10-9-2023

Design and Development of Virtual Patients for Healthcare Education: State of the Art and Research

Carolin Gellner
FernUniversität in Hagen, Germany, carolin.gellner@fernuni-hagen.de

Anne-Katrin Witte
FernUniversität in Hagen, Germany, anne-katrin.witte@fernuni-hagen.de

Till J. Winkler
FernUniversität in Hagen, Germany; Copenhagen Business School, Denmark, till.winkler@fernuni-hagen.de

Design and Development of Virtual Patients for Healthcare Education: State of the Art and Research

Research Paper

Carolin Gellner[1], Anne-Katrin Witte[1], and Till J. Winkler[1,2]

[1] FernUniversität in Hagen, Chair of Information Management, Hagen, Germany
[2]Copenhagen Business School, Department of Digitalization, Frederiksberg, Denmark
carolin.gellner@fernuni-hagen.de, a.witte@tu-berlin.de, till.winkler@fernuni-hagen.de

Abstract. The digital transformation of healthcare and the COVID-19 pandemic have accelerated research and deployment of virtual patients (VP), that is, interactive computer simulations used in healthcare education to train students on clinical processes. To help researchers and practitioners understand the state of the art in VP development, we conducted a systematic literature review of 48 papers. Our analysis focused on educational level, medical specialty, competencies, technologies, technical format, and operating systems and tools. We found that VPs are primarily used in the medical field and student education as interactive patient scenarios based on multimedia system technology. VP authoring systems were identified as the primary tool for developing primary clinical reasoning skills. Based on our findings, we suggest implications for medical education research and practice.

Keywords: Virtual Patient, Literature Review, Simulation, Technology

1 Introduction

The aim of digital transformation in healthcare is to improve the health and well-being of patients by promoting quality of care and patient autonomy (Bratan et al. 2022). To meet the evolving needs of patients and society, modern healthcare systems require high-quality medical education and training. Traditional tools like lectures and books are no longer sufficient to address challenges such as medical errors and the rapidly expanding knowledge base. More efficient learning methods, such as case-based and patient-centered learning, are deemed necessary (Berman et al. 2016).

In recent years, virtual patients (VPs) have gained significant attention as a means to train the diagnostic skills of physicians and address the challenges in medical education (Ellaway and Davies 2011; Kononowicz et al. 2019). VPs are *"[...] interactive computer simulations of real-life clinical scenarios for health professions training, education, or assessment."* (Kononowicz et al. 2019). Since the onset of the COVID-19 pandemic, VP research has gained even more importance due to the temporary closure of universities to maintain social distancing, which has deprived medical students of access to clinical departments. This has highlighted the need for clinical training methods that do not require bedside didactic activities (Furlan et al. 2021).

Current research suggests that VPs can be at least as effective as traditional training in improving skills such as clinical reasoning and procedural knowledge (Kononowicz et al. 2019). Previous literature reviews have primarily focused on VPs evaluation results, for instance, the effectiveness in developing clinical skills (Kononowicz et al. 2019), or specific in clinical reasoning (Plackett et al. 2022) and communication (Kelly et al. 2022; Lee et al. 2020), or specific domains such as pharmacy (Gharib et al. 2023; Richardson et al. 2020) and psychology (Chaby et al. 2022). Authors have called for further exploring the development of VPs to support the medical curriculum and increase the use and impact of digital technology in medical education and training (Frangoudes et al. 2021; Martini and Datt 2022). However, to date, there is limited research that provides an overview of the state of the art in VP development. Having such an overview would be crucial for VP developers to learn how to effectively develop VPs as a simulation-based learning method for healthcare education. Accordingly, our research question is as follows: *What design and development technologies have been used in VP research and for what healthcare fields and educational areas?*

This literature review aims to provide an overview of the state of the art and the state of research on VP design and development, including technologies, healthcare fields, and educational areas in VP research. The study includes insights into educational level, medical field or coverage, learning outcomes competencies, technologies, technical format, and operating systems and tools for VP development. In addition, our review identified seven categories of operating systems and tools for VP development. Among these, we found that VPs are primarily developed as interactive patient scenarios for clinical reasoning training in medical student education based on web-based multimedia systems implemented using specific VP authoring systems.

To this end, the paper gives a brief background on VPs, and explains the methodological approach, followed by the results of the literature review and a discussion of the findings, and concludes with implications and a summary of the main points.

2 Background on Virtual Patients

The current literature describes VPs as flexible and easily accessible simulation-based learning technologies that provide a technology-enabled and multimedia opportunity to practice clinical, problem-solving, and decision-making skills in real-life situations without putting patients at risk (Sahu et al. 2019; Frangoudes et al. 2021). Such simulations support the pedagogical approaches of active, problem-based, situated, and gamified learning (Sahu et al. 2019). The simulations can be effectively integrated into the medical education process by coordinating with other learning activities and assessments, and by eliminating some lectures and textbook assignments to free up space in the course (Berman et al. 2016). Previous studies on VPs have been used for cases in internal medicine and critical care, but also for cases in psychiatric or psychosocial nature, radiology, dermatology, cardiology, and surgery (Kononowicz et al. 2019).

VPs used in different ways in healthcare education and training, which are shown and described in Table 1. According to Kononowicz et al. (2015), the VPs differ in terms of competencies (e.g., clinical reasoning, patient communication skills, procedural and basic clinical skills) and technologies (e.g., multimedia system, conversational character, virtual world), whereby the predominant class is the interactive patient scenario followed by high-fidelity software simulations, and virtual standardised patients. Less frequently used forms are VP games, case presentations, human standardized patients, and high fidelity manikins (Kononowicz et al. 2015).

Table 1. VP Classes, Competencies and Technologies according to Kononowicz et al. (2015)

VP Class	Competency	Technology	Description
Case Presentation	Knowledge	Multimedia System	Interactive multimedia case presentations of a patient for knowledge teaching.
Interactive Patient Scenario	Clinical Reasoning	Multimedia System	Interactive multimedia presentation of a patient case for mainly clinical reasoning skills training.
VP Game	Clinical Reasoning, Team Training	Virtual World	Virtual world to simulate high risk scenarios for clinical reasoning or team training.
High-Fidelity Software Simulation	Procedures or Basic skills	Dynamic Simulation or Mixed Reality	Real-time simulation of physiology for procedures or basic skills training (e.g. surgical). Can include mixed reality technologies.
Human Standardized Patient	Patient Communication	Multimedia System	Multimedia system with video-recorded patient actors for teaching patient communication skills.
High Fidelity Manikins	Procedural & Basic skills, Team training	Manikin & Part-Task Trainer	Anatomically realistic manikins for complex procedural and basic clinical skills or team training (e.g. endoscopy).
Virtual Standardised Patient	Patient Communication	Conversational Character	Virtual representation of a human using artificial intelligence and natural language processing technologies to train communication skills in form of conversational characters.

The creation of VPs can be performed manually using standard web and multimedia tools or with dedicated authoring systems that offer specific VP functionalities, such as CASUS, CAMPUS classic, and OpenLabyrinth (Huwendiek et al., 2009). Kononowicz et al. (2019) identified CASUS, Web-SP, Virtual People Factory, Laerdal vSim, and Laerdal MicroSim as the most often used VP systems as well as some other, but less rarely used, systems, such as DecisionSim/VpSim and CAMPUS Card. In addition, e-learning authoring tools (e.g. Articulate Storyline), learning management systems (e.g., Moodle) or game authoring tools were used sporadically, and sometimes no special systems were used at all (Kononowicz et al. 2019).

Huwendiek et al. (2009) proposed a taxonomy for developing VPs, consisting of four categories: general (e.g., title and description), educational (e.g., objectives and outcomes), instructional design (e.g., interactivity), and technical (e.g., format). As the categories *general* and *instructional design* would not have provided useful insights into the research question, because our study did not aim to gain insights into instructional design or information such as title or identifier of a VP, we focus on categories *educational* and *technical,* which are briefly explained in Table 2.

Table 2. Selected Factors of VP Taxonomy according to Huwendiek et al. (2009)

Category	Factor	Brief description
Educa-tional	Level	Target group (e.g. undergraduate students, graduated professionals)
	Coverage	Topic areas (esp. medical field, e.g. internal medicine)
	Objectives & Outcomes	Objectives / outcomes of the VP (e.g. clinical reasoning skills)
Tech-nical	Format	Technical format used for user end (e.g. web)
	Operation System	Tool or system used for VP creation (e.g. CASUS system)

3 Literature Review Method

The literature review uses a rather (qualitative) systematic approach according to Paré et al. (2015) and review characteristics according to taxonomy by Cooper (1988). Accordingly, the presented study review has a narrow focus on design and development practices and applications in VPs, and a comprehensive search strategy is employed to gather relevant data. The collected data is integrated using a narrative synthesis method into the concept matrix. The aim is to present a neutral and exhaustive coverage of the literature with selective citation. The results are presented conceptually, catering to both scholars and practitioners in the field of information and learning systems/healthcare education. Table 3 highlights in grey the review's key characteristics.

Table 3. Literature Review Characteristics according to Cooper (1988)

Characteristic	Categories			
Focus	Research Outcomes	Research Methods	Theories	Practices / Applications
Goal	Integration	Criticism		Central issues
Organisation	Historical	Conceptual		Methodological
Perspective	Neutral Representation		Espousal of Position	
Audience	Specialised Scholars	General Scholars	Practitioners/ Politicians	General Public
Coverage	Exhaustive	Exhaustive and Selective	Representative	Central/pivotal

The literature search and selection followed the guidelines by (Webster and Watson 2002). A preliminary search for the systematic search was conducted to identify suitable databases, search terms, inclusion criteria and time frame. The systematic search used the databases PubMed, IEEE Xplore, and ACM Digital Library to cover medical and technical fields with the search string ‘virtual patient’ in abstract or title. The search term was chosen in accordance with Kononowicz et al. (2015) and in order to keep the focus on the definition of virtual patients, as other terms (e.g. simulation or digital patient) led to many inappropriate results without focus on healthcare education. Accordingly, no synonyms were used as the term is widely used in research articles and provided sufficient hits (Kononowicz et al. 2019; Kononowicz et al. 2015). However, the AISeLibrary database was not included since it did not yield any suitable hits on the term for the chosen period. The search results were limited to academic journals and conference proceedings from January 2020 to January 2023 in order to capture the most important recent developments in the field of VPs, which is reflected in the large increase in the number of research articles for this period compared to previous years, as the preliminary search showed. In the process, the first author screened and analyzed the retrieved papers and regularly discussed the analysis with the other authors. We evaluated every paper against pre-determined inclusion criteria:

- *Type*: Peer-reviewed journal or conference paper
- *Access*: As full text available for the authors
- *Language*: Written in English
- *Context*: Research in healthcare education
- *Topic*: Research on VP according to the meanings of Kononowicz et al. (2015)
- *Data*: Contains information on educational level, coverage, competence or objective, technology, technical format and operating system according to the concept matrix

The synthesis was carried out using a concept matrix (Webster and Watson 2002), which is a combination of the VP technologies and competences according to (Kononowicz et al. 2015) and the selected *educational* (level, coverage, objective) and *technical* factors (format and operating system) according to (Huwendiek et al. 2009) described in the background section. The *objectives* were grouped into the VP *competencies* and *format* into the VP *technologies*. Figure 1 shows the concept matrix including an example. In the course of the synthesis, subgroups were formed for the results in the columns *level*, *coverage* and *operating system(s)*. These additional classifications are described in detail in the results section.

Reference		Educational							Technical								
				Objective / Competency					Format / Technology					Format (add.)			
Autor(s)	Year	Level	Coverage	Knowledge	Clinical Reasoning	Team Training	Procedural & Basic Skills	Patient Communication	Multimedia System	Virtual World	Dynamic Simulation or Mixed Realitiy	Manikin and part task trainer	Conversational Character	Web	Mobile	Desktop	Operating System(s)
Example et al.	2022	medical students	internal medicine		x			(x)	x					x			OpenLabyrith

Figure 1. Concept Matrix Template Incl. Example

4 Results

The initial search results (n=419) were refined by removing duplicates and non-English papers. The remaining 335 papers were screened for context (n=138) and VP topic (n=103) based on abstract and title. The remaining papers were checked for full text access (n=81), and screened for data (n=51). Three papers were supplementary excluded because they described VPs already included in the set. Ultimately, **48** eligible papers were identified through the search and selection process (see Figure 2).

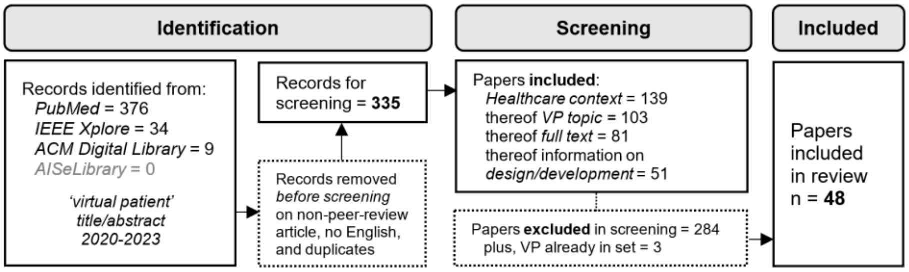

Figure 2. Search and Selection Process

Accordingly, these 48 papers were analyzed for synthesis, spanning from 2020 to January 2023. The distribution of publications by year was as follows: 18 papers in 2020, 11 papers in 2021, 18 papers in 2022, and one paper in January 2023. The papers were published across 34 journals or conference proceedings, primarily in medical and health-related fields. The top journals were BMC Medical Education, with five papers, followed by JMIR Medical Education, Journal of Medical Internet Research, and International Journal of Environmental Research and Public Health, with three papers each. The results of the synthesis and data aggregation of these papers are presented below.

4.1 Virtual Patient Application Areas in Healthcare Education

The concept matrix results were analyzed to answer the research question based on the healthcare education application areas, which represented the *coverage* and *educational level*. The classification into two educational levels, *education* and *training*, was derived from the target group described in the papers. The *education* level referred to basic education for students or trainees, while the *training* level referred to continuing education and training for healthcare professionals. The *coverage* areas were classified based on the medical specialties or diseases targeted by the VPs. Table 4 presents the results, which are described below.

Table 4. Frequency of VP Coverage and Educational Level

Coverage / Level	Medicine	Dentistry	Nursing	Mid-wifery	Phar-macy	Logope-dics	Total
Education	25	3	4	2	3	1	38
Training	11	1	1		1		14
Total	36	4	5	2	4	1	

The VPs described in the analyzed papers were focused on six *coverage* fields: medicine, dentistry, nursing, midwifery, pharmacy, and logopedics. Medicine accounted for the largest proportion of VPs at approximately 69% (n=36), while the other five fields were less represented with 1 to 5 VPs each.

Approximately 73% (n=38) of the VPs in the analysed papers targeted the *education level*, primarily in the field of medicine. The *training level* for healthcare professionals was the focus of 14 VP papers, with 11 belonging to the field of medicine.

4.2 Design and Development Technologies in Virtual Patients

We conducted a cross-analysis of the competencies and technologies synthesized in this work using the approach outlined in in Kononowicz et al. (2015) to replicate the VP classification based on more recent papers. During synthesis, we discovered that 14 VPs targeted multiple competencies, with only the predominant competency counted for the total, and additional secondary competencies integrated into the table as *(+x)*. Conversely, 34 VPs targeted only one competency. We also cross-analyzed the technologies based on the technical *format* and *operating system*, deriving tool groups after synthesis for operating system. Totals were not shown in the table for the respective technology, as several operating systems or formats were mentioned in some VPs. The results are presented in Table 5.

Table 5. Frequency of Design and Development Technologies in VPs

Technology	Multimedia System	Virtual World	Dynamic Simulation or Mixed Reality	Manikin and part task trainer	Conversational Character	*Total*
Competency	*28*	*3*	*10*	*0*	*6*	
Knowledge	**4** (+3) *Case Presentation*		1 (+3)			*5 (+6)*
Clinical Reasoning	**19** *Interactive Patient Scenario*	**2** *VP Game*	2 (+1)		1 (+1)	*25 (+2)*
Team Training			(+2)			*(+2)*
Procedural & Basis Skills	(+1)		**7** *High-Fidelity Software Simulation*			*7 (+1)*
Patient Communication	**5** (+4) *Human Standardised Patient*	1	(+1)		**5** (+1) *Virtual Standardised Patient*	*11 (+6)*
Format						
Web	**26**	3	4		3	*36*
Desktop	2	1	4		1	*8*
Mobile	2	1	2		3	*8*
Operating System						
VP	**16**		1		2	*19*
eLearning	**6**					*6*
AI	1				4	*5*
VR or Gaming		2	**10**		1	*13*
Programming	5					*5*
Graphics, Motion, Video	5	1				*6*
Communication			1		1	*2*

The majority of the analyzed VPs (25 out of 48) had *clinical reasoning* as their primary competence, e.g. McNamara et al. (2022), Furlan et al. (2021) and Kiesewetter et al. (2020), while it was a secondary competence in two other VPs. *Patient communication* was the second most common learning objective, appearing in 11 VPs, e.g. Campillos-Llanos et al. (2021) and Miles et al. (2021), and was an additional competence in six others. *Procedural & basis skills* was the primary competence in seven VPs and secondary in one. *Knowledge* was the primary objective in five VPs and a secondary objective in six others. *Team training* was not the primary competence in any VP, but as a secondary in two.

According to the technologies, the majority (n=28) were developed using a *multimedia system* technology, e.g. (Schnieders et al. 2022; Jacklin et al. 2021; Lucero et al. 2020), followed by *dynamic simulation or mixed reality* technology (n=10), e.g. Lem et al. (2022) and Lerner et al. (2020). *Conversational character* was used in six VPs, e.g. Co et al. (2022) and Suárez et al. (2022), while *virtual world* technology was employed in three VPs, e.g. Antoniou et al. (2020). The technology of *manikin and part task trainer* was not utilized.

Based on the cross-analysis of competence and technology, the *interactive patient scenario* VP class was the most represented with 19 VPs, e.g. (Fuoad et al. 2022; Mardani et al. 2020; Kikuchi et al. 2022). Seven VPs belonged to the *high-fidelity software simulation* class , e.g. (Lerner et al. 2020; Chua et al. 2022), five each to *human standardized patient*, e.g. (Rothlind et al. 2021), and *virtual standardized patient*, e.g. (Dupuy et al. 2021). In addition, four VPs corresponded to *case presentation*, two to *VP game* and none to *high-fidelity manikin*. No concrete VP class resulted for six VPs.

Most of the VPs (75%) were developed in web *format*, while approximately 17% (n=8) were implemented as either a desktop or mobile application. Some VPs were available in multiple formats. Therefore, the total number of formats for a technology does not correspond to the number of formats based on the competency in Table 5.

Finally, the results for *operating system* in the concept matrix were inductively classified into seven tool groups after synthesis including *VP authoring*, *E-Learning authoring*, *AI*, *VR or Gaming*, *Programming*, *Graphics*, *Motion*, *Video*, and *Communication*. Table 6 shows an overview of these groups including tools mentioned in the papers and which are described below in more detail.

The first group *VP authoring* covers free or commercial applications that exist specifically for the implementation of VPs or simulations in a medical educational context, and that provide functionality and templates for VP authors (Huwendiek et al. 2009). The tools were developed by universities or other educational institutions or by companies. According to Table 5, 19 VPs were implemented with such VP authoring systems in the papers analysed (e.g. (Iguacel et al. 2022; Rothlind et al. 2021; Kotwal et al. 2021; Rouleau et al. 2020; Rakofsky et al. 2020; Newsome et al. 2020)), with 12 different systems mentioned. The majority of the tools were used to develop a VP *multimedia system* such as e.g. the German CASUS and English MedicActiV, Interactive Case System (VIC), vpSim, and OpenLabyrinth. In addition, the Virtual People Factory 2.0 and the USC Standard Patient were used to develop *conversational character* and the tool Body Interact™ for *dynamic simulation or mixed reality*.

Table 6. Operating Systems and Tools for VP Design and Development

Group	Operating Systems and Tools
VP authoring	CASUS (INSTRUCT gGmbH 2022), MedicActiV (SimforHealth 2019), DecisionSim™ (Kynectiv Inc 2023), Virtual Interactive Case System (VIC) (University Health Network 2013), BSAsim (Stockholms Universitet 2019), Aquifer® (Aquifer Inc 2023), Medscape MedSims Patient Simulations (WebMD LLC 2023), SIMmersion™ (SIMmersion™ 2023), vpSim (University of Pittsburgh 2019), and OpenLabyrinth (University of Calgary 2022), Virtual People Factory 2.0 (University of Florida n.d.) and USC Standard Patient, Body Interact™ (Take The Wind 2023)
E-Learning authoring	Articulate Rise 360 and Articulate Storyline (Articulate Global LLC 2023a; Articulate Global LLC 2023b), iSpring Suite (iSpring Nordics Oy 2023), Moodle (Moodle Pty Ltd 2023), NAVID (Tehran University of Medical Sciences 2023)
AI	Dialogflow (Google Ireland Limited 2023), Natural Language Toolkit for Python (NLTK Project 2023)
VR or Gaming	Microsoft HoloLens VR platform, TweenityVR, Meta Quest 2 platform, HTC Vive platform and HTC Vive Pro headsets and controllers, Unity Games Technologies, Autodesk Maya, Adobe Mixamo, Body Interact™
Programming	HTML, CSS, JavaScript, Java, Python
Graphics, Motion, Video	Autodesk Maya, Adobe Creative Cloud (After Effects, Photoshop, Audition, Premiere Pro), Draw.io, Crazy Talk Animator, Camtasia Studio
Communication	Telegram Instant Messenger, Zoom

The second group *E-Learning authoring* covers authoring systems for the development of general e-learning applications, without a specific focus on VPs. As shown in Table 5, six VPs (Fuoad et al. 2022; Ganji et al. 2022; Kikuchi et al. 2022; McNamara et al. 2022; Schnieders et al. 2022; Mardani et al. 2020) were implemented with such e-learning authoring systems in the papers analysed, with a total of five different systems mentioned. All of the tools were used to develop *multimedia system* including the following tools such as e.g. Articulate Rise 360, and iSpring Suite, or learning management systems such as Moodle and NAVID.

The third group, *AI*, includes tools for developing conversational Artificial Intelligence (AI) solutions, for example in the form of conversational characters with natural language processing (NLP). According to Table 5, AI-tools were used rather less, with five VPs implemented (Co et al. 2022; Suárez et al. 2022; Campillos-Llanos et al. 2021; Miles et al. 2021; Furlan et al. 2021). Four of them were used to develop a VP *conversational character* technology and one for a *multimedia system*. The papers mentioned two tools, Dialogflow and the Natural Language Toolkit for Python.

The fourth group, *VR or Gaming*, includes operating systems and tools specifically for game and virtual reality development. These systems were mentioned in 13 VPs, most of which were for *dynamic simulations and mixed reality* using tools such as e.g. Microsoft HoloLens VR, Unity Games Technologies, and Adobe Mixamo.

The fifth group, *Programming*, covers the manual development of VPs using classical programming languages such as HTML or Java. According to Table 5, manual programming was used rather less, with five VPs implemented (Jacklin et al. 2021; Richardson et al. 2021; Setrakian et al. 2020; Thompson et al. 2020; Furlan et al. 2021), all of which were used to develop a VP *multimedia system* technology.

The sixth group, *Graphics, Motion, Video*, includes applications specifically for graphics, motion and video design. These applications were mentioned in six VPs (e.g.

(Thompson et al. 2020; Bahrami et al. 2021)), with most using for *multimedia systems*. Tools such as Adobe Creative Cloud, or Camtasia Studio were used.

The last group, *Communication*, includes tools for written or verbal communication such as instant messenger and videophone systems. According to Table 5, two VPs used communication tools (Suárez et al. 2022; Chua et al. 2022) where Telegram Instant Messenger and Zoom were named.

5 Discussion

To address the research question of the design and development technologies used in VP research and their application in healthcare fields and educational areas, this study conducted a literature review to identify the state of the art. Based on these findings, implications for practice and research are provided to promote the integration of more effective learning methods in healthcare education. Finally, the limitations of the study are discussed.

5.1 Design and Development in Virtual Patients

Between 2020 and January 2023, VPs were mainly developed and utilized for medical education of students and trainees, with less emphasis on training medical professionals. The scope of application was primarily focused on medicine, with sporadic use in other areas, such as nursing or pharmacy. This is consistent with Kononowicz et al. 's (2019) findings that VPs were mostly used in the field of medicine with undergraduate students. Our literature review indicates that VPs were primarily employed for training clinical reasoning skills, followed by patient communication and procedural and basic skills. VP research placed less emphasis on team training and medical knowledge acquisition. These findings are similar to Kononowicz et al.'s (2015) research, where most VPs were designed for clinical reasoning, with about half as many for patient communication and procedural and basic skills.

According to the literature review findings, VPs were primarily utilized in the development of multimedia systems technology. The second most common use was for dynamic simulations or mixed reality technologies, followed by conversational character technology as the third most frequent technology. The use of virtual world technology and VPs in the form of manikins were less prevalent. These results also follows the findings of Kononowicz et al. (2015), and also showed the Interactive Patient Scenario class as the most used, followed by High-Fidelity Software Simulation class as well as Human Standardised Patient and Virtual Standardised Patient, and Case Presentations and VP Game as least used according to Kononowicz et al. (2015).

Furthermore, VPs were predominantly developed and designed for web using VP authoring or simulation operating systems, with a focus on multimedia applications. The second most common operating systems used for VP development were those for virtual reality and gaming, primarily for dynamic simulations or mixed reality technologies. Some VP multimedia systems were created using e-learning authoring systems, graphics, motion, and video tools, and manual programming with classical programming languages. Artificially intelligent technology was utilized in the implementation of conversational characters. Communication tools were infrequently incorporated. The results go in the direction of the results by Kononowicz et al. (2019) and showed also a primary use of specific VP authoring systems, of which a few coincided with our research, but many of the systems mentioned did not appear in the papers in our research and other systems were mentioned at the same time.

In summary, the state of the art and research on design and development of VPs in healthcare education have remained largely unchanged for many years. VPs are still predominantly created as Interactive Patient Scenarios to train clinical reasoning skills, using VP authoring systems, e.g. such as CASUS, MedicActiV, DecisionSim or Virtual Interactive Case System (VIC) as web multimedia systems.

However, unlike Kononowicz et al. (2015) and Kononowicz et al. (2019), this paper offers a combination of both, providing a differentiated analysis of the tools, systems and technical formats used for each VP class, in order to show researchers and practitioners the state of the art of the tools that can be used for VP design and development, depending on the VP class and the targeted competencies. In addition, this study provides a grouped overview of the identified VP tools and systems, including those not mentioned in previous contributions.

5.2 Implications for Research and Practice

The study conducted supports Kononowicz et al.'s (2019) suggestion to increase the use and exploration of VPs (VPs) in healthcare professions beyond medicine. The study also indicates a lack of representation of VPs in areas such as nursing and pharmacy, and underutilization of VPs for continuing education and training of healthcare professionals. Therefore, it is recommended that researchers and practitioners focus on developing and studying VPs for these fields.

Traditionally, VPs have been created to train clinical reasoning. However, to enhance healthcare professionals' competencies, there is a need to focus on other areas such as patient communication, team training, and medical knowledge. Additionally, VPs are typically designed as simple multimedia applications, and thus, it is proposed that researchers and practitioners shift their focus to more interactive formats such as conversational agents or virtual worlds, like serious games.

Although there is a substantial body of literature on VPs, there is still limited or ambiguous information on the approaches and technologies used in designing and developing VPs. Most papers only briefly describe the design of VPs without technical details and focus mainly on its evaluation. Therefore, it is suggested that researchers provide a detailed description of their contributions from a design and development perspective or employ design science approaches to enhance the quality of research.

5.3 Limitations

The following limitations merit consideration. First, the search was limited to only three scientific databases and a narrow time frame. Expanding the search to additional databases and a broader time period may have resulted in more publications and potentially different outcomes. Second, the search was restricted to the use of "virtual patient" as the search term. Including other search terms related to simulations and digital patient-oriented learning methods in medical education could have resulted in additional suitable papers for synthesis. Third, while we carried out a systematic procedure, subjective bias may have influenced the selection and synthesis process due to ambiguous descriptions in some papers. This could have led to the exclusion of suitable findings or discrepancies in the classification of information in the concept matrix.

6 Conclusions

VPs have gained popularity as an effective way to train physicians' diagnostic skills in medical education and training. To provide practitioners and researchers with a comprehensive understanding of the current state of the art in VP development, we conducted a systematic literature review of 48 recent papers from a range of outlets. The analysis revealed that VPs are predominantly utilized in the medical field and student education as interactive patient scenarios based on multimedia system technology, with VP authoring systems being the primary tool for developing primary clinical reasoning skills. Based on these findings, researchers and practitioners should focus on developing and investigating underrepresented interactive VP technology approaches, competences, and educational areas. This literature review offers a comprehensive analysis of the latest research on designing and developing VPs in healthcare and educational domains. We are hopeful to assist researchers and practitioners in creating effective VPs as a digital, simulation-based learning method for healthcare education that meets the needs of patients and society in today's digitally transformed healthcare system.

Acknowledgements

This paper was produced as part of the research project "Digital competences of the medical profession for prescribing health apps [Digitale Kompetenzen der Ärzteschaft zur Verschreibung von Gesundheits-Apps]" and the associated research focus "Work-Education-Digitisation [Arbeit-Bildung-Digitalisierung]" of the FernUniversität in Hagen, founded by the German Ministry of Culture and Science of Nordrhein-Westfalen.

References

Antoniou, P. E., Arfaras, G., Pandria, N., Athanasiou, A., Ntakakis, G., Babatsikos, E., Nigdelis, V., & Bamidis, P. (2020). Biosensor Real-Time Affective Analytics in Virtual and Mixed Reality Medical Education Serious Games: Cohort Study. *JMIR Serious Games*, *8*(3), e17823. https://doi.org/10.2196/17823

Aquifer Inc. (2023). *Aquifer: Your trusted source for clinical learning*. https://aquifer.org

Articulate Global LLC. (2023a). *Articulate Rise 360*. https://articulate.com/360/rise

Articulate Global LLC. (2023b). *Articulate Storyline 360*. https://articulate.com/360/storyline

Bahrami, M., Hadadgar, A., & Fuladvandi, M. (2021). Designing Virtual Patients for Education of Nursing Students in Cancer Course. *Iranian Journal of Nursing and Midwifery Research*, *26*(2), 133–136. https://doi.org/10.4103/ijnmr.IJNMR_327_20

Berman, N. B., Durning, S. J., Fischer, M. R., Huwendiek, S., & Triola, M. M. (2016). The Role for Virtual Patients in the Future of Medical Education. *Academic Medicine : Journal of the Association of American Medical Colleges*, *91*(9), 1217–1222. https://doi.org/10.1097/ACM.0000000000001146

Bratan, T., Schneider, D., Heyen, N. B., Pullmann, L., Friedewald, M., Kuhlmann, D., Brkic, N., & Hüsing, B. (2022). *E-Health in Deutschland: Entwicklungsperspektiven und internationaler Vergleich [E-health in Germany: development perspectives and international comparison]: Studien zum deutschen Innovationssystem* (12-2022). Berlin. http://hdl.handle.net/10419/251366

Campillos-Llanos, L., Thomas, C., Bilinski, É., Neuraz, A., Rosset, S., & Zweigenbaum, P. (2021). Lessons Learned from the Usability Evaluation of a Simulated Patient Dialogue System. *Journal of Medical Systems*, *45*(7), 69. https://doi.org/10.1007/s10916-021-01737-4

Chaby, L., Benamara, A., Pino, M., Prigent, E., Ravenet, B., Martin, J.-C., Vanderstichel, H., Becerril-Ortega, R., Rigaud, A.-S., & Chetouani, M. (2022). Embodied Virtual Patients as a Simulation-Based Framework for Training Clinician-Patient Communication Skills: An Overview of Their Use in Psychiatric and Geriatric Care. *Frontiers in Virtual Reality*, *3*. https://doi.org/10.3389/frvir.2022.827312

Chua, W. L., Ooi, S. L., Chan, G. W. H., Lau, T. C., & Liaw, S. Y. (2022). The Effect of a Sepsis Interprofessional Education Using Virtual Patient Telesimulation on Sepsis Team Care in Clinical Practice: Mixed Methods Study. *Journal of Medical Internet Research*, *24*(4), e35058. https://doi.org/10.2196/35058

Co, M., John Yuen, T. H., & Cheung, H. H. (2022). Using clinical history taking chatbot mobile app for clinical bedside teachings - A prospective case control study. *Heliyon*, *8*(6), e09751. https://doi.org/10.1016/j.heliyon.2022.e09751

Cooper, H. M. (1988). Organizing knowledge syntheses: A taxonomy of literature reviews. *Knowledge in Society*, *1*(1), 104–126. https://doi.org/10.1007/BF03177550

Dupuy, L., Sevin, E. de, Cassoudesalle, H., Ballot, O., Dehail, P., Aouizerate, B., Cuny, E., Micoulaud-Franchi, J.-A., & Philip, P. (2021). Guidelines for the design of a virtual patient for psychiatric interview training. *Journal on Multimodal User Interfaces*, *15*(2), 99–107. https://doi.org/10.1007/s12193-020-00338-8

Ellaway, R. H., & Davies, D. (2011). Design for learning: Deconstructing virtual patient activities. *Medical Teacher*, *33*(4), 303–310. https://doi.org/10.3109/0142159X.2011.550969

Frangoudes, F., Hadjiaros, M., Schiza, E. C., Matsangidou, M., Tsivitanidou, O., & Neokleous, K. (2021). An Overview of the Use of Chatbots in Medical and Healthcare Education. In P. Zaphiris & A. Ioannou (Eds.), *Lecture Notes in Computer Science. Learning and Collaboration Technologies: Games and Virtual Environments for Learning* (Vol. 12785, pp. 170–184). Springer International Publishing. https://doi.org/10.1007/978-3-030-77943-6_11

Fuoad, S. A., El-Sayed, W., & Marei, H. (2022). Effect of different teaching/learning approaches using virtual patients on student's situational interest and cognitive load: A comparative study. *BMC Medical Education*, *22*(1), 763. https://doi.org/10.1186/s12909-022-03831-8

Furlan, R., Gatti, M., Menè, R., Shiffer, D., Marchiori, C., Giaj Levra, A., Saturnino, V., Brunetta, E., & Dipaola, F. (2021). A Natural Language Processing-Based Virtual Patient Simulator and Intelligent Tutoring System for the Clinical Diagnostic Process: Simulator Development and Case Study. *JMIR Medical Informatics*, *9*(4), e24073. https://doi.org/10.2196/24073

Ganji, J., Shirvani, M. A., Motahari-Tabari, N., & Tayebi, T. (2022). Design, implementation and evaluation of a virtual clinical training protocol for midwifery internship in a gynecology course during COVID-19 pandemic: A semi-experimental study. *Nurse Education Today*, *111*, 105293. https://doi.org/10.1016/j.nedt.2022.105293

Gharib, A. M., Bindoff, I. K., Peterson, G. M., & Salahudeen, M. S. (2023). Computer-Based Simulators in Pharmacy Practice Education: A Systematic Narrative Review. *Pharmacy (Basel, Switzerland)*, *11*(1). https://doi.org/10.3390/pharmacy11010008

Google Ireland Limited. (2023). *Dialogflow*. https://cloud.google.com/dialogflow

Huwendiek, S., Leng, B. A. de, Zary, N., Fischer, M. R., Ruiz, J. G., & Ellaway, R. (2009). Towards a typology of virtual patients. *Medical Teacher, 31*(8), 743–748. https://doi.org/10.1080/01421590903124708

Iguacel, I., Abecia, B., Bernal, J. L., & Martínez-Jarreta, B. (2022). Changing Attitudes towards Occupational Medicine with Blended Learning Methods Is Possible among Medical Students in Spain: A Longitudinal Study. *International Journal of Environmental Research and Public Health*, *19*(2). https://doi.org/10.3390/ijerph19020878

INSTRUCT gGmbH. (2022). *CASUS*. https://vhb.casus.net/

iSpring Nordics Oy. (2023). *iSpring Suite 11: Mit iSpring Suite Kurse entwerfen wie ein Profi*. https://www.ispringlearn.de/ispring-suite

Jacklin, S., Maskrey, N., & Chapman, S. (2021). Shared Decision-Making With a Virtual Patient in Medical Education: Mixed Methods Evaluation Study. *JMIR Medical Education*, *7*(2), e22745. https://doi.org/10.2196/22745

Kelly, S., Smyth, E., Murphy, P., & Pawlikowska, T. (2022). A scoping review: Virtual patients for communication skills in medical undergraduates. *BMC Medical Education*, *22*(1). https://doi.org/10.1186/s12909-022-03474-9

Kiesewetter, J., Sailer, M., Jung, V. M., Schönberger, R., Bauer, E., Zottmann, J. M., Hege, I., Zimmermann, H., Fischer, F., & Fischer, M. R. (2020). Learning clinical reasoning: How virtual patient case format and prior knowledge interact. *BMC Medical Education*, *20*(1), 73. https://doi.org/10.1186/s12909-020-1987-y

Kikuchi, J. Y., Le Neveu, M., Arnold, S., Offnick, A., Muñiz, K. S., Pandya, P., Feroz, R., Long, J. B., Ledebur, L. R., Patterson, D., & Chen, C. C. G. (2022). Creation and Implementation of Virtual Urogynecology Patient Cases for Medical Student Education. *MedEdPORTAL : The Journal of Teaching and Learning Resources*, *18*, 11259. https://doi.org/10.15766/mep_2374-8265.11259

Kononowicz, A. A., Woodham, L. A., Edelbring, S., Stathakarou, N., Davies, D., Saxena, N., Car, L. T., Carlstedt-Duke, J., Car, J., & Zary, N. (2019). Virtual patient simulations in health professions education: Systematic review and meta-analysis by the digital health education collaboration. *Journal of Medical Internet Research*, *21*(7). https://doi.org/10.2196/14676

Kononowicz, A. A., Zary, N., Edelbring, S., Corral, J., & Hege, I. (2015). Virtual patients - What are we talking about? A framework to classify the meanings of the term in healthcare education. *BMC Medical Education*, *15*(1). https://doi.org/10.1186/s12909-015-0296-3

Kotwal, S., Fanai, M., Fu, W., Wang, Z., Bery, A. K., Omron, R., Tevzadze, N., Gold, D., Garibaldi, B. T., Wright, S. M., & Newman-Toker, D. E. (2021). Real-world virtual patient simulation to improve diagnostic performance through deliberate practice: A prospective quasi-experimental study. *Diagnosis (Berlin, Germany)*, *8*(4), 489–496. https://doi.org/10.1515/dx-2020-0127

Kynectiv Inc. (2023). *DECISIONSIM: Technology*. https://app.decisionsim.com

Lee, J., Kim, H., Kim, K. H., Jung, D., Jowsey, T., & Webster, C. S. (2020). Effective virtual patient simulators for medical communication training: A systematic review. *Medical Education*, *54*(9), 786–795. https://doi.org/10.1111/medu.14152

Lem, W. G., Kohyama-Koganeya, A., Saito, T., & Oyama, H. (2022). Effect of a Virtual Reality Contact-Based Educational Intervention on the Public Stigma of Depression: Randomized Controlled Pilot Study. *JMIR Formative Research*, *6*(5), e28072. https://doi.org/10.2196/28072

Lerner, D., Mohr, S., Schild, J., Göring, M., & Luiz, T. (2020). An Immersive Multi-User Virtual Reality for Emergency Simulation Training: Usability Study. *JMIR Serious Games*, *8*(3), e18822. https://doi.org/10.2196/18822

Lucero, K. S., Spyropoulos, J., Blevins, D., Warters, M., Norton, A., & Cohen, J. (2020). Virtual Patient Simulation in Continuing Education: Improving the Use of Guideline-Directed Care in Venous Thromboembolism Treatment. *Journal of European CME*, *9*(1), 1836865. https://doi.org/10.1080/21614083.2020.1836865

Mardani, M., Cheraghian, S., Naeeni, S. K., & Zarifsanaiey, N. (2020). Effectiveness of virtual patients in teaching clinical decision-making skills to dental students. *Journal of Dental Education*, *84*(5), 615–623. https://doi.org/10.1002/jdd.12045

Martini, N., & Datt, A. (2022). Virtual patients in clinical decision making – A design-based research approach. *Pharmacy Education*, *22*(1), 129–141. https://doi.org/10.46542/pe.2022.221.129141

McNamara, L., Scott, K., Boyd, R. N., Farmer, E., Webb, A., Bosanquet, M., Nguyen, K., & Novak, I. (2022). Can web-based implementation interventions improve physician early diagnosis of cerebral palsy? Protocol for a 3-arm parallel superiority randomised controlled trial and cost-consequence analysis comparing adaptive and non-adaptive virtual patient instructional designs with control to evaluate effectiveness on physician behaviour, diagnostic skills and patient outcomes. *BMJ Open*, *12*(11), e063558. https://doi.org/10.1136/bmjopen-2022-063558

Miles, A., Hayden, S., Carnell, S., Halan, S., & Lok, B. (2021). What do speech pathology students gain from virtual patient interviewing? A WHO International Classification of Functioning Disability and Health (ICF) analysis. *BMJ Simulation and Technology Enhanced Learning*, *7*(4), 239–245. https://doi.org/10.1136/bmjstel-2020-000616

Moodle Pty Ltd. (2023). *Willkommen in der Moodle-Community*. https://moodle.org/

Newsome, J. S., Wallace-Gay, T. D., & Shoair, O. A. (2020). Virtual Versus Paper-based Cases in Reinforcing the Collect and Assess Elements of the Pharmacists' Patient Care Process. *American Journal of Pharmaceutical Education*, *84*(7), ajpe7806. https://doi.org/10.5688/ajpe7806

NLTK Project. (2023). *Natural Language Toolkit (NLTK)*. https://www.nltk.org/

Paré, G., Trudel, M.-C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management*, *52*(2), 183–199. https://doi.org/10.1016/j.im.2014.08.008

Plackett, R., Kassianos, A. P., Mylan, S., Kambouri, M., Raine, R., & Sheringham, J. (2022). The effectiveness of using virtual patient educational tools to improve medical students' clinical reasoning skills: A systematic review. *BMC Medical Education*, *22*(1), 365. https://doi.org/10.1186/s12909-022-03410-x

Rakofsky, J. J., Talbot, T. B., & Dunlop, B. W. (2020). A Virtual Standardized Patient-Based Assessment Tool to Evaluate Psychiatric Residents' Psychopharmacology Proficiency. *Academic Psychiatry : The Journal of the American Association of Directors of Psychiatric Residency Training and the Association for Academic Psychiatry*, *44*(6), 693–700. https://doi.org/10.1007/s40596-020-01286-x

Richardson, C. L., Chapman, S., & White, S. (2021). Establishing the acceptability and usability of an animated virtual patient simulation. *Exploratory Research in Clinical and Social Pharmacy*, *4*, 100069. https://doi.org/10.1016/j.rcsop.2021.100069

Richardson, C. L., White, S., & Chapman, S. (2020). Virtual patient technology to educate pharmacists and pharmacy students on patient communication: A systematic review. *BMJ Simulation and Technology Enhanced Learning*, *6*(6), 332–338. https://doi.org/10.1136/bmjstel-2019-000514

Rothlind, E., Fors, U., Salminen, H., Wändell, P., & Ekblad, S. (2021). Virtual patients reflecting the clinical reality of primary care - a useful tool to improve cultural competence. *BMC Medical Education*, *21*(1), 270. https://doi.org/10.1186/s12909-021-02701-z

Rouleau, G., Pelletier, J., Côté, J., Gagnon, M.-P., Martel-Laferrière, V., Lévesque, R., & Fontaine, G. (2020). Codeveloping a Virtual Patient Simulation to Foster Nurses' Relational Skills Consistent With Motivational Interviewing: A Situation of Antiretroviral Therapy Nonadherence. *Journal of Medical Internet Research*, *22*(7), e18225. https://doi.org/10.2196/18225

Sahu, P. K., Chattu, V. K., Rewatkar, A., & Sakhamuri, S. (2019). Best practices to impart clinical skills during preclinical years of medical curriculum. *Journal of Education and Health Promotion*, *8*, 57. https://doi.org/10.4103/jehp.jehp_354_18

Schnieders, E., Röhr, F., Mbewe, M., Shanzi, A., Berner-Rodoreda, A., Barteit, S., Louis, V. R., Andreadis, P., Syakantu, G., & Neuhann, F. (2022). Real-life Evaluation of an Interactive Versus Noninteractive e-Learning Module on Chronic Obstructive Pulmonary

Disease for Medical Licentiate Students in Zambia: Web-Based, Mixed Methods Randomized Controlled Trial. *JMIR Medical Education, 8*(1), e34751. https://doi.org/10.2196/34751

Setrakian, J., Gauthier, G., Bergeron, L., Chamberland, M., & St-Onge, C. (2020). Comparison of Assessment by a Virtual Patient and by Clinician-Educators of Medical Students' History-Taking Skills: Exploratory Descriptive Study. *JMIR Medical Education*, *6*(1), e14428. https://doi.org/10.2196/14428

SimforHealth. (2019). *MedicActiV: Virtual simulators for medical education*. https://www.medicactiv.com/en

SIMmersion™. (2023). *SIMmersion Immersive Simulations: Realistic People. Real Change. AI powered virtual role-players with memory and emotions*. https://www.simmersion.com/

Stockholms Universitet. (2019). *BSAsim: Välkommen till BSAsim!* https://bsa.dsv.su.se/bsasim

Suárez, A., Adanero, A., Díaz-Flores García, V., Freire, Y., & Algar, J. (2022). Using a Virtual Patient via an Artificial Intelligence Chatbot to Develop Dental Students' Diagnostic Skills. *International Journal of Environmental Research and Public Health*, *19*(14). https://doi.org/10.3390/ijerph19148735

Take The Wind. (2023). *Body Interact™: Learn with virtual patients, save real lives*. https://bodyinteract.com

Tehran University of Medical Sciences. (2023). *What is NAVID? Learning Management System used in Tehran University of Medical Sciences*. https://tumsnavid.vums.ac.ir/

Thompson, J., White, S, & Chapman, S (2020). Virtual patients as a tool for training pre-registration pharmacists and increasing their preparedness to practice: A qualitative study. *PloS One*, *15*(8), e0238226. https://doi.org/10.1371/journal.pone.0238226

University Health Network. (2013). *Virtual Interactive Case System*. https://pie.med.utoronto.ca/VIC

University of Calgary. (2022). *OpenLabyrinth*. https://openlabyrinth.ca

University of Florida. (n.d.). *Virtual People Factory 2.0*. Retrieved March 5, 2023, from http://virtualpeoplefactory.com

University of Pittsburgh. (2019). *vpSim*. http://vpsim.pitt.edu

WebMD LLC. (2023). *Medscape MedSims® Patient Simulations*. https://www.medscape.org/simulation

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, *26*(2), xiii–xxiii.