

REVIEW

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Exploring the trends of educational virtual reality games: a systematic review of empirical studies

Solomon Sunday Oyelere^{1*} , Nacir Bouali^{1,2}, Rogers Kaliisa³, George Obaido⁴, Abdullahi Abubakar Yunusa⁵ and Eburnayo R. Jimoh⁶

* Correspondence: solomon.oyelere@uef.fi

¹University of Eastern Finland, School of Computing, Joensuu, Finland

Full list of author information is available at the end of the article

Abstract

Virtual Reality (VR) and educational games are emerging technologies mediating a rapid transformation in the educational world. However, few studies have systematically analyzed Educational Virtual Reality Games (EVRGs) and how they have been applied in educational settings. This study reviewed 31 articles published in high impact journals and educational conference proceedings to unravel the *technological, pedagogical, and gaming characteristics of contemporary* EVRGs. The results show the predominance of Oculus Rift headsets and HTC Vive as the main technology used in EVRGs. Moreover, the analysis revealed that the pedagogical application of the majority of EVRGs was developed for all levels of education (e.g. tertiary, K-12, lifelong learning), with the specific target audience of each game based on the desired learning outcome. Furthermore, the application of EVRGs has primarily focused on out of class use, with healthcare education topics dominating the topics taught using EVRGs. Based on our findings, we highlight some key implications and suggestions to advance the field of EVRGs.

Keywords: Educational games, Virtual reality, Educational virtual reality games, Systematic review

Introduction

This study explores the advances of educational virtual reality games (EVRGs) and expounds its important developmental features such as technology, pedagogy and gaming. The rapid development in Information and Communication Technology (ICT) has revolutionized the computing industry and propelled a paradigm shift in the pedagogy of teaching and learning (Kaliisa, Edward, & Julia, 2019; Oyelere, Suhonen, Wajiga, & Sutinen, 2018). Contemporary computer hardware and software have improved significantly in size, speed, and precision, and a key to the creation of immersive technological applications (Bekele, Pierdicca, Frontoni, Malinverni, & Gain, 2018; Voinea, Gîrbacia, Postelnicu, & Marto, 2018). Virtual reality (VR) is a technology that has recently gained prominence as one of the core features of modern 'high-tech' with wide-ranging applications, including education (Virvou & Katsionis, 2008), gaming (Zyda,

2005), entertainment (Liu, Cheok, Mei-Ling, & Theng, 2007), military (Lele, 2013), skills training (Aggarwal, Black, Hance, Darzi, & Cheshire, 2006), tourism (Tussyadiah, Wang, Jung, & Dieck, 2018), as well as physical exercise (Finkelstein et al., 2011). VR is computer-simulated, which gives users the illusion of being physically present in the world and uses not only sight but also sound and touch to fully engage a user in the virtual world (Mandal, 2013).

In this paper, we refer to VR as the experience in which a user is fully immersed into either a virtual environment using head-mounted displays (headsets) or projection-based displays. A user through the utilization of an avatar (Carvalho, Nóbrega, da Silva, & Rodrigues, 2016) can as a result, navigate this world. This functionality differs from 3D environments visualized using headsets, but the user is only able to experience the virtual world from a fixed perspective and an onscreen visualizable three-dimensional (3D) environment. In this research, educational games are defined as the games designed, implemented, and evaluated with the purpose of teaching, or aiding in the instruction of a subject, or aiding in the learning of a specific skill within a formal or an informal setting (Oyelere, Suhonen, & Laine, 2017; Pavlidis & Markantonatou, 2018). We define Educational Virtual Reality Games (EVRGs) as educational games that exploit the 3D stereoscopic display, using a wearable headset or a Cave Automatic Virtual Environment (CAVE) system to teach or aid in the instruction of a specific topic. With such a definition non-immersive educational VR games, wherein the user navigates a virtual world using an avatar controlled by a mouse and a keyboard and/or a joystick, have been excluded.

VR technology has become increasingly a popular teaching and learning support tool across different disciplines. It provides an opportunity for students and teachers to experience, as well as interact, with real-time learning phenomena, something that would have been almost impossible in the physical world (Shin, 2017; Vesisenaho et al., 2019). VR allows for the use of multiple senses (e.g., touch, sense of heat, smell), which are used simultaneously during the learning process. In this regard, this could improve the activeness and mental alertness of both the students and teachers. This claim is supported by Lee and Wong (2014) who concluded that there is a significant interaction effect between the learning mode and the spatial ability of the students. Furthermore, other studies have established the pedagogical benefits of VR, such as the ability to support students with diverse learning styles in gaining cognitive achievement (Lee, Wong, & Fung, 2010), improving spatial thinking (Cohen & Hegarty, 2014), learning object-oriented programming concepts (Bouali, Nygren, Oyelere, Suhonen, & Cavalli-Sforza, 2019), and in facilitating collaboration (Greenwald et al., 2017).

The goal of this study was to systematically review the trends of EVRGs from the perspective of their technological, pedagogical, and gaming characteristics. The study draws on research conducted by Laine (2018), by focusing on studies that describe the design, implementation, and evaluation of EVRGs. Since Laine's (2018) study focuses strictly on mobile Augmented Reality Games (ARs), our work provides a slightly different and more comprehensive perspective by focusing on EVRGs. A review of previous studies of EVRGs would make it possible to understand in which direction the field is heading and how future EVRGs should be designed to best fit the needs of both the teacher and students to improve educational outcomes. We argue that a review of EVRGs is needed (i) to understand and conceptualize the existing body of EVRGs; (ii)

to provide evidence about the technologies that support the implementation of EVRGs across a wide range of settings and techniques used; (iii) to explore the teaching and learning attributes of VR games and how different pedagogical characteristics such as context, topics taught, and types of learners have changed over the years. We further aim (iv) to develop a set of pointers to researchers and practitioners (e.g. teachers) interested in conducting and applying VR games in research and pedagogical practice; and (v) to understand the characteristics of contemporary games to supporting educational developments. To achieve these goals, we, therefore, seek to answer the research question: *What are the technological, pedagogical, and gaming characteristics of contemporary educational VR games?*

The rest of the paper is organized as follows: presentation of related work, the methodology, and conclusion with several remarks that reinforce the critical points regarding the use of educational VR games.

Related work

Relationship between VR and education

The educational process requires the learner to grasp and comprehend abstract concepts and appreciate scenarios, as well as to understand situations which are far removed from the confines of the classroom. Duffy and Jonassen (1992) argue that the teaching of abstract phenomena, analogy and lived experiences are used to describe and ease through abstract concepts from commonly observable reality. However, over the last decade, the application of emerging technologies in education have revolutionized the pedagogical or teaching processes in the classroom, to explain better and to provide comprehension of abstract concepts.

VR is an emerging technology that has gained traction in education. Educationists have discovered that VR allows the user to interact with a computer-generated 3D model or virtual environment (Christou, 2010) which fosters the understanding of the imaginary world on a realistic scale. This makes it a useful tool for teaching and learning by transforming the way educational content is delivered (Hentsch, 2018). A study by Lee and Wong (2008), described VR as a technology that aids student learning through the visualization of information and engagement, which affords a learner with the opportunity to experience subject matter or concepts that are not easily discernible.

VR does not only relate positively to education but aligns with the constructivism school of thought, which stipulates that humans construct knowledge by learning from experience. The constructivist theory advocates that learning through interaction with sensory data allows knowledge construction from experience for which VR is suited. Christou (2010), chronicled broad application areas of VR in educational contexts used in the enhancement of core curricula in schools and colleges, application of VR in museums, edutainment, demonstrations, simulation, and training.

Comparison of VR and 3D games in education

In the past few decades, game-based learning has been an integral part of the educational process (Boboc, Orzan, Stoica, & Niculescu-Ciocan, 2018; Hwang, Wu, Chen, & Tu, 2016; Xenos, Maratou, Ntokas, Mettouris, & Papadopoulos, 2017). EVRGs are designed to assist users to grasp the concepts of a specific subject, to expand their

knowledge, and to facilitate participation. A typical example of educational virtual reality game is GridlockED, which was developed by Tsoy et al. (2019) as a collaborative learning game, targeted for medical trainees, to acquire the skills on how to treat and triage a patient. Modern educational games are played using high-end video technology such as stereoscopic 3D, or through a Head-Mounted VR environment (Snowdon & Oikonomou, 2018). These technologies use a spatial depth on the screen and offer rich learning experiences for the user.

A study by Sampaio, Ferreira, Rosário, and Martins (2010) described 3D technology as that which creates spatial depth with 3D pop-up visualizations so that objects contained in the game may appear closer to the player with the use of dedicated 3D-capable glasses. In comparison to the 3D technology, Triberti, Villani, and Riva (2016) described VR as a computer-simulated reality that uses a 3D environment whereby the player interacts with using a specialized head-mounted display (e.g. Oculus Rift, Samsung Gear VR, Google Cardboard etc.) that shows visual effects to the eyes. Unlike 3D, where the user is a just a viewer, VR allows for the user to become part of a story, offering an untethered immersive experience (Bradshaw, 2016). Therefore, a video game in VR is more realistic than one played in a 3D condition. Hence, VR technology could be applied to complement 3D modelling, ensuring better communication both in an educational or vocational training (Bradshaw, 2016). A comparative study by Roettl and Terlutter (2018) on 237 players showed that the participation and cognitive load was much higher in players using VR than just 3D. Recently, researchers have critically debated on the effects of 3D and VR technologies on issues such as adverse effects like social isolation (Nicas, 2018), discomfort, eye fatigue, and headache when using these technologies for an extended period (Bradshaw, 2016; Roettl & Terlutter, 2018; Shar-kawi, Ujang, & Abdul-Rahman, 2008).

Related EVRGs reviews

Since this article focuses on exploring current EVRGs, we consider it vital to summarize in a tabular form the existing efforts in this direction. Table 1 presents the previous attempts to review works in EVRGs.

As can be observed from the existing studies reviewing EVRGs (Table 1), the field of VR games has garnered interest amongst educational technology researchers. This may be partly as a result of an increase in innovation within the field as well as in the

Table 1 Related literature on educational virtual reality games within the systematic review

Review	Year of publication	Focus	Number of studies	Year range of reviewed studies
Immersive VR serious games for evacuation training and research: A systematic literature review	2018	VR Serious Games for Evacuation Training	15	2007–2017
A Literature Review on Immersive VR in Education: State of the Art and Perspectives	2015	Advantages of using VR in education	93	2013–2014
Computer Technology for Serious Games in Education: A Literature Review	2017	Serious Games in General with a focus on VR	6 (counting only VR serious games)	2006–2016
Using VR in Education	2017	Reviewed VR headsets	2	2012–2017

variation in the pedagogical application of VR. However, to the best of our knowledge and evaluation of the existing reviews, no study has attempted to review systematically the trends of EVRGs accounting from the viewpoints of technology, pedagogy, content, knowledge, and games. To bridge this gap, this paper centers in a systematic literature review to examine the current research on EVRGs and to provide important insights beyond the specific research findings within the individual studies.

Methodology

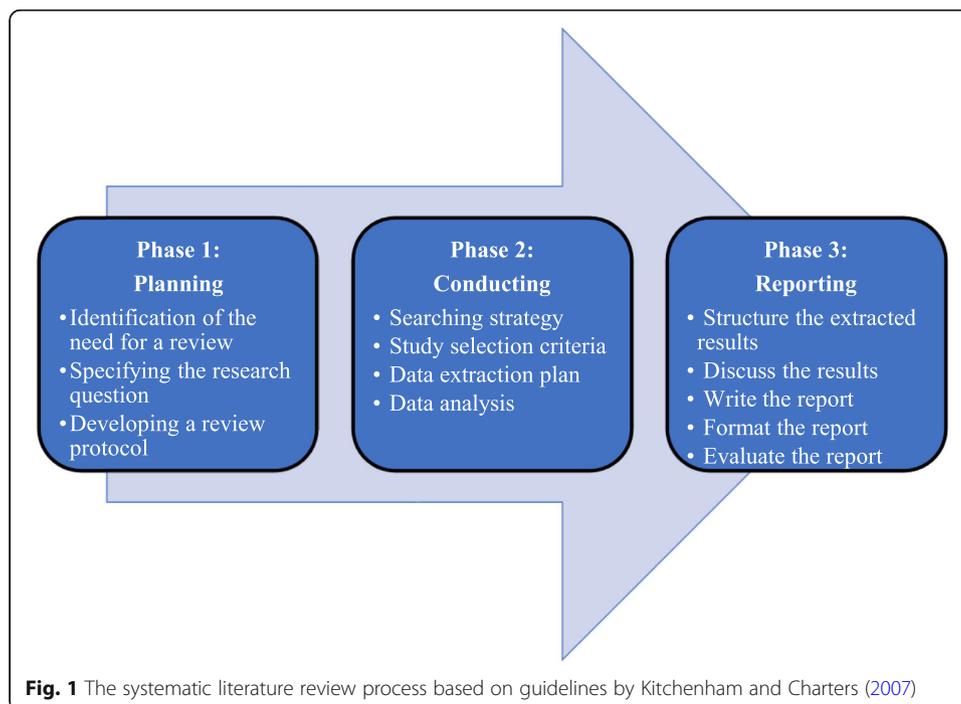
This study follows the guidelines for conducting a systematic literature review by Kitchenham and Charters (2007) (Fig. 1). The search service of the (blinded for review) library's printed and electronic resources, (blinded for review) was utilized to access databases and extract publications. Google Drive was used for collaboration among the team, and MS Excel spreadsheets were used to manage and organize the information acquired from the search.

Phase 1. Planning the review

This phase focuses on the initial preparation undertaken to achieve the goal of this literature review.

Phase 1.1 Rationale of the review

Based on the guidelines by Kitchenham and Charters (2007), we identified previous systematic reviews that addressed either our research questions or similar questions. However, as discussed in the introduction, none of the reviews focused on EVRGs. Thus, we decided to conduct a review on EVRGs with specific attention to attributes such as technology, pedagogy and gaming.



Phase 1.2. Specifying the research question

By drawing on existing accounts about the application of VR games, in the educational sphere, this study set one research question: *What are the technological, pedagogical, and gaming characteristics of contemporary educational VR games?* To answer this research question, this study analyzed existing research about EVRGs with an emphasis on profiling the games in terms of the country of research, year of production, technological attributes (e.g. platform, types of headsets), pedagogical attributes (e.g., topics, types of learners, educational settings) and the gaming attributes (e.g., player's role, the theme of play, mode, and goal of the game).

Phase 1.3. Developing a review protocol

According to Kitchenham and Charters (2007), a review protocol provides the basis to carry out the systematic review. Creating a review protocol beforehand helps to reduce the likelihood of research bias, such as potential prejudiced selections of particular studies carried out by the researcher. Formal and informal searches were used to find relevant studies in response to the research question. Table 2 presents the databases and the search strategy of the preliminary searches of existing related studies of EVRGs in education, which set the direction for this study. The databases were selected because they were either specialized in educational technology, educational games or in virtual reality applications, or that have published at least one special issue in educational virtual reality and games for learning. Thereafter, the preliminary review studies presented in Table 1 were used to create the research framework as well as the research question, which yielded a well-organized review protocol.

Phase 2. Conducting the review

The second phase of the guidelines by Kitchenham and Charters (2007) follows five stages: the search strategy, the study selection criteria, the study quality assessment, the data extraction plan, and the data analysis tool.

Phase 2.1. Search strategy

The research question of this study guided the formulation and expounding of the search strategy. As a first step, the search keywords were identified as a way of narrowing down and focusing on relevant articles for the topic under study. The search keywords were chosen according to the research theme; research question and the objective of this study (see Table 2 for search strategy and list of databases). *Search keywords:* The search space was narrowed down using Boolean search phrases and different combinations of the following terms: "virtual reality" AND "education", OR "learning", OR "game", OR "gamification", OR "serious game". While many researchers

Table 2 Search Database

Database (sources)	Search strategy
ACM Digital Library	Title
Google Scholar	Alternative search
IEEE Xplore	Title
ScienceDirect	Alternative search

use the term “educational games” to refer to games, the purpose of which is helping a learner acquire a skill, others opt for a more generic term like “serious game”. The keyword choice was made in a way to capture any game that is used in an educational context, be it formal or informal, as long as it uses VR technology, with the definition we adopted above. The time frame for publication considered within the systematic review was between 2012 and 2018. Since the field of educational technology and virtual reality games is developing very fast, articles before 2012 have been reviewed in previous studies and are not particularly relevant in this work. The screening was based on titles, abstracts, and full-text skimming and took place from 1 February 2019 to 30 May 2019.

Phase 2.2. Study selection criteria

Using the keywords and search strings presented in the section “*Phase 2.1. Search strategy*”, several articles were selected based on their relevance to the research question and inclusion criteria. A flow diagram representing the steps of the selection criteria is presented in Fig. 2. The researchers read the title, abstract, keywords and skimmed through the contents of all the papers and selected the articles that appeared to be appropriate based on VR, education, and gamification. Abstracts, posters, books, and articles that did not show an implementation that required a VR headset were excluded. Altogether, we found 162 research papers through the predefined search keywords on the four databases. However, after we applied the inclusion and exclusion criteria (Table 3), only 31 articles made it through the scrutiny (Table 4).

Phase 2.3. Data extraction and analysis

We set up a coding scheme to guide the extraction of relevant data from research articles with relevance to our research question. The coding scheme included the following overarching dimensions: Title/name of the game, description of the game, country of game implementation, player role, theme, mode, gameplay, goal, platform, VR headset, game interaction, focus, learners, educational setting, research, and evaluation methods.

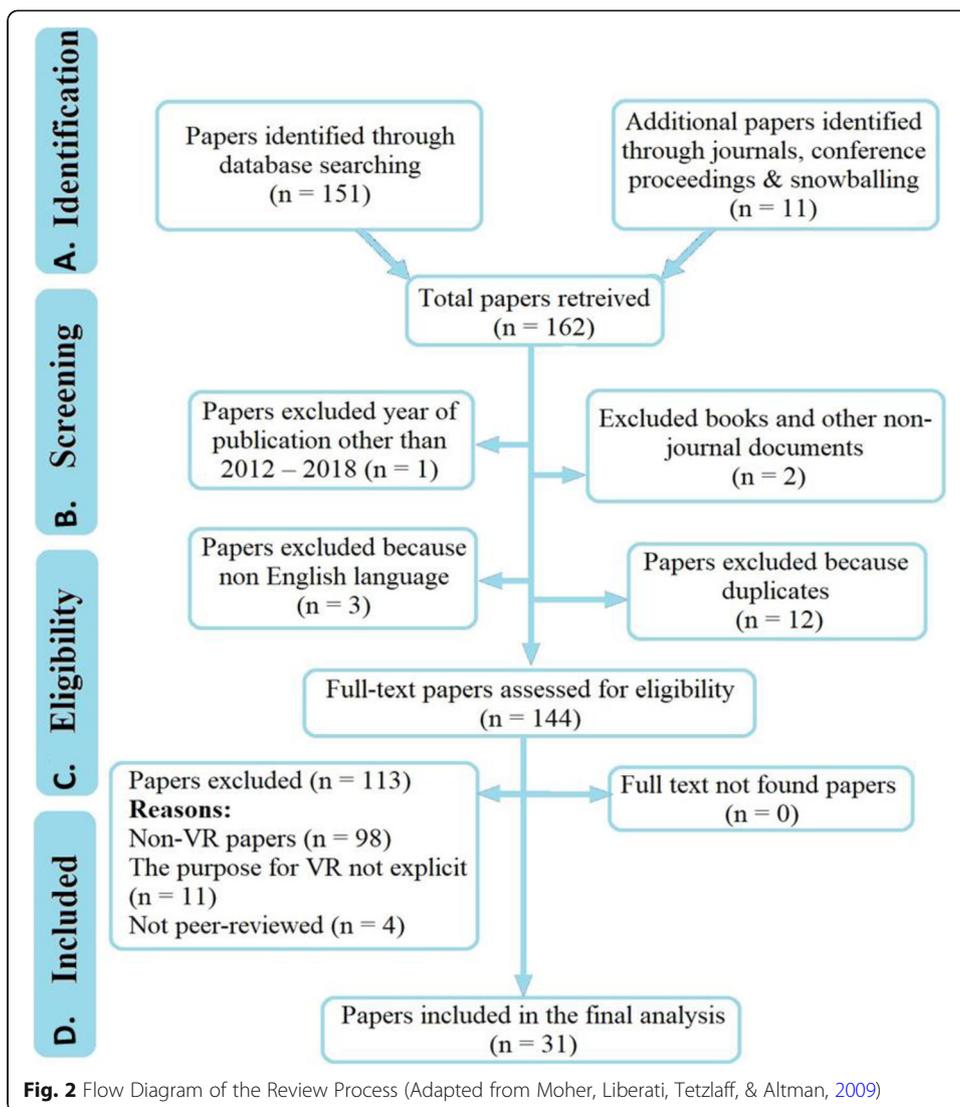
In summary, the methodology section, presented the planning and implementation process of the systematic review and these included; providing the rationale for choosing the framework adopted for the review, specifying the research questions, developing the review protocol, executing the review, identifying the keywords, drafting the study selection criteria as well as data extraction and analysis. Subsequently, the results yielded by these processes are presented in the next section.

Results

The results are organized in four main categories: A general overview of the EVRGs, technological, pedagogical, and gaming characteristics.

Overview of the VR serious games

The number of EVRGs publications appearing in each year from 2012 to 2018 is presented in Fig. 3. The bar chart shows a definite increase in the number of research works dedicated to VR educational games. Research shows that there was one study in 2014 and increases to 14 studies in 2018. Table 5 shows that EVRGs have been researched in North and South America, Europe, Asia, and Australia. See Table 5 for full details of serious games.



Technological characteristics

The review looked at the technological characteristics of the selected EVRGs in terms of platform, headset, and interaction components. As shown in Fig. 4, the Oculus Rift seems to dominate the VR headsets used in EVRGs, as it was used in nearly half of the games (45.2%). HTC Vive came in second used in almost a quarter of the games

Table 3 The inclusion criteria

Criteria	Specifics
Publication date	2012–2018
Type	Journal articles and conference proceedings
Language of publication	English
Education usage	Uses VR for education
Implementation of functionality	Present implemented artefact, not just design
Implementation of Mode	Single, Multiplayer
Implementation of Genre	Adventure, Gameplay

Table 4 Results of the literature search within the systematic review 2012–2018

Database (sources)	Items	Excluded	Included
IEEE Xplore	40	26	14
ACM Digital Library	61	54	7
Google Scholar	41	33	8
ScienceDirect	20	18	2

(22.6%). Cardboard, which is the cheapest of the VR headsets, was only used in 9.7% of the games, while under a quarter (22.6%) of the papers we reviewed, did not specify which headsets were used as target technology.

The platforms used for the games were consistent with the headsets, given that HTC Vive and Oculus Rift DK2 are PC VR devices, 83.9% of the games were playable using a PC or MAC, while 12.9% were playable using a mobile device, which matches the Cardboard requirements (Fig. 5).

In Table 6 (technological characteristics), we show the interaction techniques and hardware used in the EVRGs. While the most basic headsets (e.g. Cardboard) provide basic VR interaction mechanisms like gaze and head movements, more advanced headsets come with more sophisticated controllers. These controllers allow the users to interact with the props in the game environment and facilitate movement. Some games provide natural user interfaces, while other task-specific games provide more advanced controllers such as steering wheels. However, it is noteworthy that traditional input devices, such as a mouse or keyboard are challenging to use with VR technology, as the latter conceals the user in a virtual environment, disallowing the visibility of the surrounding real environment. Some games have, however, suggested such input devices, which makes the gaming experience slightly inconvenient.

Pedagogical characteristics

The analysis of the games showed that more than two-thirds of the educational VR games were developed for informal learning context (Fig. 6). While the topics taught in

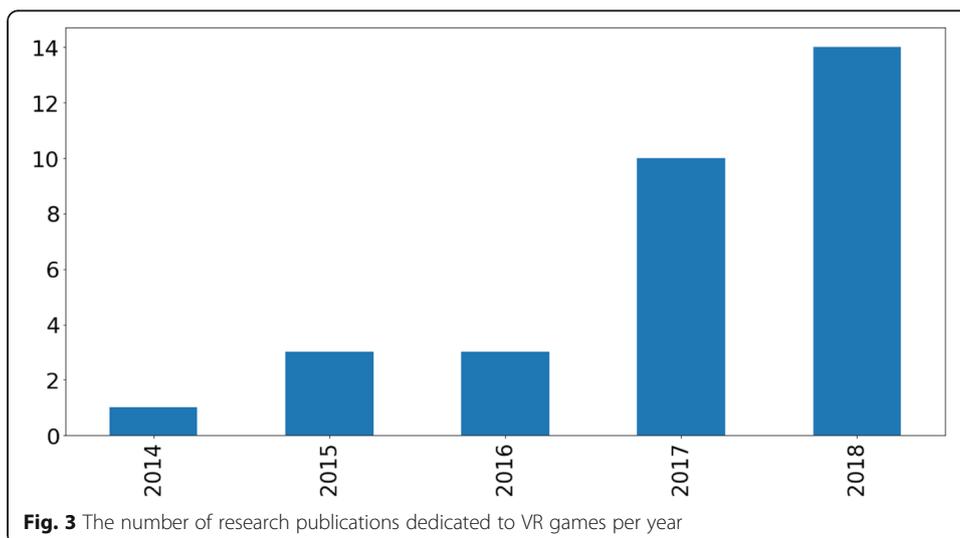


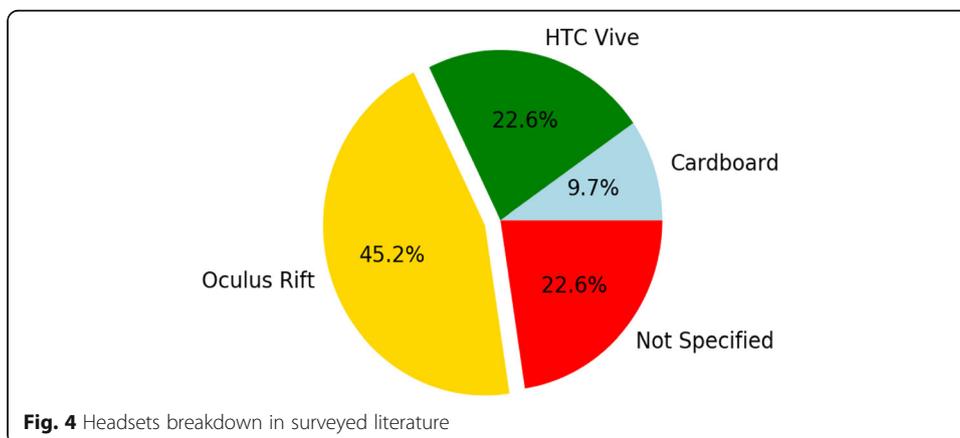
Fig. 3 The number of research publications dedicated to VR games per year

Table 5 Overview of the EVRGs

ID	Author's Name & Year	Country	Description
1	Tabak et al. (2017)	Netherlands	The authors presented a VR game to improve the training of chronic pain both in the clinical and home settings.
2	Szczurowski and Smith (2018)	Ireland	A VR serious game to teach children about road safety.
3	Roberto et al. (2017)	Italy	A cultural heritage serious game developed to illustrate the feasibility of a framework called FRACH.
4	Amal, Hend, and Hana (2018)	South Africa	An immersive game distracting the patients from pain while performing Lower Back Problem exercises.
5	Bernardes, Barros, Simoes, and Castelo-Brancon (2015)	Spain	A VR game to teach patients with autism how to use public transportation.
6	Byl, Süncksen, and Teistler (2018)	Germany	A serious game to teach medical students how to handle ultrasound probes and to understand spatial relationships in medical ultra sounding images.
7	Mihajlovic, Popovic, and Brkic (2018)	Hungary	A game that motivates users to perform neck exercises through immersion in VR.
8	Calvi et al. (2017)	Italy	The game was developed to simulate a diving experience in a virtual environment for non-divers with the purpose to create awareness in players about a conscious sustainable behavior underwater.
9	Gyutae, Hojun, Sangho, Jaekwang, and Shiho (2016)	South Korea	The study proposes a self-training VR serious game for fire evacuation drills with concurrent tele-collaboration among avatars controlled by and synchronized with multiple users in remote places.
10	Chittaro and Buttussi (2015)	Italy	This study proposed a head-mounted device-based immersive game for educating passengers about aviation safety that allows players to experience a serious aircraft emergency to survive it.
11	Zielke (2017)	United States of America	The study explored whether VR and AR technologies can provide a more natural interface, increase presence and facilitate the practice of empathy as compared to current medical education forms of simulation.
12	Dinis, Guimarães, Carvalho, and Martins (2017)	Portugal	VR interface provides tools for students to interact with virtual building models while editing geometry and properties.
13	Süncksen et al. (2018)	Germany	In the VR environment, the user generates specific radiographs of virtual patients whereby points are awarded for image accuracy within the specified time frame and radiation exposure.
14	Zikky, Fathoni, and Firdaus (2018)	Indonesia	Uses client/server architecture and brings teachers and students together into a virtual space, a specific planet.
15	(Visoottiviseth, Phungphat, Puttawong, Chantaramporn, & Haga, 2018)	Thailand	A VR game on Android for education. It is an alternative learning material for learners to gain knowledge about network security effectively.
16	Sárkány (2016)	Germany	A partly implemented serious game that uses hand gestures and eye gaze in a VR environment to help patients with dementia.
17	(Pirker, Lesjak, & Guetl, 2017)	Austria	Maroon VR provides several Lab stations for understanding Electromagnetism in Physics.
18	(Trombetta et al., 2017)	Great Britain	A serious game for post-stroke patients. It engages patients using VR to complete their rehabilitation program.
19	Knote, Edenhofer, and Mammen (2016)	United States of America	This study presents an interactive simulation game to understand the mutual interferences of competitive (ant) species by experiencing their behavior in a novel way.
20	Lovreglio, Gonzalez, Feng, and Sacks (2018)	New Zealand	A serious game that teaches the basics of evacuation training in the case of earthquakes in hospitals.

Table 5 Overview of the EVRGs (Continued)

ID	Author's Name & Year	Country	Description
21	Vourvopoulos, Faria, Ponnampalath, and Badia (2014)	United States of America	This paper presents the design, implementation, and validation of RehabCity, an online game designed for the rehabilitation of cognitive deficits through a gamified approach on activities of daily living.
22	Bryan, Campbell, and Mangina (2018)	Ireland	A VR game that allows students to learn about various locations in the world using Google Street View.
23	Shahab (2017)	Ireland	This paper presents a novel VR setup with the ability to teach music to children with autism as well as to perform an automatic assessment of their behaviors. This setup contains Social Virtual Reality Robots (V2Rs) and virtual musical instruments (i.e. xylophone and drum).
24	Likitweerawong and Palee (2018)	Thailand	A serious game that simulates a car environment and allows participants to test their driving skills.
25	Chin, Kamsani, Zhong, Cui, and Yang (2018)	China	A VR game that allows training on Remotely Operated Vehicles.
26	Moldoveanu (2017)	Romania	The paper proposes a training strategy for a sensory substitution device to improve the ability of visually impaired people to be autonomous thus, to increase the quality of their lives.
27	Chiu (2017)	Taiwan	In this study, a VR game was developed for elementary school students to learn about Taiwan's aboriginal tribe's native languages.
28	Hafsia, Monacelli, and Martin (2018)	France	A VR game to teach construction workers about safety in the work environment.
29	Diez, Andoni, Aitor, and Oyarzun (2016)	Spain	The research presents an interactive application for training experts on the prevention of occupational hazards such as fire safety in buildings.
30	Puttawong et al. (2017)	Japan	The paper explores the use of VR technology to develop a fantasy RPG called VRFIWall that teaches computer security.
31	Alrehaili (2018)	Canada	This research project discusses the design, development and evaluation of a RPG that teaches children about the lives of bees.



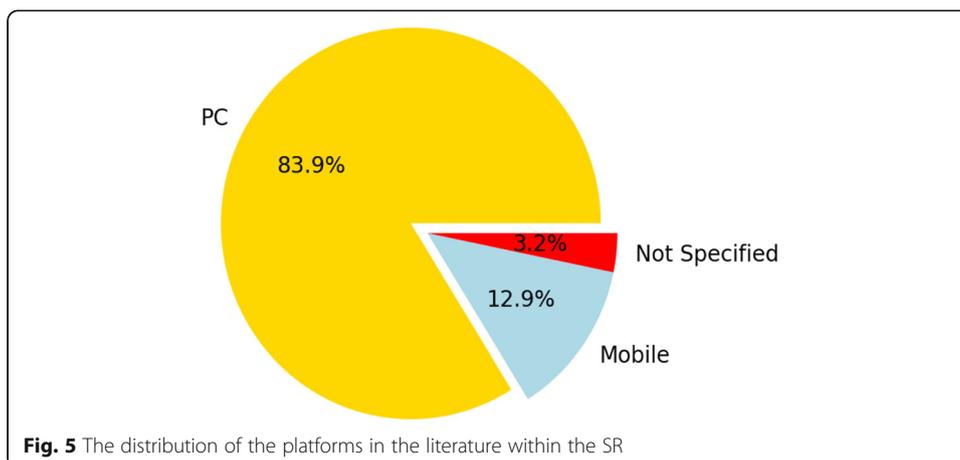
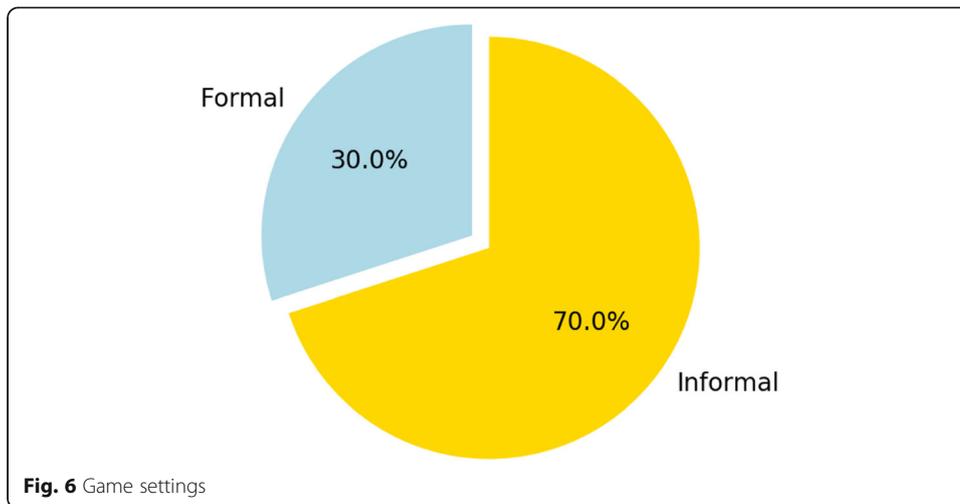


Table 6 Technological Characteristics of EVRGs

ID	Author's Name & Year	Platform	VR Headset	Interaction
1	Tabak et al. (2017)	PC	Not specified	Gaze
2	Szczurowski and Smith (2018)	PC	Oculus Rift	Head movement, gaze
3	Roberto et al. (2017)	PC	Oculus Rift	Head movement
4	Alazba, Al-Khalifa, and ALSobayel (2018)	Mobile	Cardboard	Physical movements
5	Bernardes et al. (2015)	PC	Oculus Rift	–
6	Byl et al. (2018)	PC	HTC Vive	Controllers
7	Mihajlovic et al. (2018)	PC	Oculus Rift	Head movement
8	Calvi et al. (2017)	PC	HTC Vive	Controllers
9	Gyutae et al. (2016)	PC	Not Specified	Wearable sensors, body movements
10	Chittaro and Buttussi (2015)	PC	Oculus Rift	Head movement, Kinect
11	Zielke (2017)	PC	Oculus Rift	Natural user interface (NUI)
12	Dinis et al. (2017)	PC	Not Specified	Game controller, NUI
13	Süncksen et al. (2018)	PC	HTC Vive	Controllers
14	Zikky et al. (2018)	PC	Oculus Rift	Leap motion
15	(Visoottiviseth et al., 2018)	Mobile	Not specified	Gaze
16	Sárkány (2016)	PC	Oculus Rift	Leap motion, gaze
17	(Pirker et al., 2017)	PC	HTC Vive	Teleporting and keypad controller
18	(Trombetta et al., 2017)	PC	Oculus Rift	Kinect
19	Knöte et al. (2016)	PC	Oculus Rift	Gaze
20	Lovreglio et al. (2018)	PC	HTC Vive	Controllers, vibrating seats
21	Vourvopoulos et al. (2014)	PC	Webcam	Gaze
22	Bryan et al. (2018)	PC	HTC Vive	Controllers
23	(Shahab, 2017)	PC	Oculus	Head movement
24	Likitweerawong and Palee (2018)	PC	Oculus Rift	Steering wheel joystick
25	Chin et al. (2018)	PC	Not specified	Joystick, keyboard
26	Moldoveanu (2017)	–	Not Specified	Players body orientation
27	Chiu (2017)	Mobile	Cardboard	Gaze
28	Hafsia et al. (2018)	PC	HTC Vive	Controllers
29	Diez et al. (2016)	PC	Oculus Rift	Controller - gesture movement
30	VRFIWall (2017)	Mobile	VR Headsets	Cardboard, gestures, pointing
31	Alrehaili (2018)	PC	Oculus Rift	Head movement, PC keyboard



the analyzed games were of great variety, we tried to group them under specific themes, to understand which of the tasks or learning goals were deemed VR-appropriate by the researchers. For instance, one-third of the games targeted teaching healthcare-related topics, while a quarter of the games aimed at introducing, training, or enforcing safety measures in various environments (e.g., construction sites, hospitals, or roads). Topics such as biology, physics or astronomy represent a tenth of the surveyed games (represented in Fig. 7 as natural sciences). While topics like language learning, geography, and civil engineering, received minimum interest with one VR game each.

The target audience of the EVRGs depended on the desired learning outcomes. Additionally, the VR games were developed for all levels of formal education, from K-12 to tertiary education students, as well as for lifelong learners who need to acquire some skills to deal with specific health conditions, as illustrated in Table 7.

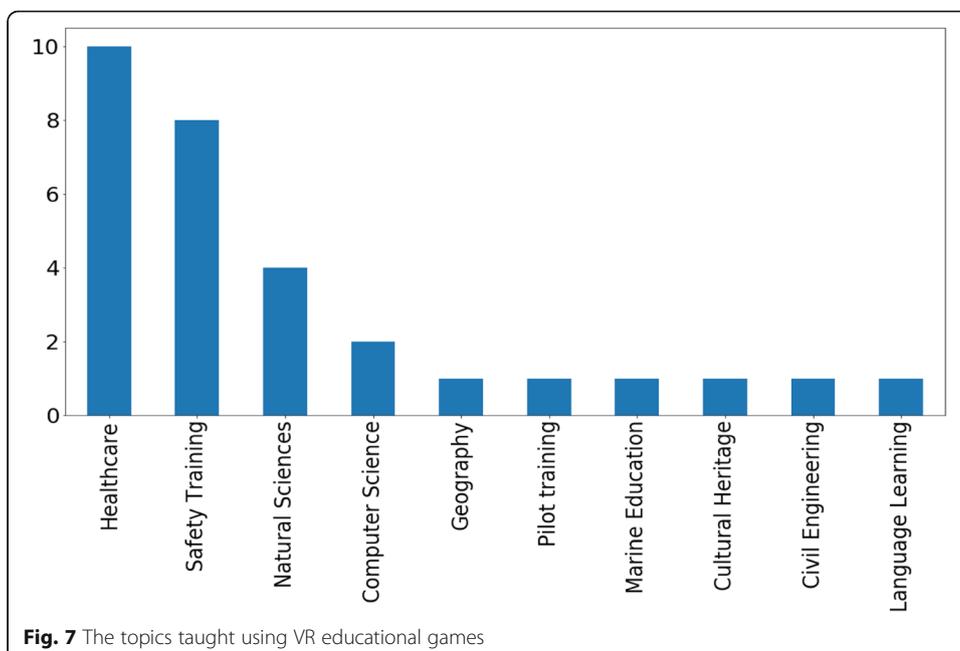


Table 7 Pedagogical characteristics of EVRGs

ID	Author's Name & Year	Subject	Learner	Setting	Research Method	Evaluation
1	Tabak et al. (2017)	Healthcare	Adults	Informal	Qualitative	Think-aloud protocol & interview
2	Szczurowski and Smith (2018)	Road Safety	Children	Informal	Qualitative	Usability test
3	Roberto et al. (2017)	Cultural heritage	students, teachers, and employers	Formal	Mixed method	Survey
4	Alazba et al. (2018)	Exercise game	People with non-specific chronic low back pain	Informal	–	–
5	Bernardes et al. (2015)	Road Safety	ASD patients	Informal	Quantitative	Interface evaluation
6	Byl et al. (2018)	Medical	Medical students	Formal	Mixed Methods	Think-aloud protocol & observation
7	Mihajlovic et al. (2018)	Healthcare	Patients with neck pain	Informal	Quantitative	User study
8	Calvi et al. (2017)	Marine Education	Students & employed	Informal	Presence questionnaire	Questionnaire
9	Gyutae et al. (2016)	Fire evacuation drill	Students & employed	Informal	Quantitative	User experience survey
10	Chittaro and Buttussi (2015)	Safety	Students & employed	Informal	Knowledge test	Between-groups study
11	Zielke (2017)	Medical Training	Medical students	Formal	–	No
12	Dinis et al. (2017)	Civil Engineering	Pre-university students	Formal	Qualitative	Case studies & experience survey
13	Süncksen et al. (2018)	Medical Training	Not specified	Formal	Mixed Methods	Usability survey
14	Zikky et al. (2018)	Astronomy	Students	Formal	–	Questionnaire
15	(Visoottiviseth et al., 2018)	Computer Networks	University Students	Informal	Qualitative	User interface survey
16	Sárkány (2016)	Healthcare	Dementia Patients	Informal	Quantitative	
17	(Pirker et al., 2017)	Physics	Students & employed	Formal	Mixed Methods	Questionnaire & interview
18	(Trombetta et al., 2017)	Healthcare-Rehabilitation	Post-stroke patients	Informal	Quantitative	Questionnaire
19	Knote et al. (2016)	Biology	Not specified	Informal	Not defined	Preliminary evaluation
20	Lovreglio et al. (2018)	Evacuation Training	General Public	Informal	Qualitative	Questionnaire
21	Vourvopoulos et al. (2014)	Healthcare	patients with brain lesion	Informal	Mixed Methods	Experiment and questionnaire
22	Bryan et al. (2018)	Geography	Educators and students	Formal	Quantitative	Questionnaire
23	(Shahab, 2017)	Healthcare	Children with Autism	Informal	Quantitative	Questionnaire
24	Likitweerawong and Palee (2018)	Road Safety	Adults	Informal	Quantitative	User experience
25	Chin et al. (2018)	Pilot training	Adults	Informal	Quantitative	Simulation
26	Moldoveanu (2017)	Healthcare	visually impaired	Informal	Not explicit	Preliminary testing
27	Chiu (2017)	Language Learning	Elementary school learners	Informal	Quantitative	Pre-post test

Table 7 Pedagogical characteristics of EVRGs (Continued)

ID	Author's Name & Year	Subject	Learner	Setting	Research Method	Evaluation
28	Hafsia et al. (2018)	Training application	Construction workers	Informal	Qualitative	User opinion
29	Diez et al. (2016)	Fire safety training	Not specified	Informal	Testing scenario	Preliminary test
30	Puttawong et al. (2017)	Computer Security	University Students	Formal	–	No
31	Alrehailli (2018)	Biology	Children	Informal	Quantitative	Knowledge test and feedback questionnaire

Gaming characteristics of EVRGs

The 31 EVRGs reviewed in this paper differ significantly in the player roles suggested to their users but are mainly dependent on the educational purpose of the tool. Most of the games suggest player roles that are adequate for the tasks the user is being prepared for, in environments similar to those that they will be working on (see Table 8 for several aspects of gaming characteristics). This shows the power of VR in providing learners with a preview of working activities and conditions.

VR facilitates collaborative learning, where many learners can be together in the same virtual world to execute some learning tasks. Only five EVRGs incorporated such a feature in their designs, while 26 games decided to allow only single-player mode. Gameplay-wise, most games suggest the user moves through the virtual world and executes tasks similar to the real-world tasks they are being prepared for, and so games genres like puzzles are quasi-inexistent in the game set that we have reviewed. This study has found that the VR games present the content to be taught as a series of entertaining challenges to the learner in a virtual environment.

Discussion

General overview

The study revealed that the number of articles or literature on emerging VR systems has been increasing since 2012, which indicates the interest VR has gained since its spread in late 2012. The study also revealed many educational topics in which VR has already been applied. A general emphasis was placed on healthcare education by VR researchers, along with a variety of other topics such as biology, computer science, astronomy, and fire training (Sárkány, 2016; Süncksen et al., 2018). VR has the potential to allow users to experience environments that are otherwise inaccessible in a very realistic way. It allows training in environments that would otherwise be hazardous for learners to train in, as is the case for fire training (Diez et al., 2016). It also allows learners to simulate training with expensive hardware on a risk-free yet realistic environment. Despite these affordances and the application of VR unraveled by this study, there appears to be a lack of research on the use of VR for language learning, failing to benefit from the technology in simulating social interactions, which are very efficient in helping learners to practice their language skills effectively.

Another key finding of this research is the absence of any VR educational games on the African continent. While North and South America, Europe, Asia and Australia

Table 8 Gaming characteristics of EVRGs

ID	Author's Name & Year	Player Role	Theme	Mode	Gameplay & Goal
1	Tabak et al. (2017)	Cook	Home environment	Single player	Simulation game
2	Szczurowski and Smith (2018)	Pedestrian	Street, roads	Single player	Manage, RPG
3	Roberto et al. (2017)	Archeologist	Archaeological site	Multiplayers	Serious game, storytelling, and puzzles
4	Alazba et al. (2018)	Goldfish	Sea/underwater	Single player	Simulation (exercise game)
5	Bernardes et al. (2015)	Human/generic	City environment	Single player	Simulation
6	Byl et al. (2018)	Medical Worker	Hospital	Single player	Select, simulation
7	Mihajlovic et al. (2018)	Human/Generic	Sky	Single player	User tracks moving objects in sky
8	Calvi et al. (2017)	Driver of a diving machine	Sea/underwater	Single user	VR dive simulation
9	Gyutae et al. (2016)	Human/generic	Building on fire	Single player	Self-training VR for fire evacuation
10	Chittaro and Buttussi (2015)	Passenger	Plane environment	Single player	VR Simulation
11	Zielke (2017)	Medical Worker	Hospital	Single player	Simulation
12	Dinis et al. (2017)	Civil Engineer	Building internal and external	Single player	Simulation
13	Süncksen et al. (2018)	Medical Worker	Operating room	Single Player	Select, Simulation
14	Zikky et al. (2018)	Student	Space/planets/stars	Multiplayer	Select, Simulation
15	(Visoottiviseth et al., 2018)	Human generic	Forest, city	Single	Educational
16	Sárkány (2016)	Human/Generic	Food table	Single Player	Build, select, RPG
17	(Pirker et al., 2017)	Physicist	Physics lab	Multiplayer	Simulation
18	(Trombetta et al., 2017)	Person doing physical exercise	Beach	Single Player	Exergame
19	Knote et al. (2016)	Biologist	Nature	Single player	Simulation
20	Lovreglio et al. (2018)	Visitor or worker in hospital	Hospital	Single Player	Simulation, manage, select, avoid
21	Vourvopoulos et al. (2014)	Human/Generic	City environment	Single player	Serious game
22	Bryan et al. (2018)	Explorer	Various real-world locations	Single player	Real-world environment
23	Shahab (2017)	Robot	Room with musical instruments	Single player	Play musical instruments
24	Likitweerawong and Palee (2018)	Driver	Inside of a car	Single Player	Move, Simulation
25	Chin et al. (2018)	Driver	Nature	Single Player	Move, Simulation
26	Moldoveanu (2017)	Human/generic	Street/home	Single player	Simulation
27	Chiu (2017)	Customer	Restaurant	Single player	Educational

Table 8 Gaming characteristics of EVRGs (*Continued*)

ID	Author's Name & Year	Player Role	Theme	Mode	Gameplay & Goal
28	Hafsia et al. (2018)	Construction Worker	Construction site	Single Player	Build, avoid, Simulation
29	Diez et al. (2016)	Fireman	Building on fire	Multiplayer	Training fire wardens
30	Puttawong et al. (2017)	Human/Generic	Forest/nature	Single player	Educational
31	Alrehaili (2018)	Bee	Nature/hive	Single Player	Manage, build, select, avoid, RPG

participated in developing EVRGs. The cost of technology seems to affect African countries from benefiting from this promising technology. One solution is to rely on affordable headsets supported by Google Cardboard (Bouali et al., 2019). Still, such headsets suffer from the lack of appropriate interaction hardware that allows users to traverse and interact with the virtual world using only gaze and head movement. Such limitation causes Cardboard-related research to engineer games that require minimum interaction while preserving the targeted learning outcomes.

Technology and gaming

Despite Cardboard being the cheapest VR device, it is the least used technology in the surveyed literature, ranking even lower than the expensive HTC Vive. This raises some questions on the level of adoption of some educational games in real educational contexts, which is not the focus of our study. Nevertheless, the study shows that various games have adopted the use of the Oculus Rift VR, despite being more expensive than Cardboard headsets. Consequently, headsets are not the only problem in VR adoption. This study reveals that interaction is also an issue. In our analysis, we found that most of the games rely on gaze as an interaction mechanism, but this is hardly ever complemented with a natural user interface or interfaces, which facilitate interactions in VR worlds, resulting in the difficulty of using other input devices like keyboards.

Games that target teaching specific skills, such as diving or driving, require more advanced input devices, like Kinect to input body movement or a steering wheel to provide a life-like controller to a vehicle in the virtual world (Calvi et al., 2017; Likitweerawong & Palee, 2018). However, this incurs that such technology can only be afforded by a handful of users, presenting a stumbling block in the adoption of VR games in real-world contexts.

Regarding gaming, most of the gaming environments and contexts were dependent on the real-world context for which the learner is being prepared. This helps in the learning process of the user as it provides him/her with tailored environments that mimic the real world to a higher level of detail. The study also reveals that most of the games developed, allowed only for a single-player mode, failing to benefit from VR's ability to connect learners in virtual worlds. The dominant game genre in the literature is Role Playing Game (RPG), which is adequate given that the learner impersonates the roles they are being trained for in the virtual world.

Pedagogy

The concept of applying digital technology to build a virtual, physical/virtual or hybrid learning environment in which a student experiences a form of play, has emerged over the years and is now gaining acceptance. The puzzle here is that despite the wide variety of VR games developed for different fields (education, healthcare, business, climate, energy, industrial, and financial) only a handful of the games focused on education. Thus, begging the question of why EVRGs have not been widely adopted in mainstream education? Considering the interactive, immersive, and multi-sensory nature of VR, coupled with its growing popularity amongst researchers in psychology, aviation, and cognitive neuroscience, we had expected that even more EVRGs could have been developed and that the technology should have been widely adopted (Alexander et al., 2019). However, there are many reasons for the lack of adoption of EVRGs in mainstream education. One reason is that people tend not to consider VR as a mainstream technology. They perceived that the hype around the technology would lose popularity and be replaced by the reality of the time, in what was called the 'trough of disillusion' (Linden & Fenn, 2003). Additionally, there seems to be a lack of know-how by learning technologists and experts on how to design learning solutions with VR. Furthermore, the costs of implementing EVRG for large-scale adoption across educational curricula constitute a limiting factor for adoption in mainstream education (Alexander et al., 2019) and health-related issues.

Christou (2010) states that the three categories of formal and informal educational application areas of VR are used to improve core curriculum subjects such as the applications for edutainment, demonstrations, cultural heritage and museum experiences, as well as an application for training. Our analysis of the pedagogical contributions of EVRGs indicated a considerable variation among the subjects that were implemented. For example, the trend of EVRGs in this study showed that 32% of the applications were developed to support medical education. In contrast, only 3% was implemented to support subjects that involve the concretization of abstract concepts such as physics and geography.

Although the learners in these studies balanced well amongst children, youth and adult learners, there are obvious variations amongst the type of learners about the kind of EVRGs. For example, most learners could have medical conditions such as patients with neck or back pain, dementia, autism spectrum disorders, post-stroke conditions, brain lesions, and visual impairment. Translating clinical procedure into EVRGs to facilitate learning and future implementation of the procedure by caregivers and patients constitute the main interest in developing medical EVRGs (Heuven et al., 2017; Mihajlovic et al., 2018). Simulating the medical procedure offer motivation, engagement, and positive learning experience among EVRGs users (Trombetta et al., 2017). Having examined an essential pedagogical attribute, of the context of the learner in this study, we noticed that the learning context for most EVRGs falls within the informal settings. As several EVRGs are developed to provide particular training solutions to the user, the informality of the setting tends to overshadow the necessity of a classroom environment (formal setting).

Limitations of this study

The limitations of this study include:

- i. The study focused on EVRGs in the educational domain without considering other uses in other facets within the gaming industry.
- ii. The study did not consider cross-cultural usage of the EVRGs, such as articles published in languages other than English.

Conclusion

Several studies have shown that the most critical value that VR adds to existing technology is the sense of immersivity in a virtual world built around the user. In education, it is theoretically crucial for learners to experience real-world scenarios from a first-person perspective compared to traditional two-dimensional (2D) screens which usually offer learners the chance to traverse the world from a third-person perspective, usually using an avatar. “Virtual Reality” as a concept, reveals some ambiguity as some of the research we surveyed referred to it as desktop VR, while others use the term to mean immersive VR. However, the inclusion criteria we developed focused on working on systems that immerse users into a virtual world rather than research that suggests a virtual world on a desktop screen.

Virtual reality, augmented reality, and mixed reality are rapidly evolving phenomena in the educational landscape. Literature has shown the positive impacts that these adaptive and immersive technologies could have on students learning when applied in the gaming contexts. The essence of this study was to contribute new knowledge using analysis and synthesis of research articles that focused on the EVRGs in different contexts. The study explores the trends of EVRGs and relevant characteristic attributes that make effective learning such as technology, pedagogy and gaming. Besides, this study considers the learning content and the technology to be the critical aspects of the transactions that go with the teaching and learning process in terms of the pedagogy.

Moreover, the review focused on the application of VR as a gaming technology, with the learner fully immersed in the environment. In the final analysis, the review exposed a growing trend of research in EVRGs studies since 2012 to 2018, while also revealing the application of VR in the sciences, healthcare and technology education spheres having the most significant attention. The mainstream education and arts (such as languages) gained the least interest of educators using VR. This scenario offers the opportunity for further research in the educational contexts with emphasis on the arts and humanities disciplines. It is therefore pertinent that through this systematic review, technology-mediated learning will be enhanced when there is a clear understanding of the trends concerning its application in the different domains of learning.

Abbreviations

ICT: Information and Communication Technology; VR: Virtual Reality; AR: Augmented Reality; MR: Mixed Reality; EVRGs: Educational Virtual Reality Games; RPG: Role Playing Game; 2D: Two-Dimension; 3D: Three-Dimension; PC: Personal Computer; NUI: Natural User Interface; HMD: Head Mounted Device; UEF: University of Eastern Finland; MS Excel: Microsoft Excel; ACM: Association for Computing Machinery; IEEE: Institute of Electrical and Electronics Engineers

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Authors' contributions

The first author made substantial contributions to the conception and design of the work. The author was involved in the acquisition, analysis, and interpretation of Google scholar data for the work. The author was involved in the drafting the methodology, discussion and conclusion part of the work and revising it critically for important intellectual content. The author was responsible for making final approval of the manuscript to be submitted for review. The second author made substantial contributions to the design of the literature review process. The author was involved in the acquisition of data from IEEE database, analysis, and interpretation of data for the work. The

author was involved in the drafting of the result and discussion section of the work and revising it critically for important intellectual content. The third author made substantial contributions and participated in data searching in ScienceDirect database, collection and analysis, writing and reviewing the article. The author was involved in the drafting of some aspect of the literature review section of the work and revising it critically for important intellectual content. The fourth author made substantial contributions to the design of the literature review process. The author was involved in the acquisition of data from Google scholar database, analysis, and interpretation of data for the work. The author was involved in the drafting of the result and discussion section of the work, proofreading, and revising it critically for important intellectual content. The fifth author made substantial contributions and reviewed articles related to ACM database within the scope of the systematic review. The author was involved in drafting some aspects of the literature review section. The author was also responsible for analysis, and interpretation of data for the work and edited some portions of the manuscript and drafted the conclusion as well as the abstract. The sixth author made substantial contributions and participated in data searching in IEEE database, collection and analysis, and reviewing the article. The author was involved in the drafting of some aspects of the literature review section of the work and revising it critically for important intellectual content. General note: It is important to mention here that the manuscript went through circles of reading, proofreading and editing by all the authors. The authors' read and approved the final manuscript.

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Author details

¹University of Eastern Finland, School of Computing, Joensuu, Finland. ²Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, Enschede, NB 7522, The Netherlands. ³Department of Education, University of Oslo, Oslo, Norway. ⁴University of the Witwatersrand, Johannesburg, South Africa. ⁵Usmanu Danfodiyo University, Sokoto, Nigeria. ⁶Crown Hill University, Eiyekorin, Ilorin, Kwara State, Nigeria.

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