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DEVELOPMENT ARTICLE

Virtual reality and gamification in education: a systematic review

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Abstract
This study aims to analyze the use of virtual reality and gamification in education by examining the existing literature. In addition to virtual reality, this study focuses on gamified virtual reality learning environments which refer to virtual reality learning environments that integrate gamification elements and mechanisms. Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, a systematic literature review was carried out. No limitations were set regarding educational level, type of study, subject, and publication year. The related articles were retrieved from 5 databases (ERIC, Google Scholar, IEEE, SCOPUS, and Web of Science). A total of 112 articles were included, 16 research questions were explored, and a thematic analysis was conducted. To evaluate the quality of the articles included, the Mixed Methods Appraisal Tool (MMAT) was used. According to the findings, gamification and virtual reality support several pedagogical theories and approaches. Their adoption to and integration into education can enrich and transform traditional teaching and learning and were assessed positively by students and teachers. Gamification elements significantly affected students' achievements. In comparison to traditional learning environments, gamified virtual reality learning environments were more motivating, engaging, and interactive and offered more opportunities for personalized and collaborative learning. Through the realistic and interactive experiences offered, students' immersion and social presence can be enhanced, knowledge acquisition can be improved, and material comprehension can be facilitated. Positive changes in student attitude, behavior, and mentality as well as improved cognitive, physical, and social–emotional development were observed. When using learning environments that integrate both virtual reality and gamification, students' learning outcomes, motivation, engagement, and self-efficacy were increased. Additionally, students' academic performance, active involvement, and satisfaction were improved. Students' curiosity, imagination, focus, and interest were enhanced and their skills and competences were developed. Finally, gamified virtual reality emerged as an effective educational tool that can improve learning at all educational levels, subjects, and contexts.

Keywords Educational technology · Virtual reality · Gamification · Education · Extended reality · Learning technologies · Immersive technologies · Technology-enhanced learning · Digital games

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Introduction

The emergence of modern technological applications and their adoption in educational settings have challenged the effectiveness of traditional educational systems, approaches, and methodologies to meet the new educational and societal requirements and satisfy students' demands for more active, engaging, and insightful learning (de Castro & García-Peñalvo, 2022; DiLullo et al., 2011). In the context of Education 4.0, the adoption and integration of technology-enhanced learning are imperative (Bayne, 2014; Hussin, 2018). As the integration of novel technologies and applications in the education process becomes more common, ineffective practices and approaches are being substituted (Hughes et al., 2006; Zawacki-Richter & Latchem, 2018).

To provide high quality education, the educational processes should adapt to the needs of digital native students and take their habits, knowledge, personality traits, competences, and interests into account (Prensky, 2001; Robinson et al., 2013). Additionally, when students play an active role in teaching and learning activities and participate more eagerly and willingly, improved learning outcomes can be yielded (Rupp et al., 2019). The use of Extended Reality (XR) technologies in education is gaining ground as they can satisfy the new educational demands and students' requirements (Lampropoulos et al., 2022). Due to their interactive and immersive nature, XR technologies can assist in developing new pedagogical approaches, lead to more meaningful learning, promote lifelong learning, and create learning environments that students find more enjoyable, intriguing, motivating, and engaging (Beck, 2019; Calvet et al., 2019). XR technologies are composed of Mixed Reality (MR), Virtual Reality (VR), and Augmented Reality (AR) with VR being closer to the virtual environment while AR closer to the physical environment (Milgram & Kishino, 1994). These technologies provide users with a sense of immersion and aim at creating an MR in which the simultaneous existence of both real and digital objects is feasible, the human sense perceptions are substituted with ones that are created by computers, and the borders between the perceived virtual and real environments become blurred (Schmalstieg et al., 2002; Slater & Sanchez-Vives, 2016; Suh & Prophet, 2018). Additionally, gamification is a novel approach that can be combined with XR technologies to enrich and improve the teaching and learning activities (Lampropoulos et al., 2022). Gamification can transform traditional education by incorporating game mechanisms and elements into its processes to create more absorbing, fun, motivating, and interesting learning environments and experiences that promote inclusion and student-centered learning (Majuri et al., 2018; Nah et al., 2014; Pozo-Sánchez et al., 2022).

Even before the COVID-19 pandemic the educational domain had to address the new demands that were brought about by the digitalization of everyday life through adopting and incorporating new approaches, methods, and technological applications as well as transforming and enriching teaching and learning activities (Burbules & Callister, 2018). This fact was further amplified due to the pandemic (Ratten & Jones, 2021). Both gamification and virtual reality share a number of similarities which enable them to be used in conjunction. Particularly, the integration of gamified virtual reality learning environments in educational settings can offer various benefits. Their use can potentially help meet the new educational demands, enrich the educational process, improve learning achievements, and assist toward the materialization of the digital transformation of education.

Despite the interest and the studies regarding the educational use of virtual reality and gamification being increased (Martí-Parreño et al., 2016; Rojas-Sánchez et al., 2022; Swacha, 2021), little is known about their impact and effectiveness when they are combined.

Therefore, this study aims at examining the use of gamified virtual reality learning environments through a systematic literature review. Specifically, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was followed and no limitations were set regarding the educational level, subject, and publication year. The below-mentioned research questions (RQ), which are based on the study of Lampropoulos et al. (2022), have been set to be explored and answered:

- RQ1: What benefits are brought about when incorporating virtual reality and gamification into the educational process?
- RQ2: How are the related studies distributed among empirical studies, proposal and prototype papers as well as review, conceptual, and theoretical articles?
- RQ3: Which are the countries which conducted the most studies related to the topic?
- RQ4: What is the distribution and frequency of publications throughout the years?
- RQ5: What are the main findings of the related studies?
- RQ6: Which is the educational level that more widely adopted the use of virtual reality and gamification?
- RQ7: What most studies focus on regarding students' development?
- RQ8: What is the most commonly used sample in the related studies?
- RQ9: Which are the main objectives and aims of the related studies?
- RQ10: What are the main areas, topics and subjects the use of virtual reality and gamification is more widely studied and applied in?
- RQ11: Which instruments, research methods and categories, variables, and measures are mostly used to examine the given topic?
- RQ12: Which development tools, methodologies, and operating systems are mostly used to develop gamified virtual reality applications for educational purposes?
- RQ13: Which are the most commonly used devices to carry out the experiments?
- RQ14: What degrees of freedom (dof) and representation are used within the gamified virtual reality applications in education?
- RQ15: Which are the most widely used gamification mechanisms and elements in gamified virtual reality applications in education?
- RQ16: Do the main findings of the different types of studies examined lead to the same conclusions?

Virtual reality in education

Virtual reality aims at immersing users in real or virtual environments and experiences which perceptually surround them and are generated through computational units to simulate their physical presence within them (Lampropoulos et al., 2020). More specifically, virtual reality is mainly characterized by the elements of interaction, immersion, immediacy, involvement, and presence (Freina & Ott, 2015; Psotka, 1995; Ryan, 2015; Sherman & Craig, 2003), uses computational systems to create "*all-inclusive, sensory illusion of being present in another environment*" (Biocca & Delaney, 1995, p. 63), and capitalizes on social and psychological aspects and processes to make users perceive these virtual environments and experiences as real (Blascovich & Bailenson, 2011).

The interdisciplinary nature of virtual reality, which arises from the field of computer science, allows it to be applied in several domains (Rashid et al., 2021), including education in which it is gaining more ground as an immersive, interactive, and useful teaching and learning tool (Hu-Au & Lee, 2017; Martín-Gutiérrez et al., 2017; Radianti et al., 2020), as it contributes toward more engaging (Annetta et al., 2009) and meaningful learning (Huang et al., 2010). The recent advances and the lower cost of digital devices and equipment have facilitated the adoption of virtual reality even further (Olmos et al., 2018).

Virtual reality impacts students' affective domain, social interactions, and learning outcomes (Hew & Cheung, 2010). Additionally, it can be used in educational settings in a variety of ways, such as face-to-face, distance, and blended learning, as it creates safe, immersive, and unique environments that support various teaching and learning styles, increase involvement and motivation, and enable real-time communication and interaction between educators and learners even in cases in which traditional learning would not have been feasible (Bronack et al., 2006; Dalgarno et al., 2011; Dickey, 2005; Fan et al., 2015; Freina & Ott, 2015; Han, 2020). Within these safe, interactive, and controlled environments, students experience experiential learning and practice complicated and demanding tasks to develop their cognitive skills (Çaliskan, 2011; Hamilton et al., 2021).

Moreover, as virtual reality promotes autonomous decision-making (Martí-Parreño et al., 2016a) and enables the representation of abstract concepts in a tangible manner, it enhances the overall learning process (Persky & McBride, 2009). Specifically, virtual reality improves students' motivation (Garris et al., 2002), interactivity, and active participation (Roussou, 2004) and enhances knowledge acquisition and retention for the students who adapt better at kinesthetic, visual or auditory learning (Leite et al., 2010). When combined with experiential and project-based learning, virtual reality can boost students' soft skills, communication capabilities and academic performance, enhance their critical and reflective thinking and knowledge dissemination and increase their psychomotor, cognitive, and social-emotional skills development and enjoyment (Araiza-Alba et al., 2021; Halabi, 2020; Jensen & Konradsen, 2018).

By embodying design principles that capitalize on gesture, voice, and hand controls (Johnson-Glenberg, 2018) in virtual environments, allowing students to interact with multimedia lessons and acquire knowledge easily and intuitively (Parong & Mayer, 2018) and combining various instructional techniques, the overall educational effectiveness and experience can be enhanced and applied in several educational levels, contexts, and subjects (Bowman et al., 1999). As a result, and due to the immersiveness and interactivity that virtual reality offers, it can lead to increased learning outcomes when compared to only instructor led teaching (Bailenson et al., 2008; Bowman et al., 2009; Webster, 2016). Despite this fact, teachers' role is crucial in order for immersive technologies to be effectively applied within educational settings. Virtual reality enriches teacher education programs and provides future learning opportunities (Billingsley et al., 2019). Specifically, virtual reality can help fill in the gaps of training pre-service teachers by exposing them to various teaching and learning experiences and environments and enabling them to practice and hone their skills in fully controlled and safe environments (Christensen et al., 2011).

Several recent systematic literature review, overview, scientific mapping, meta-analysis, and bibliometric studies have examined the use of virtual reality in different educational levels and contexts (Cheng et al., 2022; Freina & Ott, 2015; Kavanagh et al., 2017; Luo et al., 2021; Radianti et al., 2020; Rojas-Sánchez et al., 2022; Villena-Taranilla et al., 2022) as well as the use of virtual reality head-mounted displays in educational activities (Jensen & Konradsen, 2018). Virtual reality can bring about positive learning behaviors and attitudes and through the hands-on experiences it offers, it supports effective learning experiences in both K-12 and higher education contexts (Natale et al., 2020) as it creates new opportunities to enrich students' learning, support diverse teaching approaches and enhance students' stimuli and motivation (Araiza-Alba et al., 2022). Consequently, virtual reality can be effectively applied in numerous educational settings and subjects (Merchant et al., 2014), such as science, technology, engineering, art, and mathematics (STEAM) (Birt & Cowling, 2017), chemistry (Edwards et al., 2019; Jiménez, 2019), physics (Bogusevschi et al., 2020), biology (Lee et al., 2010), mathematics (Kaufmann et al., 2000), geometry (Kaufmann & Schmalstieg, 2006), geography (Šašinka et al., 2018), language learning (Blyth, 2018), environmental science (Markowitz et al., 2018), geology (Klippel et al., 2019), engineering (Abulrub et al., 2011; Halabi, 2020), communication skills (Shorey et al., 2020), medical and healthcare (Pears et al., 2020; Yiannakopoulou et al., 2015), nursing and midwifery (Fealy et al., 2019), vocational designing (Kim et al., 2020), etc.

Gamification in education

Gamification can be applied in several contexts and has become a multidisciplinary field of study (Nacke & Deterding, 2017). Gamification is related to gameful experiences, gamefulness, and games in general, and it integrates the game elements, mechanisms, and principles that lead to games being fun, challenging, interesting, and engrossing into contexts that are not related to games to improve end-users' engagement, motivation, and experience (Deterding, 2012; Deterding et al., 2011; Seaborn & Fels, 2015). As active methodologies are at the core of gamification and since game designs and theories capitalize on the psychological theoretical backgrounds of learning, the adoption and incorporation of gamification in educational settings to improve students' learning outcomes, engagement, and experiences was anticipated. (Bai et al., 2020; Cechetti et al., 2019; Landers, 2014). Due to its nature, gamification can make the learning experience more interactive and entertaining and enhance students' interest in the learning subjects, their involvement, self-efficacy, engagement, focus, and motivation and encourage them to achieve better academic outcomes (Bouchrika et al., 2019; Kim et al., 2017; Yildirim, 2017). The motivational elements of gamification can result in desired student behaviors and enhanced psychological states (Hamari et al., 2014; Hanus & Fox, 2015; Palomino et al., 2019).

Recent studies have gone over the merits, challenges, and limitations of adopting and integrating gamification in education (de Borges et al., 2014; Dicheva et al., 2015; Huang et al., 2020; Majuri et al., 2018; Manzano-León et al., 2021; Martí-Parreño et al., 2016; Nadi-Ravandi & Batooli, 2022; Nah et al., 2014; Sailer & Homner, 2019; Subhash & Cudney, 2018; Swacha, 2021). Gamification is an effective didactic approach that enriches the traditional education process and can bring about new potentials owing to its ability to be used in conjunction with other approaches and technologies (O'Donovan, 2012; Sanchez et al., 2011). Due to the benefits gamification could bring in education, studies have been conducted across all educational levels and in several subjects (Lampropoulos et al., 2022). Many studies have put emphasis on science, technology, engineering, art, and mathematics (STEAM) related subjects (López et al., 2021; Ortiz et al., 2016), such as physics (Rose et al., 2016), chemistry (Chans & Castro, 2021; Mellor et al., 2018), mathematics (Jagušt et al., 2018; Lo & Hew, 2018), geometry (Kamalodeen et al., 2021), and astronomy (Barringer et al., 2018). Other studies have focused on natural science (Rivas et al., 2019), environmental science (Jung, 2017; Ouariachi et al., 2020), and geography (Mahat et al., 2021). Particular interest has been shown in medical and healthcare education (Ang et al., 2018; McCoy et al., 2016; Nevin et al., 2014; Sandrone & Carlson, 2021), history and cultural heritage education (Bonacini & Giaccone, 2021; Moseikina et al., 2022), and language learning (Dehganzadeh & Dehganzadeh, 2020; Dehghanzadeh et al., 2019). Gamification has also brought about positive learning outcomes in music education (Gomes et al., 2014), sports and physical education (Fernandez-Rio et al., 2020; Ferriz-Valero et al., 2020) as well as vocational education (Jayalath & Esichaikul, 2020).

Methodology

After having analyzed the theoretical background of this study, it is important to present the methodology used. As this is a systematic literature review, it is essential for all the steps followed and choices made to be clearly displayed and analyzed to ensure the reproducibility of the process and results. Hence, this section presents the research design followed and goes over the literature review process.

Research design

A systematic literature review following the PRISMA statement (Page et al., 2021) was conducted to address the aims of this study and the aforementioned research questions. This approach was selected due to the scope and nature of the specific study as it examined empirical studies, proposal and prototype papers, as well as review, conceptual and theoretical articles. Due to its high standards, its rigorous rules, and its being successfully implemented and validated in diverse contexts and topics, the well-established PRISMA statement was adopted (Higgins et al., 2019; Liberati, 2009; Webster & Watson, 2002).

A thorough combination of keywords and five databases, that is ERIC, Google Scholar, IEEE, SCOPUS, and Web of Science (WoS), were used to retrieve related to the topic documents. The databases which had the most related and accurate documents were SCOPUS and WoS which further justifies their being considered as highly impactful scientific databases (Mongeon & Paul-Hus, 2015; Zhu & Liu, 2020).

Systematic literature review process

Aiming at covering the literature around this interdisciplinary topic, a thorough search formula was used which involved studies of all educational levels, types, and subjects throughout the years. As a result, the following query which integrates logical operators and wildcards was utilized: "('virtual reality' OR 'vr') AND ('gamif*') AND ('college*' OR 'education*' OR 'learn*' OR 'pupil*' OR 'school*' OR 'student*' OR 'teach*' OR 'universit*')". The query searched in the title, abstract, and keywords parameters (topic) of the related documents of the ERIC, IEEE, SCOPUS, and WoS databases. In the case of Google Scholar, the operator "allintitle" was used in combination with the keywords in succession (e.g., 'virtual reality' AND 'gamification' AND 'college,' 'virtual reality' AND 'gamified' AND 'students', etc.).

Figure 1 depicts the whole process and steps taken which adhered to and followed the PRISMA statement guidelines and rules. A total of 950 related documents were initially reported in the five databases (21 in ERIC, 39 in Google Scholar, 157 in IEEE, 492 in SCOPUS, and 241 in WoS) on 1st of August 2022. Of these documents, 270 duplicates were identified and removed. Therefore, a total of 680 documents were screened. To minimize subjective judgments, inclusion criteria were established by both authors. More specifically, the main inclusion criteria set were for each study: (i) to use virtual reality and gamification elements in conjunction; (ii) to refer to education or educational contexts;

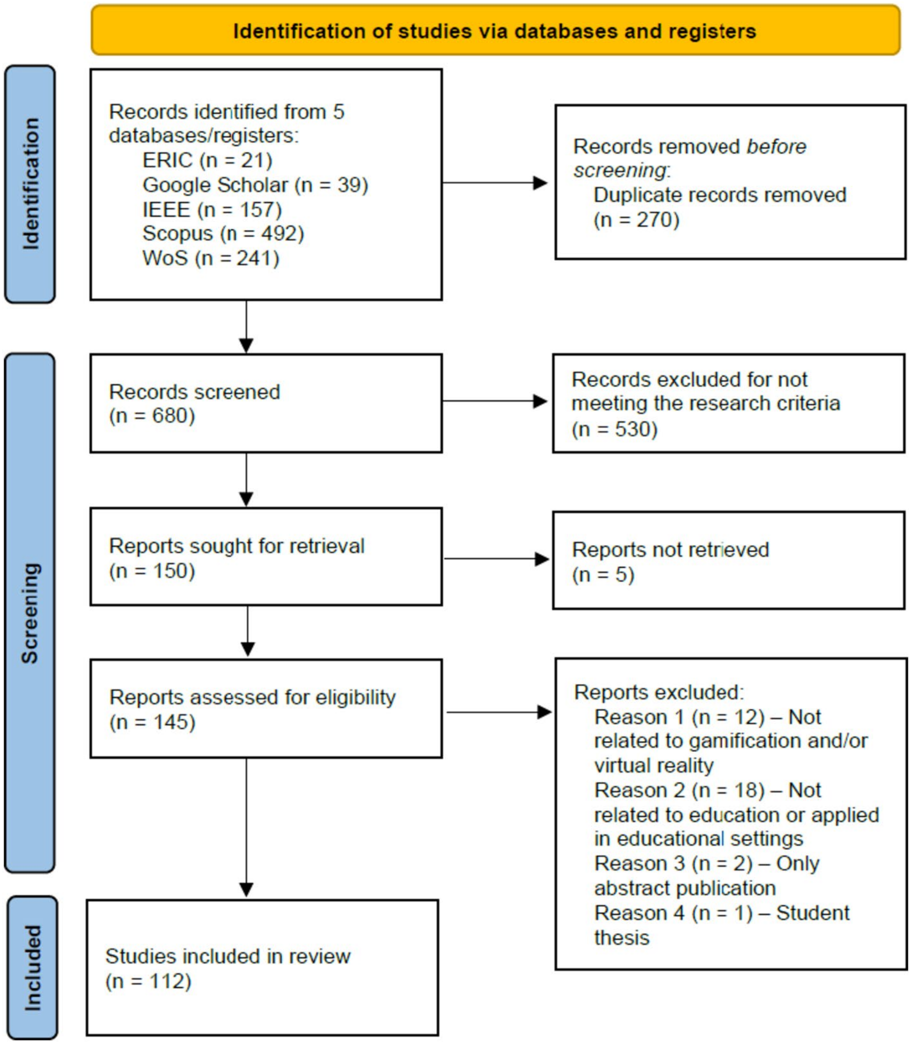

Fig. 1 Flow diagram of the PRISMA statement

and (iii) to involve either an empirical study, the development of an educational application, a proposal or prototype, a systematic review, overview, or theoretical contributions. Both researchers of this study have independently screened the 680 documents based on the inclusion criteria set and focusing on the title, abstract, and keywords of the documents. After having completed this process, the researchers compared their results and resolved any disagreements through consensus between them. This process was selected to improve the reliability of the review and the outcomes.

Following this process, 530 documents were not included in the study as they did not conform to the research criteria. The remaining 150 documents were sought for retrieval and except for 5, the rest (145) were successfully retrieved. The eligibility of the remaining 145 documents was examined. Specifically, the researchers reviewed the method section of each study to further verify it meeting the inclusion criteria and the purposes of this study. Due to their not complying with the research criteria set, 33 more documents were eliminated. As a result, this review involves and examines 112 studies. An objective data extraction form was used. The specific kind of form was selected to minimize the threat of missing relevant information and of subjective interpretation. Additionally, the form was used by both researchers and the extracted information was cross-validated.

These specific studies were grouped into the following categories: (1) Empirical studies (66 articles, 58.93%); (2) Proposal and prototype papers (design-oriented without being applied in educational contexts) (31 articles, 27.68%); and (3) Review, conceptual and theoretical articles (15 articles, 13.39%) (RQ2). The area of focus, aims, suggestions, and main findings of the proposal and prototype articles were looked into. The review, conceptual, and theoretical articles were examined and their main findings were analyzed and presented. Finally, for the empirical studies, the following variables were identified and analyzed: (1) Country of experiment conduct; (2) Educational level; (3) Area of focus; (4) Developmental category; (5) Sample; (6) Main aims; (7) Research methodology; (8) MMAT category; (9) Main variables; (10) Measurement - Research instruments and tools; 11) Measures; 12) Application name; 13) Application development methodology; 14) Development tools; 15) Operating system; 16) Devices used in the experiment; 17) Degrees of freedom (DoF); 18) Representations; 19) Gamification elements; and 20) Main findings.

It is worth noting that due to the nature of this study, studies that adopt qualitative, quantitative, and mixed methods approaches are included within the Empirical studies category. Therefore, to further examine the studies included in this systematic review and more rigorously evaluate their quality, the Mixed Methods Appraisal Tool (MMAT) systematic assessment tool was used (Hong et al., 2018). This particular tool includes methodological criteria and five core quality criteria for each of the five categories in which it divides Empirical studies based on their study design. These categories are: (i) Qualitative, (ii) Randomized controlled, (iii) Non-randomized, (iv) Quantitative descriptive, and (v) Mixed methods (Hong et al., 2018).

Results

To analyze the data, a mixed-method research approach was followed (Creswell & Clark, 2017). The results are categorized into empirical studies (Tables 1, 2, 3 and 4), proposal and prototype papers (Table 5), and review, conceptual, and theoretical articles (Table 6). Figure 2 presents the countries in which the experiment and/or the study were conducted as well as the frequency of each type of study.

The complete results of the countries in which the studies took place are displayed in Fig. 2, both as the total number of published documents and based on their categories. Spain, Germany, the United States, Peru, and the United Kingdom were the countries that conducted most empirical studies. The countries that mostly contributed with proposal and suggestion papers were: Greece, Germany, Brazil, Malaysia, and Romania. Portugal and the United Kingdom were the two countries that contributed the most with review, conceptual, and theoretical articles. When taking all types of studies into consideration, Spain, the United Kingdom, Germany, Greece, and the United States were the countries that conducted the most studies on the use of gamification and virtual reality in education (RQ3). The publication frequency and type of study of each year are depicted in Fig. 3.

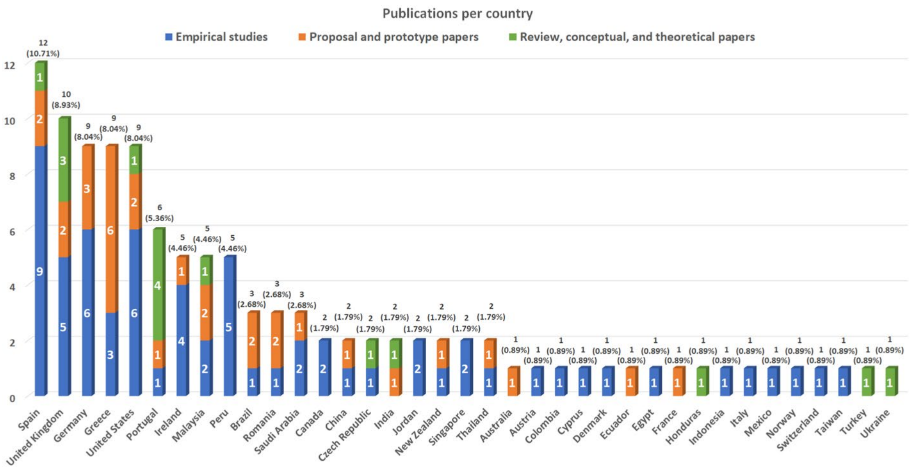

Fig. 2 Countries in which the experiments/studies were conducted

The years 2019, 2020, and 2022 were the ones with the highest numbers of related publications (RQ4).

Due to the volume of studies explored and the variables analyzed, the data is grouped and presented into four tables. Table 1 displays the empirical study basic information (e.g., country, educational level, area of focus, developmental category, sample, and aims). The information related to the research approach (e.g., research method, main variables, and measurement-research tools) is presented in Table 2. The information concerning the developed application or system as well as the gamification mechanisms used (e.g., application name, development tools, operating system, device, and gamification elements) is depicted in Table 3. It must be mentioned that in Table 3 when there is only the indication "game-like features and mechanisms" in a study, it refers to the fact that a virtual reality game that entails gamification aspects was used but the specific gamification elements identified in other studies were not implicitly mentioned in the text or shown within the figures of the corresponding studies. Nonetheless, based on the inclusion criteria and scope of this study, such studies are deemed appropriate for inclusion as they combine virtual reality with gamification and are applied in educational settings. Finally, the main findings of each study are presented in Table 4 (RQ5).

Several observations can be made based on the aforementioned information. Higher education (71.21%) was by far the educational level that most studies focused on, followed by secondary education (10.61%). Primary education (4.55%) and K-12 (3.03%) had fewer related studies. In total, 7 studies (10.61%) did not specify a particular age group or educational level. Figure 4 presents the information related to the educational level that the studies focused on (RQ6). As shown in Fig. 5 (RQ7), increasing student cognitive development (93.94%) was the main focus of the experiments while fewer studies put emphasis on student cognitive and social-emotional development (4.55%) and physical development (1.52%).

Furthermore, the experiment sample consisted mostly of students, but there were also studies that explored the attitude, experience, and views of teachers (RQ8). The goal of most studies was to provide students with an interactive, fun, and interesting learning environment to improve their learning experience and outcomes and enhance their engagement

Table 1 Empirical studies: General information

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Villagrasa et al., 2014a)	Spain	Higher education	Arts	Cognitive	65 university students	To present the benefits of integrating gamification and virtual reality in Engineering and Architecture classes.
(Grivokostopoulou et al., 2016)	Greece	Higher education	Computer science (Programming)	Cognitive	44 university students	To explore the effectiveness and motivational aspects of using gamified virtual reality environments to support artificial intelligence search algorithms learning.
(Reitz et al., 2016)	Germany	–	Language learning (English)	Cognitive and social–emotional	26 participants	To present and evaluate the impact of a cooperative application that uses virtual reality and gamification to enhance students' authentic language acquisition and training.
(Vagg et al., 2016)	Ireland	Higher education	Medical education	Cognitive	5 university students	To showcase a gamified virtual reality application that aims at supporting medical students' learning and training.
(Zhang et al., 2016)	Ireland	Higher education	Language learning (English)	Cognitive	8 university students	To demonstrate a gamified virtual reality application that aims at increasing students' engagement and language learning.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Becerra et al., 2017)	Peru	Higher education	Physics	Cognitive	University teachers	To showcase and assess a gamified virtual reality application that aims at increasing students' motivation and improving Physics learning.
(Fonseca et al., 2017a)	Spain	Higher education	Architecture	Cognitive	75 university students	To explore the use of virtual reality and gamification as an educational tool that supports Architecture learning.
(Stigall & Sharma, 2017)	United States	Higher education	Computer science (Programming)	Cognitive	20 university students	To discuss the process of designing, developing, testing, and assessing a virtual reality instructional module that uses gamification elements.
(Wang, 2017)	China	Secondary education	History	Cognitive	20 high school students	To highlight the benefits of integrating gamified virtual reality exhibitions in History learning.
(Wilson et al., 2017a)	United Kingdom	Higher education	Medical education	Cognitive	15 university students	To showcase and assess a gamified virtual reality application that aims at improving medical students' learning and training.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Wilson et al., 2017b)	United Kingdom	Higher education	Ophthalmology	Cognitive	15 university students and 8 teachers	To present and evaluate an application that uses virtual reality and gamification to improve ophthalmology training.
(Besoain et al., 2018)	Spain	Higher education	Biology	Cognitive	8 university students	To present a virtual reality experience that uses gamification to improve Biology learning.
(Bryan et al., 2018)	Ireland	Primary education	Astronomy	Cognitive	53 primary education students and teachers	To present a gamified virtual reality application that uses real–life environments to increase students' learning motivation and engagement.
(Edwards et al., 2019)	Malaysia	–	Chemistry	Cognitive	13 participants	To showcase an immersive virtual reality system that aims at supporting teaching and learning of organic chemistry.
(Gonzalez & Garnique, 2018)	Peru	Higher education	Medical education	Cognitive	30 university students	To present a gamified virtual reality simulation and assess its use as a learning tool for medical students.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Nicola et al., 2018)	Romania	Higher education	Computer science (Programming)	Cognitive	30 university students	To present and assess a virtual reality application that uses gamification elements to increase students' learning interest and interactivity and support the learning of sorting algorithms.
(Šašinka et al., 2018)	Czech Republic	Higher education	Geography	Cognitive and social-emotional	12 university students	To investigate how immersive virtual reality environments and gamification elements affect students' social and cognitive aspects and geography competence development.
(Stranger-Johannessen, 2018)	Norway	Primary education	Mathematics	Cognitive	116 primary education students	To demonstrate and evaluate the effectiveness of a gamified virtual reality application for Mathematics learning.
(Suncksen et al., 2018)	Germany	Higher education	Medical education	Cognitive	50 participants	To showcase a gamified virtual reality simulation for medical students' training.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(AlKhateeb et al., 2019)	Saudi Arabia	Secondary education	Tajweed	Cognitive	20 secondary education students	To demonstrate a virtual reality application that uses game mechanisms to support and improve students' knowledge of Tajweed.
(Almousa et al., 2019)	Canada	–	Cardiopulmonary Resuscitation Training	Cognitive	10 participants	To present a gamified virtual reality application that supports cardiopulmonary resuscitation training.
(Garcia et al., 2019)	United States	–	Language learning (Spanish)	Cognitive	4 participants	To present and evaluate a virtual reality application that aims at improving Spanish language learning.
(Gordon et al., 2019)	United States	Higher education	Word learning - vocabulary	Cognitive	27 university students	To present and assess the impact of a gamified virtual reality application on vocabulary building.
(Grivokostopoulou et al., 2019a)	Greece	Higher education	Entrepreneurship education	Cognitive	86 university students	To present the design and evaluation of an immersive virtual reality environment that uses game mechanisms to support the efficiency of learning activities.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Huaman et al., 2019)	Peru	Higher education	Arts	Cognitive	15 university students	To demonstrate the merits of using gamified virtual reality environments in the History of Art learning.
(Iquira et al., 2019)	Peru	Higher education	Physics	Cognitive	86 university students	To demonstrate and assess the effect of immersive virtual reality and gamification on physics learning in mobile learning environments.
(Makled et al., 2019)	Egypt	Higher education	Medical education	Cognitive	8 university students	To showcase and evaluate the effectiveness of virtual reality and gamification in medical students' training.
(Makransky et al., 2019)	Denmark	Higher education	Genetics	Cognitive	208 university students	To investigate the impact of a desktop-based virtual reality application that incorporates gamification elements on laboratory simulation in the field of genetics.
(Molloy et al., 2019)	New Zealand	Higher education	Music	Cognitive	23 university students	To explore the potential of integrating gamified immersive technologies in music education.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Oberhauser & Lecon, 2019)	Germany	Higher education	Computer Science (Programming)	Cognitive	6 participants	To showcase and assess the effectiveness of virtual reality and gamification in teaching and learning software structure.
(Parong & Mayer, 2019)	United states	Higher education	Educational related cognitive skills	Cognitive	81 university students	To explore if the short-term use of a gamified virtual reality application can improve students' cognitive skills.
(Pinzón-Cristancho et al., 2019)	Colombia	–	Engineering	Cognitive and social-emotional	University students	To present an educational strategy that involves the use of virtual reality and gamification to increase students' soft skills development.
(Rosmansyah et al., 2019)	Indonesia	–	Agriculture	Cognitive	60 participants	To propose and assess a design framework for creating gamified virtual learning environments.
(Sanchez-Sepulveda et al., 2019)	Spain	Higher education	Architecture	Cognitive	31 university students	To explore the effect of immersive technologies in Architecture studies.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Luigini et al., 2020)	Italy	Primary education	Cultural heritage	Cognitive	36 primary education students	To present and assess a virtual reality environment that incorporates game mechanisms and project-based learning to support cultural heritage learning.
(Alharbi et al., 2020)	Saudi Arabia	K-12 education	Street-crossing	Cognitive	122 teachers and parents of children with autism spectrum disorder and 5 specialists	To present the design principles and the development of a gamified virtual reality application that aims at enhancing students with autism spectrum disorder (ASD) street-crossing skills.
(Azar & Tan, 2020)	Malaysia	Secondary education	Language learning (English)	Cognitive	63 participants	To comprehend how students perceive mobile-assisted learning, gamification, and virtual reality and their influence on English language learning.
(Bedregal-Alpaca et al., 2020)	Peru	Higher education	Astronomy	Cognitive	Teachers and students	To present the findings of incorporating a gamified virtual reality application to support astronomy leaning.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Chen et al., 2020)	Singapore	Higher education	Biopharmaceutical engineering	Cognitive	29 university students	To present and evaluate a virtual reality application that uses gamification elements as a training environment to improve biopharmaceutical engineering teaching and learning.
(Geus et al., 2020)	Brazil	Higher education	Electrical engineering	Cognitive	19 participants	To showcase a gamified virtual reality environment that focuses on supporting and improving electricians' learning experience.
(Doumanis & Economou, 2020)	United Kingdom	Secondary education	Spatial skills	Cognitive	42 secondary school students and teachers	To present the design elements and evaluate a virtual reality application that uses gamification elements to enhance students' leaning experience.
(Fonseca et al., 2020)	Spain	Higher education	Architecture	Cognitive	70 university students and 39 teachers	To demonstrate students' and teachers' viewpoints regarding the use of immersive virtual reality and gamification as a means to gain and improve visual management competence.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Gonzalez-Gonzalez, 2020)	Spain	Higher education	Virtual learning environments	Cognitive	106 university students	To go over different gamified educational environments and experiences using different techniques and tools, including immersive technologies in higher education.
(Hartfill et al., 2020)	Germany	Higher education	Language learning (Japanese)	Cognitive	29 participants	To showcase and evaluate a virtual reality application that incorporates game elements to improve vocabulary learning.
(Chávez et al., 2020)	Mexico	Higher education	Healthcare education	Cognitive	78 university students	To examine how gamified virtual reality applications can impact students' learning outcomes.
(May & Denecke, 2020)	Switzerland	Higher education	Medical education	Cognitive	30 university students and 15 random participants	To showcase a gamified virtual reality application to increase learning motivation regarding medical education.
(Mouronte-López et al., 2020)	Spain	Secondary education	Engineering	Cognitive	178 secondary education students	To assess the impact of gender on the interest in engineering and technical subjects through the use of a gamified virtual reality application.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Mystakidis, 2020)	United Kingdom	Higher education	Distance education	Cognitive	14 university students	To present the potential of using virtual technologies and gamified instructional design and strategies as a means to improve students' active participation in online education.
(Senecal et al., 2020)	Cyprus	–	Dance	Physical	40 participants	To present and assess a gamified virtual reality application that aims at improving dancing teaching and learning.
(Tiefenbacher, 2020)	Austria	Higher education	Healthcare education	Cognitive	102 university students	To explore how different gamification elements affect the effectiveness of virtual reality applications in education.
(Abuhammad et al., 2021)	Jordan	Higher education	Medical chemistry	Cognitive	41 university students	To present and evaluate a gamified virtual reality application that focuses on improving medical chemistry teaching and learning.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Chiang, 2021)	Taiwan	Secondary education	Environmental education	Cognitive	64 secondary education students	To showcase a gamified virtual reality application that aims at increasing students' immersion in learning activities and generating empathy toward the environment.
(Falah et al., 2021)	Jordan	Higher education	Medical chemistry	Cognitive	420 university students	To present and evaluate a gamified virtual reality application that supports the delivery of complex educational topics.
(Fonseca et al., 2021)	Spain	Higher education	Architecture and Design	Cognitive	133 university students	To present a gamified virtual reality environment that supports architectural and urban design.
(Palmas et al., 2021)	Germany	Higher education	Public speaking	Cognitive	200 undergraduate students	To examine how students perceive and accept the use of virtual reality and gamification in education.
(Silva et al., 2021)	Portugal	Higher education	Culinary	Cognitive	University teachers	To present the benefits of using immersive technologies and gamification in the learning process to promote self-learning and continuous improvement

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Smith et al., 2021)	Canada	Higher education	Nuclear Engineering	Cognitive	5 university students	To showcase a dynamic virtual reality model that supports attenuating radiation visualization in learning contexts.
(Theethum et al., 2021)	Thailand	Higher education	Computer science (Programming)	Cognitive	20 university students	To demonstrate a virtual reality application that incorporates gamification elements to enhance students' knowledge and programming skills.
(Vidal et al., 2021)	Spain	Higher education	Arts	Cognitive	17 university students	To present a gamified virtual reality application that aims at enhancing students' academic performance.
(Ahlers et al., 2022)	Germany	Higher education	Language learning (German)	Cognitive	2 university students	To showcase and evaluate a virtual reality application which uses game mechanisms to improve language learning and communication skills.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Alexander et al., 2022)	United States	Higher education	Computer science (Programming)	Cognitive	14 university students	To present and assess an immersive virtual reality application that uses gamification elements and focuses on enhancing students' understanding of sorting algorithms.
(Jiang et al., 2022)	United States	Higher education	Hospitality education	Cognitive	209 university students	To investigate students' learning experience and behavioral intentions in a gamified virtual reality environment for Hospitality education.
(Roumana et al., 2022)	Greece	K-12 education	Cultural heritage	Cognitive	Small group of participants	To present and assess a virtual reality application which integrates gamification elements and aims at increasing the dissemination of cultural heritage content to students.
(Tan et al., 2022)	Singapore	Secondary education	Manufacturing	Cognitive	29 secondary education students	To investigate the use of a virtual reality environment that uses gamification elements and aims at enhancing students' knowledge of manufacturing concepts.

Table 1 (continued)

Article	Country	Educational level	Focus Area	Developmental category	Sample	Aims
(Xu T et al., 2022)	Ireland	Higher education	Protein design	Cognitive	20 university students	To demonstrate and evaluate a gamified virtual reality application which aims at improving students' knowledge of protein design.
(Zhang & Bryan-Kinns, 2022)	United Kingdom	Higher education	Music	Cognitive	24 participants	To present and evaluate a virtual reality application which integrates gamification and focuses on increasing learners' knowledge of Chinese musical instruments and their ability to use them.

and motivation (RQ9). The main area of focus of the empirical studies was STEAM-related fields (e.g., physics, chemistry, computer science, arts, mathematics), followed by medical and healthcare education, language learning, and engineering (RQ10).

Based on Table 2, most studies adopted a quantitative research approach (63.64%), followed by mixed-method approach (24.24%) and qualitative approach (12.12%). The variation of methods used assists in acquiring collective insights to improve user experience (UX) (Nielsen, 2000). Figure 6 presents the related to the research methodology information (RQ11). Moreover, the research approach of the studies was further examined using the MMAT. Particularly, most studies adopted a Quantitative descriptive approach (39.39%), followed by mixed methods (Qualitative and Quantitative descriptive) approach (16.67%), Randomized controlled approach (13.64%), Qualitative approach (12.12%), and Non-randomized approach (10.61%). The Mixed methods (Qualitative and Randomized controlled) (4.55%) and Mixed methods (Qualitative and Non-randomized) (3.03%) approaches were also used but to a lesser extent. The relevant to the MMAT category information is showcased in Fig. 7 (RQ11). Several validated in the educational context questionnaires were used. Some examples of those are: the System Usability Scale (SUS) (Brooke, 1996), the Presence Questionnaire (Witmer & Singer, 1998), the Game Engagement Questionnaire (GEQ) (Brockmyer et al., 2009), Technology Acceptance Model (TAM) (Davis, 1993), the Simulator Sickness Questionnaire (Kennedy et al., 1993), the NASA task load index (Hart & Staveland, 1988), the Presence Questionnaire (PQ) and the Immersive Tendencies Questionnaire (ITQ) (Witmer & Singer, 1998), the Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 2002), the User Experience Questionnaire (UEQ) (Laugwitz et al., 2008), the Immersion and Presence Questionnaire (IPQ) (Schubert et al., 2001), the Virtual Reality Sickness Questionnaire (VRSQ) (Kim et al., 2018), the Use, Satisfaction, Ease to use (USE) questionnaire (Lund, 2001), and the Questionnaire to Assess Current Motivation in Learning Situations (CQM) (Rheinberg et al., 2001). Beyond the use of already validated questionnaires, most studies implemented ad hoc questionnaires or surveys. There were also studies, such as (Chávez et al., 2020; Chiang, 2021; Falah et al., 2021; Makransky et al., 2019; May & Denecke, 2020; Palmas et al., 2021), which adopted items from existing evaluation tools (RQ11). Most of the studies used student related variables, such as experience, acceptance, motivation, performance, satisfaction, feedback, and viewpoints (RQ11). Additionally, given the tools used, the variables analyzed, and the participants, the measures of each study were divided into objective, subjective, or both. The measures of the vast majority of the studies were subjective (68.18%), followed by objective and subjective (21.21%), and objective (10.61%). The related to the measures information is depicted in Fig. 8.

It was obvious that there was a clear lack of detailed descriptions regarding the development approaches, processes, and tools used as well as of a display of examples of the application and the experiments. Additionally, the paucity of technical information and of provision of resources and repositories was apparent. Design-based research methodology (Ahlers et al., 2022; Rosmansyah et al., 2019), collaborative design (Wilson et al., 2017a), user-centered approach (Wilson et al., 2017b), and instructional design approach (Vagg et al., 2016) were some examples of the methodologies and approaches used to develop the educational applications. Most studies used Windows as the operating system of their application (56.06%), followed by android (12.12%), while some studies developed cross-platform applications (12.12%). A significant number of studies did not report a specific operating system (27.27%) or devices used (12.12%) (RQ12). Furthermore, the HTC Vive head-mounted devices were mostly used to conduct the experiments (37.88%), followed by general purpose head-mounted devices (27.27%),

Table 2 Empirical studies: Research methods, variables, and tools

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Villagrasa et al., 2014a)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' viewpoints	14-item ad hoc questionnaire and analysis using Bipolar Laddering (Pifarré & Tomico, 2007)	Subjective
(Grivokostopoulou et al., 2016)	Quantitative	Randomized controlled	Students' opinions, attitudes, learning outcomes, motivation, and experience	15-item ad hoc questionnaire, pre-test, and post-test	Objective and subjective
(Reitz et al., 2016)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Participants' communication and language skills, motivation, and attitudes	Ad hoc questionnaire, the Questionnaire to Assess Current Motivation in Learning Situations (CQM) (Rheinberg et al., 2001), observations, and application-related data	Subjective
(Vagg et al., 2016)	Qualitative	Qualitative	System usability and students' interactions and behaviors	Observations	Subjective
(Zhang et al., 2016)	Qualitative	Qualitative	Students' experience and performance	Observations	Subjective
(Becerra et al., 2017)	Quantitative	Quantitative descriptive	Teachers' viewpoints	18-item ad hoc questionnaire	Subjective
(Fonseca et al., 2017a)	Quantitative	Non-randomized	Students' viewpoints	18-item ad hoc questionnaire, pre-test, and post-test	Subjective
(Stigall & Sharma, 2017)	Quantitative	Quantitative descriptive	Students' viewpoints and acceptance and system usability	Ad hoc survey	Subjective
(Wang, 2017)	Quantitative	Quantitative descriptive	Students' viewpoints, feedback, and acceptance	6-item ad hoc survey	Subjective
(Wilson et al., 2017a)	Quantitative	Quantitative descriptive	Students' viewpoints and the application usefulness and ease to use	8-item ad hoc questionnaire	Subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Wilson et al., 2017b))	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' and teachers' viewpoints and system usability	20-item ad hoc survey and interviews	Subjective
(Besoain et al., 2018)	Quantitative	Quantitative descriptive	Students' virtual reality sickness and satisfaction and the application usefulness and ease of learning and using	The Virtual Reality Sickness Questionnaire (VRSQ) (Kim et al., 2018) and the Use, Satisfaction, Ease to use (USE) questionnaire (Lund, 2001)	Subjective
(Bryan et al., 2018)	Quantitative	Quantitative descriptive	Participants' viewpoints and experience	2 ad hoc questionnaires	Subjective
(Edwards et al., 2019)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' viewpoints and experience	Ad hoc survey, observations, and discussion	Subjective
(Gonzalez & Garnique, 2018)	Quantitative	Quantitative descriptive	Students' score, accuracy, errors, sequence of steps, task completion, time, immersion, haptic, e-stress, and usability	Application-related data	Objective and subjective
(Nicola et al., 2018)	Quantitative	Quantitative descriptive	Students' performance	Application-assessment form	Objective
(Šašinka et al., 2018)	Qualitative	Qualitative	Students' viewpoints and experience	Observations and interviews	Subjective
(Stranger-Johannessen, 2018)	Quantitative	Randomized controlled	Students' learning outcomes	Pre-test and post-test	Objective
(Suncksen et al., 2018)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	System usability and user experience	The User Experience Questionnaire (UEQ) (Laugwitz et al., 2008) and interviews	Subjective
(AlKhateeb et al., 2019)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Application effectiveness and students' viewpoints, experience and feedback	2 ad hoc online surveys and observations	Subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Almousa et al., 2019)	Qualitative	Qualitative	Users' perspectives, experience, engagement, immersion, performance, and skills	Interviews	Objective and subjective
(Garcia et al., 2019)	Qualitative	Qualitative	Participants' experience and viewpoints	Interviews and discussions	Subjective
(Gordon et al., 2019)	Quantitative	Quantitative descriptive	Students' performance, task completion rate, error rates, and reaction time	Word-color matching tasks	Objective
(Grivokostopoulou et al., 2019a)	Quantitative	Randomized controlled	Students' performance, attitudes, experience, and motivation	14-item ad hoc questionnaire, pre-test, and post-test	Objective and subjective
(Huaman et al., 2019)	Quantitative	Quantitative descriptive	Usability and effectiveness of the virtual learning environment	2 11-item ad hoc questionnaires	Subjective
(Iquira et al., 2019)	Mixed	Mixed methods (Qualitative and Non-randomized)	Usability, knowledge gain, performance, and completion-rate	Ad hoc 12-item questionnaire and application-related data	Objective and subjective
(Makled et al., 2019)	Quantitative	Quantitative descriptive	Spatial presence, involvement, and realism	The Immersion and Presence Questionnaire (IPQ) (Schubert et al., 2001)	Subjective
(Makransky et al., 2019)	Quantitative	Non-randomized	Students' perspectives, intrinsic motivation, and self-efficacy	30-item ad hoc questionnaire adapted from (Pintrich & Groot, 1990), (Deci et al., 1994) and (Makransky et al., 2016), pre-test, and post-test	Subjective
(Molloy et al., 2019)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' viewpoints and system usability	Recorded comments and feedback, and the System Usability Scale (SUS) (Brooke, 1996)	Subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Oberhauser & Lecon, 2019)	Q uantitative	Quantitative descriptive	Learning performance	Application-related data	Objective
(Parong & Mayer, 2019)	Quantitative	Randomized controlled	Perceptual attention, working memory, mental rotation, visual processing speed and field of view, and visualization skills	Ad hoc questionnaire, pre-test, and post-test	Objective
(Pinzón-Cristancho et al., 2019)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' soft skills, experience, and opinions	Observations and rubric scoring	Subjective
(Rosmansyah et al., 2019)	Quantitative	Randomized controlled	Participants' knowledge acquisition, perceived usefulness and enjoyment	Ad hoc survey, pre-test, and post-test	Objective and subjective
(Sanchez-Sepulveda et al., 2019)	Quantitative	Quantitative descriptive	System efficiency and usability and students' profiles and satisfaction	10-item ad hoc survey	Subjective
(Luigini et al., 2020)	Quantitative	Quantitative descriptive	Knowledge and skills acquired, presence, and experience	The Presence Questionnaire (PQ) and the Immersive Tendencies Questionnaire (ITQ) (Witmer & Singer, 1998).	Subjective
(Alharbi et al., 2020)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Stakeholders' and specialists' viewpoints	Ad hoc questionnaire and interviews	Subjective
(Azar & Tan, 2020)	Quantitative	Quantitative descriptive	Participants' viewpoints	19-item ad hoc online questionnaire	Subjective
(Bedregal-Alpaca et al., 2020)	Quantitative	Quantitative descriptive	Students' perceived usefulness and satisfaction	Ad hoc questionnaire and the Technology Acceptance Model (TAM) (Davis, 1993)	Subjective
(Chen et al., 2020)	Mixed	Mixed methods (Qualitative and Randomized controlled)	Students' viewpoints, attitudes, knowledge acquisition, and comprehension	7-item ad hoc questionnaire, interviews, pre-test, and post-test	Objective and subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Geus et al., 2020)	Mixed	Mixed methods (Qualitative and Non-randomized)	Learning outcomes, perceived benefits and usability	Interviews and application-related data	Objective and subjective
(Doumanis & Economou, 2020)	Quantitative	Quantitative descriptive	Task completion rate, user error, sketch maps, rating, satisfaction, and usability	3 ad hoc questionnaires and the Post-Study System Usability Questionnaire (PSSUQ) (Lewis, 2002)	Objective and subjective
(Fonseca et al., 2020)	Quantitative	Quantitative descriptive	Students' and teachers' perception	Ad hoc survey	Subjective
(Gonzalez-Gonzalez, 2020)	Quantitative	Quantitative descriptive	Students' viewpoints and learning outcomes	Ad hoc survey and application-related data	Objective
(Hartfill et al., 2020)	Quantitative	Randomized controlled	Participants' experience, enjoyment, motivation, and perceived difficulty, success, and duration	Ad hoc questionnaire, the System Usability Scale (SUS) (Brooke, 1996), simulator sickness questionnaire (Kennedy et al., 1993), and the NASA task load index (Hart & Staveland, 1988)	Subjective
(Chávez et al., 2020)	Quantitative	Randomized controlled	Students' learning performance, perceived usefulness and ease of use, and the impact of gamification elements on learning	Ad hoc questionnaire based on the Technology Acceptance Model (TAM) (Davis, 1993) and post-test	Objective and subjective
(May & Denecke, 2020)	Quantitative	Non-randomized	User experience and system usability	Ad hoc questionnaire based on the ISO 9241 standard and the usability heuristics presented in (Nielsen, 1994)	Subjective
(Mouronte-López et al., 2020)	Quantitative	Non-randomized	Students' viewpoints, knowledge gain, interest, and experience	11-item ad hoc questionnaire, 4-item ad hoc questionnaire, pre-test, and post-test	Objective and subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Mystakidis, 2020)	Qualitative	Qualitative	Chat transcripts and game recordings	Observations	Subjective
(Senecal et al., 2020)	Quantitative	Non-randomized	Users' skills, style, rhythm, and guidance	Music-related Motion Features (MMF) and Laban Motion Analysis (LMA) features analysis	Objective
(Tiefenbacher, 2020)	Quantitative	Non-randomized	Students' attitudes, experiences, and viewpoints	2 ad hoc questionnaires	Subjective
(Abuhammad et al., 2021)	Quantitative	Quantitative descriptive	Students' feedback and viewpoints	22-item ad hoc online questionnaire	Subjective
(Chiang, 2021)	Quantitative	Randomized controlled	Students' learning effectiveness, empathy, behaviors, and immersion	Ad hoc questionnaire adapted from (Davis, 1983; Mehrabian & Epstein, 1972; Witmer et al., 2005)	Subjective
(Falah et al., 2021)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' viewpoints and attitudes	33-item ad hoc questionnaire based on Technology Acceptance Model (TAM) (Davis, 1993) and interviews	Subjective
(Fonseca et al., 2021)	Mixed	Mixed methods (Qualitative and Quantitative descriptive)	Students' viewpoints	Ad hoc questionnaire and interviews	Subjective
(Palmas et al., 2021)	Quantitative	Randomized controlled	Students' acceptance, intrinsic motivation, behavioral intention, and perceived ease of use and usefulness	Ad hoc questionnaire adapted from (Davis, 1993; Davis et al., 1992; Paul, 1966; Thompson et al., 1991)	Subjective
(Silva et al., 2021)	Quantitative	Quantitative descriptive	Control, sensory, distraction, and realism factors of the overall experience	The Presence Questionnaire (Witmer & Singer, 1998)	Subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Smith et al., 2021)	Quantitative	Quantitative descriptive	Completion time and rate, radiation dose, system usability, and students' engagement	The Game Engagement Questionnaire (GEQ) (Brockmyer et al., 2009), the System Usability Scale (SUS) (Brooke, 1996), and application-related data	Objective and subjective
(Theethum et al., 2021)	Mixed	Mixed methods (Qualitative and Randomized controlled)	Students' viewpoints, knowledge acquisition, calorie consumption, and degree of satisfaction	Ad hoc questionnaire, pre-test and post-test, application-related data, and interviews	Objective and subjective
(Vidal et al., 2021)	Quantitative	Non-randomized	Students' viewpoints and degree of satisfaction and the application usefulness and difficulty	16-item ad hoc online survey	Subjective
(Ahlers et al., 2022)	Q ualitative	Qualitative	Students' participation, learning performance, and fun	Discussions	Subjective
(Alexander et al., 2022)	Quantitative	Quantitative descriptive	The application usability and effectiveness	Ad hoc survey	Subjective
(Jiang et al., 2022)	Quantitative	Quantitative descriptive	Students' perceived usefulness, enjoyment, flow experience, behavior intention, and ease of use	23-item ad hoc questionnaire	Subjective
(Roumana et al., 2022)	Qualitative	Qualitative	The application usefulness, convenience, and ability to create immersive environments	Observations and discussions	Subjective
(Tan et al., 2022)	Quantitative	Quantitative descriptive	Students' viewpoints and experience	10-item ad hoc survey	Subjective

Table 2 (continued)

Article	Research method	MMAT category	Main variables	Measurement tools - Research tools	Measures
(Xu T et al., 2022)	Quantitative	Quantitative descriptive	Students' experience and feedback	5-item ad hoc questionnaire	Subjective
(Zhang & Bryan-Kinns, 2022)	Mixed	Mixed methods (Qualitative and Randomized controlled)	Presence, enjoyment, usability, and expectations	16-item ad hoc questionnaire and interviews	Objective and subjective

Table 3 Empirical studies: Application development information and gamification elements

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Villagrasa et al., 2014a)	–	Unity, Sketchfab, Autodesk 3dsMax, and Oculus Rift Development Kit	Windows	Oculus Rift	6-DoF	Immersive virtual reality	Game-like features and mechanisms, points, virtual rewards, and badges
(Grivokostopoulou et al., 2016)	–	Open-Simulator	–	–	6-DoF	Immersive virtual reality	Points, tasks, and puzzles
(Reitz et al., 2016)	Haunted	Unreal Engine 4	Windows	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms, points, tasks, levels, and virtual rewards
(Vagg et al., 2016)	–	Unreal Engine 4, Blender, and Oculus Rift Development Kit	Windows	Oculus Rift	6-DoF	Immersive virtual reality	Points, tasks, and feedback
(Zhang et al., 2016)	–	Unity	Windows	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks points, mini-games, quiz questions, and leaderboard
(Becerra et al., 2017)	–	Unity and Google VR SDK	Android	Google Cardboard and Ritech II	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and score
(Fonseca et al., 2017a)	–	Unreal Engine 4	Windows	HTC Vive	6-DoF	360-degree	Game-like features and mechanisms
(Stigall & Sharma, 2017)	–	Vizard and Oculus Rift Development Kit	Windows	Oculus Rift and Corner Cave	6-DoF	Immersive virtual reality	Game-like features and mechanisms, points, quiz questions, and feedback

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Wang, 2017)	WtRUAK	Unity, JanusVR, and Autodesk Maya 3D	–	–	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, points, and quiz questions
(Wilson et al., 2017a)	–	Unity	Android	Ritech II	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, points, and virtual rewards
(Wilson et al., 2017b)	–	Unity and Google VR SDK	Android	Google Cardboard	3-DoF	Immersive virtual reality	Game-like features and mechanisms, quiz questions, score, points, virtual rewards, and badges
(Besoain et al., 2018)	–	Unity and SteamVR	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, puzzles, and points
(Bryan et al., 2018)	Scenic Spheres	Unity, VRTK, and SteamVR	Windows	HTC Vive	3-DoF	360-degree	Game-like features and mechanisms, tasks, points, quiz questions, leader-board, timer, and feedback
(Edwards et al., 2019)	VR Multisensory Classroom (VRMC)	Unity	Windows	Head-mounted device	3-DoF	Immersive virtual reality	Game-like features and mechanisms

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of free-dom	Representations	Gamification elements
(Gonzalez & Gar-nique, 2018)	–	Unity	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, points, and timer
(Nicola et al., 2018)	BubbleVR	Unity and Google VR SDK	Android	Head-mounted device	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, points, and timer
(Šašinka et al., 2018)	CIVE	SteamVR	Windows	HTC Vive	6-DoF	Immersive virtual reality	Tasks, levels, and feedback
(Stranger-Johannes-sen, 2018)	–	–	–	Head-mounted device	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and points
(Suncksen et al., 2018)	–	Unity	Windows	HTC Vive	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, points, quiz questions, and levels
(AlKhateeb et al., 2019)	Qee	Unity and Blender	Windows	HTC Vive	6-DoF	Immersive virtual reality	Game-like features and mechanisms, score, tasks, and quiz questions
(Almousa et al., 2019)	–	Unity	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms, timer, points, leaderboard, and quiz questions
(Garcia et al., 2019)	–	Unity and Oculus Rift Development Kit	Windows	Oculus Rift	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and points

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Gordon et al., 2019)	–	Unreal Engine 4	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms and tasks
(Grivokostopoulou et al., 2019a)	–	–	–	–	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, hints, feedback, quiz questions, and score
(Huaman et al., 2019)	–	Unity	Windows	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms and tasks
(Iquira et al., 2019)	–	Unity	–	Head-mounted device	3-DoF	Immersive virtual reality	Points, tasks, and achievements
(Makled et al., 2019)	PathogeniusVR	–	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms
(Makransky et al., 2019)	–	–	–	Head-mounted device	3-DoF	Immersive virtual reality	Game-like features and mechanisms, quiz questions, and points
(Molloy et al., 2019)	MRPT	Unity	Windows	HTC Vive Pro	3-DoF	Immersive virtual reality	Game-like features and mechanisms, score, and feedback
(Oberhauser & Lecon, 2019)	VR-GaImS	Unity and SteamVR	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and points

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Parong & Mayer, 2019)	Cerevrum (developed by Cerevrum Inc.)	–	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms, mini-games, points, tasks, and levels
(Pinzón-Cristancho et al., 2019)	Second Life (developed by Linden Lab)	–	macOS, Windows and Linux	–	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Rosmansyah et al., 2019)	3DMUVLE	–	–	Head-mounted device	6-DoF	Immersive virtual reality	Points, tasks, and quiz questions
(Sanchez-Sepulveda et al., 2019)	EduGame4City	–	Windows	HTC Vive	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Luigini et al., 2020)	–	Oculus Rift Development Kit, OctaneRender, and Pano2VR Pro	Windows	Oculus Rift	3-DoF	360-degree	Game-like features and mechanisms, tasks, storytelling, quiz questions, and score
(Alharbi et al., 2020)	–	Unity	–	–	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Azar & Tan, 2020)	–	–	–	–	6-DoF	Immersive virtual reality	-
(Bedregal-Alpaca et al., 2020)	–	Unity	Android	Google Cardboard	3-DoF	Immersive virtual reality	Game-like features and mechanisms, achievements, virtual rewards, points, tasks, and leaderboard
(Chen et al., 2020)	–	Unity	Android	HTC Vive	6-DoF	Immersive virtual reality	Tasks, achievements, challenges, and tasks

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Geus et al., 2020)	–	Unreal Engine 4	–	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, score, and feedback
(Doumanis & Economou, 2020)	REVERIE VG	–	–	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms, points, virtual rewards, ranking, and tasks
(Fonseca et al., 2020)	EduGame4City	–	Windows	HTC Vive	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Gonzalez-Gonzalez, 2020)	–	Mozilla Hubs	–	Head-mounted device	6-DoF	Immersive virtual reality	Quiz questions and points
(Hartfill et al., 2020)	Word Saber	Unity	Windows	HTC Vive	3-DoF	Immersive virtual reality	Game-like features and mechanisms, points, and timer
(Chávez et al., 2020)	MediTool	–	–	Head-mounted device	6-DoF	Immersive virtual reality	Badges, challenges, rankings, and score table
(May & Denecke, 2020)	CLAIRE	Unity, Syn.Bot, and Google VR SDK	iOS, Android and Windows	Google Cardboard	6-DoF	Immersive virtual reality	Game-like features and mechanisms and tasks
(Mouronte-López et al., 2020)	STEM VR (developed by 3 M Foundation)	Unity, Autodesk 3D Studio Max, and Adobe Photoshop	Orbis OS	Sony PlayStation VR	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Mystakidis, 2020)	–	–	–	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Senecal et al., 2020)	–	Unity	Windows	HTC Vive	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and score
(Tiefenbacher, 2020)	–	Unity and OpenVR SDK	Windows	Oculus Rift S	3-DoF	Immersive virtual reality	Game-like features and mechanisms, ranking, achievements, points, and timer
(Abuhammad et al., 2021)	MedChemVR	Unity and Autodesk Maya 3D	Android	BOBOVRZ4 head-mounted display and mobile devices	6-DoF	Immersive virtual reality	Game-like features and mechanisms, quiz questions, timer, and points
(Chiang, 2021)	–	–	–	Head-mounted device	3-DoF	360-degree	Game-like features and mechanisms, quiz questions, and storytelling
(Falah et al., 2021)	MedChemVR	Unity and Autodesk Maya 3D	Android	Head-mounted device	3-DoF	Immersive virtual reality	Game-like features and mechanisms, quiz questions, timer, and points
(Fonseca et al., 2021)	GAME4City 3.0	Unreal Engine 4	Windows	HTC Vive Pro	6-DoF	Immersive virtual reality	Game-like features and mechanisms, timer, and points
(Palmas et al., 2021)	–	Unity	Windows	HTC Vive Pro	6-DoF	Immersive virtual reality	Game-like features and mechanisms, feedback, and score

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of freedom	Representations	Gamification elements
(Silva et al., 2021)	–	Virtual Reality Toolkit	–	Head-mounted device	6-DoF	Immersive virtual reality	Game-like features and mechanisms, points, rules, levels, tasks, badges, and achievements
(Smith et al., 2021)	–	Unity	–	Head-mounted device and VR controller	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Theethum et al., 2021)	Thinkercise	Oculus Rift Development Kit	Windows	Oculus Rift	3-DoF	Immersive virtual reality	Game-like features and mechanisms, quiz questions, timer, and points
(Vidal et al., 2021)	–	Unity	Windows	HTC Vive Pro	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Ahlers et al., 2022)	Hololingo	Unity and VRChat	Windows	HTC Vive Pro	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, puzzles, and mini-games
(Alexander et al., 2022)	Computer Science Virtual Interactive Laboratory (CSVIL)	Unity and SteamVR	Windows	HTC Vive	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Jiang et al., 2022)	–	–	–	–	3-DoF	360-degree	Game-like features and mechanisms and tasks
(Roumana et al., 2022)	–	Unity	Windows	HTC Vive Pro	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and puzzles

Table 3 (continued)

Article	Application Name	Development tools	Operating system	Device	Degrees of free-dom	Representations	Gamification elements
(Tan et al., 2022)	–	–	Windows	HTC Vive Pro	6-DoF	Immersive virtual reality	Game-like features and mechanisms and tasks
(Xu T et al., 2022)	Schedio-Pro	Unity	Windows	Oculus Rift	6-DoF	Immersive virtual reality	Game-like features and mechanisms
(Zhang & Bryan-Kinns, 2022)	QiaoLe	Unity	Windows	Oculus Rift	6-DoF	Immersive virtual reality	Game-like features and mechanisms, tasks, and feedback

Table 4 Empirical studies: Main findings

Article	Main findings
(Villagrasa et al., 2014a)	The application improved the learning process effectiveness and students' academic performance, comprehension, and creativity.
(Grivokostopoulou et al., 2016)	The experience was enjoyable, useful and interesting, the application was easy to use and students' motivation, learning efficiency, and understanding improved.
(Reitz et al., 2016)	The application offered a challenging experience and promoted intrinsically motivated communication. Students' improved communication skills and increased eagerness and motivation to complete the assigned tasks were observed.
(Vagg et al., 2016)	The application was positively viewed and the learning experience was regarded as interesting, engaging, motivating, and fun. The need to take students' feelings of nausea during the virtual experience into account was highlighted.
(Zhang et al., 2016)	The virtual application resulted in increased collaborative learning opportunities, playful experiences, and cross-cultural understanding.
(Becerra et al., 2017)	The application was positively assessed and a general acceptance toward its use in educational settings was evident.
(Fonseca et al., 2017a)	Students viewed the application positively and regarded it as a helpful educational tool. Increase in students' comprehension and motivation was observed.
(Stigall & Sharma, 2017)	The application was easy to use and was regarded as an effective educational tool by students.
(Wang, 2017)	Students were satisfied with the application effectiveness and positively assessed it. They also demonstrated increased learning motivation, enjoyment, and engagement.
(Wilson et al., 2017a)	Students found the application useful, informative, usable, and easy to learn. Their skills and confidence in performing the assigned tasks improved.
(Wilson et al., 2017b)	Teachers regarded the application as helpful and usable. Students found the application useful, informative, usable, and easy to learn. Student skills and confidence in performing the assigned tasks improved.
(Besoain et al., 2018)	The application was positively evaluated and was regarded as an easy to learn and use, fun, pleasant, and useful educational tool.
(Bryan et al., 2018)	The application was assessed as helpful, easy to learn, and easy to use while providing an engaging and fun learning experience.
(Edwards et al., 2019)	The use of gamification and virtual reality led to an increase in students' learning performance, engagement, and motivation.
(Gonzalez & Garnique, 2018)	The application increased students' learning outcomes and motivation.
(Nicola et al., 2018)	The application was positively assessed in terms of effective learning, didactic utility, and educational value. An increase in students' knowledge acquisition and understanding of the concepts was observed.
(Šašinka et al., 2018)	The crucial role of the social dimension was highlighted as participants highly valued communication and collaboration within the learning experience.
(Stranger-Johannessen, 2018)	Students' learning performance increased.
(Suncksen et al., 2018)	The user-friendly nature and realism of the simulation and the engaging and motivating aspects introduced via gamification were highly regarded and appreciated.

Table 4 (continued)

Article	Main findings
(AlKhateeb et al., 2019)	The participants showcased enthusiasm and excitement when using the application. The design elements and the challenging nature of the application were appreciated. The need to provide concise and clear information was highlighted.
(Almousa et al., 2019)	The application was assessed as a reliable educational tool that offered real-time feedback and interactive, realistic, and engaging experiences.
(Garcia et al., 2019)	Learning experiences were more interesting, effective, and enjoyable compared to the conventional ones.
(Gordon et al., 2019)	The immersive sensorimotor experiences led to enhanced learning outcomes.
(Grivokostopoulou et al., 2019a)	Students' entrepreneurship skills, mentality and competence, motivation, and performance increased. Gamified experiences that are defined by high levels of realism and require students to put theoretical knowledge into practice lead to better learning outcomes.
(Huaman et al., 2019)	Although the application increased students' interactions, participation, and completion rate, negative elements and difficulties were also observed.
(Iquira et al., 2019)	The application was easy to use and improved students' problem-solving skills, motivation, interest, and performance. Its role as a supplementary educational tool and not as a replacement of teachers and the traditional educational process was highlighted.
(Makled et al., 2019)	Students found the learning experience more interactive, appealing, enjoyable, and engaging than conventional learning.
(Makransky et al., 2019)	An Increase in knowledge acquisition and comprehension, self-efficacy, intrinsic motivation, and academic performance was evident.
(Molloy et al., 2019)	Students regarded the application as interesting, intuitive, fun, and motivating.
(Oberhauser & Lecon, 2019)	Students' motivation, focus, participation, and enjoyment improved.
(Parong & Mayer, 2019)	The short-term use of the application did not lead to increased knowledge acquisition and learning outcomes.
(Pinzón-Cristancho et al., 2019)	The application was positively assessed and improved learning outcomes and increased interaction were observed.
(Rosmansyah et al., 2019)	Students demonstrated increased enjoyment, immersion, knowledge gain, performance, and curiosity. The perception of usefulness and the enjoyment aspects were the most significant factors that affected students' behavioral intentions of using the application.
(Sanchez-Sepulveda et al., 2019)	Students' motivation, knowledge gain, digital competence, and decision-making skills were enhanced.
(Luigini et al., 2020)	Students appreciated and positively evaluated the experience. Their interest, engagement, and attention increased.
(Alharbi et al., 2020)	Clarity of instructions, realism, brief prompts, user-centered design, repetition, and encouragement were defined as the main aspects that must be taken into account when designing gamified virtual reality applications.
(Azar & Tan, 2020)	The use of gamification and virtual reality was positively assessed and characterized as a relaxing, fun, enjoyable, comfortable and effective way of teaching and learning.
(Bedregal-Alpaca et al., 2020)	Students demonstrated an increase in learning motivation and perceived satisfaction regarding their personal achievements.

Table 4 (continued)

Article	Main findings
(Chen et al., 2020)	Although tangible improvements regarding reduced equipment requirements and increased learning engagement, comprehension, motivation, and performance were evident, traditional in-person training was still more effective.
(Geus et al., 2020)	The application was highly regarded due to its usefulness, usability and effectiveness and was characterized as a significant tool to support traditional training.
(Doumanis & Economou, 2020)	Although the application did not increase students' spatial performance, it facilitated the teaching process by reducing distractions and increased students' engagement.
(Fonseca et al., 2020)	The results indicate that there is a gender and age gap in the acceptance of immersive technologies in education.
(Gonzalez-Gonzalez, 2020)	Students' increased engagement and academic performance were observed.
(Hartfill et al., 2020)	The application was assessed as a useful educational tool and resulted in high level of motivation, fun, and engagement for the participants.
(Chávez et al., 2020)	Students preferred the gamified virtual reality application and their learning motivation and performance increased.
(May & Denecke, 2020)	The application was evaluated as an acceptable, useful, and usable educational tool that is easy to use and can increase learners' motivation.
(Mouronte-López et al., 2020)	Although there are gender and age differences, the application was evaluated as an efficient and motivating educational tool that can be integrated into classrooms to enhance students' knowledge acquisition.
(Mystakidis, 2020)	An increase in students' engagement, immersion, and academic performance was observed.
(Senecal et al., 2020)	The experience was positively assessed and an increase in learning outcomes was observed.
(Tiefenbacher, 2020)	Using the appropriate for each case gamification elements is essential as diverse gamification elements affect the overall experience in a different way. The inclusion of high scores and achievements led to decreased levels of motivation. Participants had a positive attitude toward the use of the application in the educational process.
(Abuhammad et al., 2021)	The application enhanced flexibility, cost-effectiveness, and accessibility and was positively assessed by the students who found the experience engaging and enjoyable.
(Chiang, 2021)	The application increased students' learning performance. Gender differences were observed with female students performing better in actual behaviors and empathy. The cost of the required equipment and the need for specific educational material to be designed were highlighted as the main limitations.
(Falah et al., 2021)	Gamified virtual reality applications can support teaching and learning activities and help meet educational goals.
(Fonseca et al., 2021)	Gender differences were observed regarding the acceptance of virtual reality in education with females showcasing higher levels. The application had good usability, was motivating and drew students' interest. Students highly regarded the potential of such applications in education.
(Palmas et al., 2021)	When designing educational virtual reality applications, individuals' different characteristics should be taken into consideration and meaningful, personalized, and direct feedback should be included.
(Silva et al., 2021)	The application helped students develop their skills and acquire new knowledge and experiences in interactive and safe environments.

Table 4 (continued)

Article	Main findings
(Smith et al., 2021)	The gamified virtual reality application was regarded as more engaging and usable compared to the non-gamified one as participants felt less frustrated and more competent and immersed. Participants' completion time was better in the non-gamified application.
(Theethum et al., 2021)	The learning experience was enjoyable and positively assessed, students' physical condition improved and their learning performance increased in comparison to self-learning.
(Vidal et al., 2021)	Students' motivation, engagement, active participation, knowledge acquisition, and interest were enhanced. The application was characterized as creative, different, and novel.
(Ahlers et al., 2022)	The application created a fun and exciting experience and a positive and entertaining atmosphere and led to students' improved communication, learning skills, and learning outcomes.
(Alexander et al., 2022)	The application facilitated the teaching of abstract concepts, offered hands-on experiences, and increased students' motivation and engagement.
(Jiang et al., 2022)	The application was positively viewed by the students who regarded it as a useful, attracting, and enjoyable learning tool.
(Roumana et al., 2022)	Using the application, a more immersive, interesting and fun learning environment was created. Given that the necessary 3D assets are either available or can be created, immersive technologies can be effectively integrated into different educational domains.
(Tan et al., 2022)	The application was positively viewed and perceived as an effective and interesting learning tool. The ability to use virtual reality environments to substitute in-person site visits was highlighted.
(Xu T et al., 2022)	The application was assessed as enjoyable, interesting and easy to use and led to a more interactive and immersive learning experience.
(Zhang & Bryan-Kinns, 2022)	An increase in user experience, interaction, realism, and motivation was observed.

and the Oculus Rift (13.64%). Figure 9 presents the information related to the application operating system while Fig. 10 depicts the frequency of the devices used during the experiments. Although several studies did not specify the Software Development Kit (SDK) that they used, based on those which did, Unity was by far the most commonly used SDK (56.06%), followed by Unreal Engine 4 (9.09%), Oculus Rift Development Kit (9.09), and Google VR SDK (6.06%) (RQ13). To further analyze and understand the specifications and nature of the gamified virtual reality applications used in education, their DoF and their representation of content were examined. The vast majority of applications used 6-DoF (62.12%), followed by 3-DoF (37.88%) as it can also be seen in Fig. 11 (RQ14). Additionally, the overwhelming majority of applications used immersive virtual reality content and environments (92.42%) while only a few used 360-degree content (7.58%). The representations used in the applications examined are presented in Fig. 12 (RQ14). Regarding gamification elements, the use of game-like features and mechanisms was widely adopted and elements, such as points and scores, tasks and quests, quiz questions, virtual achievements and rewards, difficulty levels, feedback, mini-games, and leaderboards were integrated within the educational applications (RQ15).

Table 5 Proposal and prototype papers

Article	Country	Educational level	Focus Area	Aims
(Villagrasa et al., 2014b)	Spain	–	Street crossing	To describe how the use of gamification and virtual reality technologies could support and improve the teaching and learning activities in higher education to enhance students' learning motivation and engagement.
(Lima et al., 2016)	Brazil	Higher education	Anatomy	To describe a gamified virtual environment that enriches teaching and learning activities for medicine students and professors and increases students' knowledge acquisition.
(Anastasovitis et al., 2017)	Greece	Higher education	Cultural heritage	To showcase three gamified virtual reality applications that aim at supporting cultural heritage education, their aspects, technical details and design solutions.
(Deggim et al., 2017)	Germany	Higher education	History	To describe an interactive and gamified virtual reality application that aims at improving students' historical knowledge.
(Fonseca et al., 2017b)	Spain	Higher education	Social culture	To describe an educational project which aims at using gamification and virtual reality to support architecture education along with its main objectives, design concepts, and assessment methodology.
(Parakh et al., 2017)	United States	Higher education	Quantum cryptographic	To go over a virtual reality project-based gamified application that supports and improves the quality of STEM education.
(Stelian et al., 2017)	Romania	Higher education	Architecture	To present a gamified virtual reality application that will enable medical students to study the human skeleton in a more realistic and interactive manner.
(Vega et al., 2017)	United States	–	COVID-19 measures	To present a gamified virtual reality application that aims at increasing students' campfire safety knowledge to reduce human-caused wildfires.
(Yampray & Jirapanthong, 2017)	Thailand	K-12 education	British sign language	To showcase a virtual reality application that uses gamification elements to support users' acquaintance with Thailand's etiquette and customs.
(Mas et al., 2018)	France	–	Archaeology	To present a proposed treasure hunting game that is based on gamification principles and virtual reality that can be integrated into pre-existing training approaches to increase learners' navigation skills.

Table 5 (continued)

Article	Country	Educational level	Focus Area	Aims
(Papagiannakis et al., 2018)	Greece	Higher education	Medical education	To propose a gamified virtual reality simulation that enriches surgical training in realistic, safe, and controlled environments.
(Stelian & Lacramioara, 2018)	Romania	Higher education	Medical education	To showcase four educational applications that generate gamified virtual environments through the use of augmented and virtual reality to create more enjoyable and interesting learning settings.
(Angelino et al., 2019)	Portugal	Higher education	TV program production	To propose educational applications that use virtual reality and gamification to enhance students' learning motivation and engagement.
(Grivokostopoulou et al., 2019b)	Greece	Higher education	Genomics	To present a framework for training in topics related to information technology and STEM in virtual environments.
(Jiang & Zeng, 2019)	China	Higher education	Mining engineering education	To discuss the potential advantages of using a virtual reality application with gamification elements in the context of TV program production.
(Patterson et al., 2019)	Australia	Higher education	Forest protection	To present a prototype application that uses virtual reality and gamification elements to support learning and increase students' engagement in topics related to human genomics.
(Ribeiro et al., 2019)	Brazil	Higher education	Campfire safety	To showcase an immersive virtual reality environment that incorporates gamification elements to improve medical students' dental anesthesia training by providing learning in a more playful and interactive manner.
(Suppes et al., 2019)	Germany	Higher education	Navigation skills training	To describe the development process of a virtual reality application that incorporates gamification, flipped classroom, and blended learning elements to support mining engineering education.
(Yusoffa & Shafirilb, 2019)	Malaysia	K-12 education	Criminology	To propose a framework for creating a gamified virtual reality experience that improves students' learning performance in regard to forest protection.

Table 5 (continued)

Article	Country	Educational level	Focus Area	Aims
(Adjorlu & Serafin, 2020)	Saudi Arabia	K-12 education	Dentistry	To present the development of a gamified virtual reality application which aims at increasing students diagnosed with autism spectrum disorder street-crossing.
(Frøland et al., 2020)	Norway	Higher education	Education in general	To showcase a virtual reality laboratory that integrates game mechanisms to increase students' biomedical knowledge and discuss the main requirements of developing such applications.
(Kiourt et al., 2020)	Greece	K-12 education	Audiovisual production	To demonstrate the potential of a gamified virtual reality application that aims at supporting laboratory-based training.
(Krauter et al., 2021)	Germany	Higher education	Entrepreneurship	To demonstrate a virtual reality application that uses gamification elements to improve students' good practices related to COVID-19 measures (e.g., social distancing).
(Liritzis & Volonakis, 2021)	Greece	Higher education	STEM	To present a virtual reality laboratory that uses gamification elements to improve students' problem-solving skills in relation to archaeological science.
(Banjar & Campbell, 2022)	Ireland	Higher education	Computer science (Programming)	To present the design and development process of a gamified mixed reality application which aims at enriching dentistry education and training.
(Chrysanthakopoulou et al., 2022)	Greece	Higher education	Education in general	To present the design and development of an educational application that uses virtual reality and gamification and incorporates escape-room and treasure hunting games.
(Economou et al., 2022)	United Kingdom	–	Biomedical education	To present a work-in-progress study which aims at assessing the use of scaffolding instructions, gamification and immersive technologies to support British sign language teaching and learning.
(Flandoli et al., 2022)	Ecuador	Higher education	Self-directed learning	To present the development of a project-based virtual reality application which integrates game mechanisms to support and facilitate the teaching of audiovisual production.

Table 5 (continued)

Article	Country	Educational level	Focus Area	Aims
(Gerard et al., 2022)	United Kingdom	Higher education	Arts	To present a work-in-progress study which aims at integrating an application that uses virtual reality and gamification in educational environments to support criminology education.
(Sathya et al., 2022)	India	Higher education	Medical education	To present a gamified virtual reality application to enhance students' programming learning.
(Xu J et al., 2022)	Malaysia	Higher education	Dental anesthesia	To present the design, methodology, and development of a gamified virtual reality scaffolding application that improves students' self-directed learning in STEAM related subjects.

Table 6 Review, conceptual and theoretical articles

Article	Country	Aims	Main findings
(Maines et al., 2015)	United Kingdom	To present an overview regarding the evolution of virtual campus tours and examine the use of virtual learning environments and object-based gamification as educational tools to increase students' active participation.	The use of game technologies, gamification, and immersive technologies can lead to improving students' knowledge and comprehension of a given topic.
(Gordon & Brayshaw, 2017)	United Kingdom	To highlight the benefits and issues regarding the use of virtual reality in education and propose a framework for creating virtual learning environments that incorporate gamification elements among others.	Although the integration of immersive technologies in education can bring about several benefits, there still remain open issues (e.g., inclusivity, sense of presence, evaluation, etc.) that need to be addressed.
(Symonenko et al., 2019)	Ukraine	To provide an overview of the impact of virtual reality in foreign language learning while taking the use of gamification elements into account.	Virtual reality can constitute a significant educational tool in language learning as it increases students' motivation and active participation, improves their communication skills, and prepares them for real-life and professional situations. Immersion, gamification, and realistic simulations are the most determining aspects of effective virtual learning environments.
(Yengin & Bayrak, 2019)	Turkey	To discuss and highlight the benefits of integrating virtual reality applications in gamified learning contexts.	Gamified virtual learning experiences can offer students safe learning environments that can save time, space, and money. Within these environments, students are able to freely explore, get instantaneous feedback, gain hands-on experiences, enhance their social and communication skills, and improve their problem-solving and analytical skills.
(Bilro et al., 2020)	Portugal	To identify, propose, and discuss the practical applications and benefits of integrating gamification elements and virtual reality in higher education to enhance students' motivation, performance, and active participation.	The use of virtual reality and gamification in educational settings is still at its early stages and it is expected to further evolve. Hence, their popularity and adoption will increase. These immersive virtual environments are not equally accepted or efficient. In order for them to be successfully implemented, users' characteristics and user experience should be taken into account and the appropriate assessment methods should be followed.

Table 6 (continued)

Article	Country	Aims	Main findings
(Klippel et al., 2020)	United States	To present a research framework for immersive place-based learning that utilizes virtual reality and gamification elements to create immersive virtual field trips and go over related studies.	Based on the studies presented, the framework brought about positive outcomes to the learning and teaching activities.
(Loureiro et al., 2020)	Portugal	To analyze the effect of virtual reality and gamification on education from a marketing and service perspective.	In order for virtual reality and gamification to be satisfactorily adopted and implemented into education, more research into related applied theories, teaching methodologies, learning experience and motivation factors as well as students' engagement is necessary.
(Poulova et al., 2020)	Czech Republic	To present virtual applications that use gamification elements to support tourism education and discuss how virtual reality and simulations could be used in the educational process.	Virtual learning environments assist students in improving their planning and analysis skills and enhancing their knowledge application in the strategic business planning process.
(Redondo et al., 2020)	Spain	To provide an overview of a research project related to the use of virtual reality, game strategies and game elements in teaching and learning activities of collaborative urban design.	The combination of game elements and virtual reality had a positive effect on the learning process and increased students' motivation. The nature and the realism of the scenarios were determining factors. The need for specialized head-mounted devices was highlighted as the main drawback.
(Motejlek & Alpay, 2021)	United Kingdom	To analyze the existing augmented and virtual reality taxonomies and their interconnection with gamification elements.	A proposed taxonomy which classifies immersive technologies based on several attributes including gamification and its facets was showcased.
(Pinto et al., 2021)	Portugal	To comprehend and highlight if and how gaming elements and strategies within virtual reality environments can support and benefit foreign language learning through a systematic review.	Using gaming strategies along with immersive technologies can facilitate and enhance foreign language learning. Learning was the most highly assessed variable. Primary and lower secondary education were mostly investigated. English was the most widely examined language.

Table 6 (continued)

Article	Country	Aims	Main findings
(Bahrin et al., 2022)	Malaysia	To examine and discuss the concept and role of enjoyment and fun within gamified virtual reality environments of informal learning.	Gamified virtual reality experiences can be used in both formal and informal learning and in different research contexts and educational domains as they can create immersive, enjoyable, and fun environments.
(Bilro et al., 2022)	Portugal	To explore the use of gamification and virtual reality in higher education and recommend practical applications and research directions.	In order for virtual reality and gamification to be successfully integrated into education, user experience and users' characteristics should be taken into consideration and proper assessment and managerial methods should be used.
(Muñoz et al., 2022)	Honduras	To examine software and hardware applications that use augmented reality, virtual reality, and game technologies and were developed for ophthalmology education and training.	The use of immersive technologies can play a crucial role in medical education and in training new surgical skills while reducing costs and minimizing risks in the future.
(Punyani et al., 2022)	India	To go over and identify the potentials of integrating immersive technologies and gamification in physiotherapy education and training.	The use of virtual reality and gamification in education can yield several merits and has a lot of potentials.

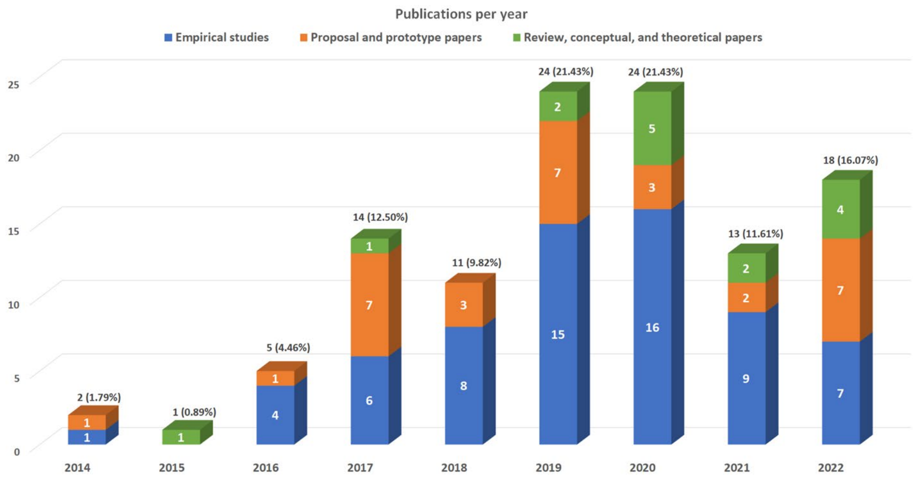

Fig. 3 Annual number of publications

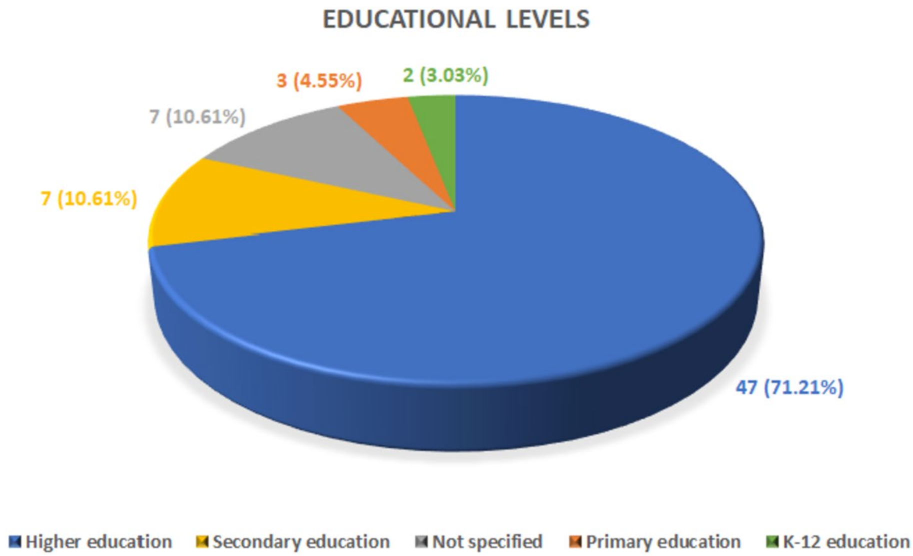

Fig. 4 Empirical studies: Educational levels

The main findings of the related empirical studies are presented in Table 4. Most results revealed positive learning outcomes and acceptance by the educational community. More details and comments on the results are listed in the summary and discussion sections.

Information regarding the proposal and prototype studies are presented in Table 5. Based on the results, most studies focused on higher education (74.19%), followed by K-12 (12.90). Some studies (12.90%) did not specify the educational level or age group that their proposed application was aiming at (Fig. 13). In this category of studies, there was no study that was targeting at primary or secondary education. STEM-related fields,

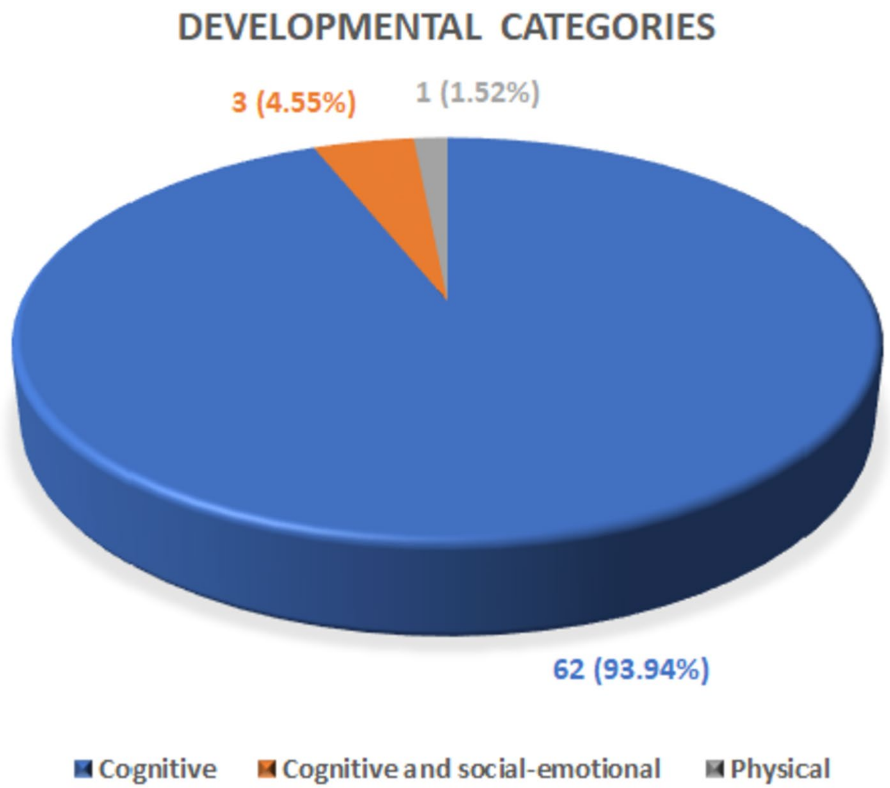

Fig. 5 Empirical studies: Developmental categories

medical and healthcare education, and engineering were the main focus areas of these studies (RQ10). Finally, the aims and main findings of the review, conceptual and theoretical articles are presented in Table 6.

Summary of the results and main findings

When taking into consideration the findings of the studies analyzed, it can be concluded that the use of gamification and virtual reality, as well as their combination in education can affect the educational process positively and yield benefits for both teachers and students (RQ16). To answer RQ1, the conclusions, results, and findings of the related studies were summarized. In the context of this study, the educational benefits that can be yielded through the use of gamified virtual reality refer to the aspects that render teaching and learning more effective, the new educational opportunities that arise, the positive learning outcomes, the elements that lead to the cognitive, social-emotional, and physical development of students, as well as the aspects that result in students' personal development and well-being. The integration of gamification and virtual reality in education can support technology-enhanced learning and the transformation of traditional education, facilitate and support teachers, and satisfactorily meet students' educational needs and requirements; thus, improving the overall teaching and learning

Fig. 6 Empirical studies: Research methods

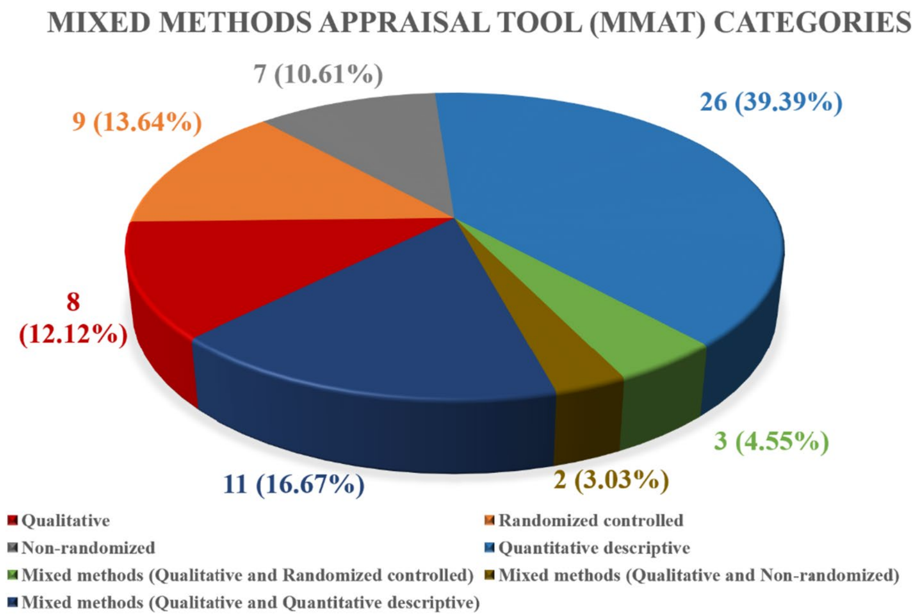

Fig. 7 Empirical studies: MMAT category

experience. But in order for this to be achieved, student habits, knowledge, requirements, personalities, experiences, and characteristics must be taken into account and appropriate educational strategies and methods should be adopted. By utilizing virtual

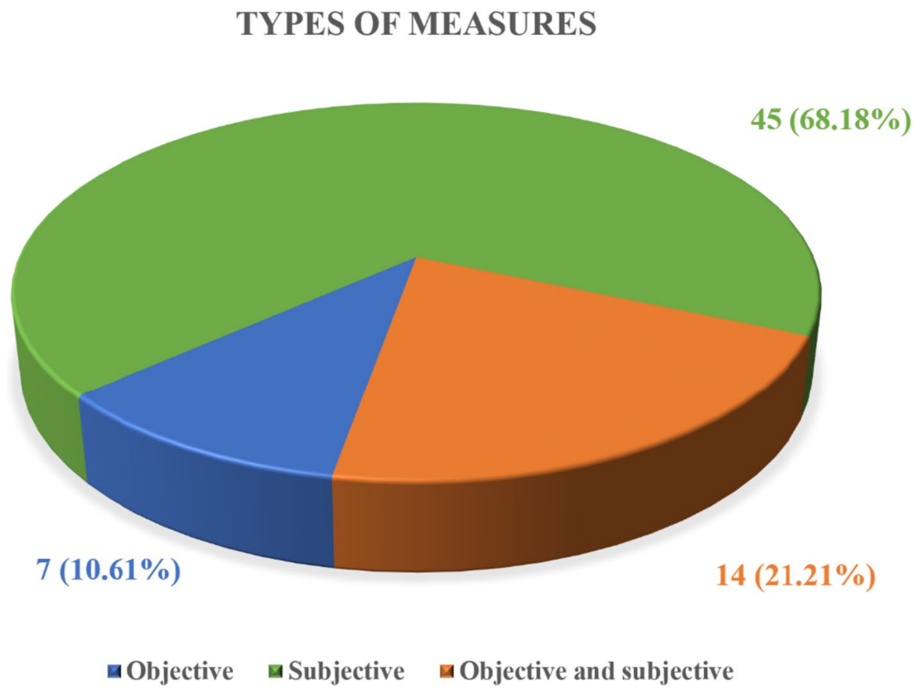

Fig. 8 Empirical studies: Types of measures

reality and gamification in conjunction, secure, safe, immersive, and interactive learning environments that have students at their core can be created. These environments promote active involvement, offer a sense of presence, provide personalized learning experiences, allow students to learn both individually and collaboratively, to experience environments and situations, and to participate in activities that would not be possible otherwise. Students that experienced learning in such gamified environments demonstrated better academic performance, enhanced motivation and engagement, improved psychological states and behaviors, and increased knowledge acquisition and retention. Students felt that these environments made them more focused, stimulated their imagination and curiosity, facilitated the comprehension of the subject, and were more intriguing, fun, and interesting compared to traditional learning. Most studies reported positive outcomes and very few reported some neutral or negative results (e.g., motion sickness).

It is important to note that besides students' assessing the use of gamification and virtual reality in the educational process positively, teachers were also favorable toward it and willing to familiarize themselves with using them and to create related educational material. This is particularly significant since teachers' role is essential for student development and the productive and efficient conduct of the educational process. Hence, teachers' acceptance of virtual reality and gamification and acknowledgement of the benefits they can yield is determining for their adoption and integration in educational settings. Based on the results, and the research instruments used to assess the applications, the development and validation of assessment instruments is a must.

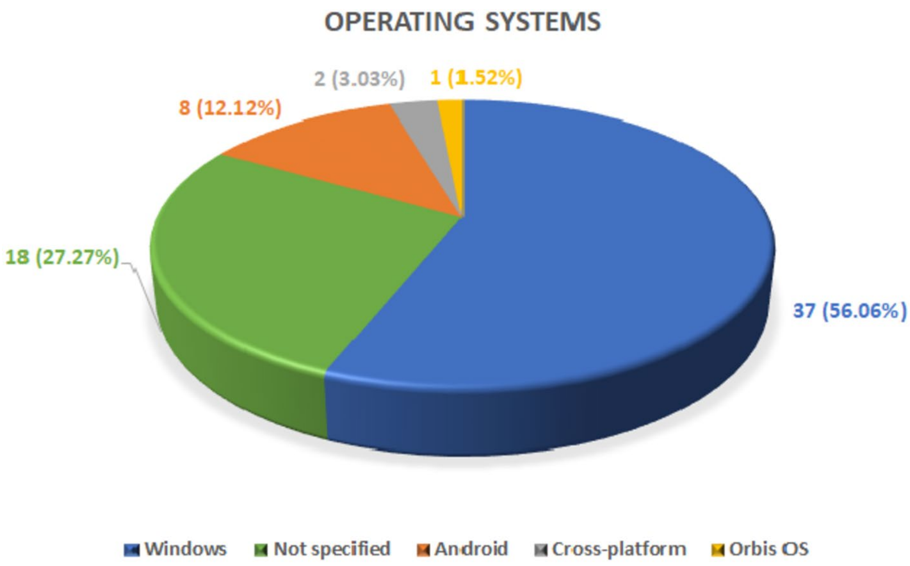

Fig. 9 Empirical studies: Operating systems

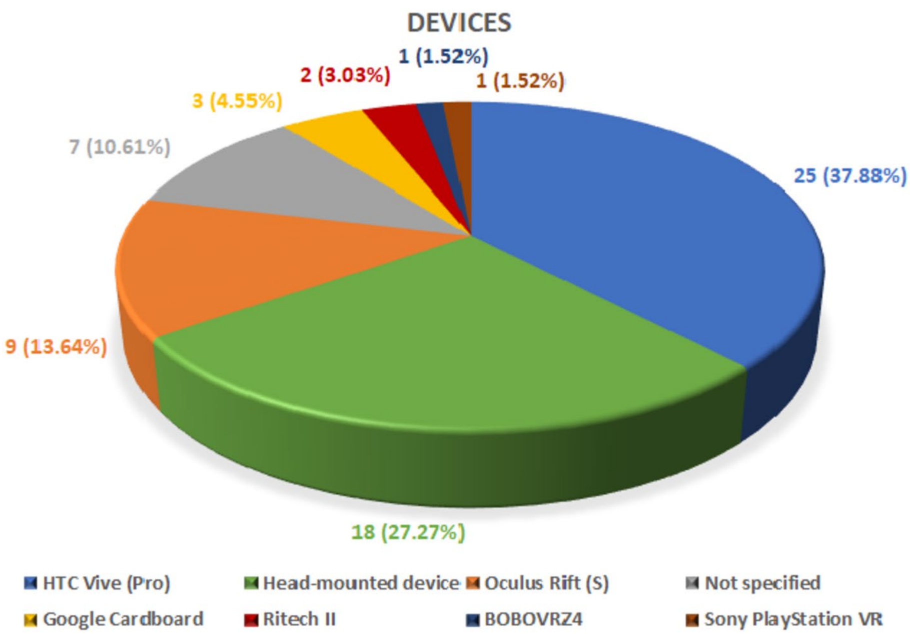

Fig. 10 Empirical studies: Devices used

According to the aforementioned results, the countries which explored the use of gamification and virtual reality in teaching and learning activities the most were Spain, the United Kingdom, Germany, Greece, and the United States. The studies were

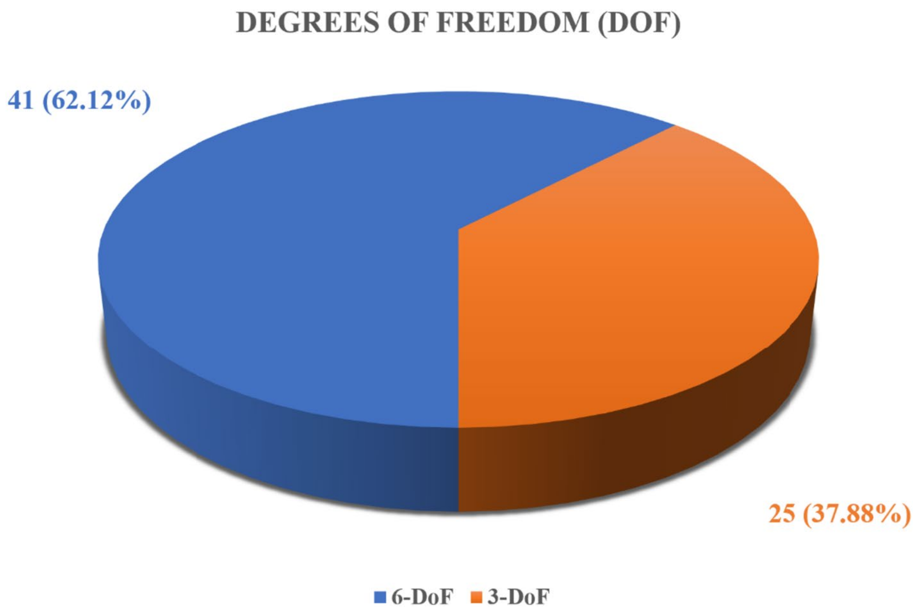

Fig. 11 Empirical studies: Devices used

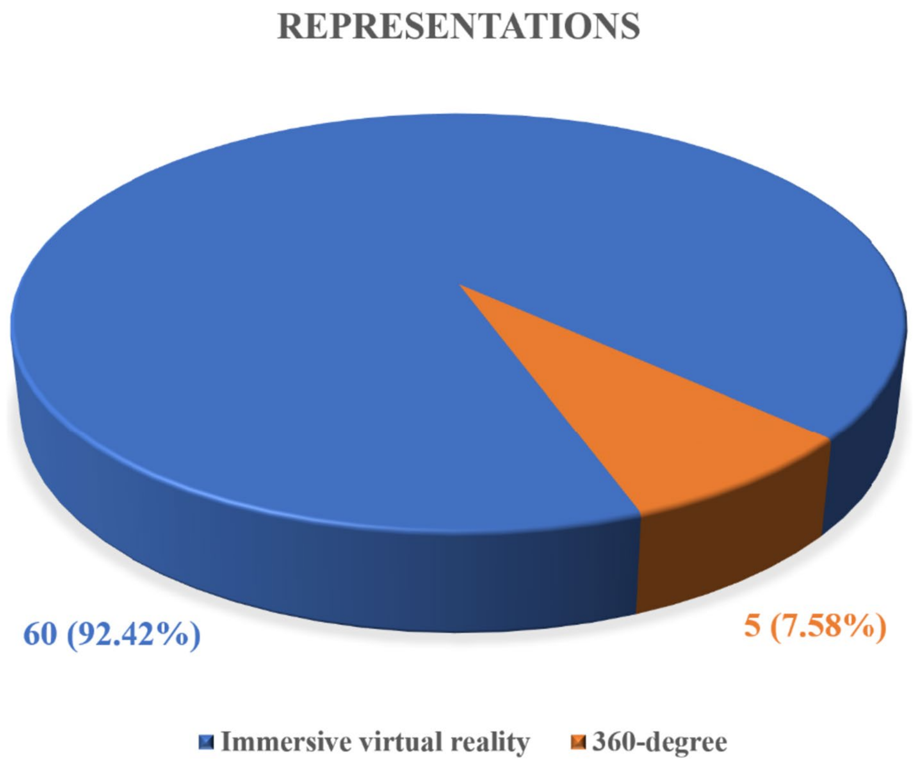

Fig. 12 Empirical studies: Devices used

conducted in 37 different countries around all inhabited continents; thus, supporting the idea that the use of virtual reality and gamification in education has attracted worldwide interest. Most studies were published during the years 2019, 2020, and 2022, focused on higher education and put emphasis on medical and health-care education, STEM subjects, language learning, and computer science. The majority of studies involved students, used quantitative research methods, and aimed at evaluating the effect of gamification and virtual reality in education and understanding the participants' perceptions and experience. As a result, most of the measures were subjective. Based on the MMAT, the quantitative studies mostly adopted the Quantitative descriptive approach, followed by Randomized controlled and Non-randomized approaches which were used to a lesser extent. The mixed methods studies mostly used a qualitative approach in combination with a Quantitative descriptive approach, followed by qualitative and Randomized controlled as well as qualitative and Non-randomized approaches to a far less extent. The most popular device was HTC Vive (Pro), Windows was the most widely used operating system, and Unity was by far the most commonly used development platform. It is worth noting that several studies did not use any specialized equipment but low-cost head-mounted devices which led to positive results, nevertheless. Students' cognitive development was the main focus of most studies; hence, the need to further analyze and comprehend the effect of gamification and virtual reality on student social-emotional and physical development is evident.

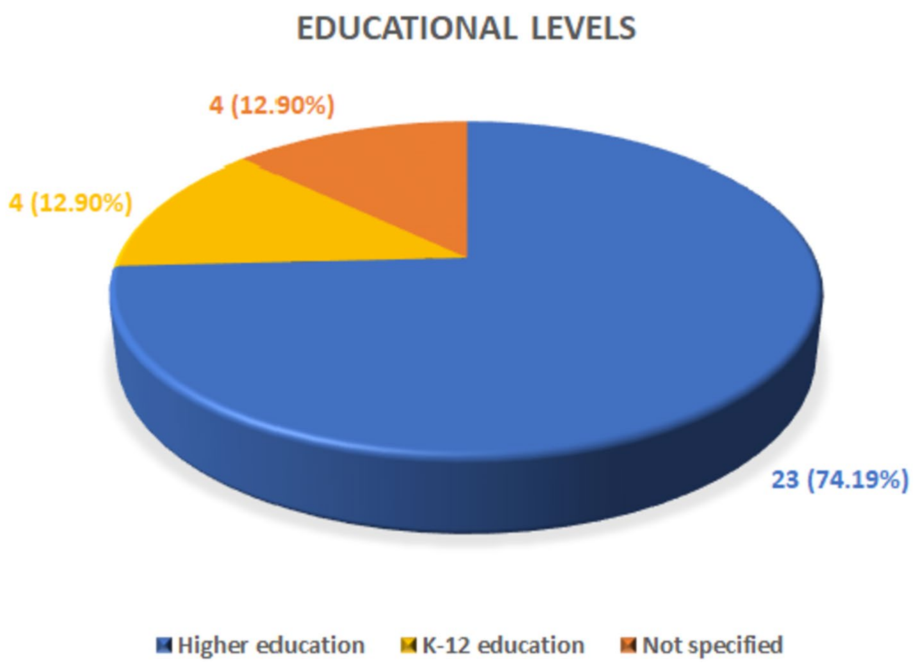

Fig. 13 Proposal and prototype papers: Educational levels

Discussion

Educational and societal needs and demands evolve along with technology; hence, the emergence of new pedagogical approaches and the use of technological applications in teaching and learning are inevitable (Ribeiro et al., 2019). Ethical, moral, and cultural factors (Hincapie et al., 2021; Lally et al., 2012) and students' needs, pursuit for more active and meaningful learning, characteristics, personality traits, and learning styles should be taken into account to facilitate the adoption and integration of Information and Communication Technologies (ICT) in education and to create educational experiences and activities that will lead to better learning outcomes (Bayne, 2014; DiLullo et al., 2011; Hussin, 2018). By incorporating technology-enhanced learning and multimedia learning into educational contexts, traditional teaching and learning activities can be transformed, the educational process becomes more student-centered and personalized and the educational material can be enriched with multimedia to be more effective and interactive (Djurovic & Djurovic, 2010; Sung et al., 2016).

Virtual reality supports multimedia learning and the cognitive theory of multimedia learning (Parong & Mayer, 2018) which states that when compared to solely textual information, the use of audiovisual information can lead to more engaging learning experiences which, in turn, result in improved learning outcomes (Mayer, 2020; Mayer & Moreno, 1998). As it becomes more widely adopted, the number of related applications and educational material increases while the required equipment becomes more affordable and advanced (Jensen & Konradsen, 2018). Additionally, although the devices used affect the overall student experiences and learning outcomes (Alamäki et al., 2021; Merchant et al., 2014), when designing student-centered approaches that take the unique student characteristics and environment conditions into consideration, even lower-end devices can bring about increased learning results (Adnan et al., 2020). Consequently, the use of virtual reality is gaining ground in both K-12 education (Merchant et al., 2014) and higher education (Freina & Ott, 2015). The effectiveness of virtual reality in education can be further increased through the use of gamification, several aspects of which are based on educational psychology (Kapp, 2012; Simões et al., 2013). The integration of gamification in education can positively affect students' cognitive and affective domains (Mullins & Sabherwal, 2020; Ritzhaupt et al., 2021), increase their intrinsic and extrinsic motivations (Dicheva et al., 2015; Van Roy & Zaman, 2018), and improve their behavioral and psychological states (Kim et al., 2017) which, in turn, can increase learning outcomes and student engagement (Wigfield et al., 2019).

Both virtual reality and gamification play a vital role in transforming traditional education and enriching current teaching and learning activities as well as in creating new instructional media, theories, and designs as well as novel pedagogical approaches and methodologies (An, 2021; Beck, 2019; Johnson et al., 2015). Specifically, immersive and interactive learning experiences, which occur in safe and secure virtual environments and can result in new teaching and learning opportunities and educational benefits, can be created through the use of gamification and virtual reality (Dede, 2009; Shapley et al., 2011). These environments are in line with active learning methodologies (Bai et al., 2020; Murillo-Zamorano et al., 2021), the motivational theory (Malone & Lepper, 1987), the engagement theory (Kearsley & Shneiderman, 1998), and the instructional theory (Dede et al., 2017; Rupp et al., 2019) as they motivate students to be engaged, participate actively, and remain committed to the educational activities and they enable them to cultivate their skills through hands-on experiences in both real-like and imaginary scenarios and conditions that otherwise would be impossible. As these immersive environments support experiential learning and offer personalized and authentic learning experiences, they allow students to play a central role in the learning activities which they can control and personally experience at their own pace (Brown et al., 1989; Kolb, 2014). As a result, students become more eager, inclined, focused, enthusiastic, and motivated to learn and actively participate in educational activities, stay engaged and interested longer, and attain better learning achievements (Barab et al., 2007; Robson et al., 2015; Roseth et al., 2008; Sharan, 2010). The gamified virtual reality environments can provide meaningful learning (Fan et al., 2015), increase student learning motivation and involvement (Alsawaier, 2018; Buckley & Doyle, 2014), and positively affect their emotions (López-Faican & Jaen, 2020) which are essential aspects of effective education (Pekrun & Linnenbrink-Garcia, 2014; Tokan & Imakulata, 2019) and can bring about positive learning attitudes and behaviors (Kiili, 2005) and increase students' engagement (Swartout & Lent, 2003), higher-order thinking (Crocco et al., 2016), knowledge acquisition, and learning outcomes (Huang et al., 2020). These environments create an interactive and positive climate (Hamari et al., 2014), promote and support inclusive and ubiquitous learning, foster social interactions, cooperation, satisfaction, and positive behaviors, and create opportunities for effective collaborative learning (Gimbert & Cristol, 2003; Hamari & Koivisto, 2015; Liu et al., 2017; Pozo-Sánchez et al., 2022). Therefore, besides the benefits in terms of learning outcomes and knowledge acquisition, students can also cultivate their 21st century skills, critical thinking, decision-making, emotional awareness, and social skills which are vital in modern society in these immersive environments (National Research Council, 2012; Romasz et al., 2004).

Therefore, due to the potential impact that the adoption and integration of gamified virtual reality applications and experiences can yield in the educational domain, this study focuses on analyzing the existing literature to achieve a deeper understanding of the topic. Several valuable findings and insights emerged from this analysis. Despite the recency of the specific topic, empirical studies, proposal and prototype papers as well as review, conceptual and theoretical articles have already been published. This fact further validates the significance of the topic and its vast potentials to enrich the educational process. In contrast to the number of empirical studies and proposal and prototype papers that have already been published, there is a clear lack of theoretical articles that analyze the state-of-the-art and create the theoretical basis of this expanding research area. This specific study aims at filling this gap in the existing literature. Based on the data, the years of 2019 and 2020 had the largest number of related documents published. Given the fact that virtual reality HMDs became more easily accessible in 2016, the interest in them has been increasing since 2017 which is justifiable as new technologies require additional time to start being adopted in education. Moreover, Occulus Rift and HTC Vive and the different versions of theirs, which were mostly used in the studies examined, have been released since 2016 which led to an increase in empirical studies being conducted. The number of related documents being published has increased over the years and as the required equipment becomes more affordable, advanced, and accessible, it is expected that this number will be increasing. The reach and interest in this topic can also be observed since countries around all inhabited continents have actively been exploring this area of study. This is particularly interesting when taking the different social, cultural, economic, and political aspects that characterize education around the world into account. This fact highlights the applicability and suitability of gamified virtual reality applications and experiences to be adopted and integrated in different environments. Despite the fact that 37 different countries have contributed in this field, there is a clear lack of cross-country and cross-cultural studies being conducted. It, thus, remains difficult to generalize and specify how particular characteristics and elements of gamified virtual reality applications affect education and learners around the world since direct comparisons cannot be made due to the numerous differences. Therefore, there is a clear need for more such studies to be carried out so that the implications and effects of gamified virtual reality applications can be objectively studied in depth and from different dimensions.

Due to its nature, the use of gamified virtual reality applications has been adopted and examined in all educational levels. This fact highlights their flexibility, adaptability, and usability to be integrated to meet learners' needs throughout their development. However, the vast majority of empirical studies as well as proposal and prototype papers focused on higher education, as it can be seen in Table 7. This outcome can be attributed to several reasons. For example, higher education students are more familiar with and accustomed to using new technologies, have a better understanding of their learning needs, and a better cohesion of technological applications. The topics and subjects being actively examined are more complex and suitable for higher education students and the evaluation tools used more appropriate for them as well. Additionally, it is easier to conduct virtual reality experiments involving higher education students since in some cases feelings of nausea have been reported with younger students. Another reason can be the differences in bureaucratic processes and ethical concerns that are required to carry out experiments between adults and underage participants. Finally, although the required equipment is becoming more accessible, higher education institutes are better and more appropriately equipped to carry out experiments, particularly the ones that are actively researching and developing virtual reality contents and applications. Despite this fact, there is a clear need for more studies that focus on primary, secondary, and K-12 education to be conducted so that the effect of gamified virtual reality applications on education can be more objectively assessed.

As far as the Empirical studies are concerned, the vast majority of studies (69.70%) used only students as their sample (Fig. 14). Some studies did not specify the exact sample nor provided age or background details and referred to the educational stakeholders that responded as participants (19.70%). Studies also focused on analyzing teachers' perspectives. This fact highlights the important role of meeting students' needs and having them at the core of new technology integration in education. Hence, it is important to take students' viewpoints and feedback into account when developing gamified virtual reality applications and incorporating them in cooperative design approaches. Nonetheless, there is a need for more empirical studies to be conducted focusing on teachers to better comprehend their viewpoints, attitudes, acceptance, and readiness to integrate such solutions. Identifying teachers' needs and the specific skills they lack to integrate gamified virtual reality in their classrooms would assist in creating and organizing appropriate and more effective training programs that would improve their skills and enhance their readiness to adopt such novelties. Moreover, the overwhelming majority of the studies examined focused on developing and testing gamified virtual reality applications to assess the participants' viewpoints and the impact they can have in education. As the topic is in its infancy, specialized aims were not observed. Therefore, future studies should put emphasis on analyzing how gamified virtual reality applications can influence specific areas of the educational process or specific variables associated with students' learning rather than focus on more generalized aims.

Due to its nature, gamified virtual reality can be applied in various subjects across all educational levels. Hence, the studies examined span across several educational topics, subjects, and areas. As it can be seen in Tables 8 and 9 topics emerged when clustering the documents based on the subject they involve. The topics that emerged based on the most popular areas of study are medical and healthcare education (21.21%), followed by language learning (10.61%), STEM (10.61%), arts (9.09%), computer science (9.09%), engineering (7.58%), general skills (7.58%), architecture and design (6.06%), and cultural heritage (6.06%). As the name suggests, studies that could not be included in one of these categories and could not be grouped with others into new categories were clustered in the "Other educational topics" category (12.12%). Furthermore, no matter the subject, educational level, or sample, the significant majority of studies focused solely on the cognitive developmental area (92.42%). Only 3 out of the 66 empirical studies explored social-emotional development (Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Šašinka et al., 2018) and only a single study focused entirely on participants' physical development (Senecal et al., 2020). Specifically in education, understanding how a specific intervention can affect all developmental areas of students and learners is crucial for ensuring its effective and appropriate adoption and integration. Hence, there is a clear need for more studies that take into account the influence of gamified virtual reality applications on participants' social-emotional and physical development.

Regarding the research approach and based on Table 10, most of the studies adopted a quantitative approach (63.64%), followed by Mixed (24.24%) and qualitative (12.12%) approaches. Moreover, based on the MMAT tool, the quantitative studies were separated into Quantitative descriptive (39.9%), Randomized controlled (13.64%), and Non-randomized (10.61%) categories while the mixed method studies were divided into Qualitative and Quantitative descriptive (16.67%), Qualitative and Randomized controlled (4.55%),

Table 7 Studies distribution according to educational level

Educational level	References
Higher education (71.21%)	(Abuhammad et al., 2021; Ahlers et al., 2022; Alexander et al., 2022; Anastasovitis et al., 2017; Angelino et al., 2019; Banjar & Campbell, 2022; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Chávez et al., 2020; Chen et al., 2020; Chrysanthakopoulou et al., 2022; Deggim et al., 2017; Falah et al., 2021; Flandoli et al., 2022; Fonseca et al., 2017a, b, 2020, 2021; Frøland et al., 2020; Gerard et al., 2022; Gonzalez & Garnique, 2018; Gonzalez-Gonzalez, 2020; Gordon et al., 2019; Grivokostopoulou et al., 2016, 2019a, b; Hartfill et al., 2020; Huaman et al., 2019; Iquira et al., 2019; Jiang & Zeng, 2019; Jiang et al., 2022; Krauter et al., 2021; Lima et al., 2016; Liritzis & Volonakis, 2021; Makled et al., 2019; Makransky et al., 2019; May & Denecke, 2020; Molloy et al., 2019; Mystakidis, 2020; Nicola et al., 2018; Oberhauser & Lecon, 2019; Palmas et al., 2021; Papagiannakis et al., 2018; Parakh et al., 2017; Parong & Mayer, 2019; Patterson et al., 2019; Ribeiro et al., 2019; Sanchez-Sepulveda et al., 2019; Šašinka et al., 2018; Sathya et al., 2022; Silva et al., 2021; Smith et al., 2021; Stelian & Lacramioara, 2018; Stelian et al., 2017; Stigall & Sharma, 2017; Suncksen et al., 2018; Suppes et al., 2019; Theethum et al., 2021; Tiefenbacher, 2020; Vagg et al., 2016; Vidal et al., 2021; Villagrasa et al., 2014; Wilson et al., 2017a, 2017b; Xu J et al., 2022; Xu T et al., 2022; Zhang & Bryan-Kinns, 2022; Zhang et al., 2016)
K-12 education (3.03%)	(Adjorlu & Serafin, 2020; Alharbi et al., 2020; Kiourt et al., 2020; Roumana et al., 2022; Yampray & Jirapanthong, 2017; Yusoffa & Shafirilb, 2019)
Secondary education (10.61%)	(AlKhateeb et al., 2019; Chiang, 2021; Doumanis & Economou, 2020; Mouronte-López et al., 2020; Tan et al., 2022; Wang, 2017)
Primary education (4.55%)	(Bryan et al., 2018; Luigini et al., 2020; Stranger-Johannessen, 2018)
Nor specified (10.61%)	(Almousa et al., 2019; Edwards et al., 2019; Garcia et al., 2019; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Rosmansyah et al., 2019; Senecal et al., 2020)

and Qualitative and Non-randomized (3.03%) categories. This fact highlights the multidimensional nature of this topic and its ability to be examined from different angles and using different methods. In addition to the different approaches used to explore this topic, the studies examined used various measurement and research tools (Table 9). The vast majority of studies used ad hoc questionnaires and surveys (66.67%), followed by existing validated tools (27.27%) with TAM (Davis, 1993) being the most commonly used tool. Interviews and discussions (21.21%) as well as observations (13.64%) were also used but to a lesser extent. Studies that used pre-test and post-test (16.67%) or application related data (12.12%) were also conducted and led to more objective results. Few studies (6.06%) used specific task-related tools to evaluate the impact of gamified virtual reality applications.

Given the different methods, approaches, and tools used, several variables have been examined throughout the studies included in this systematic review. When clustering the variables based on the frequency of use, 7 main variables were identified (Table 11). In particular, the studies focused on analyzing: (i) the participants' viewpoints, attitudes, and experiences (59.09%), (ii) usability and ease of use (31.81%), (iii) learning outcomes, achievements, and skills development (30.30%), (iv) enjoyment, satisfaction, and acceptance (19.70%), (v) effectiveness (13.64%), (vi) motivation (9.09%), as well as (vii) knowledge acquisition and comprehension (7.58%). When looking into the approaches, the tools, the sample, and the main variables used, it is not surprising that the measures of the vast majority of studies were subjective (68.18%) as it can be seen in Table 12. Some studies (21.21%), mostly those that applied mixed method approaches, resulted in both objective and subjective measures. Finally, few of the studies led to strictly objective measures (10.61%) and these were mostly studies that adopted pre-tests and post-tests or used application-related data. Based on the aforementioned results, it can be concluded that there is a clear need for more standardized and validated tools to be developed to more effectively evaluate gamified virtual reality learning experiences and to a greater extent extended

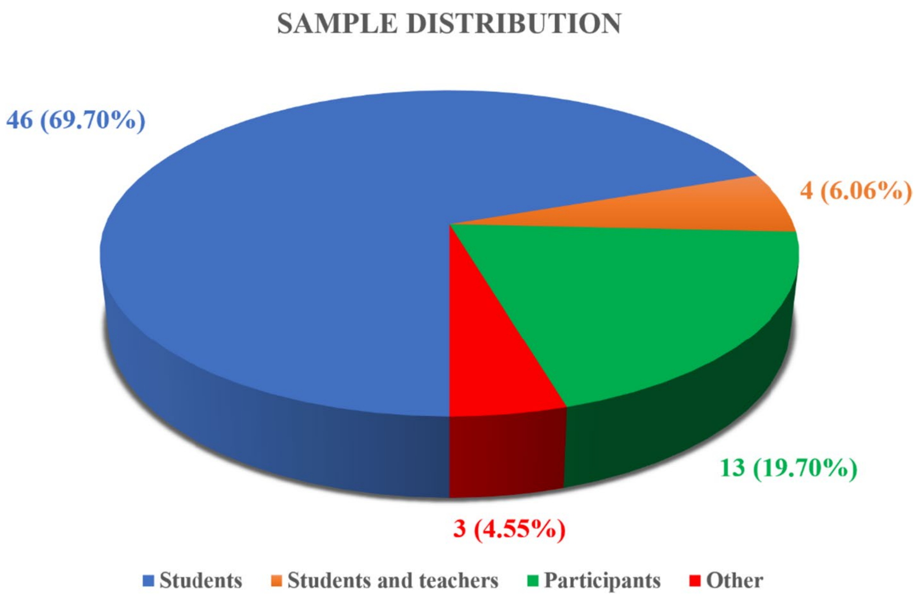

Fig. 14 Sample distribution

reality experiences. These tools will also allow for comparative studies to be conducted. Additionally, more studies should focus on providing objective measures rather than rely solely on subjective measures through the analysis of the participants' perspectives, opinions, and experiences. Finally, many studies focus solely on collecting and analyzing data derived only after the intervention which hinders the understanding of its true impact. Hence, future studies should focus on collecting data prior to the intervention so that comparisons with the data gathered after the intervention can be made to better comprehend the influence of the intervention. Comparative studies among different populations and topics should be promoted.

Although many of the studies did not provide many details and specifications about the development of their application (e.g., the application development methodologies or system design), some findings emerged from the data extracted. Most studies used Windows (59.09%) as the operating system of their application, followed by android (13.64%) and few studies (4.55%) used different operating systems (Table 13). It is worth noting that only two studies (May & Denecke, 2020; Pinzón-Cristancho et al., 2019) explicitly indicated that their applications can be used in multiple operating systems. When we take into account the development tools used, of which Unity was by far the most used platform (56.06%) and given its ability to allow cross-platform development, it should be mentioned that potentially more applications could be cross-platform but were only examined using specific operating systems and devices. Other popular

Table 8 Topics, subjects, and areas examined

Topic, subject, or area	References
Architecture and design (6.06%)	(Fonseca et al., 2017a, 2020, 2021; Sanchez-Sepulveda et al., 2019)
Arts (9.09%)	(Huaman et al., 2019; Molloy et al., 2019; Senecal et al., 2020; Vidal et al., 2021; Villagrasa et al., 2014; Zhang & Bryan-Kinns, 2022)
Computer Science (9.09%)	(Alexander et al., 2022; Grivokostopoulou et al., 2016; Nicola et al., 2018; Oberhauser & Lecon, 2019; Stigall & Sharma, 2017; Theethum et al., 2021)
Cultural heritage (6.06%)	(Jiang et al., 2022; Luigini et al., 2020; Roumana et al., 2022; Wang, 2017)
Engineering (7.58%)	(Chen et al., 2020; Geus et al., 2020; Mouronte-López et al., 2020; Pinzón-Cristancho et al., 2019; Smith et al., 2021)
General skills (7.58%)	(Alharbi et al., 2020; Doumanis & Economou, 2020; Palmas et al., 2021; Parong & Mayer, 2019; Silva et al., 2021)
Language learning (10.61%)	(Ahlers et al., 2022; AlKhateeb et al., 2019; Garcia et al., 2019; Gordon et al., 2019; Hartfill et al., 2020; Reitz et al., 2016; Zhang et al., 2016)
Medical and healthcare education (21.21%)	(Abuhammad et al., 2021; Almousa et al., 2019; Chávez et al., 2020; Falah et al., 2021; Gonzalez & Garnique, 2018; Makled et al., 2019; Makransky et al., 2019; May & Denecke, 2020; Suncksen et al., 2018; Tiefenbacher, 2020; Vagg et al., 2016; Wilson et al., 2017a, 2017b; Xu T et al., 2022)
Other educational topics (12.12%)	(Azar & Tan, 2020; Chiang, 2021; Gonzalez-Gonzalez, 2020; Grivokostopoulou et al., 2019a; Mystakidis, 2020; Rosmansyah et al., 2019; Šašinka et al., 2018; Tan et al., 2022)
STEM (10.61%)	(Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Bryan et al., 2018; Edwards et al., 2019; Iquira et al., 2019; Stranger-Johannessen, 2018)

Table 9 Measurement and research tools distribution

Measurement and research tools	References
Ad hoc questionnaires and surveys (66.67%)	(Abuhammad et al., 2021; Alexander et al., 2022; Alharbi et al., 2020; AlKhateeb et al., 2019; Azar & Tan, 2020; Becerra et al., 2017; Bryan et al., 2018; Chávez et al., 2020; Chávez et al., 2020; Chen et al., 2020; Chiang, 2021; Doumanis & Economou, 2020; Edwards et al., 2019; Falah et al., 2021; Fonseca et al., 2017a, 2020, 2021; Gonzalez & Garnique, 2018; Gonzalez-Gonzalez, 2020; Grivokostopoulou et al., 2016, 2019a; Hartfill et al., 2020; Huaman et al., 2019; Iquira et al., 2019; Jiang et al., 2022; Makransky et al., 2019; May & Denecke, 2020; Mouronte-López et al., 2020; Palmas et al., 2021; Parong & Mayer, 2019; Reitz et al., 2016; Rosmansyah et al., 2019; Sanchez-Sepulveda et al., 2019; Stigall & Sharma, 2017; Tan et al., 2022; Theethum et al., 2021; Tiefenbacher, 2020; Vidal et al., 2021; Villagrasa et al., 2014; Wang, 2017; Wilson et al., 2017a, 2017b; Xu T et al., 2022; Zhang & Bryan-Kinns, 2022)
Existing validated tools (27.27%)	(Besoain et al., 2018; Chávez et al., 2020; Chávez et al., 2020; Chiang, 2021; Doumanis & Economou, 2020; Falah et al., 2021; Hartfill et al., 2020; Luigini et al., 2020; Makled et al., 2019; Makransky et al., 2019; May & Denecke, 2020; Molloy et al., 2019; Palmas et al., 2021; Reitz et al., 2016; Senecal et al., 2020; Silva et al., 2021; Smith et al., 2021; Suncksen et al., 2018)
Interviews and discussion (21.21%)	(Ahlers et al., 2022; Alharbi et al., 2020; Almousa et al., 2019; Chen et al., 2020; Edwards et al., 2019; Fonseca et al., 2021; Garcia et al., 2019; Geus et al., 2020; Roumana et al., 2022; Šašinka et al., 2018; Suncksen et al., 2018; Theethum et al., 2021; Wilson et al., 2017a; Zhang & Bryan-Kinns, 2022)
Pre-tests and Post-tests (16.67%)	(Chávez et al., 2020; Chen et al., 2020; Fonseca et al., 2017a; Grivokostopoulou et al., 2016, 2019a; Makransky et al., 2019; Mouronte-López et al., 2020; Parong & Mayer, 2019; Rosmansyah et al., 2019; Stranger-Johannessen, 2018; Theethum et al., 2021)
Observations (13.64%)	(AlKhateeb et al., 2019; Edwards et al., 2019; Mystakidis, 2020; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Roumana et al., 2022; Šašinka et al., 2018; Vagg et al., 2016; Zhang et al., 2016)
Application related data (12.12%)	(Geus et al., 2020; Gonzalez & Garnique, 2018; Gonzalez-Gonzalez, 2020; Iquira et al., 2019; Oberhauser & Lecon, 2019; Reitz et al., 2016; Smith et al., 2021; Theethum et al., 2021)
Other tools (6.06%)	(Gordon et al., 2019; Molloy et al., 2019; Nicola et al., 2018; Pinzón-Cristancho et al., 2019)

Note. The studies belong to the empirical studies category and due to their approaches, some of them have adopted various measurement and research tools. Hence, they appear in multiple categories

development tools and platforms (Table 14) that were used to develop the applications were: Unreal Engine (9.09%), Oculus Rift Development Kit (9.09%), SteamVR (7.58%), and Google VR SDK (6.06%). Different types of HTC Vive head-mounted devices were most widely used (37.88%) to carry out the experiments. General purpose head-mounted devices (27.27%) as well as the Oculus Rift (13.64%) were also used. These outcomes highlight several areas that can be further examined in the future. Due to the variety of the tools, the applications, and the approaches used as well as the differences in environments and settings, comparisons regarding the effects that different devices, platforms, and operating systems might have could not be explored. As the operating system and the platform may not significantly affect the outcomes, given the fact that

Table 10 Research method and MMAT category distribution

Research method	MMAT category	References
Quantitative (63.64%)	Quantitative descriptive (39.9%)	(Abuhammad et al., 2021; Alexander et al., 2022; Azar & Tan, 2020; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Bryan et al., 2018; Doumanis & Economou, 2020; Fonseca et al., 2020; Gonzalez & Garnique, 2018; Gonzalez-Gonzalez, 2020; Gordon et al., 2019; Huaman et al., 2019; Jiang et al., 2022; Luigini et al., 2020; Makled et al., 2019; Nicola et al., 2018; Oberhauser & Lecon, 2019; Sanchez-Sepulveda et al., 2019; Silva et al., 2021; Smith et al., 2021; Stigall & Sharma, 2017; Tan et al., 2022; Wang, 2017; Wilson et al., 2017a; Xu T et al., 2022)
	Randomized controlled (13.64%)	(Chávez et al., 2020; Chiang, 2021; Grivokostopoulou et al., 2016, 2019a; Hartfill et al., 2020; Palmas et al., 2021; Parong & Mayer, 2019; Rosmansyah et al., 2019; Stranger-Johannessen, 2018)
	Non-randomized (10.61%)	(Fonseca et al., 2017a; Makransky et al., 2019; May & Denecke, 2020; Mouronte-López et al., 2020; Senecal et al., 2020; Tiefenbacher, 2020; Vidal et al., 2021)
Mixed (24.24%)	Mixed methods (Qualitative and Quantitative descriptive) (16.67%)	(Alharbi et al., 2020; AlKhateeb et al., 2019; Edwards et al., 2019); Falah et al., 2021; Fonseca et al., 2021; Molloy et al., 2019; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Suncksen et al., 2018; Villagrasa et al., 2014; Wilson et al., 2017b)
	Mixed methods (Qualitative and Randomized controlled) (4.55%)	(Chen et al., 2020; Theethum et al., 2021; Zhang & Bryan-Kinns, 2022)
	Mixed methods (Qualitative and Non-randomized) (3.03%)	(Geus et al., 2020; Iquira et al., 2019)
Qualitative (12.12%)	Qualitative (12.12%)	(Ahlers et al., 2022; Almousa et al., 2019; Garcia et al., 2019; Mystakidis, 2020; Roumana et al., 2022; Šašinka et al., 2018; Vagg et al., 2016; Zhang et al., 2016)

many end-users are unaware of or disinterested in them, future studies should focus on exploring which devices can lead to better outcomes through the comparison of different devices in the same experimental settings. Additionally, future studies should provide more specifications about their applications and the development process so that their influence could be examined in more detail. It would also be worth exploring how different design and development approaches and methodologies could affect the impact of gamified virtual reality applications.

Presence and immersion are vital aspects in any virtual reality experience. Based on the results of the studies examined, the higher the presence and the immersion of a student is, the better the learning outcomes and educational benefits are. DoF and content representation are elements that affect students' presence and immersion in the virtual environment. Based on Table 15, the vast majority of studies used 6-DoF (62.12%) while the rest used 3-DoF (37.88%). It is worth noting that most recent studies opted to use 6-DoF. Hence, it can be inferred that it is preferrable to allow students to more freely move within the virtual world and interact with their surroundings rather than restrict them as they will be able to become fully immersed and explore the virtual environments on their own. Nonetheless, based on the topic or subject to be explored, in some cases 3-DoF was used and led to increased learning outcomes. To determine how different DoF affect students and their learning experiences and outcomes, there is a clear need for carrying out more studies that directly compare applications with the same content and overall experience but with different DoF in the same settings and environments. Regarding content representation (Table 16), the overwhelming majority of the studies used immersive virtual reality (92.42%) rather than 360-degree content (7.58%). Based on the results, it can be inferred that by engaging themselves in immersive virtual reality environments and interacting with contents, objects, and other users, students become more engaged and immersed in the overall experience which, in turn, increases the educational benefits yielded. Gamification elements can also affect students' presence and immersion as well as the overall learning experience and outcomes. Although game-like features and mechanisms were widely used across all studies examined in this systematic review, particular gamification elements including scores and points, quests and tasks, quizzes, virtual rewards and achievements, difficulty levels and challenges, feedback, mini-games, and leaderboards were observed in the majority of studies. Despite the fact that different gamification elements can affect learners' presence, immersion, experience, and learning to a different degree, the variety in the nature of the applications, the experiments, and the environments did not allow the examination of the most optimal and impactful use of gamification elements. Future studies should focus on examining and comparing the influence that different gamification elements and their combination can have to determine the ones that improve and enrich the educational process more. In addition, besides the impact they can have on the educational process, future studies can also look into how different gamification elements can affect students.

Examining the impact of gamified virtual reality applications and experiences on education was a focal point of this study. It is worth noting that differences in terms of gender and age were also observed with younger participants showcasing more openness and acceptance of the integration of gamification and virtual reality learning experiences. Additionally, girls showcased higher levels of immersion and acceptance (Chiang, 2021; Fonseca et al., 2017a, 2020; Mouronte-López et al., 2020). Despite this fact, the overwhelming majority of the studies reported positive educational outcomes. To better understand the benefits and merits yielded through the integration of gamification

Table 11 Most frequently examined variables

Variable	References
Viewpoints, attitudes, and experiences (59.09%)	(Abuhammad et al., 2021; Alharbi et al., 2020; AlKhateeb et al., 2019; Almousa et al., 2019; Azar & Tan, 2020; Becerra et al., 2017; Bryan et al., 2018; Chen et al., 2020; Edwards et al., 2019; Falah et al., 2021; Fonseca et al., 2017a, 2020, 2021; Garcia et al., 2019; Gonzalez-Gonzalez, 2020; Grivokostopoulou et al., 2016, 2019a; Hartfill et al., 2020; Jiang et al., 2022; Luigini et al., 2020; Makransky et al., 2019; Molloy et al., 2019; Mouronte-López et al., 2020; Pinzón-Cristancho et al., 2019; Šašinka et al., 2018; Silva et al., 2021; Stigall & Sharma, 2017; Suncksen et al., 2018; Tan et al., 2022; Theethum et al., 2021; Tiefenbacher, 2020; Vidal et al., 2021; Villagrasa et al., 2014; Wang, 2017; Wilson et al., 2017a, 2017b; Xu T et al., 2022; Zhang & Bryan-Kinns, 2022; Zhang et al., 2016)
Usability and ease of use (31.81%)	(Alexander et al., 2022; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Doumanis & Economou, 2020; Geus et al., 2020; Gonzalez & Garnique, 2018; Huaman et al., 2019; Jiang et al., 2022; May & Denecke, 2020; Molloy et al., 2019; Palmas et al., 2021; Roumana et al., 2022; Sanchez-Sepulveda et al., 2019; Smith et al., 2021; Stigall & Sharma, 2017; Suncksen et al., 2018; Vagg et al., 2016; Vidal et al., 2021; Wilson et al., 2017a, 2017b; Zhang & Bryan-Kinns, 2022)
Learning outcomes, achievements, and skill development (30.30%)	(Ahlers et al., 2022; Almousa et al., 2019; Chávez et al., 2020; Chiang, 2021; Doumanis & Economou, 2020; Geus et al., 2020; Gonzalez & Garnique, 2018; Gonzalez-Gonzalez, 2020; Gordon et al., 2019; Grivokostopoulou et al., 2016, 2019a; Iquira et al., 2019; Nicola et al., 2018; Oberhauser & Lecon, 2019; Parong & Mayer, 2019; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Stranger-Johannessen, 2018; Vagg et al., 2016; Zhang et al., 2016)
Enjoyment, satisfaction, and acceptance (19.70%)	(Ahlers et al., 2022; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Hartfill et al., 2020; Jiang et al., 2022; Palmas et al., 2021; Rosmansyah et al., 2019; Sanchez-Sepulveda et al., 2019; Stigall & Sharma, 2017; Theethum et al., 2021; Vidal et al., 2021; Wang, 2017; Zhang & Bryan-Kinns, 2022)
Effectiveness (13.64%)	(Alexander et al., 2022; AlKhateeb et al., 2019; Bedregal-Alpaca et al., 2020; Huaman et al., 2019; Jiang et al., 2022; Rosmansyah et al., 2019; Roumana et al., 2022; Sanchez-Sepulveda et al., 2019; Wilson et al., 2017a)
Motivation (9.09%)	(Grivokostopoulou et al., 2016, 2019a; Hartfill et al., 2020; Makransky et al., 2019; Palmas et al., 2021; Reitz et al., 2016)
Knowledge acquisition and comprehension (7.58%)	(Chen et al., 2020; Luigini et al., 2020; Mouronte-López et al., 2020; Rosmansyah et al., 2019; Theethum et al., 2021)

and virtual reality in education, a thematic analysis of the benefits identified was conducted, the results of which can be seen in Table 17. A total of 18 broad categories were identified. More specifically, the adoption and integration of virtual reality and gamification in the educational process is positively viewed and accepted by the educational

Table 12 Measures distribution

Measures	References
Subjective (68.18%)	(Abuhammad et al., 2021; Ahlers et al., 2022; Alexander et al., 2022; Alharbi et al., 2020; AlKhateeb et al., 2019; Azar & Tan, 2020; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Bryan et al., 2018; Chiang, 2021; Edwards et al., 2019; Falah et al., 2021; Fonseca et al., 2017a, 2020, 2021; Garcia et al., 2019; Hartfill et al., 2020; Huaman et al., 2019; Jiang et al., 2022; Luigini et al., 2020; Makled et al., 2019; Makransky et al., 2019; May & Denecke, 2020; Molloy et al., 2019; Mystakidis, 2020; Palmas et al., 2021; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Roumana et al., 2022; Sanchez-Sepulveda et al., 2019; Šašinka et al., 2018; Silva et al., 2021; Stigall & Sharma, 2017; Suncksen et al., 2018; Tan et al., 2022; Tiefenbacher, 2020; Vagg et al., 2016; Vidal et al., 2021; Villagrasa et al., 2014; Wang, 2017; Wilson et al., 2017a, 2017b; Xu T et al., 2022; Zhang et al., 2016)
Objective and subjective (21.21%)	(Almousa et al., 2019; Chávez et al., 2020; Chen et al., 2020; Doumanis & Economou, 2020; Geus et al., 2020; Gonzalez & Garnique, 2018; Grivokostopoulou et al., 2016, 2019a; Iquira et al., 2019; Mouronte-López et al., 2020; Rosmansyah et al., 2019; Smith et al., 2021; Theethum et al., 2021; Zhang & Bryan-Kinns, 2022)
Objective (10.61%)	(Gonzalez-Gonzalez, 2020; Gordon et al., 2019; Nicola et al., 2018; Oberhauser & Lecon, 2019; Parong & Mayer, 2019; Senecal et al., 2020; Stranger-Johannessen, 2018)

Table 13 Operating system distribution

Operating system	References
Windows (59.09%)	(Ahlers et al., 2022; Alexander et al., 2022; AlKhateeb et al., 2019; Almousa et al., 2019; Besoain et al., 2018; Bryan et al., 2018; Edwards et al., 2019; Fonseca et al., 2017a, 2020, 2021; Garcia et al., 2019; Gonzalez & Garnique, 2018; Gordon et al., 2019; Hartfill et al., 2020; Huaman et al., 2019; Luigini et al., 2020; Makled et al., 2019; Molloy et al., 2019; Oberhauser & Lecon, 2019; Palmas et al., 2021; Parong & Mayer, 2019; Reitz et al., 2016; Roumana et al., 2022; Sanchez-Sepulveda et al., 2019; Šašinka et al., 2018; Senecal et al., 2020; Stigall & Sharma, 2017; Suncksen et al., 2018; Tan et al., 2022; Theethum et al., 2021; Tiefenbacher, 2020; Vagg et al., 2016; Vidal et al., 2021; Villagrasa et al., 2014; Xu T et al., 2022; Zhang & Bryan-Kinns, 2022; Zhang et al., 2016; May & Denecke, 2020; Pinzón-Cristancho et al., 2019)
Android (13.64%)	(Abuhammad et al., 2021; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Chen et al., 2020; Falah et al., 2021; Nicola et al., 2018; Wilson et al., 2017a, 2017b; May & Denecke, 2020)
Other (4.55%)	(May & Denecke, 2020; Pinzón-Cristancho et al., 2019; Mouronte-López et al., 2020)

stakeholders and they are regarded as effective educational tools that can enrich and improve teaching and learning in all educational levels. Furthermore, the use of gamification and virtual reality applications can increase learning outcomes and academic performance and improve motivation, engagement, and active participation.

Being enriched with gamifiation elements and mechanisms, virtual reality experiences can also increase interaction, communication, and collaboration and improve knowledge acquisition and material comprehension. The gamified virtual reality environments offer enhanced immersion and provide students with realistic experiences which increase their satisfaction and enjoyment, improve their concentration and focus, and enhance their curiosity and creativity. Students' social presence and sense of

Table 14 Development tool distribution

Development tool	References
Unity (56.06%)	(Abuhammad et al., 2021; Ahlers et al., 2022; Alexander et al., 2022; Alharbi et al., 2020; AlKhateeb et al., 2019; Almousa et al., 2019; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Bryan et al., 2018; Chen et al., 2020; Edwards et al., 2019; Falah et al., 2021; Garcia et al., 2019; Gonzalez & Garnique, 2018; Hartfill et al., 2020; Huaman et al., 2019; Iquira et al., 2019; May & Denecke, 2020; Molloy et al., 2019; Mouronte-López et al., 2020; Nicola et al., 2018; Oberhauser & Lecon, 2019; Palmas et al., 2021; Roumana et al., 2022; Senecal et al., 2020; Smith et al., 2021; Suncksen et al., 2018; Tiefenbacher, 2020; Vidal et al., 2021; Villagrasa et al., 2014; Wang, 2017; Wilson et al., 2017a, 2017b; Xu T et al., 2022; Zhang & Bryan-Kinns, 2022; Zhang et al., 2016)
Unreal Engine 4 (9.09%)	(Fonseca et al., 2017a, 2021; Geus et al., 2020; Gordon et al., 2019; Reitz et al., 2016; Vagg et al., 2016)
Oculus Rift Development Kit (9.09%)	(Garcia et al., 2019; Luigini et al., 2020; Stigall & Sharma, 2017; Theethum et al., 2021; Vagg et al., 2016; Villagrasa et al., 2014)
SteamVR (7.58%)	(Alexander et al., 2022; Besoain et al., 2018; Bryan et al., 2018; Oberhauser & Lecon, 2019; Šašinka et al., 2018)
Google VR SDK (6.06%)	(Becerra et al., 2017; May & Denecke, 2020; Nicola et al., 2018; Wilson et al., 2017b)

belonging to a group of people and relating to them can also be improved. As students are able to participate in experiential learning and gain hands-on experience in safe and secure environments, their skills, competences, and knowledge are increased and as a result, their self-efficacy is improved. When students experience environments that are characterized by high levels of realism and apply their theoretical knowledge into practice, better learning achievements can be yielded. These interactive environments that are easy to use and navigate can offer adaptive and personalized experiences and feedback and provide enjoyable, fun, and interesting learning environments. Based on the aforementioned, it is clear that the use of virtual reality and gamification in education can improve and enrich the overall educational process and create opportunities for new teaching and learning experiences. Through these immersive environments, students can experience ubiquitous learning in environments and settings that would have been impossible otherwise.

Other benefits were also observed but to a lesser extent. These benefits include: improved cross-cultural understanding (Zhang et al., 2016), creation of learning experiences that would have been impossible otherwise (Silva et al., 2021; Tan et al., 2022), opportunities for hands-on experiences in safe environments (Alexander et al., 2022), reduced costs and resources (Yengin & Bayrak, 2019), minimized risks (Muñoz et al., 2022), enhanced physical condition (Theethum et al., 2021), flexibility and accessibility (Abuhammad et al., 2021), as well as opportunities to create new formal and informal learning experiences (Bahrin et al., 2022) among others.

As technology improves and people around the world are becoming more connected through it, new opportunities arise to experience learning surrounded by and interacting with people and experts from all over the world within completely virtual environments, such as the metaverse. Although various educational benefits emerged in these studies, it is important for future studies to focus on objectively assessing and measuring the degree of

Table 15 Degrees of freedom (DoF) distribution

Measures	References
6-DoF (62.12%)	(Abuhammad et al., 2021; Ahlers et al., 2022; Alexander et al., 2022; Alharbi et al., 2020; AlKhateeb et al., 2019; Azar & Tan, 2020; Chávez et al., 2020; Chen et al., 2020; Doumanis & Economou, 2020; Fonseca et al., 2017a, 2020, 2021; Garcia et al., 2019; Geus et al., 2020; Gonzalez-Gonzalez, 2020; Grivokostopoulou et al., 2016, 2019a; Huaman et al., 2019; May & Denecke, 2020; Mouronte-López et al., 2020; Mystakidis, 2020; Palmas et al., 2021; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Rosmansyah et al., 2019; Roumana et al., 2022; Sanchez-Sepulveda et al., 2019; Šašinka et al., 2018; Senecal et al., 2020; Silva et al., 2021; Smith et al., 2021; Stigall & Sharma, 2017; Suncksen et al., 2018; Tan et al., 2022; Vagg et al., 2016; Vidal et al., 2021; Villagrasa et al., 2014; Wang, 2017; Xu T et al., 2022; Zhang & Bryan-Kinns, 2022; Zhang et al., 2016)
3-DoF (37.88%)	(Almousa et al., 2019; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Bryan et al., 2018; Chiang, 2021; Edwards et al., 2019; Falah et al., 2021; Gonzalez & Garnique, 2018; Gordon et al., 2019; Hartfill et al., 2020; Iquira et al., 2019; Jiang et al., 2022; Luigini et al., 2020; Makled et al., 2019; Makransky et al., 2019; Molloy et al., 2019; Nicola et al., 2018; Oberhauser & Lecon, 2019; Parong & Mayer, 2019; Stranger-Johannessen, 2018; Theethum et al., 2021; Tiefenbacher, 2020; Wilson et al., 2017a, 2017b)

impact that the use of virtual reality and gamification can have in education across different settings, educational levels, countries, cultures, and subjects in comparison to traditional face-to-face learning, online learning, and other novel solutions.

To design and develop such multimodal environments that offer meaningful learning experiences and increased learning outcomes and do not overload students with extensive information (Moreno & Mayer, 2007), several factors should be considered (Dondlinger, 2007; El-Masri & Tarhini, 2015; Nicholson, 2014) and specific design principles should be followed (Mayer, 2020). Additionally, to create effective learning experiences that integrate

Table 16 Representation distribution

Measures	References
Immersive virtual reality (92.42%)	(Abuhammad et al., 2021; Ahlers et al., 2022; Alexander et al., 2022; Alharbi et al., 2020; AlKhateeb et al., 2019; Azar & Tan, 2020; Becerra et al., 2017; Bedregal-Alpaca et al., 2020; Besoain et al., 2018; Bryan et al., 2018; Chiang, 2021; Edwards et al., 2019; Falah et al., 2021; Fonseca et al., 2017a, 2020, 2021; Garcia et al., 2019; Hartfill et al., 2020; Huaman et al., 2019; Jiang et al., 2022; Luigini et al., 2020; Makled et al., 2019; Makransky et al., 2019; May & Denecke, 2020; Molloy et al., 2019; Mystakidis, 2020; Palmas et al., 2021; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Roumana et al., 2022; Sanchez-Sepulveda et al., 2019; Šašinka et al., 2018; Silva et al., 2021; Stigall & Sharma, 2017; Suncksen et al., 2018; Tan et al., 2022; Tiefenbacher, 2020; Vagg et al., 2016; Vidal et al., 2021; Villagrasa et al., 2014; Wang, 2017; Wilson et al., 2017a, 2017b; Xu T et al., 2022; Zhang et al., 2016)
Objective (7.58%)	(Gonzalez-Gonzalez, 2020; Gordon et al., 2019; Nicola et al., 2018; Oberhauser & Lecon, 2019; Parong & Mayer, 2019; Senecal et al., 2020; Stranger-Johannessen, 2018)

virtual reality and gamification, teaching and learning styles (Fan et al., 2015; Huang et al., 2019), learning objectives (Kiryakova et al., 2014), gamification elements (Tiefenbacher, 2020), student characteristics, and the specific activities, contexts, and environment conditions should be taken into account (Kukulska-Hulme et al., 2020). Creating or acquiring the required educational material, the cost of equipment, and the feelings of nausea that some younger students sometimes experience should also be taken into consideration (Chiang, 2021; Vagg et al., 2016). These experiences should provide clear and concise instructions and aims (AlKhateeb et al., 2019; Mayer, 2005), guided activities that stimulate student intrinsic and extrinsic motivations (Zichermann & Cunningham, 2011), real-time and personalized feedback (Palmas et al., 2021; Sweetser & Wyeth, 2005), and allow students to learn at their own pace, reflect upon their results, and control the activities themselves (Moreno & Mayer, 2007). Hence, student-centered approaches should be followed when designing and creating such experiences (Alharbi et al., 2020). The role of educators in the adoption and integration of new technologies and ICT in educational activities is vital (Comi et al., 2017; Iquira et al., 2019). Therefore, educators along with students should be actively involved in the design and development of educational activities and applications

Table 17 Educational benefits of gamified virtual reality applications and experiences

Educational benefits-merits. Virtual reality applications and experiences that are enriched with gamification elements and mechanisms:	References
Are effective educational tools that improve learning	(Alexander et al., 2022; Almousa et al., 2019; Azar & Tan, 2020; Besoain et al., 2018; Bryan et al., 2018; Doumanis & Economou, 2020; Falah et al., 2021; Fonseca et al., 2017a; Garcia et al., 2019; Geus et al., 2020; Grivokostopoulou et al., 2016; Hartfill et al., 2020; Jiang et al., 2022; Mouronte-López et al., 2020; Nicola et al., 2018; Punyani et al., 2022; Roumana et al., 2022; Stigall & Sharma, 2017; Tan et al., 2022; Villagrasa et al., 2014; Wilson et al., 2017a, 2017b)
Are positively assessed and accepted by educational stakeholders	(Abuhammad et al., 2021; AlKhateeb et al., 2019; Azar & Tan, 2020; Becerra et al., 2017; Besoain et al., 2018; Chávez et al., 2020; Fonseca et al., 2017a, 2021; Jiang et al., 2022; Luigini et al., 2020; Pinzón-Cristancho et al., 2019; Senecal et al., 2020; Suncksen et al., 2018; Tan et al., 2022; Theethum et al., 2021; Tiefenbacher, 2020; Vagg et al., 2016; Wang, 2017; Wilson et al., 2017b)
Increase learning outcomes and academic performance	(Chávez et al., 2020; Chen et al., 2020; Chiang, 2021; Edwards et al., 2019; Gonzalez & Garnique, 2018; Gonzalez-Gonzalez, 2020; Gordon et al., 2019; Grivokostopoulou et al., 2016, 2019a; Huaman et al., 2019; Iquira et al., 2019; Klippel et al., 2020; Makransky et al., 2019; Mystakidis, 2020; Pinzón-Cristancho et al., 2019; Rosmansyah et al., 2019; Smith et al., 2021; Stranger-Johannessen, 2018; Theethum et al., 2021; Villagrasa et al., 2014)
Increase motivation	(Alexander et al., 2022; Bedregal-Alpaca et al., 2020; Chávez et al., 2020; Chen et al., 2020; Edwards et al., 2019; Fonseca et al., 2017a, 2021; Gonzalez & Garnique, 2018; Grivokostopoulou et al., 2016, 2019a; Hartfill et al., 2020; Makransky et al., 2019; May & Denecke, 2020; Molloy et al., 2019; Mouronte-López et al., 2020; Oberhauser & Lecon, 2019; Redondo et al., 2020; Reitz et al., 2016; Sanchez-Sepulveda et al., 2019; Suncksen et al., 2018; Symonenko et al., 2019; Vagg et al., 2016; Vidal et al., 2021; Wang, 2017; Zhang & Bryan-Kinns, 2022)
Increase engagement and active participation and involvement	(Abuhammad et al., 2021; Alexander et al., 2022; Almousa et al., 2019; Bryan et al., 2018; Chen et al., 2020; Doumanis & Economou, 2020; Edwards et al., 2019; Fonseca et al., 2017a; Gonzalez-Gonzalez, 2020; Hartfill et al., 2020; Huaman et al., 2019; Iquira et al., 2019; Luigini et al., 2020; Makled et al., 2019; Mystakidis, 2020; Oberhauser & Lecon, 2019; Reitz et al., 2016; Smith et al., 2021; Suncksen et al., 2018; Symonenko et al., 2019; Vagg et al., 2016; Vidal et al., 2021; Wang, 2017)

Table 17 (continued)

Educational benefits-merits. Virtual reality applications and experiences that are enriched with gamification elements and mechanisms:	References
Improve knowledge acquisition/gain and material comprehension/understanding	(Chen et al., 2020; Fonseca et al., 2017a; Grivokostopoulou et al., 2016; Maines et al., 2015; Makransky et al., 2019; Mouronte-López et al., 2020; Nicola et al., 2018; Poulova et al., 2020; Rosmansyah et al., 2019; Sanchez-Sepulveda et al., 2019; Silva et al., 2021; Vidal et al., 2021; Villagrasa et al., 2014)
Improve interaction, communication, and collaboration	(Almousa et al., 2019; Huaman et al., 2019; Pinzón-Cristancho et al., 2019; Reitz et al., 2016; Šašinka et al., 2018; Xu T et al., 2022; Yengin & Bayrak, 2019; Zhang & Bryan-Kinns, 2022; Zhang et al., 2016)
Increase self-efficacy	(Makransky et al., 2019; Smith et al., 2021; Wilson et al., 2017a, 2017b)
Enhance skill and competence development	(Grivokostopoulou et al., 2019a; Iquira et al., 2019; Poulova et al., 2020; Sanchez-Sepulveda et al., 2019; Silva et al., 2021; Yengin & Bayrak, 2019)
Improve focus and concentration	(Luigini et al., 2020) and (Oberhauser & Lecon, 2019)
Enhance immersion and social presence	(Bahrin et al., 2022; Gordon et al., 2019; Mystakidis, 2020; Rosmansyah et al., 2019; Roumana et al., 2022; Smith et al., 2021; Symonenko et al., 2019; Xu T et al., 2022)
Enhance creativity and curiosity	(Rosmansyah et al., 2019; Vidal et al., 2021; Villagrasa et al., 2014)
Improve satisfaction	(Bedregal-Alpaca et al., 2020; Wang, 2017)
Offer realistic experiences	(Alharbi et al., 2020; Almousa et al., 2019; Grivokostopoulou et al., 2019a; Redondo et al., 2020; Suncksen et al., 2018; Symonenko et al., 2019; Zhang & Bryan-Kinns, 2022)
Provide real-time personalized feedback	(Almousa et al., 2019; Palmas et al., 2021; Yengin & Bayrak, 2019)
Offer enjoyable and fun learning experiences	(Abuhammad et al., 2021; Ahlers et al., 2022; Azar & Tan, 2020; Bahrin et al., 2022; Besoain et al., 2018; Bryan et al., 2018; Garcia et al., 2019; Grivokostopoulou et al., 2016; Hartfill et al., 2020; Jiang et al., 2022; Makled et al., 2019; Molloy et al., 2019; Oberhauser & Lecon, 2019; Rosmansyah et al., 2019; Roumana et al., 2022; Theethum et al., 2021; Vagg et al., 2016; Wang, 2017; Xu T et al., 2022; Zhang et al., 2016)
Provide interesting and enthusiastic learning experiences	(AlKhateeb et al., 2019; Besoain et al., 2018; Fonseca et al., 2017a, 2021; Garcia et al., 2019; Grivokostopoulou et al., 2016; Makled et al., 2019; Molloy et al., 2019; Roumana et al., 2022; Tan et al., 2022; Vagg et al., 2016; Vidal et al., 2021; Xu T et al., 2022)

Table 17 (continued)

Educational benefits-merits. Virtual reality applications and experiences that are enriched with gamification elements and mechanisms:	References
Are easily usable	(Azar & Tan, 2020; Besoain et al., 2018; Bryan et al., 2018; Fonseca et al., 2017a, 2021; Geus et al., 2020; Grivokostopoulou et al., 2016; Iquira et al., 2019; May & Denecke, 2020; Stigall & Sharma, 2017; Suncksen et al., 2018; Wilson et al., 2017a, 2017b; Xu T et al., 2022)

as their experiences and viewpoints can help develop more effective learning experiences and environments that lead to increased academic performance (Cober et al., 2015). Moreover, it is crucial to provide teachers with the required training to develop both their technical and pedagogical digital competencies (Tømte, 2015) and not only to familiarize themselves with new technologies and approaches and learn how to effectively use and integrate them in their classroom, but also to create appropriate digital educational material (Davis & Roblyer, 2005). As the process of developing virtual reality applications can be challenging and complicated for non-tech-savvy people, there is a clear need to create educational tools that will facilitate the design and development process and will enable teachers to produce educational material for virtual reality environments. Finally, as the use of gamification and virtual reality in education is becoming more widespread, the need to develop widely accepted standards, guidelines, and reliable assessment instruments and validate them in different contexts is imperative.

Conclusions

As educational and societal needs and demands have changed, traditional learning needs to be reinforced and transformed through the use of new technological applications and approaches to adapt and meet the new requirements. The use of gamification and virtual reality in educational contexts is becoming more popular as a means to satisfy students' pursuit for more interactive, immersive, engaging, and meaningful learning.

Aiming at examining the existing literature regarding the adoption and integration of virtual reality and gamification in education, this study involved the conduct of a systematic literature review following the PRISMA statement. Particularly, no limitations were set in terms of year of publication, educational levels, type of study, and subjects to provide a more comprehensive overview of the topic. Using a versatile search query, 950 related documents were retrieved from 5 scientific databases. After having examined the articles, in total 112 were included in this study. These articles were separated into empirical studies, proposal and prototype papers, and review, conceptual, and theoretical articles. Moreover, 16 research questions were set and answered through the analysis of these articles.

Based on the results, the use of gamification can positively influence educational activities and enrich virtual reality experiences to create more interactive, engaging, and motivating learning environments. The vast majority of studies reported positive outcomes regarding learning achievements and student satisfaction. Both students and teachers positively assessed their use in education, highly regarded their role in transforming traditional teaching and learning activities, and greatly valued the merits that they can bring in the educational process by facilitating and supporting teachers and successfully meeting student requirements and demands for more effective learning. Additionally, the use of gamification and virtual reality is in line with several pedagogical theories and approaches.

Learning environments that integrate virtual reality and gamification allow students to individually and collaboratively experience environments, situations, and conditions and partake in educational activities that otherwise would be impossible. Within these virtual, safe, and secure environments, students can get hands-on experiences and cultivate their skills. These environments offer personalized learning experiences, provide a sense of presence, and promote active participation. Furthermore, the gamified virtual reality environments facilitate comprehension of the subjects taught, allow students to be more focused, and increase their curiosity and imagination. When compared to traditional learning, these environments are more intriguing, interactive, and enjoyable. Students' learning experiences in such settings resulted in improved learning outcomes and academic performance, increased motivation and engagement, and enhanced knowledge acquisition. Positive changes in students' attitude, behavior, and mentality and improved cognitive, physical, and social–emotional development were also observed. To design and develop more effective learning environments that integrate gamification and virtual reality and reap their full benefits, appropriate strategies, principles, and methods should be followed, teachers' digital literacy skills and ability to incorporate such environments in their classrooms should be taken into account, and students' unique personality traits and characteristics, knowledge, interests, habits, and preferences should be considered.

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Data availability The dataset analyzed in this study is available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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