalmology	Maloca PM, de Carvalho JER, Heeren T, Hasler PW, Mushtaq F, Mon-Williams M, et al

Augmented reality fundus biomicroscopy: a working clinical prototype	2001	Ophthalmology	Berger JW, Madjarov B
Objective assessment of activity limitation in glaucoma with smartphone virtual reality goggles: a pilot study	2018	Science Technology	Goh RLZ, Kong YXG, McAlinden C, Liu J, Crowston JG, Skalicky SE
Simulator/On-road Study Group. Agreement of driving simulator and on-road driving performance in patients with binocular visual field loss	2018	Ophthalmology	Ungewiss J, Kübler T, Sippel K, Aehling K, Heister M, Rosenstiel W
Seeing other perspectives: evaluating the use of virtual and augmented reality to simulate visual impairments	2020	Surgical	Jones PR, Somoskeöy T, Chow-Wing-Bom H, Crabb DP
Impact of peripheral field loss on the execution of natural actions: a study with glaucomatous patients and normally sighted people	2016	Ophthalmology	Dive S, Rouland JF, Lenoble Q, Szaffarczyk S, McKendrick AM, Boucart M.

Effect of glaucoma on eye movement patterns and laboratory-based hazard detection ability	2017	Ophthalmology	Lee SS, Black AA, Wood JM.
Three-dimensional digital visualization of phacoemulsification and intraocular lens implantation	2019	Ophthalmology	Qian Z, Wang H, Fan H, Lin D, Li W.

## 2.6 Ophthalmoscopy Simulators

Six studies examined the effectiveness of extended reality as an educational tool for ophthalmoscopy. The simulators used in these studies included the EyeSi Augmented Reality Direct (n=1) and Binocular Indirect (n=3) ophthalmoscopy simulators. Additionally, two novel self-made simulators were utilized, namely the HTC Vive Virtual Reality-Head-Mounted Display (n=1) and the RITECH II Virtual Reality-Head-Mounted Display (n=1).

The efficacy of the EyeSi Binocular Indirect Ophthalmoscopy simulator was evaluated in two randomized trials. Both studies revealed that participants who received training with the EyeSi simulator outperformed those who underwent traditional training methods.

Validity assessments were conducted in three studies to evaluate the EyeSi Binocular Indirect Ophthalmoscopy simulator (n=2) and the EyeSi Binocular Direct Ophthalmoscopy simulator (n=1) for training and assessment purposes. These studies

demonstrated the existence of relationships with other variables as a form of validity evidence and indicated that participants with more experience achieved significantly higher scores in ophthalmoscopy evaluations. Content validity was addressed in all studies, while only one study assessed the internal structure by evaluating the internal consistency between simulator modules. Additionally, one study examined the consequences by determining pass or fail scores.

Two user perception studies investigated the opinions of medical students regarding self-assembled virtual reality direct ophthalmoscopy simulators. The results indicated that these simulators were perceived as usable and beneficial for improving ophthalmoscopy skills.

## **2.7 Optometry Training Simulators**

Two research studies examined the initial user experience of an augmented reality optometry simulator that consisted of a head-mounted display, a slit-lamp instrument, and a simulated eye. This simulator enabled the simulation of various optometry training tasks. The studies involved undergraduate optometry students and indicated that the simulator successfully simulated the task of foreign body removal for training purposes. Furthermore, the user studies reported a high level of satisfaction among the participants regarding the simulator's feasibility and effectiveness.

## **2.8 Diagnostics**

### **2.8.1 Overview**

A total of five studies examined the application of extended reality in the creation of immersive and interactive content for diagnostic purposes. Among these, two studies specifically assessed the utilization of extended reality in displaying ocular imaging data, while the remaining three studies focused on investigating the validity of extended reality as a simulation tool for assessing the functionality of patients with ophthalmic diseases.

### **2.8.2 Ocular Imaging**

The presentation of ocular imaging modalities in virtual reality (VR) and augmented reality (AR) environments was assessed in two separate case series. Maloca et al conducted a study to evaluate the feasibility of displaying optical coherence tomography (OCT) images using a virtual reality-head-mounted display (VR-HMD). The study involved 57 participants, and a user perception survey revealed that the VR display of OCT images was well tolerated with minimal side-effects.

In another case series, Berger et al demonstrated a method for directly overlaying photographic and angiographic fundus images onto a real-time slit lamp fundus view. This technique was tested on five participants, and the study confirmed the feasibility of this approach.

## 2.9 Simulators for Functional Assessment

Three research studies examined the application of extended reality simulators for assessing the functional abilities of patients with ophthalmic diseases. In one study, Goh et al conducted a trial using the Virtual Reality Glaucoma Visual Function Test, which utilized a smartphone paired with the Google Cardboard head-mounted display. The study focused on assessing the visual function of glaucoma patients. The results indicated that the scores obtained from stationary test individuals demonstrated criterion and convergent validity, establishing a relationship with other variables.

Another study conducted by Ungewiss et al compared the assessment of driving performance between a driving simulator and a real vehicle among patients with glaucoma (n=10), hemianopia (n=10), and healthy controls (n=20). The findings revealed that patients with hemianopia and glaucoma exhibited poorer driving performance compared to the healthy controls in the driving simulator, thereby providing validity evidence through a relationship with other variables.

In a separate study by Jones et al, the use of a head-mounted display was evaluated to simulate visual impairment in glaucoma using both virtual reality and augmented reality. The study successfully replicated and objectively measured functional impairments associated with visual impairments. Notably, when simulating inferior visual field loss, significantly greater impairments were observed compared to simulating superior visual field loss, aligning with the experiences of real patients with glaucoma.

## 2.10 Summary

Although a wide range of ophthalmic applications of extended reality have been examined, our focus primarily centers around education, diagnostics, and therapeutics. In the field of education, simulators have proven effective and valid in enhancing ophthalmoscopy skills. In the realm of diagnostics, extended reality devices have showcased potential in displaying ocular imaging data and assessing the functionality of individuals with glaucoma. When it comes to therapeutics, heads-up surgical systems have emerged as safe and efficient alternatives to conventional microscope surgery.

Research has demonstrated that practicing complex motor tasks through multiple short training sessions, spaced over time and involving variable tasks, yields the most effective results. Simulation-based training facilitates this approach, and numerous efficacy studies have indicated that extended reality ophthalmoscopy simulators can enhance diagnostic performance for specific procedures. Simulation training appears particularly beneficial for less experienced doctors, reducing complications, and also for experienced practitioners who have had a hiatus in performing procedures.

Studies assessing ophthalmoscopy simulators have revealed improvements in both direct and indirect ophthalmoscopy skills. However, compared to surgical simulators, ophthalmoscopy simulators have not been widely adopted in ophthalmic training curricula. One possible explanation lies in the nature of the simulated task. Inexperienced novices performing surgery pose a greater risk to patients, whereas ophthalmoscopy is relatively low-risk in terms of patient discomfort and time.

Therefore, the demand for surgical simulators with proven efficacy and validity may be more critical than that for ophthalmoscopy simulators.

In the field of diagnostics, the visualization of ocular imaging data, such as optical coherence tomography, fundus photography, and angiography, in virtual reality and augmented reality environments can provide insights into intraocular spatial relationships and facilitate interactive exploration of imaging data for educational, disease understanding, clinical assessment, and therapeutic purposes. While these studies have shown proof-of-concept, further research is required to evaluate their efficacy and accuracy for clinical use. Extended reality applications have also demonstrated validity evidence and feasibility in objectively assessing functional limitations and driving performance in patients with glaucoma and hemianopia. However, the scope of their application is currently limited due to the limited number of studies and sources of validity evidence. It is worth noting that extended reality simulations may not fully account for nonvisual cues, such as sound and touch, that individuals with ophthalmic diseases rely on in their daily functioning.

The cost of extended reality technologies remains a significant concern for potential users. A study conducted in 2013 estimated that the EyeSi surgical simulator could save an average US ophthalmic residency program \$4,980 per year in nonsupply costs based on time saved in the operating room, taking approximately 34 years to recoup the simulator's cost. Another study from 2013 found that the nonsupply cost savings from EyeSi usage were higher in larger residency programs but still insufficient to recoup costs within 10 years. However, these cost analyses do not compare extended reality simulators with conventional methods of ophthalmic surgical training. Extended

reality surgical simulators have the advantage of simulating surgical scenarios that are otherwise impossible to replicate in a wet lab, such as specific types of cataracts or challenging anatomical conditions. These intangible cost savings in terms of additional supervision, staff resources, and scheduling could have implications for ophthalmic surgical education. Further comparative studies that provide these comparisons would contribute to defining the role of extended reality simulators in surgical training from a cost perspective.

Extended reality shows promise in various applications by surpassing the limitations of the unalterable physical environment. In the field of ophthalmic surgical education, extended reality surgical simulators have demonstrated efficacy and validity in improving surgical performance. However, before these simulators can be considered competitive alternatives to traditional ophthalmic surgical training, two main barriers need to be addressed: cost and the need for high-quality comparative studies. Until these issues are resolved, surgical simulators will likely play a supporting role in surgical training programs, despite their versatility and ability to provide quantitative feedback. In the realm of therapy, extended reality heads-up surgical systems have gained popularity in ophthalmic surgery, as literature suggests that these systems offer effective and safe visualization during procedures. On the other hand, diagnostic and therapeutic applications beyond heads-up surgery mostly demonstrate proof-of-concept without robust comparative evidence. Encouraging additional comparative studies with rigorous designs to obtain a high level of evidence would help explore the efficacy of extended reality in these various ophthalmic applications. As extended reality is still an emerging

technology, we anticipate its continued demonstration of value and provision of novel alternatives in ophthalmic education, diagnostics, and therapy.

