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ORIGINAL ARTICLE

Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature

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Abstract

There has been an increasing interest in applying immersive virtual reality (VR) applications to support various instructional design methods and outcomes not only in K-12 (Primary and Secondary), but also in higher education (HE) settings. However, there is a scarcity of studies to provide the potentials and challenges of VR-supported instructional design strategies and/or techniques that can influence teaching and learning. This systematic review presents a variety of studies that provide qualitative and/or quantitative data to investigate the current practices with VR support focusing on students' outcomes, performance, alongside with the benefits and challenges of this technology concerning the analysis of visual features and design elements with mobile and desktop computing devices in different learning subjects. During the selection and screening process, forty-six ($n = 46$) articles published from the middle of 2009 until the middle of 2020 were finally included for a detailed analysis and synthesis of which twenty-one and twenty-five in K-12 and HE, respectively. The majority of studies were focused on describing and evaluating the appropriateness or the effectiveness of the applied instructional design processes using various VR applications to disseminate their findings on user experience, usability issues, students' outcomes, and/or learning performance. This study contributes by reviewing how instructional design strategies and techniques can potentially benefit students' learning performance using a wide range of VR applications. It also proposes some recommendations to guide and lead effective instructional design settings in several teaching and learning contexts to outline a more accurate and up-to-date picture of the current state of literature.

Keywords Immersive technologies · Virtual reality · Human–computer interface · Simulations · Systematic review

1 Introduction

The rapid growth of immersive virtual reality (VR) has globally received much attention during the last 10 years. VR uses computer-supported technologies to create and simulate realistic (or not) applications. Each user has the illusion of "being there" (sense of presence) surrounded by a three-dimensional (3D) simulated realistic in a 360-degree (360°) environment to explore it freely, interact with visual objects, and participate in hands-on experimental tasks using a wide range of computing devices, such as head-mounted displays and body sensors (Burdea and Coiffett 1994). It also provides significant potentials covering a demanding range of exercises and tasks related to hands-on practices due to Pellas et al. (2020) and Potkonjak et al. (2016): (a) the image quality of computer graphics displays a visually appealing 3D environment that increases the degree of realism concerning large-scale content and spatial areas comprises many objects/elements with high representational fidelity

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encompassing functional or well-designed features, and (b) the execution of tasks in real time and in the same place with sensory experience and feedback on the user's interaction is provided via 3D objects/elements.

Due to the surge of computing devices, the common sense of providing realistic simulated user-centered learning experiences with a high level of perceived reality, sense of presence, and interactivity requires the development of VR applications that can immerse users inside a virtual environment. Four categories of the most essential computing devices which can provide different ways of interaction displayed on a computer screen are as follows: (a) room-sized 3D displays that are also called as Cave Automatic Virtual Environments (CAVEs) (Limniou et al. 2009), (b) Head-mounted display (HMD), such as Oculus Rift or HTC Vive as well as handheld displays, such as tablets and other smart phones (Wolfartsberger 2019), (c) mobile VR, like Samsung Gear VR or Google Cardboard (Southgate et al. 2019), and (d) wearable 360° spherical video-based VR (Chang et al. 2018). Interactivity and immersive user experience are provided on display devices and control mechanisms. In desktop-based VR applications, content is displayed by computer monitors, and control mechanisms are executed by using a keyboard and a mouse. In HMD-based VR interaction, the virtual content is displayed by headsets with a small display optic in front of each user's eye, and interaction is achieved by using hands-on controllers (Limniou et al. 2009; Markowitz et al. 2018).

The abundance of computing resources and devices that support new dimensions of VR technology alongside the realistic simulated representational fidelity of visual objects and elements generated by computer graphics create unprecedented opportunities in teaching and learning. Nowadays, it is necessary to construct "*know-how*" on effective VR applications for teaching and learning; to establish under what circumstances and conditions scholars, educators, administrators, and policymakers in primary and secondary (K-12) and higher education (HE) can be utilized by acknowledging problems and instructional methods that need to overcome in order to "augment" the learning experience. For example, several educational sectors face a significant number of constraints that can create drawbacks in teaching and learning, in which students should study ranging from complex transportation to a location with several laboratories to tasks or experiments that might be too dangerous or expensive. Additionally, any access to real sources is sometimes time-consuming, and lack of support from the instructor(s) or the administrative staff can usually cause students' frustration and dissatisfaction (Alfalah 2018; Potkonjak et al. 2016).

During the last decade, a growing number of studies have been published to advance hands-on practices in different learning subjects. To this notion, national US science standards (National Science Teachers' Association 2014) were used to classify the topics covered in the studies that were finally reviewed. More specifically, twenty-one ($n=21$) studies have utilized VR technology in K-12 subjects that consist of environmental science (Abdullah et al. 2019; Alrehaili and Osman 2019; Wu et al. 2019), biology (Hite et al. 2019; Huang 2019; Huang et al. 2019; Wang et al. 2019), geology (Chang et al. 2018, 2019a, b), technology (Chen et al. 2019; Han 2019; Segura et al. 2019; Shi et al. 2019; Southgate et al. 2019), mathematics (Blume et al. 2019), history (Cheng and Tsai 2019; Ferguson et al. 2020; Taranilla et al. 2019), English language learning (Chien et al. 2019), and music (Innocenti et al. 2019). Additionally, twenty-five ($n=25$) studies have utilized VR in HE subjects that entail of Science (Kartiko et al. 2010; Lamb et al. 2019; Limniou et al. 2009; Makransky et al. 2019; Markowitz et al. 2018; Meyer et al. 2019; Pirker et al. 2018; Shu et al. 2018; Šašinka et al. 2018; Yeh et al. 2013), Technology (Alfalah 2018; Bailenson et al. 2009; Huang and Lee 2019; Kozhevnikov et al. 2013; Selzer et al. 2019; Starr et al. 2019; Bonfil et al. 2020; Webster 2016), Nursing (Taçgın 2019), Engineering (Gavish et al. 2015; Wolfartsberger 2019), Cultural learning (Li et al. 2020), Dutch language learning (van Ginkel et al. 2019), Legal education (McFaul and FitzGerald 2019), and Library guidance (Lin et al. 2019).

In addition to the abovementioned studies, several efforts were published to review the relevant scientific literature of VR uses in K-12 and HE settings. For instance, previous reviews have paid attention to the description of virtual laboratories in science, technology, and engineering (Potkonjak et al. 2016), the systematic analysis of VR-supported implementations exclusively in teacher education (Billingsley et al. 2019), and lastly, the use of HMD VR-supported instruction and skill training applied solely in post-secondary or higher education (Concannon et al. 2019). Despite previous reviews have provided important aspects and considerations about the use of VR in education, there was no explicit focus identified by reviewing systematically previous studies regarding the instructional design contexts using HMD and desktop-based VR devices. As VR continues to be utilized at an exponential rate, it is of great importance to identify any missing studies that analyzed and presented any potential benefits of using this technology with different computing devices. Hence, there is a reasonable need to conduct a systematic synthesis of previous studies to delve into the use of students' experience, outcomes, achievements, and performance within specific VR-supported instructional design contexts in different K-12 and HE settings.

Based on the above, the current study presents a systematic literature review of experimental studies providing qualitative and/or quantitative data to investigate the current VR-supported practices with different computing devices in various learning subjects. The main purpose of this review is two-fold. First, it identifies the instructional design contexts and applications' elements that were applied and analyzed as the main tendencies in K-12 and HE settings. This review also provides insights for software developers and educators to develop and apply design features and elements using different computing devices in VR-supported instructional design contexts. Second, it outlines critically and systematically the impact of VR applications on students' learning performance, outcomes, and achievements using different instructional design methods. The objectives of this review are related to the aggregation of previous studies to understand better the implementation of learning scenarios in K-12 and HE settings and identify any possible benefits, challenges, and drawbacks within specific instructional contexts raised by implementing VR applications. Therefore, the following research questions (*RQs*) were formulated to fulfill the main purpose and objectives of this review:

1. What VR-supported instructional design methods were embedded into K-12 and HE settings?
2. How were students' learning performance and/or outcomes affected by VR-supported interventions across different learning subjects?
3. What methodological research methods were followed, such as research design, data collection, and sample size?
4. What computing devices and design elements of VR applications served in the instruction of different learning subjects?
5. What are the potential benefits and shortcomings of VR-supported instructional design methods?

2 Research methods

The current review follows the guidelines and protocol template for systematic literature reviews proposed by Kitchenham et al. (2007). It is one of the most well-documented and cited works for conducting a systematic review. StArt (state-of-the-art through systematic review) was utilized as the main software tool to extract the information in this systematic review's protocol that assisted in data extraction and monitoring.

2.1 Search criteria

To achieve the initial screening, a manual search for peer-reviewed international journal articles was conducted. For this review, the search terms (keywords) from any included terms related to VR in conjunction with several terms that could describe possible outcomes, impacts or effects by utilizing VR-supported instruction and implementation in K-12 and HE settings. Therefore, specific criteria consisting of two parts that defined are as follows:

- C1 is a string made up of keywords related to VR such as "immersive technologies," ''*virtual reality*,'' "VR," "*virtual environments,*" ''*virtual reality learning*,'' and ''NOT.''
- C2 is a string made up of keywords related to education such as ''education,'' "K-12", "Primary education," "Secondary education," "Higher education," ''learning,'' and ''teaching.''

To widen and combine literature searches, several were also the techniques that were utilized to search key terms including the use of Boolean operators such as "*OR*" to identify any synonyms or "*AND*" to combine any search term for each of the main concepts. The Boolean expression search criteria were ''C1 AND C2.'' An example of a search done in the electronic databases is (''Immersive Technologies'' *OR* ''VR'' OR ''Virtual Reality'' *OR* ''NoT'') *AND* (''Education'' *OR* ''primary education'' *OR* ''secondary education''). The search string was composed in each database manually based on the search functionality offered by each one. Table 1 outlines the key search terms.

Beyond the database search, all authors of this review also checked any potential reviewed reference list from each included study to identify other relevant articles that had not been in the regular search. Branching searches were performed by using forward and backward search procedures from the reference lists, which were consulted at earlier stages and described in "Appendix".

2.2 Inclusion and exclusion criteria

To determine whether a study should be included in this review, the following inclusion and exclusion criteria were used. Considering the five research questions of this review,

Table 1 Key search terms

Search terms
(Immersive technologies* *OR* Virtual reality* *OR* VR)
AND (Primary education* *OR* Secondary education* OR Higher education*)
Virtual reality *OR* Immersive technologies* *OR* VR*)
(Primary education *OR* Secondary education *OR* Higher education)

the inclusion and exclusion criteria for the studies of this review were agreed and depicted in Fig. 1.

2.3 Study search and selection

For study search and selection, relevant evidence that fits the prespecified eligibility criteria and can give answers in specific research questions needs to be collated in the following steps. Any relevant evidence that fits the prespecified eligibility criteria can give answers to specific research questions and need to be collated the following specific steps (Moher et al. 2009). For this study, the review process was divided into three steps proposed by Kitchenham et al. (2007): (a) planning, (b) conducting the review, and (c) reporting the review. The initial stage was guided by the principles of the PRISMA statement (Moher et al. 2009). It is indicated by Liberati et al. (2009) as one of the most appropriate protocols that authors can use to transparently report strengths and weaknesses of any review investigation. It is a well-structured process that describes adequately all eligibility criteria for study collection, information sources, remove duplicates, screen records, data collection process, and finally synthesize the results.

To begin, the first author conducted a systematic search and identification of literature using the identified electronic databases focusing on educational technology, computer science, and social science in favor of performing an exhaustive search. JSTOR, SCOPUS, ScienceDirect, ESCBO, ERIC, Wiley, Web of Science, and IEEEXplore were the most relevant. All searches were made separately to each database. The period for the search was limited from January 2009 until the middle of 2020, when this review was completed, because VR educational uses with innovative devices had gained ground after 2009. During the search strategy, eight electronic databases were selected to search for scientific articles. The search results, ninety-nine ($n=99$) articles were downloaded, organized, and entered with the aid of the StArt tool. Also, Fig. 2 depicts the four steps based on the PRISMA statement to select the studies, which were finally reviewed. After identifying articles using the various search procedures described above and removing duplicates, a number of sources were included and excluded at each phase should be tabulated. One option for presenting information regarding forty-six articles meeting the inclusion criteria is shown in Fig. 2.

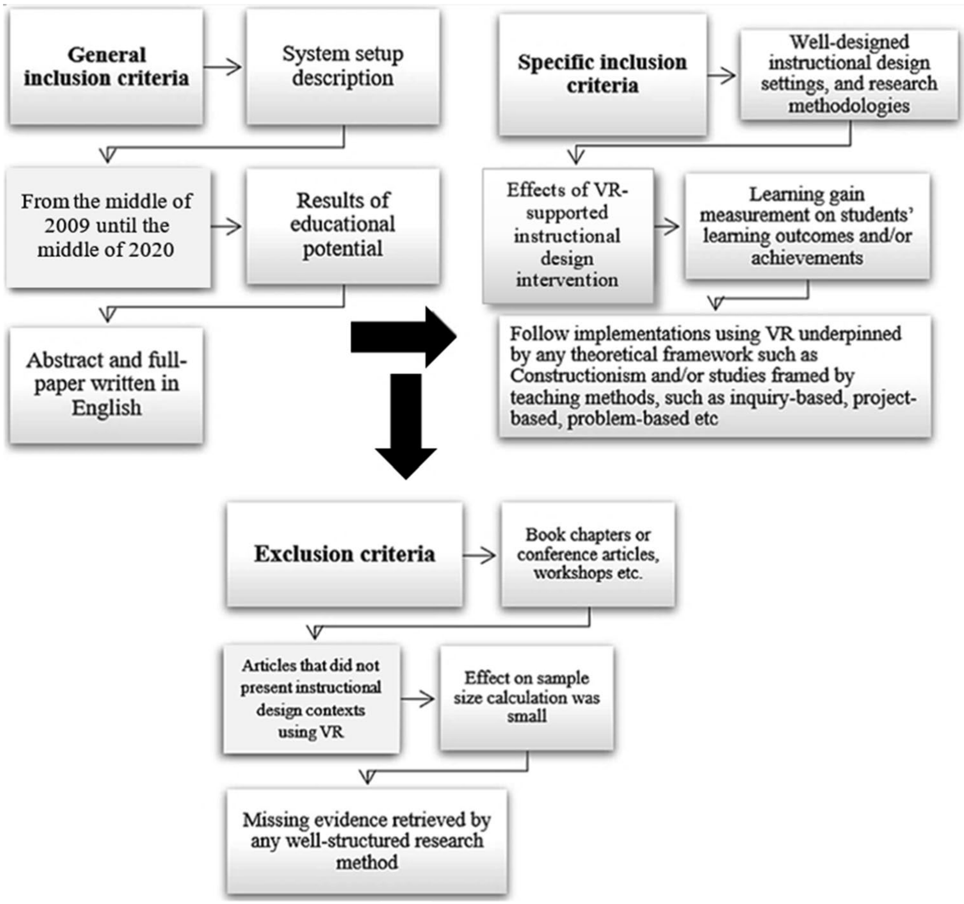


Fig. 1 Inclusion and exclusion criteria

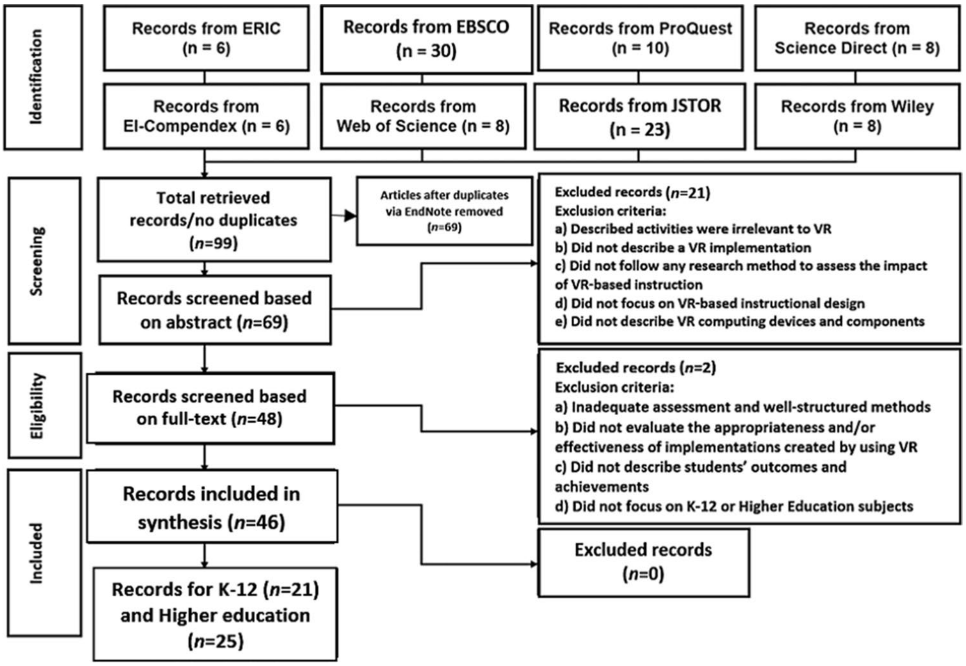


Fig. 2 A flow diagram of the article selection process. [Adapted by Moher et al. (2009)]

2.4 Collection of unbiased studies

To have an unbiased search strategy (Kitchenman et al. 2007), a set of steps was taken. These are the following:

To avoid unnecessary publication bias, firstly, a search through the most popular databases started, in which anyone can find information related to HCI issues, such as computer science/engineering and educational technology. Such an approach would increase the number of articles, which can be found, and could provide much more information to understand whether the use of VR implementations had not only positive, but also some negative results. This decision was deemed as necessary since this review would not only focus solely on the presentation of positive results, but also to some negative consequences, which may be provided by giving challenges to future works.

To avoid any selection bias that refers to the deterioration of statistical analysis owing to the criteria used to select the publications, it was decided the following: (a) to identify specific research questions and used specific key terms to find in the search strategy from nine different databases, (b) to utilize a multistage process in order to extract information from articles in each stage, thus all authors assessed the content of each study based on predetermined inclusion and exclusion criteria, and (c) to include studies from a wide range of educational domains which focused exclusively on the educational uses of VR

To reduce any potential inaccuracy in data extraction and misclassification among authors to extract and interpret information from previous studies having different opinions, this review's authors read compulsory all the selected in full-text papers retrieved by JCR SCI and JCR SSCI lists. To acknowledge any agreement or disagreement arising by the selected papers' assessment, various meetings were conducted before conducting the final stage and deciding which of all selected studies needed (or not) finally to be included.

2.5 Study quality assessment

To assess initially the methodological quality of all studies, which were selected for this review, a set of quality criteria adopted by Guyatt et al. (2003) and tabulated in Table 2.

Table 2 The quality criteria for study selection

Criteria	Responding grading	Percentage acceptance of the studies reviewed (%)
1. Are the research questions and objectives of this study clearly defined?	[1, 0.5, 0] (yes, nominally, no)	75
2. Does the in-text context address the main research well?	[1, 0.5, 0] (yes, nominally, no)	73
3. Are the results clearly stated?	[1, 0.5, 0] (yes, nominally, no)	65
4. Can the results of this study provide valuable information?	> 80% = 1, < 20%, and in-between = 0.5	85

The assessment of each study was conducted using specific questions with a view to designate the extent that each one can give answers on our *RQs* alongside the use of synthesis findings provided by following the Kitchenham et al.'s (2007) guidelines.

The fourth quality criterion "*can the results of this study provide valuable information*" was approved by all authors of this review to provide a quality score for each study. All the examined articles had normalized scores based on specific criteria. All authors agreed that a 50% quality score was the minimum score of accepting studies. Since all the included studies were published in peer-reviewed journals, there was not identifying any of the forty-six articles that were included to be excluded based on the quality score.

After finishing the initial search and screening process, all articles were chosen and coded for a qualitative analysis, to define the final analytic sample that builds the main data set. Specific steps were taken to maximize coding accuracy and avoid any challenges inherent in categorizing the range of research approaches across all studies. To strengthen further the total weight of evidence, each study was calculated by adding the scores on each of the abovementioned criteria. To assess the inter-rater reliability for the quality coding of the selected articles, a sub-sample of thirty-six from a total of forty-six included articles (78%) was coded independently by all authors of this review. The inter-rater reliability (*r*) for the total scores was 0.85, showing a good agreement among the authors about the quality of the articles reviewed, which finally included.

3 Research results

A variety of positive contributions and challenges for VR on K-12 and HE are provided from the extracted data regarding the utilization of different instructional design methods. An instructional design method comprises strategies and techniques. The former entails a set of certain steps within a range of learning approaches for instructive-guided, autonomous, and/or collaborative practices. The latter are application practices for the implementation of an instructional strategy that can assist students to cultivate their skills, share their ideas, and use their prior knowledge on a learning subject (Akdeniz 2016). To elaborate the discussion on the benefits and shortcomings, information and reported aggregation of a state-of-the-art overview from the analysis of all the included studies was made to answer the main research questions.

In response to the *RQ1*, studies that took place in K-12 settings featured several instructional design approaches. One cluster of studies ($n=9$) deployed approaches related to project-based learning (e.g., Chang et al. 2018; Chen et al. 2019; Southgate et al. 2019), game-based learning (e.g., Ferguson et al. 2020; Segura et al. 2019; Shi et al. 2019; Shu et al. 2018; Wang et al. 2019), and problem-based learning (Abdullah et al. 2019). Another cluster of studies ($n=8$) featured teacher-centered within specific instructional design approaches, such as observation of spherical (360°) videos in-class and tours in informal settings, such as virtual field trips (e.g., Cheng and Tsai 2019; Han 2019).

Table 3 tabulates the instructional design strategies and techniques followed by Akdeniz's guidelines (2016, pp. 25–26). To this notion, the twenty-one studies in K-12 education were reviewed and grouped into five categories: activity-based, discovery, presentation, experiential, and collaborative.

Activity-based as an instructional design strategy allows students to be grouped by attending in-class and study within different tasks at their own pace under guidance. For instance, in Chien et al. (2019) study, the teacher introduced the VR system, gave an orientation about the lesson, trained the students to provide the appropriate feedback in each training phase.

Discovery is an instructional strategy that supports self-directed and constructivist learning conditions as learners need to construct knowledge by themselves when they can discover and then discuss why something is current or not (Bruner 1961). Four studies followed the scientific discovery strategy. For example, in biology lessons, any content topic was related with the exploration of the cell structure in the human body using an HMD VR (Huang et al. 2019). In other cases, the objectives of the scientific practice activities are proposed the situational problem in scientific inquiry settings (Wu et al. 2019).

Table 3 VR-supported instructional design strategies in K-12 settings

Instructional design strategies	Primary author (year of publication)
Activity-based	Chien et al. (2019), Segura et al. (2019) and Shi et al. (2019)
Discovery	Ferguson et al. (2020), Huang (2019), Huang et al. (2019) and Wu et al. (2019)
Presentation	Blume et al. (2019), Han (2019), Innocenti et al. (2019) and Taranilla et al. (2019)
Experiential	Abdullah et al. (2019), Alrehaili and Al Osman (2019), Chang et al. (2018, 2019a, b), Cheng and Tsai (2019), Chen et al. (2019) and Hite et al. (2019)
Collaborative	Southgate et al. (2019) and Wang et al. (2019)

In four different VR applications reviewed, presentation was followed as instructional design strategy. Students had the chance to view in detail the learning content using mostly 360° video or images in HMD VR with no haptic controllers to interact with the visual content, and then present their ideas which are progressively differentiated in terms of understanding a learning subject. VR applications such as the one presented by Han (2019) are virtual field trips using *Google Expeditions*, which includes more than 500 trips viewable on a smartphone. In other studies, students were able to select the most appropriate point of view for the 3D virtual models and objects for music genre identification into a VR multiplatform (Innocenti et al. 2019).

There was identified a shred of strong evidence by the relevant literature ($n=8$), indicating that students can "learn by doing" through a range of tasks based on their personal experience following experiential instructional design strategies. For example, Chang et al. (2019a, b) advocated that students had not only better learning achievements in natural science topics, but also VR-supported instruction enhanced their learning motivation because the representational fidelity of learning materials and environmental resources assisted them to answer questions for solving problems more effectively. Abdullah et al. (2019) admitted that students learned how to solve open-ended problems through exercises in science topics, in which they involved by questioning, reflecting, and reaching their conclusions depending on the experience gained.

Finally, two studies were guided by a collaborative instructional design strategy. Such studies used "hybrid" learning environments, where a VR learning tool was used individually, and the collaboration was carried out in the real world. For instance, in a study carried out by Southgate et al. (2019) in computing tasks and by Wang et al. (2019) for biology. While in the former, students used *Minecraft* and, in the latter, a VR prototype game for collaborative problem-solving tasks, in both studies, the participants studied collaboratively in-class settings to share their understanding and then reach out to a solution all together.

From the classification of instructional techniques provided by Gündüz (2016), five instructional learning techniques can be categorized in K-12 education as follows (Table 4): educational game, field trip, observation, role-play, and simulation.

Educational games were used in five studies. VR games integrated several activities that took advantage in terms of providing immersion in context, rewards for correctness, and immediate feedback. Participants were able to respond and interact with digital elements and known about their achievements via game board, the player's character emotions or power life, decoration elements, and action menu aligned with specific learning objectives. For example, in Alrehaili and Al Osman (2019), the player's role was to become a honeybee into a virtual world mimicking the real conditions to understand through immersive experiential learning contexts. Another study of Shi et al. (2019) presented an alternative VR-based game, where students asked to solve mathematical problems, such as quadratic functions developing a VR basketball court in a virtual park, in which the wall had Cartesian coordinates marked in different colors so as to provide location information.

Another technique that provides a more active learner's role is field trips outside the typical classroom settings. Two studies deployed a structured observation, in which students were allowed to observe any content under the guidance of their instructor. Cheng and Tsai (2019) developed an example of a structured observation that was used in studies supported by 360° panoramic images in *Google Expeditions*, where students synchronously explored a scene with a VR device (e.g., Cardboard) and the instructor utilized the assets of "World War II". Han (2019) used the same Android-based application for "Reef Sharks" using HMDs. Students were able to observe freely by choosing both the content and the order in which to explore it and following the teacher's guidance watched the same content through a TV only for 10 min.

A study was considered to use observation as an instructional technique when learners only observed digital information, such as 3D models, pop-up texts or animation to interact with VR-based tools without having structured instructional settings. By using the observation technique, any student passively receives information in contrast to

Table 4 VR-supported instructional design techniques in K-12 settings

Instructional design techniques	Primary author (year of publication)
Educational game	Alrehaili and Al Osman (2019), Ferguson et al. (2020), Segura et al. (2019), Shi et al. (2019) and Wang et al. (2019)
Field trip	Cheng and Tsai (2019) and Han (2019)
Observation	Blume et al. (2019), Innocenti et al. (2019), Taranilla et al. (2019) and Wu et al. (2019)
Role-play	Chien et al. (2019) and Southgate et al. (2019)
Simulation	Abdullah et al. (2019), Chen et al. (2019), Chang et al. (2018, 2019a, b), Huang (2019), Huang et al. (2019) and Hite et al. (2019)

field trips. Four studies deployed structured observation, in which students were allowed to observe any content under the guidance of their instruction. For instance, students were immersed in music performance of different genres, such as classical, country, jazz, and swing, navigating inside several musical rooms (Innocenti et al. 2019). Blume et al. (2019) illustrated a virtual classroom design with 25 students. One virtual teacher arranged in a U-shaped fashion for mathematics, in which any further events that can distract students' attention, such as opening and closing doors, the paper plane flies or behavior by other peers (e.g., whispering, turning around) occurred randomly. Wu et al. (2019) followed scientific inquiry instruction, in which students learned in tasks included a 360° aperture image, which helps them to be fully absorbed in the introduction process of pinhole imaging and to observe experimental phenomena from different views.

The fourth instructional technique that was used in the two studies reviewed was role-play. Chien et al. (2019) reported that playing the assessor's role motivated students to be more critical of their work and increased their critical thinking skills for their English oral presentations. Additionally, the teacher's role motivated students' assessors by knowing how to improve their learning performance for in-class VR-supported interventions. Even in collaborative settings, Southgate et al. (2019) highlighted the role of ongoing reflection and dialog, which is a mainstay of participatory research, when instructor and students have specific roles.

In most studies ($n = 8$), simulations were integrated into VR to develop a learning system. As the purpose of a simulation is to provide students with means of discovery and active learning in problem-solving contexts, VR may enable visualization and simulation of narratives and true-to-life scenarios via its 3D virtual environment in different learning subjects, which are related to (a) a biodiversity topic, objects such as flowers, trees, rivers, hills, birds, butterflies, for science course topics (Abdullah et al. 2019) and (b) the different views of an external heart (cardiac anatomy) using 3D images with 360° views of active heart function (physiology) in real time and haptic feedback of heart rate (Hite et al. 2019). To summarize, the completion of VR-supported problem-solving (hands-on) simulation tasks was mostly provided by previous studies as a valid indicator of students' conceptual understanding of underlying concepts in science and technology concepts.

Table 5 tabulates the instructional design strategies and techniques followed by the twenty-five studies reviewed in HE settings.

Four studies followed an activity-based instructional design strategy allowing students to proceed to specific activities under the guidance of the trainer. For instance, in Gavish et al.'s (2015) study, the instructor watched each student using a prototype haptic device to manipulate virtual components. Similarly, in Webster's (2016) study, students performed well in specific activities and answered several questions regarding the domain of the educational immersive game. Nonetheless, in Taçgın's (2019) study, students executed specific activities with surgical instruments.

Discovery strategy was implemented by five studies. For example, in Markowitz et al.'s (2018) study, the students had to interact with the virtual objects and discover various information about ocean acidification. Similarly, in Shu et al. (2018) study, students needed to discover the actions they have to undertake and prepared for an earthquake. In both cases, students explore and interact with the virtual world and the provided objects to discover and construct appropriate knowledge. This interaction was mediated by the appropriate hand controllers.

Six studies followed presentation as an instructional strategy, where students were able to watch predefined specific educational content. For instance, in Kartiko et al.'s (2010) study, there was no user interaction with VR support. In the same study the VR content was projected on a 6 m-wide canvas and students just watched the content. Nevertheless, in other two studies (Bailenson et al. 2009; McFaul and FitzGerald 2019) students observed 3D objects or animations to understand better several scientific phenomena; whereas in other two, the main student interaction in a CAVE was head movement to different directions to see different aspects of a virtual world or walked and observed them apparently (Alfalah 2018; Limniou et al. 2009). In addition, Bailenson et al. (2009) provided students with a game pad to record their responses and allowed them

Table 5 VR-supported instructional design strategies and techniques in HE settings

Instructional design strategies	Primary author (year of publication)
Activity-based	Gavish et al. (2015), Taçgın (2019), Webster (2016) and Bonfil et al. (2020)
Discovery	Lin et al. (2019), Markowitz et al. (2018), Meyer et al. (2019), Selzer et al. (2019) and Shu et al. (2018)
Presentation	Alfalah (2018), Bailenson et al. (2009), Kartiko et al. (2010), Lamb et al. (2019), Limniou et al. (2009) and McFaul and FitzGerald (2019)
Experiential	Kozhevnikov et al. (2013), Makransky et al. (2019), Pirker et al. (2018), Starr et al. (2019), Wolfartsberger (2019), Huang and Lee (2019) and Van Ginkel et al. (2019)
Collaborative	Šašinka et al. (2018) and Yeh et al. (2013)

to answer the questions when this was necessary. Such a strategy becomes the simplest one and requires the less user interaction in comparison with others. In this line, Lamb et al. (2019) pointed out that VR can impact students' critical thinking only as a supplement to textbooks in lexical density and complexity for argumentative writing in science topics; thus, the same authors suggested that such technology alone cannot become valuable.

Seven studies adopted the experiential instructional strategy allowing students to learn through practice. For instance, in Wolfartsberger's (2019) study, students took the role of a mechanical engineer and tried to point out faults in a 3D engineering model through a VR-supported review approach. In van Ginkel et al.'s study (2019), students were the presenters and took feedback after their presentation. In Starr et al.'s (2019) study, each student assumed the role of a computer scientist and tried to find out his/her identity as a researcher in favor of discovering possible stereotype threats.

Lastly, two studies supported the collaborative instructional strategy. This instructional strategy requires from the educational software designers to allow multiple users interacting simultaneously with others using the same VR application. Šašinka et al. (2018) provided an advanced VR system where users can see the avatar of their colleagues in a virtual world and work together, in the same virtual room to solve a problem (problem-based learning). A simpler approach was followed by Yeh et al. (2013), where students showed the same projection on a canvas, wearing 3D glasses, and using haptic controllers to interact with the VR system. At the same study, both students are at the same lab and can collaborate in the real world (speaking with each other) while they share the same projection screen.

The same five instructional learning techniques as in K-12 settings are analyzed below for all the studies reviewed in HE settings (Table 6).

Game-based learning is a very popular learning approach in K-12 settings, whereas in HE settings, only two studies followed this approach. More specifically, in Shu et al.'s (2018) study, students played a game where they have to follow specific tasks that allow them to better be prepared for an earthquake. The same authors tried to educate students for such a natural disaster through a game to provide the students with the appropriate knowledge without stressing them out. Webster (2016) investigated declarative knowledge acquisition through a VR serious game where military personnel should perform specific activities and answer to questions to achieve the game objectives.

The field trip technique was used in three of the HE studies allowed students to virtually visit specific sites. For instance, in Selzer et al. (2019) students observed the wetland of Villa del Mar, Buenos Aires, Argentina, which is a place of great relevance for the ecosystem of a local environment. Similarly, in Lin et al.'s (2019) study, participants were introduced to a library building and Pirker et al. (2018) explored an educational physics lab.

Four studies adopted observation as an instructional technique in HE settings. One use of this technique is providing learners with different learning conditions to study eventual differences. For instance, Bailenson et al. (2009), allowed students to observe a virtual lecture and is trying to discover the digital transformation under different conditions. Similarly, Kartiko et al. (2010) investigated learning outcomes by providing students with different type of cartoons (flat, 2D cartoon and lifelike cartoon). Lamb et al. (2019) compared the writing skills of students who used VR applications and textbook settings. Limniou et al. (2009) compared chemical knowledge of students after their exposure to 2D or 3D virtual educational content.

Another instructional technique that was followed is the role-play. For example, Markowitz et al. (2018) investigated whether a student's role affect ocean acidification knowledge, environmental attitude, and presence. Students in one condition immerse themselves as a scuba diver and in another condition as a coral in the ocean. In Starr et al.'s (2019) study, students participated as a computer scientist and researchers discovered possible stereotype threats, while in Gavish et al. (2015), trainees had the role of engineers. An interesting approach was also followed by McFaul and FitzGerald (2019), where students as avatars were audience members to ask questions in favor of facilitating group delivery of presentations and allowing module tutors to enter

Table 6 VR-supported instructional design techniques in HE settings

Instructional design techniques	Primary author (year of publication)
Educational game	Shu et al. (2018) and Webster (2016)
Field trip	Lin et al. (2019), Pirker et al. (2018) and Selzer et al. (2019)
Observation	Alfalah (2018), Bailenson et al. (2009), Kartiko et al. (2010), Lamb et al. (2019) and Limniou et al. (2009)
Role-play	Bonfil et al. (2020), Markowitz et al. (2018), Starr et al. (2019), Gavish et al. (2015) and McFaul and FitzGerald (2019)
Simulation	Kozhevnikov et al. (2013), Makransky et al. (2019), Meyer et al. (2019), Pirker et al. (2018), Taçgın (2019), Wolfartsberger (2019), Yeh et al. (2013), Bonfil et al. (2020), Van Ginkel et al. (2019), Huang and Lee (2019) and Šašinka et al. (2018)

into a virtual world for assessment, feedback, and teaching purposes.

Finally, the most used technique in HE settings was the simulation. Eleven studies adopt this technique in HE settings. Simulation is a very useful technique to provide students with details about various physical phenomena that are difficult to be reproduced in the real world or to allow them to discover the knowledge through problem-based learning tasks. A category of studies used simulation to introduce students to the "invisible" or difficult phenomena to see by human eyes. For instance, in Kozhevnikov et al.'s study (2013), students investigated if 1D or 2D simulation had any effect on their learning in relative motion. In Yeh et al. (2013), students were introduced to forces of physics. In Meyer et al. (2019), students had a journey inside a human Cell. In Šašinka et al.'s study (2018), students discovered how a valley can be flooded through experimentation and problem-solving contexts. Other researchers developed various simulations for research or professional training, such as scientific labs (Makransky et al. 2019; Pirker et al. 2018), surgery rooms (Taçgın 2019), engineering professional environments (Bonfil et al. 2020; Wolfartsberger 2019), and 3D modeling interfaces (Huang and Lee 2019).

Immersive VR applications were commonly utilized more in HE settings for simulated real-world scenarios giving the chance to all users interacting with objects and elements with high representational fidelity. This is reasonable since HE contexts should provide students with specialized knowledge on their study domain. Simulation training allows experimentation, active learning in problem-solving contexts, without the fear of damage or destruction of physical objects.

With regard to *RQ2*, nineteen from the overall twenty-one studies which were conducted in K-12 education reported some positive findings on student learning in terms of a VR-supported intervention effectiveness. Specifically, learning approaches with hands-on activities and collaborative project-based learning provided significant empirical evidence indicating improvements on the use of different instructional contexts in comparison with control conditions. A noticeable observation is that all studies conducted in K-12 gathered their data by comparing experimental groups following VR-supported interventions and conventional ones, either in terms of assessing students' learning performance improvements/achievements or perceptions and attitudes based on user experience evaluation. First, comparative studies investigated the positive impact between VR-supported instruction and lectures (Chen et al. 2019; Innocenti et al. 2019), textbooks (Taranilla et al. 2019) or block-based programing courses (Segura et al. 2019). Students in VR-supported teaching interventions were able to improve their attention (Blume et al. 2019; Innocenti et al. 2019), self-directed learning (Shi et al. 2019), motivation (Chang et al. 2019a, b), group work skills and self-regulated learning (Abdullah et al. 2019), knowledge recall (Ferguson et al. 2020), problem-solving and inquiry skills (Wu et al. 2019), self-efficacy and critical thinking tendencies (Chang et al. 2019b), student learning performance (Chen et al. 2019; Chien et al. 2019; Taranilla et al. 2019), and satisfaction (Cheng and Tsai 2019; Huang 2019; Huang et al. 2019). To identify perceptions and attitudes about learning based on user experience evaluation, the results from two studies showed an overall enhancement on students' virtual presence with the use of immersive virtual field trips (Han 2019) and perceived control understanding of spatial rotation using haptic-enabled, VR-supported instructional settings in Science (Hite et al. 2019). The effects of VR applications are categorized and summarized in Table 7.

In contrast to the above, Alrehaili and Al Osman (2019) found that the immersion level for both tested VR role-playing games (RPGs) did not have a significant effect on learning. Nevertheless, the same study showed an improvement in knowledge retention to those users who played a serious game in VR than their counterparts who followed a conventional method, i.e., by reading a book. The results from the VR-supported interventions showed also that users

Table 7 The impact of VR applications in K-12 settings

K-12 education	Studies	Number of studies and percentage (%)
Improved students' learning outcomes and/or achievements	Abdullah et al. (2019), Ferguson et al. (2020), Innocenti et al. (2019), Shi et al. (2019) and Wu et al. (2019)	6 (28%)
Increased motivation, self-efficacy, and engagement for knowledge acquisition	Chang et al. (2018, 2019a, b), Cheng and Tsai (2019), Huang (2019) and Huang et al. (2019)	6 (28%)
Students' learning performance improvement	Alrehaili and Al Osman (2019), Chen et al. (2019), Chien et al. (2019) and Taranilla et al. (2019)	4 (19%)
Positive perceptions and attitudes about learning based on user experience evaluation	Han (2019), Hite et al. (2019) and Segura et al. (2019)	3 (14%)
Enhanced interaction and collaboration in several learning tasks	Southgate et al. (2019) and Wang et al. (2019)	2 (10%)

of the immersive and desktop VR RPGs were motivated and engaged significantly compared to those of the conventional method. Also, Chang et al. (2018) noticed that there were nonsignificant differences in terms of students' learning achievement and learning motivation in the experimental and control groups. Nonetheless, a remarkable point of view was that students in the former group succeeded better achievements on the in-depth knowledge test on natural geomorphological knowledge, thus providing evidence that any VR-supported hands-on approach assisted them to cultivate problem-solving and metacognitive skills.

In HE settings, twenty-one from the overall twenty-five studies provided the positive impact of VR technology on students' learning outcomes and performance in experimental setups (Lamb et al. 2019; Limniou et al. 2009; Lin et al. 2019; Markowitz et al. 2018; Pirker et al. 2018; Selzer et al. 2019; Starr et al. 2019; Webster 2016) with animated virtual actors based on the cognitive theory of multimedia learning (Kartiko et al. 2010), virtual lectures (Bailenson et al. 2009; McFaul and FitzGerald 2019), and observation of virtual lab environments and experiments (Kozhevnikov et al. 2013). Such teaching approaches allowed users to view any visualized content to navigate and explore the VR environment but not to experiment or execute specific activities and tasks. A cluster of five studies used practice-based tasks/exercises (Gavish et al. 2015; Makransky et al. 2019; Wolfartsberger 2019), where students had to complete specific tasks and experiments, or game-based learning approaches (Šašinka et al. 2018; Webster 2016).

More specifically, seven studies have reported better learning performance and outcomes (Van Ginkel et al. 2019; Kozhevnikov et al. 2013; Lamb et al. 2019; Limniou et al. 2009; Lin et al. 2019; Markowitz et al. 2018; Meyer et al. 2019; Šašinka et al. 2018; Selzer et al. 2019; Starr et al. 2019; Webster 2016) for students who utilized VR applications, albeit three studies did not find any significant difference in learning outcomes (Gavish et al. 2015; Kartiko et al. 2010; Wolfartsberger 2019). There was only one that reported negative learning achievements (Makransky et al. 2019), due to overload and distraction of users when using VR simulations. The rest of the studies either did not apply a comparative experiment method or their focus was generally on the investigation of user experience (UX) issues, such as social dynamics (Bailenson et al. 2009), emotional statements (McFaul and FitzGerald 2019; Pirker et al. 2018), presence and collaboration (Yeh et al. 2013). There was also one study that its purpose was to allow stakeholders discovering students' knowledge and common mistakes to improve training (Bonfil et al. 2020).

A portion of previous studies also reported positive users' attitudes and perceptions regarding the VR usage, such as engagement (Pirker et al. 2018), motivation (Alfalah 2018; Limniou et al. 2009; Lin et al. 2019; Makransky et al. 2019; Starr et al. 2019), presence (Yeh et al. 2013; Makransky et al. 2019; Selzer et al. 2019), increased self-efficacy (Shu et al. 2018), which could reduce students' learning anxiety (Chien et al. 2019), and lastly perceived enjoinment (Meyer et al. 2019).

Other studies have provided some opposite results. For example, McFaul and FitzGerald (2019) pointed out that VR harmed students' engagement. Also, Makransky et al. (2019) noticed that learning science with VR support may overload and distract students' attendance and participation to understand any learning material. In addition, Selzer et al. (2019) concluded that low-end VR devices had significantly higher simulator sickness scores in comparison with high-end VR devices. Alfalah (2018) pointed out some of the barriers of VR from the instructors' side. The faculty members' concerns lie on how to integrate VR technology within learning contexts and its appropriateness to specific disciplines, the cost of technological equipment, the usability issues of software and interface devices, fear of technology, and the lack of students' technological skills. To this end, Gavish et al. (2015) indicated that VR and Augmented Reality (AR) training groups have required longer training time compared to the control groups. Kozhevnikov et al. (2013) noticed some minor disadvantages of VR equipment such as the HDM weight and the difficulty in control. The main observed positive effects of VR in HE settings are summarized in Table 8.

There are many interesting insights indicated by comparing studies based on different VR applications and computer technologies. Some studies compared on-screen 2D videos, animations, and environments with 3D virtual content via HMD (Kozhevnikov et al. 2013; Lin et al. 2019; Meyer et al. 2019; Wolfartsberger 2019) or room size instances, such as CAVE™ (Limniou et al. 2009). Also, others compared VR simulators via HMD in contrast to the screen projection of a 3D simulator (Makransky et al. 2019; Selzer et al. 2019), projection of 2D or 3D animated virtual actors (Kartiko et al. 2010), the combination of VR presentation and textbook in contrast to textbook/VR presentation (Lamb et al. 2019). An important aspect provided by Makransky et al. (2019) who claimed that instructional media can increase the fun of a simulation, such as the sense of presence, but it does not necessarily make someone learn better. The same authors provided evidence from a comparative study indicating that cutting-edge high-immersion VR can increase in processing demands on working memory and decrease in knowledge acquisition, as compared to conventional media with a computer monitor. In the same line, Selzer et al. (2019) compared VR applications with low or high-end devices. The same authors found that although low-end devices were less immersive and produce a lower level of a virtual presence than high-end VR systems, the former is preferable for the development and utilization of educational applications. Lastly, active VR user participation in "drill-and-practice"

Table 8 The impact of VR applications in HE settings

Higher education	Studies	Number of studies and percentage (%)
Increased motivation and engagement for knowledge acquisition	Alfalah (2018), Limniou et al. (2009), Lin et al. (2019), Makransky et al. (2019), Kartiko et al. (2010), Pirker et al. (2018), Selzer et al. (2019) and Shu et al. (2018)	8 (32%)
Improved students' learning outcomes and/or achievements	Gavish et al. (2015), Kozhevnikov et al. (2013), Lamb et al. (2019), Limniou et al. (2009), Starr et al. (2019) and Webster (2016)	6 (24%)
Positive perceptions and attitudes about learning based on user experience evaluation	Huang and Lee (2019), Markowitz et al. (2018), Meyer et al. (2019), Taçgın (2019) and Yeh et al. (2013)	5 (20%)
Enhanced interaction and collaboration in several learning tasks	Bailenson et al. (2009), Pirker et al. (2018), Šašinka et al. (2018) and Wolfartsberger (2019)	4 (16%)
Students' learning performance improvement	Bonfil et al. (2020) and Van Ginkel et al. (2019)	2 (8%)

settings was compared with the passive observation of tasks (Gavish et al. 2015), different views and settings (Bailenson et al. 2009; Markowitz et al. 2018; Pirker et al. 2018, Šašinka et al. 2018; Yeh et al. 2013) or content (Starr et al. 2019) were projected by HMD. Nevertheless, Han (2019) noticed that students felt that learning was not favorable with HMDs, possibly due to the novelty of VR technology uses.

Some interesting results have been revealed by other comparative studies. For example, Pirker et al. (2018) advocated that room-scale VR setup can lead to higher levels of engagement, presence within enjoyable contexts. Yeh et al. (2013) denoted that awareness and (social) presence in VR-supported contexts are highly correlated to usefulness, ease to use, and playfulness, fostering the acceptance to the new type of technology system. Markowitz et al. (2018) examined correlations among dependent variables to test the relationship between knowledge, attitudes, and presence and they found that participants' reported levels of presence, or the feeling that the virtual world was unmediated, was positively associated with post-test learning scores. Similarly, Webster (2016) mentioned that higher levels of immersion, engagement, and motivation can lead to increased learning. Taçgın et al. (2019) admitted that if the students have a positive attitude toward the virtual learning environment, they can feel more confident and learn better. If students feel more confident, they can learn better, and their attitudes will be affected positively to the virtual learning environment. According to Shu et al. (2018), VR HMD applications could provide students with a sensation of realism, thereby facilitating deeper memories, stimulating real body movements, influencing their emotions, and making it easier to be engaged mentally. Lamb et al. (2019) revealed that if VR is combined with textbooks, it can help students to achieve better writing performance. Šašinka et al. (2018) studied the impact of collaboration in VR applications and mentioned that collaborative discovery learning in pairs is more effective compared to individual work. Some interesting results were provided by comparing high-end devices, such as Oculus Rift and HTC Vive with low-end VR devices (configuration consisted of a VR-Box low-cost headset and a mobile smartphone). For instance, in Selzer et al.'s study (2019) VR-supported instruction caused higher simulator sickness because of generating a different levels of virtual presence; however, it seems that the learning outcome has not any significant difference.

However, Markowitz et al. (2018) pointed out that any physical movement of the participant's right hand, proxied by the movement of the virtual right-hand model, significantly predicted inquisitiveness. The results from Huang and Lee's (2019) study, indicated that there are still some challenges regarding the complexity and functional integration of a VR system for users. Such obstacles may affect the overall usability of the VR system. For example, the interactive guidance on 3D modeling may be is not adequate in a VR system.

To summarize, the majority of studies in K-12 settings reported that students were able to achieve deep learning of complex knowledge (Shi et al. 2019), as well as to cultivate their cognitive thinking skills related to creativity (Segura et al. 2019), problem-solving (Wu et al. 2019), critical thinking (Chien et al. 2019), and metacognition (Chang et al. 2018). In HE settings, VR can assist students to learn more and have better learning performance, especially when they succeed in deeper immersion and presence. In addition, users seemed to have positive attitudes and perceptions using VR applications even if technology limitations and potential complexity are factors that need to be addressed in the future.

With regards to *RQ3*, in K-12 settings many studies used different research design analysis and data tools to gather information, such as qualitative ($n=2$), quantitative ($n=16$) or mixed ($n=3$) for data collection as Table 9 provides.

Figure 3 shows the combination of the research design and data analysis method. Most studies in K-12 education

Table 9 Data collection methods in K-12 settings

Type of research method	Studies	Number of studies and percentage (%)
Quantitative	Abdullah et al. (2019), Alrehaili and Al Osman (2019), Blume et al. (2019), Chang et al. (2018, 2019a), Chen et al. (2019), Cheng and Tsai (2019), Ferguson et al. (2020), Han (2019), Hite et al. (2019), Huang (2019), Huang et al. (2019), Segura et al. (2019), Shi et al. (2019), Taranilla et al. (2019) and Wu et al. (2019)	16 (75%)
Mixed (collection and analysis of quantitative and qualitative data)	Chang et al. (2019b), Chien et al. (2019) and Innocenti et al. (2019)	3 (25%)
Qualitative	Southgate et al. (2019) and Wang et al. (2019)	2 (10%)

reported data analysis gathered by conducting: (a) experimental study ($n = 14$), (b) user experience testing ($n = 1$), (c) usability testing ($n = 2$), (d) qualitative ($n = 2$), and (e) mixed methods ($n = 2$).

Several experimental studies reported descriptive statistics as identified that this category had also employed ANOVA, ANCOVA, paired *t* tests, Pearson's correlation coefficient, MANOVA, and other quantitative data analysis methods. Two studies provided qualitative data using observation and participants' interviews to present their perceptions and opinions regarding VR-supported teaching interventions. Specifically, two studies (Southgate et al. 2019; Wang et al. 2019) gathered data using qualitative methods and synthesized information to review and revise from observations, semi-structured interviews, and video data.

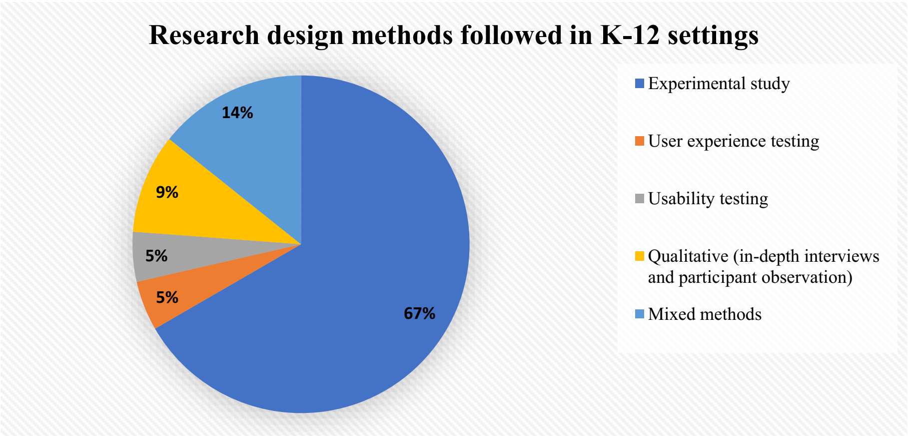
Nineteen from a total of twenty-one studies in K-12 settings took place inside classrooms and the other two in laboratories (Blume et al. 2019; Han 2019). The majority of VR-supported learning interventions were kept shortly, less than 50 min at an average in each study. Sample sizes varied from 24 to 162 participants, with the most common experimental setup including from 40 to 80 participants. Most studies with teacher-centered or observations used mainly quantitative methods. On the contrary, studies that provided data gathered by mixed research or qualitative designs gave evidence to explain, describe, and understand the effects of VR-supported interventions (Fig. 4).

In HE settings, many studies used different research design analysis and data tools to gather information, such as quantitative ($n = 13$), qualitative ($n = 2$), and mixed ($n = 10$) research methods (Table 10).

As indicated in Fig. 5, the combination of research design and data analysis method is provided. Most studies in HE settings reported data analysis which were gathered by conducting: (a) experimental study ($n = 8$), (b) user experience testing ($n = 1$), (c) usability testing ($n = 3$), (d) qualitative ($n = 2$), (e) case study ($n = 1$) and (f) mixed methods ($n = 10$).

Several experimental studies reported descriptive statistics by employing ANOVA, ANCOVA, paired *t* tests, Pearson's correlation coefficient, MANOVA, and other quantitative data analysis methods. Only two studies reported qualitative data using observation and participants' interviews to present their perceptions and opinions regarding VR-supported interventions. More importantly, two studies (McFaul and FitzGerald 2019; Šašinka et al. 2018) gathered data by using qualitative methods and synthesized information to review and revise from observations, semi-structured interviews, and video data (Fig. 6).

Fig. 3 Research design methods from studies conducted in K-12 education



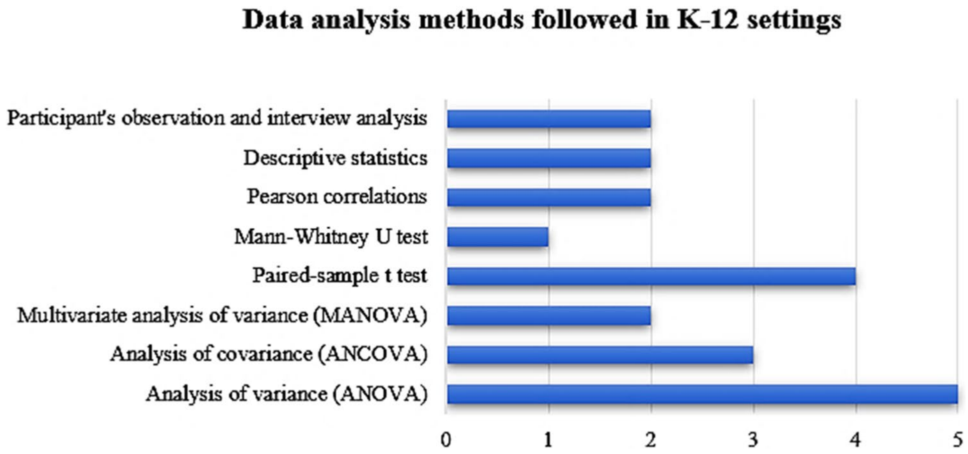


Fig. 4 Data analysis methods from studies conducted in K-12 education

Table 10 Data collection method in HE settings

Type of research method	Studies	Number of studies and percentage (%)
Quantitative	Bailenson et al. (2009), Bonfil et al. (2020), Huang and Lee (2019), Gavish et al. (2015), Kartiko et al. (2010), Lamb et al. (2019), Lin et al. (2019), Li et al. (2020), Makransky et al. (2019), Shu et al. (2018), Yeh et al. (2013), van Ginkel et al. (2019) and Taçgın (2019)	13 (52%)
Mixed (collection and analysis of quantitative and qualitative data)	Alfalah (2018), Kozhevnikov et al. (2013), Limniou et al. (2009), Markowitz et al. (2018), Meyer et al. (2019), Pirker et al. (2018), Selzer et al. (2019), Starr et al. (2019), Webster (2016) and Wolfartsberger (2019)	10 (40%)
Qualitative	McFaul and FitzGerald (2019) and Šašinka et al. (2018)	2 (8%)

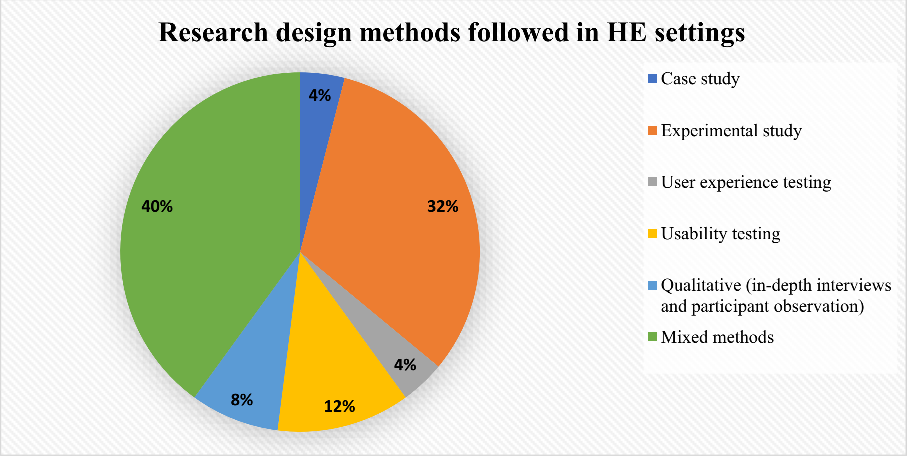


Fig. 5 Research design methods from studies conducted in HE settings

Seventeen studies took place inside laboratories, six into classrooms, and other two outside of laboratories or classrooms for practical exercises/specialized training in specific workplaces (Bonfil et al. 2020; Gavish et al. 2015). Most of the studies applied one-session interventions lasted less than 1 h. Nonetheless, in most cases, the actual time participants spent in VR was much shorter between 5 and 15 min. There is an exception provided by Wolfartsberger's (2019) study, in which students had to collaborate and spent 40 min as a group in VR-supported instructional settings. This reveals a limitation of VR that requires one device per student in contrast to other technologies, such as video projection. The sample sizes varied from 14 to 200 participants, with most of the experiments to have from 40 to 90 participants.

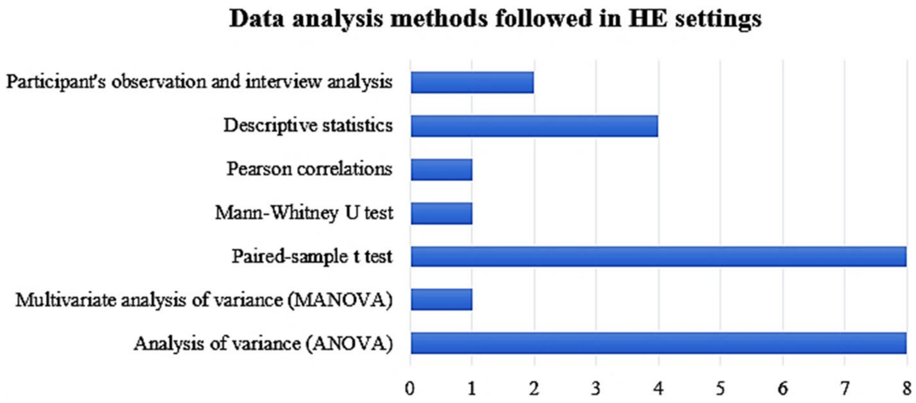


Fig. 6 Data analysis methods from studies conducted in HE settings

In relation to *RQ4*, the hardware devices (apparatus), development tools and assets to be achieved user interactions with VR hardware which were used in K-12 education are classified into three major categories: (a) spherical video VR ($n=6$), (b) wearable mobile VR ($n=10$), and (c) tethered HMD-based VR with hand controllers ($n=5$). VR-supported teaching interventions in the first two categories used mostly existing, free or commercial, 3D resources (Cheng and Tsai 2019; Han 2019; Wu et al. 2019), platforms (Chang et al. 2019a, b; Chen et al. 2019; Hite et al. 2019), mobile applications (Huang et al. 2019; Taranilla et al. 2019), games (Ferguson et al. 2020) or software applications (Huang 2019). Existing VR resources and software packages have been widely used in learning subjects where the access to physical resources would be much more difficult, time-consuming or expensive, such as the anatomy of a frog (Huang et al. 2019) in biology or the exploration of ancient Rome in history (Taranilla et al. 2019).

Studies in which students used HMD-based VR with hand controllers designed and developed exclusively custom applications to serve specific educational purposes, such as games (Ferguson et al. 2020; Segura et al. 2019; Shi et al. 2019; Wang et al. 2019) and simulations (Blume et al. 2019; Southgate et al. 2019). Game prototypes had specific embedded learning material and exercises for skills practice as part of the gameplay, in which students were immersed in 3D realistic simulated environments to learn by playing into enjoyable and interactive tasks with virtual objects/elements.

According to Table 11, "*head movement detection through sensors embedded in the headset*" was the most common in use tools for VR-supported interaction of users in different STEM learning subjects (Segura et al. 2019; Huang 2019). To this end, the participants were able to explore and understand concrete and abstract knowledge using 3D technology that offers realistic simulated representational fidelity of visual objects and elements. Nonetheless, in social science topics, "*head movement detection through observation*" was mostly utilized as indicated by the previous studies reviewed (Cheng and Tsai 2019; Taranilla et al. 2019).

It is of great importance to mention the variety of development tools for VR applications in different learning subjects. On the one side, 360° spherical images and videos were mostly utilized for students at an elementary level with VR support in field trips or in-class presentations for social science topics such as English language learning (Chien et al. 2019), historical events from the Second World War (Cheng and Tsai 2019), and exploration of scientific (Huang 2019) or natural phenomena (Han 2019; Chang et al. 2018). Such an option of having images would be preferable and not so confusing to those students who do not have extensive experience with immersive games or tasks applied by more advanced computing devices. Other studies used native applications developed for Android mobile-based VR devices, such as *Google Expeditions* (Han 2019) or *VirTimePlace* (Taranilla et al. 2019). Researchers might have taken such a decision because Android-based wearables are less expensive as well as the support plenty of free available applications in the *Google Play Store*.

Another significant perspective in VR-supported learning tasks is that several authors from the included studies developed their applications frequently using unity as a development platform for more advanced graphics and visual objects in modeling simulated realistic with high representational fidelity learning tasks in Science and Technology (Alrehaili and Al Osman 2019; Wang et al. 2019) or games (Ferguson et al. 2020). Such tasks are demanding and addressing generally educators and researchers who have advanced programming background.

A wide range of already known computing devices have been mentioned by the some researchers for VR-supported learning tasks in K-12 settings, such as (a) *PlayStation VR platform* (Ferguson et al. 2020), (b) *Samsung smartphone* (Huang 2019), (c) *Android-based wearable VR glasses* (Han 2019; Taranilla et al. 2019), (d) *Oculus Rift with Minecraft* (Southgate et al. 2019), and (e) a web platform to combine video-based VR with real scenes and learning content (Chang et al. 2019a, b). A possible explanation of the logical reasons or principles employed in choosing to utilize consciously some of the most well-known computing devices is

Table 11 Development tools and assets of VR applications in K-12 settings

Primary author (year of publication)	Development tools	Design elements	User interaction with VR system components
Abdullah et al. (2019)	Blender & VRML Pad	3D interactive animations	Motion and infrared sensors were used to transcribe head movements of pitch (up-down), yaw (side to side), and roll (rotational)
Alrehaili and Al Osman (2019)	Unity	3D interactive animations	Head movement detection through sensors embedded in the headset
Blume et al. (2019)	Not specified	3D interactive objects and features	Head movement detection through sensors embedded in the headset
Chang et al. (2018)	EduVenture® VR system	360° pictures and texts	Head movement detection for passive observation
Chang et al. (2019a)	EduVenture® VR system	360° pics and texts through the learning material editing system module	Head movement detection through observation
Chang et al. (2019b)	EduVenture® VR system	360° pics and texts through the learning material editing system module	Head movement detection for passive observation
Chen et al. (2019)	Unity	3D interactive animations	Head movement detection through sensors embedded in eyewear and 2D conversion glasses
Cheng and Tsai (2019)	Not specified	360° spherical images, pop-up texts	Head movement detection for passive observation
Chien et al. (2019)	Not specified	360° spherical images	Head movement detection for passive observation
Ferguson et al. (2020)	Unity	3D interactive animations, pop-up text messages to control virtual objects	PlayStation VR headset, PlayStation Dual Shock 4 controller and over-ear headphones for audio and head movements detection
Han (2019)	Native application (Android)	Real-world 360° panoramic images	Head movement detection through sensors embedded in the headset
Hite et al. (2019)	Not specified	3D geometric objects and models	Head movement detection through a head tracking camera, polarized eyewear combined with a 3D stereoscopic display and a haptic stylus
Huang (2019)	Unity	3D geometric objects and models	Head movement detection through sensors embedded in the headset
Huang et al. (2019)	Unity	3D geometric objects and models	Head movement detection through sensors embedded in the headset
Innocenti et al. (2019)	Unity	3D models with animations and drawings	Head movement detection for passive observation
Segura et al. (2019)	Unity	3D interactive models and animations	Head movement detection through sensors embedded in the headset
Shi et al. (2019)	Unity	3D interactive models and animations	Head movement detection through sensors embedded in the headset
Southgate et al. (2019)	Not specified	3D interactive objects and animations	Head movement detection through sensors embedded in the headset
Taranilla et al. (2019)	Native application (Android)	3D interactive animations and objects	Head movement detection for passive observation
Wang et al. (2019)	Unity	3D models with animations and pop-up texts	Head movement detection through sensors embedded in the headset
Wu et al. (2019)	Not specified	Panoramic VR films and 360° aperture images	Head movement detection for passive observation

Table 12 Development tools and assets of VR applications in HE settings

Primary author (year of publication)	Development tools	Design elements	User interaction with VR system components
Alfalah (2018)	Not specified	3D interactive objects and elements	Head movement detection for passive observation
Bailenson et al. (2009)	Vizard	3D virtual class	Head movement detection through sensors embedded in the headset and gamepad to record user responses
Bonfil et al. (2020)	Not specified	2D/3D animations	Computer keyboard/mouse and computer screen
Gavish et al. (2015)	Not specified	3D virtual components controlled by haptic structures, AR with visual information, educational videos	Haptic device
van Ginkel et al. (2019)	Unity	3D interactive models and animations	HTC VIVE HMD with Microsoft Kinect sensors for movements detection
Huang and Lee (2019)	Not specified	3D interactive objects and elements	Head movement detection through the headset and hands-on tasks with handheld controllers
Kartiko et al. (2010)	Blender combined with Vue, Gimp, Inkscape	2D/3D animations	No user interaction. VR content was projected on a 6m-wide semi-cylindrical canvas (160-degree field of view)
Kozhevnikov et al. (2013)	Not specified	3D interactive models and animations	Head movement detection through the headset
Lamb et al. (2019)	Developed by a third-party company	3D interactive objects and features	Head movement detection through the headset
Li et al. (2020)	Unity and Maya	360° interactive objects and features	Head movement detection through the headset
Limniou et al. (2009)	3D studio Max™	3D interactive animations	Head and hand are tracked with Polhemus or Ascension tethered electromagnetic sensors.
Lin et al. (2019)	EduVenture® VR system	360° pictures and pop-up texts	Head movement detection through the headset (mobile phone)
Makransky et al. (2019)	Developed by a third-party company	3D interactive objects and elements	Head movement detection through the headset
Markowitz et al. (2018)	Vizard	3D interactive objects and features	Head movement detection through the headset and a PC mouse for interaction with the objects
McFaul and FitzGerald (2019)	Native application (Android and iOS)	3D virtual class	Head movement detection through sensors embedded in the headset (Google cardboard)
Meyer et al. (2019)	Developed by a third-party company	3D interactive objects and features	Head movement detection through the headset (mobile phone)
Pirker et al. (2018)	Unity	3D interactive objects and elements	Head movement detection through the headset and hands-on tasks with handheld controllers
Šašinka et al. (2018)	Unity	3D interactive animations and objects	Head movement detection through sensors embedded in the headset and handheld controllers with sensors for hand movements detection
Selzer et al. (2019)	Unity	3D interactive models and animations and texts through the learning material editing	Head movement detection through sensors embedded in the headset and wireless joystick
Shu et al. (2018)	Unity	3D interactive models and animations	Head movement detection through sensors embedded in the headset and handheld controller with sensors for hand movements detection

Table 12 (continued)

Primary author (year of publication)	Development tools	Design elements	User interaction with VR system components
Starr et al. (2019)	Unity	3D interactive models and animations	Head movement detection through sensors embedded in the headset and motion tracking through wall-mounted base-stations
Taçgin (2019)	Not specified	3D interactive models and animations	Head movement detection through sensors embedded in the headset
Webster (2016)	Vizard	3D models with animations and pop-up texts	Head movement detection through sensors embedded in the headset and motion detection through Microsoft Kinect sensors
Wolfartsberger (2019)	Unity	3D interactive objects and elements	Head movement detection through sensors embedded in the headset and handheld controller with sensors for hand movements detection
Yeh et al. (2013)	Not specified	3D geometric objects and models	Head movement detection through sensors embedded in the headset and handheld controller with sensors for hand movements detection

the fact that high school students have such devices in their everyday life, thus any relevant information to come forward would be much easier to be presented and analyzed.

To sum up, any elaborated feedback with pop-up texts and sounds or video images for further explanations of learning situations was preferred for declarative tasks where the use of VR applications intended to assist students memorizing factual knowledge such as theoretical concepts, historical events or scientific abstract knowledge. Based on this systematic review, learning subjects in K-12 and HE settings, such as environmental studies (Abdullah et al. 2019), science simulation (Makransky et al. 2019), history (Cheng and Tsai 2019), English language (Chien et al. 2019), music (Innocenti et al. 2019), and biology (Wang et al. 2019) used declarative knowledge focusing on learning content for visualization and motivation of students with a different socio-cognitive background.

Regarding the software development tools for the VR applications and systems in HE settings as Table 12 tabulates, unity was the most used ($n=7$). After that follows Vizard ($n=3$) or combination of development tools, such as Blender combined with Vue, Gimp, Inkscape ($n=1$), native applications for Android-based devices ($n=1$) or Unity and Maya ($n=1$). In contrast to K-12 education, three applications were developed from a third-party company. This is may be due to the expertise required for educational environments development in HE settings. Another outcome regarding development tools is that nine studies used free-of-charge development environments to create low-cost VR experiences. Eight studies did not specify the software used for the development of VR applications.

The classification of the hardware devices has its own differences. The most used ($n=11$) infrastructure for VR experiences is the tethered HMD-based VR devices with hand controllers (Bailenson et al. 2009; Huang and Lee 2019; Kozhevnikov et al. 2013; Lamb et al. 2019; Markowitz et al. 2018; Pirker et al. 2018; Šašinka et al. 2018; Starr et al. 2019; Webster 2016; Wolfartsberger 2019; Shu et al. 2018). Seven studies used wearable HMD VR, such as Oculus Go VR headset (Li et al. 2020), Google Cardboard (Lin et al. 2019) or similar low-cost HMDs (McFaul and FitzGerald 2019), VR-box low-cost headset and a Motorola Moto G5 Plus (Selzer et al. 2019), Samsung Gear VR with Samsung mobile device (Makransky et al. 2019; Meyer et al. 2019), Oculus Rift or HTC Vive (Pirker et al. 2018; Taçgin 2019). There is one category of researches ($n=4$) that instead of HMDs uses large area displays, such as CAVE (Limniou et al. 2009) or large spherical canvas (Kartiko et al. 2010), large canvas (Yeh et al. 2013) or large screens and monitors (Alfalah 2018; Gavish et al. 2015). In only one study, McFaul and FitzGerald 2019 were used a mobile application that is freely available for both iOS and Android devices called “*Open Justice VR*”.

In contrast to K-12 education, only one study used 360° spherical video (Lin et al. 2019). Trying to assess the user interaction, three studies utilized external sensors (such as Microsoft Kinect) for motion detection (van Ginkel et al. 2019; Webster 2016; Starr et al. 2019). Another two studies use haptic devices and controllers (Gavish et al. 2015; Yeh et al. 2013), and only one (Bonfil et al. 2020) computer screen and mouse.

Two studies (Pirker et al. 2018; Selzer et al. 2019) compared the applicability of using wearable mobile VR and HMD-based VR with hand controllers. There are also some studies focused on how the representation of the projected objects affect the students' knowledge acquisition and attitudes. For example, Limniou et al. (2009) compared 3D with 2D molecules animations in the CAVE environment. Šašinka et al. (2018) examined users' performance when they had to work using 3D or 2D maps into a 3D virtual space. Kartiko et al. (2010) provided findings from three types of "animated-virtual actors" (Flat, Cartoon, and Lifelike-3D) to compare students' presence, rating, and retention.

Some other VR setups included specific sensors to gather quantitative data during the experiment from users' interactions. Bailenson et al. (2009) presented a VR HMD with eye-tracking support discovering how teachers use eye gaze to engage their students. Makransky et al. (2019) developed and used an electroencephalogram to obtain a direct measure of cognitive processing during learning. Another reason that studies used a set of different setups is the provision of better user interaction with VR support. To this end, Yeh et al. (2013) and Gavish et al. (2015) enhanced VR with custom haptic controllers to assist user have a more accurate and realistic user experience without the real-world constrains.

Based on Table 11, "*head movement detection through sensors embedded in the headset*" was the most common in use tools for VR-supported interaction of users ($n=8$), while in another seven ($n=7$) cases users have an additional handheld controller for better interaction with the VR environment (Bailenson et al. 2009; Huang and Lee 2019; Pirker et al. 2018; Šašinka et al. 2018; Selzer et al. 2019; Shu et al. 2018; Wolfartsberger 2019). In three ($n=3$) studies, users in motion were being tracked through external devices such as Kinect (Webster 2016; van Ginkel et al. 2019) and through wall-mounted base-stations (Starr et al. 2019). Gavish et al. (2015) and Yeh et al. (2013) used haptic devices for user interaction while in contrast in other studies such as Bonfil et al. (2020) and Markowitz et al. (2018) a simple computer mouse was used or there was no interaction with the environment (Kartiko et al. 2010).

A considerable amount from the studied literature relates to procedural knowledge where the application of the correct action and response is essential for practical tasks. VR assistance with sound and visual feedback can facilitate "hands-on" and "*learn by doing*" tasks, such as knowing how to perform correctly in several engineering processes. Responding to such engineering practices-related procedural tasks, students studied into VR-supported analytical and problem-solving contexts for industrial maintenance and assembly tasks training (Gavish et al. 2015), communication, and collaboration for assembly planning and virtual prototyping (Wolfartsberger 2019). Soft skills related to creativity and communication were also provided as important aspects of knowledge acquisition for programing and generally computer science courses (Segura et al. 2019; Southgate et al. 2019). The majority of previous studies provided VR applications for experimental setup for first prototyping and testing with students' socio-cognitive background.

With reference to *RQ5*, many studies in K-12 settings used affordable solutions for VR-supported teaching interventions, in which students were able to achieve higher levels of spatial presence and realism beneficial to cognitive and emotional learning aspects (Han 2019). Nonetheless, interactive VR applications can offer noticeable potentials, such as the visualization of (a) abstract concepts to understand and make assessments what is and is not real (Hite et al. 2019), (b) points of view that are impossible to display in a real environment exploring hidden or scientific phenomena (Chen et al. 2019), and (c) virtual product design and simulation operation tests (Abdullah et al. 2019). Simulated real-world elements are rendered as 3D objects. Adopting VR technologies in problem-solving contexts enables teachers to form virtual world narratives and cases akin to problems in scientific topics following experiential instructional design strategies and simulations (Abdullah et al. 2019; Chang et al. 2018). The projection of realistic multisensory stimulation can allow student engagement in tasks with a high degree of interactivity to observe facts of real-life following presentation as an instructional design strategy mostly in social science topics, such as History (Taranilla et al. 2019) and Musical genre (Innocenti et al. 2019). Several studies utilized educational game prototypes. The development of students' cognitive skills and attitudes can be greatly enhanced by interacting with the 3D objects and exploring freely with learning content based on the user's movements either in a CAVE (Limniou et al. 2009) or in laboratories by wearing HMD VR (van Ginkel et al. 2019). Furthermore, learning scenarios are inspired by real-life conditions to provoke users' emotions giving them a sense of unlimited freedom to design and apply their knowledge through haptics-enhanced tasks (Huang and Lee 2019; Yeh et al. 2013). For example, game-like 3D environments (Segura et al. 2019) or serious games development can support students' achievements and learning motivation (Shi et al. 2019) in activity-based exercises. This can be achieved by implying that most schoolteachers who might be able to develop the learning content in case they do not have any computing devices with low-tech capabilities to enhance common sense, creative thinking, and systematic reasoning. Other studies (Chien et al. 2019; Hite et al. 2019) reported that the use of real images or videos on their own with 360° images and videos as learning materials not only increased the authenticity of learning contexts, but also reduced the students' public speaking anxiety by having them exposed to a lecture hall with audiences of different size based on their training level.

However, some of the studies reviewed in K-12 education have reported several shortcomings. First, as K-12 education is closely associated with classroom predefined instructional contexts, it is unrealistic to have a large number of students to use HMD-based VR applications simultaneously in the classroom for an extended time (Chen et al. 2019). Moreover, spatial arrangements of schools did not usually accommodate tethered HMD installations (Southgate et al. 2019). The lack of constant availability of connected personal devices like mobile VR devices is another worth noting point of view that may negatively affect students' learning performance (Chien et al. 2019). The second most observed difficulty was cognitive overload (Chang et al. 2018; Hite et al. 2019; Huang et al. 2019; Innocenti et al. 2019). Multimodal stimuli in VR applications can potentially distract learners from the main task and cause confusion. The current attributes of technological equipment using HMDs caused physical discomfort and dizziness to some participants after 50 min. Also, VR equipment has a minimum age restriction for young users aged between 11 and 12 years old, while their use can cause physical and health effects, such as sickness and fatigue (Chang et al. 2019a, b). Thus, a third one was dizziness (Cheng and Tsai 2019). This limits the amount of time allocated to a VR-supported learning intervention. Therefore, learners need to study under fading scaffolding instructive-guided conditions, within specific time frames having as well as the assistance from the instructor(s) to learn something meaningfully (Blume et al. 2019; Chang et al. 2018). Additionally, students who utilized HMD VR constant monitoring in a physical space can solve eventual technical problems related to the equipment or any physical movement restrictions (Southgate et al. 2019). In the realm of emotions, two studies (Blume et al. 2019; Han 2019) took place in solitary, single-user VR systems, without other peers to be involved together. For some participants, such tasks created a feeling of isolation when they studied and perceived complexity of learning content.

Most studies in HE settings have paid attention to specialized knowledge and training supported by VR technology within predefined instructional contexts. In specific, many studies followed a VR-supported instruction to present abstract concepts (Kozhevnikov et al. 2013; Limniou et al. 2009; Yeh et al. 2013), complex phenomena (Markowitz et al. 2018), and science lab simulation (Makransky et al. 2019; Starr et al. 2019). Other studies provided the potentials of using VR on several training sessions, asking users to complete specific tasks on various learning subjects. HMD VR advances users experience, enhanced with auditory, haptic, or other sensory (hands-on) feedback to give the virtual world a genuine look and feeling of "being there" and experiment without physical drawbacks to explore and understand complex phenomena through discovery tasks (Kozhevnikov et al. 2013; Markowitz et al. 2018). VR gives students the opportunity not only to explore new areas of search and applying their constructions in problem-solving settings, but also to make predictions, to perform design experiments and to interpret their results for engineering design in greater detail (Wolfartsberger 2019). There were also studies which applied VR-supported interventions about corrosion prevention and control for military purposes (Webster 2016), earthquake preparedness (Shu et al. 2018), present virtual lectures environments in order to allow students to participate (McFaul and FitzGerald 2019) or track educators' actions in different lecture settings (Bailenson et al. 2009). Several studies investigated the impact of VR on stereotype threats among undergraduate women that is related to the low rate of their employment as computer scientists (Starr et al. 2019), and lastly study the usability of 3D modeling interfaces (Huang and Lee 2019). Situated action can facilitate knowledge gain in problem-solving learning, when students can actively be engaged in visually rich contexts due to the authenticity of environment and consequences of actions have a sense of "realism" reflected on activity-based tasks with specific role-playing conditions (Bonfil et al. 2020; Gavish et al. 2015).

However, the main shortcomings reported from studies conducted in HE settings were as follows. The use of VR applications was limited when students participated in an optional activity that took place outside the university class hours due to students' time constraints and drawbacks (McFaul and FitzGerald 2019). Moreover, students were sometimes nervous about dealing with this "immersive" technology and presented a lack of confidence in engaging tasks with new technology. Wolfartsberger (2019) reported another common, potential difficulty resulted by the spatial isolation of users. Finally, VR has a limitation on the possible number of students concurrently receiving the instruction (Webster 2016). For this reason, many researchers used cost-effective low-end devices (Lin et al. 2019; Makransky et al. 2019; Meyer et al. 2019; Pirker et al. 2018).

4 Discussion

VR can provide various learning benefits for instructors and students who want to have access to high-quality educational resources with realistic simulated representational fidelity generated by different computing devices and natural user interface with modalities, such as touch, gestures or voice on an unprecedented scale without spatiotemporal and time constraints. In K-12 education, a connection was observed between the sophistication of deployed VR technology and instructional design choices. For instance, many studies that used high-end HMD systems adopted active, learner-centered instructional approaches, such as game-based and project-based learning (Shi et al. 2019; Wang et al. 2019). In contrast, studies that used simpler or more affordable technologies resorted to less sophisticated, passive instructional approaches, such as observation-based learning or teacher-led instruction (Han 2019; Huang 2019; Taranilla et al. 2019).

Even teacher-led instruction yielded positive results on students' performance, learning outcomes and motivation. The access to high-end VR technology was not a prerequisite to effective pedagogies. A growing body of literature (Chen et al. 2019; Ferguson et al. 2020; Wu et al. 2019) concluded that with access to more affordable VR equipment and software solutions, researchers and instructional designers could use them meaningfully by applying social constructivist principles so as to engage students emotionally in favor of improving their learning performance and interest.

Two essential elements in VR educational games and simulations that opens several opportunities for educators are the role of narrative and realistic-visually appealing feedback from the interaction among users and objects. Students can have access to VR narrative-driven environments as fully instructional-guided or gamified experiences or in a mode of free exploration either in terms of using 360° videos (Ferguson et al. 2020) or games (Wang et al. 2019). Depending on instructional decisions in HE settings, VR-supported interventions with storylines can be experienced in multiple modes, incorporating flexibly into learning scenarios to support specific cognitive and affective learning outcomes. Such learning scenarios can integrate VR-supported applications either during or before and after classroom-based learning. Innovative learning approaches can incorporate VR as part of planned group projects that combine collaborative inquiry, problem-solving analysis, decision-making, documentation, design, construction, using hands-on practices (Chen et al. 2019; Wu et al. 2019). A possible explanation about the limited number of studies (Shu et al. 2018; Webster 2016) utilized game-based learning is the fact that in HE settings students should participate in simulated real-world scenarios following specific guidelines. Hence, it is more difficult to provide them as educational games.

Another significant point of view was the comparison within specific instructional learning conditions interestingly between immersive, HMD, and desktop VR systems with controversial findings. On the one side, Han (2019) reported that HMDs created an overall enhancement in students' experiences and presence with the use of immersive in-class virtual field trips; however, such devices do not necessarily lead to an enhanced perception of learning, as they did not feel that learning was favorable with HMDs.

On the other side, Shu et al. (2018) concluded that not only students' presence and immersion increased significantly with HMD-supported instruction, but also their self-efficacy. VR-supported instructional design contexts can be equally effective in education even when they are mediated via a computer screen and 3D glasses (Hite et al. 2019). HMD VR can be beneficial in situations, where "virtually being" and experiencing within a specific simulated environment in first-person view (Markowitz et al. 2018; Taranilla et al. 2019), and practicing with accuracy, such as testing a machine design (Chen et al. 2019), exploring industrial tasks (Gavish et al. 2015), and operating specialized or laboratory equipment (Pirker et al. 2018). An interesting direction, compatible with "*Bring your own device*" (BYOD) strategies, is the cross-platform collaboration that allows flexible participation of users inside a multiuser, social VR environment as demonstrated by Wang et al. (2019). Also, the proliferation of untethered, wireless, and stand-alone HMDs with hand controllers or hand tracking will enable wider adoption, easier installation, and deployment of VR systems in education. These findings indicate a powerful effect of psychological immersion in desktop-based 3D environments such as virtual worlds as well as the need to use immersive VR in situations and conditions where the multisensory immersion and user experience via an HMD and tactile feedback are beneficial over a screen monitor.

VR is of limited use when students are not motivated or have the option to avoid using this technology. For instance, McFaul and FitzGerald (2019) pointed out that applications in Android-based devices for distance education harmed students' engagement due to a pilot project intervention; thus, the limited period of time for their familiarization did not allow their meaningful participation. Makransky et al. (2019) admitted that learning science in VR-supported instructional settings may overload and distract students' attendance and participation to understand any learning material. Thus, virtual communication differs from communication in objective reality and it may be impersonal or inappropriate. VR applications and setups need to provide different communication styles and strategies to maintain personal and social communication. This review is in-line with previous ones (Concannon et al. 2019; Potkonjak et al. 2016) advocating that even though VR is a cutting-edge technology available to anyone, it does not necessarily mean that instructors and students can utilize its full potentials in various training situations without concerning any unique perspectives that come from this technology.

The adoption of immersive technologies, like VR, requires users to handle several devices and software tools in order to have smooth learning experience. In some cases, the only form of interactivity was navigation (Pirker et al. 2018). Even if controllers were available, participants could make only a limited number of gestures and they must learn to work with it (Šašinka et al. 2018). Nonetheless, most of the time, students cannot extensively understand how to use this technological equipment, and thus presenting high levels of cognitive overload (Makransky et al. 2019; McFaul and FitzGerald 2019). The mass-scale adoption of VR depends on the cost of the software and hardware (Selzer et al. 2019). On the one side, high-end VR systems are still prohibitive in this aspect, and even more in developing countries. On the other, low-end VR headsets, such as Google Cardboard provide cost-effective, dynamic, and mobile learning experiences and can be easily set up for in-class learning experiences (Pirker et al. 2018). Nevertheless, such low-end systems have been reported that are responsible for the physical difficulties that students have in using VR applications on their smartphones and for higher simulator sickness value (Cheng and Tsai 2019). Therefore, VR applications should provide better forms of interaction and navigation closer to the real-world.

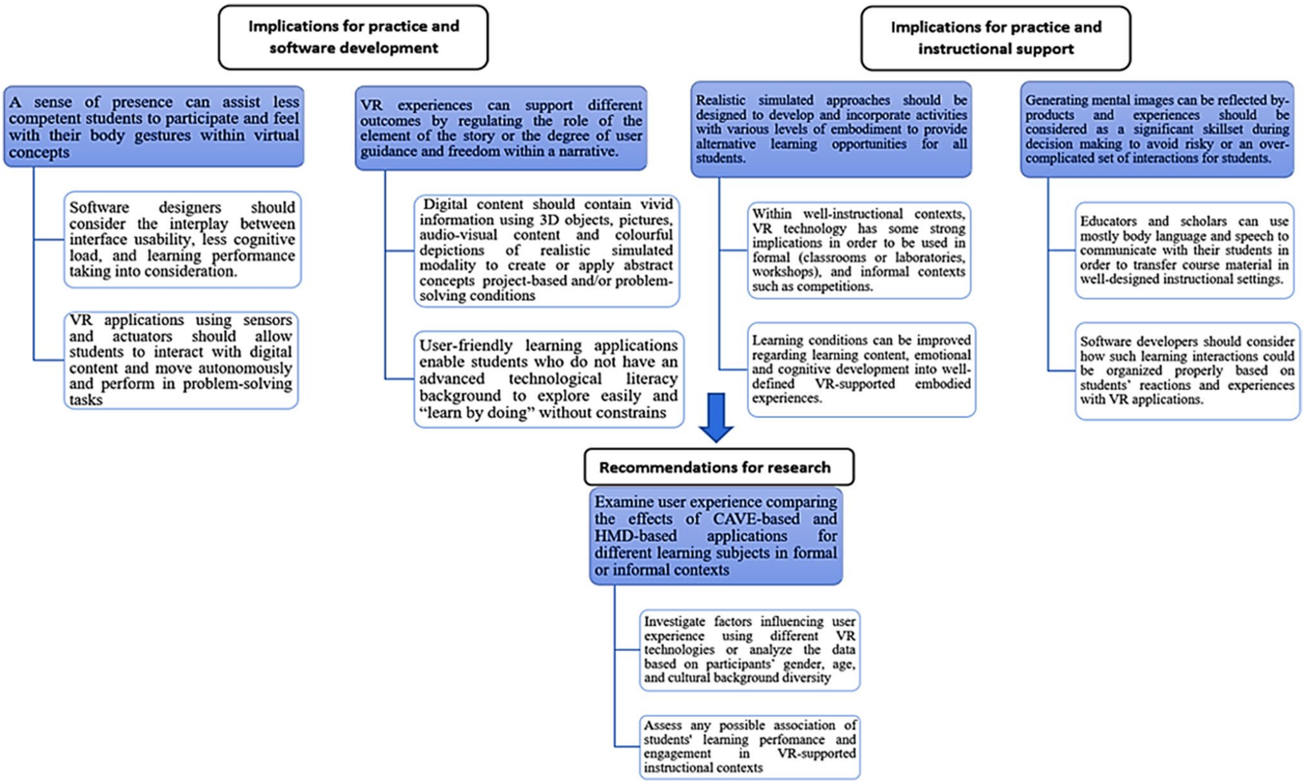
Another limitation of most immersive VR systems is the possible number of students concurrently receiving instructor's feedback and support (Webster 2016). For a large group, lecture-based instruction is generally more cost-effective but as well as not always supportive and efficient in different learning subjects. If a goal is to promote learning, rather than simply to promote a sense of presence, it appears that VR simulations should not be converted from a desktop computer medium to an immersive VR medium (Makransky et al. 2019). Another limitation that should be taken into consideration regarding VR applications is not only the development time to create a prototype application, but also the time required for the implementation of VR-supported teaching interventions ranging from the installation of technological equipment until the final use. In most of the studies, considerable time is needed for VR applications development and application in-class for learner tasks within time-limited contexts (less than 50 min in average). Also, the implementation and programing procedures require specialized researchers and programmers as indicated by previous studies that unity was the most reliable platform for integrating learning content into 3D VR applications (Chen et al. 2019; Huang 2019). Therefore, a free, open-source, and/or easy-to-use tool for VR application development for non-programmers is still lacking today.

VR technology has long been recognized by a growing body of literature as an "immersive technology" that can be applied differently in several learning subjects. While in this review are included articles based on specific inclusion and exclusion criteria, a significant number of hardware equipment supporting VR uses were finally reviewed and analyzed. For instance, this review includes a portion of inclusion terms concerning immersive technologies ranging from Oculus Rift, Samsung Gear, Google Cardboard to 360° videos and CAVE. Nevertheless, there is still a debate about the use of specific devices which can provide a more concrete understanding of the equipments supporting effective and efficient VR devices concerning the demands and needs of different learning subjects in K-12 and HE settings. As far as there are still considered many technological hurdles due to high priced HMDs, the utilization of low-end ones may provide some evidence regarding their potentials against the former. In almost all articles reviewed, different VR applications were developed and utilized, especially in science topics focusing on environmental studies, engineering (mechanical, industrial, etc.), and technology focusing on computer science or programing. In the case of the latter, it seems that learning how to code via colored blocks (Segura et al. 2019), and the utilization of already known environments like *Minecraft* (Southgate et al. 2019) received attention. This means that instructional designers and researchers have already acknowledged that some approaches cannot easily be avoided in case of acceptance by many students and instructors who utilized them before having VR technology on their hands. Therefore, comparative studies need to be conducted by investigating whether the enhanced sense of users' presence in a VR-supported environment is associated with the high representational fidelity of objects/elements and if it can significantly impact students' outcomes and performance.

5 Implications for educational practice and research

This systematic review points out some important shortcomings which, however, pave a pathway to several challenges that educators and instructors need to overcome in their VR-supported instructional settings:

- The majority of the applications which were described and used by the instructors were short-formed and time-limited.
- The use of VR is not something that appears to be done typically even if instructors "know how" to use games. Any inappropriate support to researchers, instructors, and trainers on the correct use of VR can negatively affect the potential use of this technology or leave them with unanswered questions about any exposed usage to a wider pedagogical selection; and
- Several VR applications and games are often not curriculum-aligned, in spite of having some already known as learning how to program with block-based tasks.



Implications for practice and software development

A sense of presence can assist less competent students to participate and feel with their body gestures within virtual concepts

Software designers should consider the interplay between interface usability, less cognitive load, and learning performance taking into consideration.

VR applications using sensors and actuators should allow students to interact with digital content and move autonomously and perform in problem-solving tasks

VR experiences can support different outcomes by regulating the role of the element of the story or the degree of user guidance and freedom within a narrative.

Digital content should contain vivid information using 3D objects, pictures, audio-visual content and colourful depictions of realistic simulated modality to create or apply abstract concepts project-based and/or problem-solving conditions

User-friendly learning applications enable students who do not have an advanced technological literacy background to explore easily and "learn by doing" without constrains

Implications for practice and instructional support

Realistic simulated approaches should be designed to develop and incorporate activities with various levels of embodiment to provide alternative learning opportunities for all students.

Within well-instructional contexts, VR technology has some strong implications in order to be used in formal (classrooms or laboratories, workshops), and informal contexts such as competitions.

Learning conditions can be improved regarding learning content, emotional and cognitive development into well-defined VR-supported embodied experiences.

Generating mental images can be reflected by-products and experiences should be considered as a significant skillset during decision making to avoid risky or an over-complicated set of interactions for students.

Educators and scholars can use mostly body language and speech to communicate with their students in order to transfer course material in well-designed instructional settings.

Software developers should consider how such learning interactions could be organized properly based on students' reactions and experiences with VR applications.

Recommendations for research

Examine user experience comparing the effects of CAVE-based and HMD-based applications for different learning subjects in formal or informal contexts

Investigate factors influencing user experience using different VR technologies or analyze the data based on participants' gender, age, and cultural background diversity

Assess any possible association of students' learning perfomance and engagement in VR-supported instructional contexts

Fig. 7 Implications for practice and research

Taking one step further in order to envisage the VR usage and most importantly applications based on the studies reviewed in K-12 and HE settings, this review presents several implications for educators, scholars, policymakers, curriculum designers, and software developers. Figure 7 depicts the most important.

6 Conclusion

This review's findings advance the knowledge about the use of VR applications to support different subjects in K-12 and HE settings providing several contributions. From a theoretical-instructional perspective, this review may be of great interest to instructional designers and educators who want to design and/or want to apply their VR-supported implementations through formal or informal instructional contexts focused on students' motivation, engagement, and performance. From an instructional-practical design perspective, results gathered by previous experimental studies provide empirical evidence and valuable information on how and whether the use of VR with different computing devices can create purposeful teaching and learning conditions. Also, many studies have provided evidence from quantitative data drawn from course assessments and user experience. Another ongoing body of literature advocated that students who followed VR-supported instruction had successfully achieved better outcomes than their counterparts in traditional (lecture-style) formats, notwithstanding most studies, there are noticed crucial challenges. Nevertheless, the number of studies that experimented with up to thirty participants was sparse to understand phenomena in-depth.

From a practical-instructional perspective, the lack of using theoretical underpinnings for proposing frameworks based on learning theories and further information for the design and development of VR applications in each learning field is still missing from the relevant literature. Aligned with this, most articles do not adequately employ a wide range of problem-solving strategies with multiple acceptable solutions to a given problem, which may be ill-defined like *Minecraft*. Although independent "learn by doing" tasks were supported by the reviewed VR applications, some of these applications were developed to support simple learning tasks, description of historical events or games without reasonable purposes, indicating that VR is still in its infancy. Lastly, there was not any significant effort to provide evidence based on collaborative learning among students, either within real-world's contexts or in new "social" VR platforms, such as in "*Facebook Horizon*". Most applications reflected "*instructionism*," being more instructor-driven, or in other cases, autonomous learning approaches identified, although students have a small period to exercise with any learning content. Therefore, providing the necessary theoretical underpinnings based on learning theories would pave a pathway to those instructors and researchers who want to build innovative educational VR applications in the future.

The current review contributes to the existing body of literature as follows. First, it summarizes good practices and recommendations to propose instructive-guided design guidelines with specific elements and features in VR-supported teaching interventions. Second, it offers several insights to researchers regarding the impact of VR uses on several learning subjects in K-12 and HE. Third, it provides evidence on under what teaching conditions, computing devices, and design elements can potentially increase students' learning performance, participation, and engagement.

7 Limitations and future work

There are some noteworthy limitations in this review. First, because of the often-sparse definitions of VR searching specific databases from the middle of 2009 to 2019 for articles published exclusively in international journals. Nonetheless, several studies, which could be included and retrieved by relevant conference proceedings or book chapters, were not finally aggregated. To this notion, it would be difficult to identify other studies systematically that could not be included. Second, this review's findings are restricted by focusing on studies that used immersive VR in K-12 and HE during the last decade. Third, this review could not consider all the electronic databases such as *IGI Global*, inhibiting authors to read and have access to some articles, and consequently, other published studies that could not be found and analyzed. Fourth, many articles had a small sample size of participants with limited aspects, and thus, their results could not be easily generalized.

Future work should conduct, firstly, controlled mixed-method longitudinal studies with a larger sample size in the long term to investigate the efficacy of VR. Secondly, the combination of VR computing devices with data analytics and tracking tools are recommended to have a more holistic research approach and measure students' learning performance and engagement toward personalized immersive learning.

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Availability of data and materials Data can be accessed by contacting the first author.

Compliance with ethical standards

Conflict of interest No conflict of interest declared.

Appendix: The protocol that was executed in each database

Database	Protocol	Note
JSTOR	((((learn or learning or engagement or learning outcomes or learning achievements) <in>ab) <and> ((Virtual Reality or Gaming Virtual Reality or Gaming Reality) <in>ab)) <in>ab) <and> ((qualitative or quantitative)) <and> ((school or K-12) <in>ab)) <and> (pyr >Ό 2009 <and> pyr <Ό 2020)	Search on the field "Abstract"
SCOPUS	ab: ((teaching or learning or education or educational) and (Virtual Reality or Gaming Virtual Reality or Gaming Reality) and (Higher or Primary or Secondary education)) Content Type > Journal Articles Publication Date > Between Saturday, January 01, 2009 and Thursday, March 30, 2020	Search on the fields "Abstract", "Title" and "Keywords"

Database	Protocol	Note
Science Direct	(learning OR teach OR learn OR education OR educational) <in> Smart Search AND (Virtual Reality or Gaming Virtual Reality or Gaming Reality) <in> Smart Search AND (Primary OR Secondary OR K-12) <in> Smart Search AND Date: between 2009 and 2020 AND Limited to: PEER_REVIEWED In Education Full Text	Search on the field "Abstract" – Term K-12 replaced by primary or high school or middle school by restriction of the database – Terms "teach" and "learn" suppressed limiting quantity of terms used to search the database. Variations to the terms removed were used and can be identified that did not compromise the result
ESCBO	Publication Type: "Journal Articles" and Full-Text Available	Search on the field "Keywords (all fields)"
ERIC	(Publication Date: 2009–2020) ((Keywords: teaching OR Keywords: teach OR Keywords: learn OR Keywords: learning OR Keywords: education OR Keywords: educational) and (Keywords: Virtual Reality OR Keywords: Virtual Reality OR Gaming Virtual Reality OR Gaming Reality OR Keywords: qualitative and quantitative research method OR Keywords: Higher, K-12)	Search on the field "Keywords (all fields)"
Wiley	((learning or engagement or educational) <in>ab) <and> ((Virtual Reality or Gaming Virtual Reality or Gaming Reality) <in>ab)) <and> ((Primary or Secondary or Higher education) <in>ab)) <and> (pyr>Ó 2009 <and> pyr<Ó 2019)	– Search on the field "Abstract"
Web of Science	((learning or K-12 or Higher education) <in>ab) <and> ((Virtual Reality or Gaming Virtual Reality or Gaming Reality) <in> ab)) <and> ((Primary or Secondary) <in>ab)) <and> (pyr>Ó 2009 <and> pyr<Ó 2020)	– Search on the field "Abstract"
IEEEXplore	(learning OR teach OR learn OR education OR educational) <in> Smart Search AND (Virtual Reality or Gaming Virtual Reality or Gaming Reality) <in> Smart Search AND (Primary OR Secondary OR k-12) <in> Smart Search AND Date: between 2009 and 2020 AND Limited to: PEER_REVIEWED In Education Full Text	Search on the field "Keywords (all fields)"

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