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How personalized and effective is immersive virtual reality in education? A systematic literature review for the last decade

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Abstract
During the last decade, there has been a substantial increase of interest in studies related to Virtual Reality (VR) as a learning tool. This paper presents a systematic literature review of personalization strategies utilized in immersive VR for educational objectives in the classroom. For the purposes of this review, 69 studies between 2012 and 2022 were analyzed in terms of their benefits, limitations and development features. The novelty of the study mainly arises from the in-depth analysis and reporting of personalization strategies as well as gamification techniques used in VR applications. The significance of this research lies in the observation that earlier studies' applications did not sufficiently incorporate adaptive learning content, indicating the necessity for more research in this field and revealing a research gap. In conclusion, as it encourages future research of this field, this study may be a beneficial reference for those interested in researching the implementation of Virtual Reality in education, including academics, students, and professionals.

Keywords Virtual reality · Personalization · Systematic review · Gamification · Education

1 Introduction

Over the last decade, education has shown to be a forward-thinking field that is actively looking for better approaches of employing innovative and effective methods within the traditional classroom confines [85].

Virtual reality (VR) provides learners with a beneficial and engaging experience. VR currently offers opportunities as it has broken through technical barriers that have previously prevented it from attaining widespread acceptance and acknowledgment among researchers and consumers [57, 105, 109]. Immersive VR provides new dimensions due to its technical capabilities and motivates educators to shift from *Virtual Learning Environments (VLEs)* to *Virtual Reality Learning Environments (VRLEs)* and from desktop computers to contemporary *Head Mounted Displays (HMDs)* [16, 105].

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VLEs have grown in popularity as a means of delivering educational content to learners in recent years. VLEs are designed to facilitate a variety of teaching and learning activities, such as online courses, collaborative projects, and self-paced learning [121]. A VLE often comprises a variety of tools and resources that students may access via a web-based platform, such as course materials, discussion forums, and assessment tools.

VRLEs, on the other hand, leverage VR technology to provide immersive and interactive educational experience. VRLEs may provide students an interesting and immersive learning experience that allows them to engage with the virtual environment and gain a better understanding of the educational curriculum [103]. VRLEs, for example, may be used to replicate real-world events such as medical procedures or engineering projects, providing crucial hands-on teaching experiences that would be hard to provide in a conventional classroom environment.

While VLEs and VRLEs have certain characteristics, such as the capacity to provide instructional content online, they also have significant distinctions. VLEs are primarily focused on material delivery and collaboration and assessment tools, whereas VRLEs are aimed to offer an immersive and interactive learning experience. Moreover, VRLEs need specific hardware and software, such as VR headsets and motion controllers, which can be more costly to acquire.

One of the benefits of VR as an instructional medium is the advanced interaction with controllers that provide intuitive control to users. The most essential quality that distinguishes VR from other media-based learning methodologies is immersion, which is the core ingredient that makes VR stand out. Nilsson et al. [81] propose a three-dimensional taxonomy of conceptualizations. The first category describes immersion as a system feature. The second category is a subjective response to the narrative's substance. The third is a subjective response to challenges. HMDs, according to Witmer et al. [122], can achieve high degrees of immersion for the user by providing an intuitive interaction between the user and the artificial environment, improving immersion and therefore reinforcing the sense of presence.

Immersion and presence have evolved over time as VR technology has progressed. Immersion is dependent on the technological qualities of the system that provides the experience, according to the research by Bowman and McMahan [19]. It is also a measured feature of a technology that's objective and varies from one system to another, offering various levels of immersion. In the same study of Bowman and McMahan [19], presence was defined as the users' impression of "being there" and it was reported that each user's level of experience differed even when they used the same systems and conditions.

VR in education has already been used in a range of fields, including medical sciences [32, 67], architecture [99], astronomy [78], biology [33], chemistry [11], engineering [20], history [21], mathematics [3], physics [90], psychology [37] and others.

While there have been past review studies on the use of VR in education [24, 39, 83, 88, 119], to the best of our knowledge, reviewing personalization approaches in VR educational environments is yet insufficiently researched. As a result, the novelty of this systematic review lies in bridging this gap, as well as analyzing and presenting the VR-related components and gamification strategies, identified in the reviewed literature.

The following research questions are addressed in order to further explore the components related to VR in education:

Research questions (RQs):

RQ1: Which VR personalization techniques have been employed for educational purposes?
RQ2: To what extent have gamification techniques been used in VR for educational purposes as a means of personalization?
RQ3: What are the advantages, limitations and effectiveness of VR as a learning method?
RQ4: What are the apparatus characteristics included in the selected studies?

This systematic review examines the use of virtual reality (VR) in education with a focus on personalization techniques. The review covers 69 studies published between 2012 and 2022, with the majority of papers coming out in 2019 and 2020. The United States and Indonesia have the most studies, with Africa being the only continent not represented. The most popular target group for acquiring conclusions was university undergraduate students, and chemistry and engineering were the most frequent topics. The review identifies the most important finding as the personalization mechanisms of the developed VR applications, with 50 of the 69 articles including at least one personalization mechanism. Gamification strategies were also highlighted as methods of producing personalized experiences in the studies reviewed. The most frequently positively evaluated component of VR was the enhancement of content knowledge. Limitations of the studies include the absence of control groups in 19 of the studies and the small sample size in nearly half of the studies.

The studies related to this systematic review are discussed in Section 2 of the study, titled “Relevant literature.”

Section 3 outlines the planning of a systematic literature review on virtual reality (VR) in education, following the guidelines of Kitchenham. The section covers the research objectives, search strategy as also as inclusion and exclusion criteria.

Section 4 presents the sample demographics, educational topics, contemporary HMDs and VR-related systems of the included research. Furthermore, an in-depth examination of the personalization techniques employed, as well as gamification techniques used as personalization techniques in the included studies, are addressed. The advantages of using VR in education are broken down into categories in the same section, and the apparatus used in the selected research is outlined as well. Also, Section 4 discusses the several variations of the word “Virtual Reality” that have been identified in some of the included studies. Finally, in Section 5, the conclusions of this study are drawn,” serving as a clear indication of the section’s purpose.

2 Relevant literature

This section presents other review works of the existing literature relevant to the research topic.

Checa et al. [24] conducted a systematic review of articles regarding VR in combination with serious games for educational or training purposes. The review focused on two major factors: first, the user’s level of immersion and second the user’s acquisition of knowledge and development of new competencies. Aside from students and professionals, the demographics of the research sample included a classification from general public. The fact that this classification accounted for over a quarter of the study shows that some of the results reported also come from a group with diverse features.

Furthermore, nearly half of the papers are dedicated to professional training and a significant number are related to sports, an area that cannot be linked to educational or training applications that do not involve physical activity. The study also does not examine the advantages and limitations of VR as an educational approach in the publications that were included.

Similarly, Oyelere et al. [83] presented the results of a systematic review related also to VR serious games referred as *Educational Virtual Reality Games (EVRGs)*. The aspects of technology, pedagogy and gaming connected to the publications that were included were highlighted in this review. Almost two-thirds of the 31 papers included in this systematic review are related to health sciences or safety training, resulting in a limited range of topics and EVRG features. The review also leaves out details about the advantages, limitations and development characteristics of each EVRG, such as the software used for development.

Pellas et al. [88] examined studies related to the implementation of learning scenarios in K-12 and higher education settings, as well as any possible benefits, challenges, or drawbacks that integrating VR applications in certain instructional contexts may bring. The study also takes a holistic approach to VR educational settings, providing information on the hardware and software used, as well as the educational topics covered and the benefits. While the study makes a significant contribution to the field, it lacks an examination of the distinctions between fully immersive and less immersive systems, personalization techniques, an analysis of the gamified features of the applications utilized throughout the included studies, or an analysis of the sizes of the study's evaluated groups.

In contrast to the aforementioned studies, Hamilton et al. [39] published a systematic review that examined the effects of using immersive HMD-based VR educational applications in comparison to less immersive methods like desktop-based VR. The research also investigates the cognitive components and learning outcomes of VR, analyzing them according to the subject of study, such as engineering, computer science and medical studies. However, it ignores other aspects in VR systems, such as how users view it as a learning tool, their perceived motivation, engagement, enjoyment, ease of use and usefulness. The limitations of the studies included in this review, as well as their development characteristics, are not addressed.

Scavarelli et al. [100] explore the possibilities of VR and augmented reality (AR) in enhancing social learning spaces. The study looks into several studies that utilized VR and AR technology in educational contexts, emphasizing their benefits for providing immersive learning experiences, enhancing student engagement, and allowing collaborative learning. The authors also highlight the challenges and limitations of adopting these technologies in social learning environments, such as the high cost of hardware and the requirement for specific technical skills. The study concludes that VR and AR have the potential to convert traditional classroom settings into dynamic and engaging learning experiences.

Radianti et al. [92] performed an in-depth analysis of studies on the use of immersive virtual reality (IVR) in higher education. The authors address the design elements, lessons learned, and research objectives of educational IVR applications. According to the review, IVR may create immersive and engaging learning experiences, encourage active learning, and improve information retention. The authors, however, identify major issues such as the high cost of building IVR applications and the requirement for specific technical skills. The study concludes by recommending a research strategy that fills gaps in the existing literature while emphasizing IVR's potential to enhance solely higher education.

Luo et al. [61] conducted a systematic review of literature on the application of virtual reality (VR) in K-12 and higher education from 2000 to 2019. The review looks at the benefits and disadvantages of employing VR technology in educational contexts. According to the review, VR can increase student engagement and motivation, improve learning outcomes, and provide opportunities for immersive and genuine learning experiences. The analysis concludes with future research areas and recommendations for incorporating VR into educational practice.

Additionally, Di Natale et al. [29] undertook a 10-year systematic review of empirical studies on the use of immersive virtual reality (IVR) in K-12 and higher education. Their review investigates the influence of IVR on learning outcomes, student engagement, and motivation. According to the review, IVR can improve learning by giving chances for active and experiential learning, enhancing student motivation and engagement, and improving learning outcomes. The evaluation closes by providing future research paths and recommendations for incorporating IVR into educational practice.

Loureiro et al. [60] provide a review of the potential applications of virtual reality (VR) and gamification focusing in marketing higher education. The review investigates how virtual reality and gamification may be utilized to improve student engagement, enrolment, and learning outcomes. The analysis finishes with a research agenda that focuses on examining the effectiveness of VR and gamification in marketing higher education, as well as exploring new methods to integrate these technologies.

Nesenbergs et al. [80] conducted a systematic review of the application AR and VR in remote education. The paper explores the potential of augmented reality and virtual reality to improve distant learning experiences and learning outcomes. The authors discuss previous studies on the use of AR and VR in remote education rather than classroom instruction, identifying limitations, benefits, and how this technology approach affects the learning experience.

The main point of agreement among the aforementioned relevant publications to our systematic review is the absence of exploration of personalization strategies. None of these studies focus on the methods that have been developed to take into account the educational needs, requirements, preferences and abilities of cognitively diverse learners [56, 72, 73] and deliver a personalized experience to them, similar to intelligent tutoring systems [107, 113].

3 Planning the review

The research objectives and strategies, the inclusion and exclusion criteria of the studies, as well as the exclusion process and how the selected studies were screened, are detailed in this section.

This work follows Kitchenham's guideline [53], which attempts to assist senior and junior researchers in conducting systematic literature reviews in the field of software engineering. The stages of a systematic review are broken down into three primary sections in this document: planning the review, conducting the review and reporting the review.

3.1 Research objectives

This review aims to provide researchers and educators with a comprehensive view of the findings related to VR in education and tutoring, with a particular emphasis on how personalized they are for the learners (RQ1, RQ2). The apparatus employed in the studies to deliver VR experiences to study participants (RQ4), the educational subjects relevant to each study, and the demographics of the participants are all elements of our research. Potential concerns and limitations, as well as how VR has been employed by educators

Table 1 Search Keywords

Search keywords using Boolean operators
("virtual reality" OR "VR") AND ("education" OR "learning" OR "training" OR "tutoring" OR "teaching") AND ("higher education" OR "university" OR "college" OR "high school" OR "high school" OR "secondary school" OR "primary school") AND ("personalization" OR "gamification")

during the last decade and to what degree it is beneficial to users, are important topics that are being highlighted, as indicated by the authors of existing literature (RQ3).

3.2 Search strategy

Scopus[1] was selected as the database from which the required literature was obtained in alignment with the research objectives. The *Scopus* platform's search tools and filters were used to get the essential results on identifying the relevant works that match better the search parameters. To narrow down the repository's database number of articles to the desired results, the *Boolean* operators "AND" and "OR" were firstly used to conduct a manual search in peer-reviewed studies with selected keywords as seen below in Table 1. The repository's database searched every publication's abstract, keywords and title using terms like "*education" OR "*learning" *OR "*training" *OR "*tutoring" *OR"* teaching", as well as terms like *"higher education" OR* college *OR "*high school" *OR "high school" OR "secondary school" OR "primary school"* as a query. This truly aided in the identification of relevant studies in the field of education. As a result, with the modified search criteria, the number of relevant studies that appeared as an initial result of a search with the additional parameters "virtual reality" *AND* "education" and "personalization" OR "gamification" AND VR was 1884 studies.

3.3 Inclusion and exclusion criteria

In order to assess whether or not a study should be included in this systematic review, inclusion and exclusion criteria were developed to ensure that the related research questions could be answered.

Using the search filters, provided by *Scopus*, we filtered the years from 2012 to 2022 to define the time frame. Because it was necessary to have a thorough and up-to-date perspective on publications related to VR and education, the specified timeframe was chosen with 2022 as the end year. In addition, 2012 was chosen as the starting year to encompass a decade in which VR technology was redefined. Furthermore, the year 2012 was selected as the starting point to encompass a decade in which VR technology offered opportunities for consumers and academics [43]. Technology's popularity increased in the middle of the decade, when new VR devices like the Oculus and Vive were widely available [46].

What people were searching for during the last decade, according to Google Trends, supports the preceding. Google Trends analyzes a significant number of actual Google search engine queries and organizes them into categories. It also includes statistical and geographic data that may be viewed in either non-real-time or schematic form and extends back to 2004.[2] To assess relative popularity, Google divides each data point by the total number of searches for the specific geographical place and time period it reflects. The

[1] https://www.scopus.com/.

[2] https://support.google.com/trends/answer/4365533?eng=eng&hl=en.

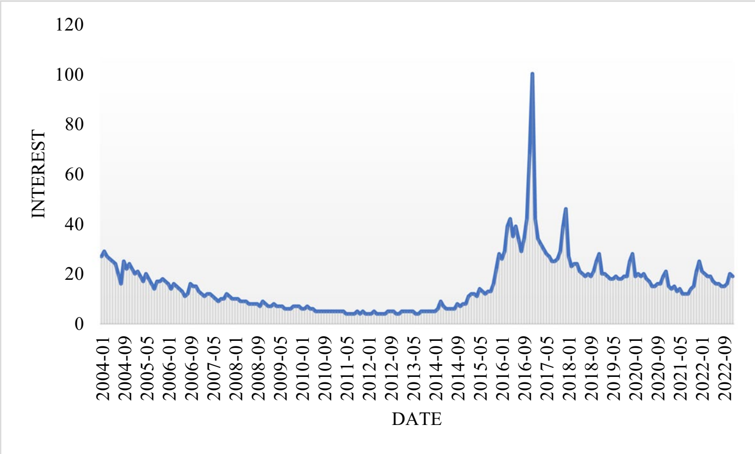

Fig. 1 Popularity of VR over the last decade according to *Google Trends* (https://trends.google.com/trends/explore?date=all&q=virtual%20reality)

expected values are then categorized on a scale of 0 to 100, with the number of searches on each topic compared to all searches on all topics.

As seen in Fig. 1, in contrast to prior years, the search term "virtual reality" began to acquire popularity around 2014 as a result of *Facebook's* acquisition of the *Oculus VR* startup and peaked in 2016 with the arrival of *Sony's PlayStation VR*.

The general and specific inclusion criteria, as well as the exclusion criteria based on the abstract and full text, are described in Tables 2 and 3.

3.4 Exclusion process and screening the papers

After examining the titles, abstracts and keywords, the papers were manually chosen based on the general and specific inclusion criteria resulting in 998 studies. A total of 703 papers were excluded based on the exclusion criteria based on abstract (Table 3). These included activities irrelevant to VR, non-immersive VR, not in-class use, physical activities or neurological treatments, as well as surgical procedures and medical training.

Physical activities, neurological treatment and rehabilitation related studies were excluded since they fall into a different approach in terms of educational characteristics than the ones examined in this review. Rather than in-class educational or cognitive

Table 2 General and specific inclusion criteria

General inclusion criteria	Specific inclusion criteria
Years from 2012 to 2022	Educational environments and research methodologies that are well-constructed
Full text available	VR intervention significance on instructional strategies
The abstract and the manuscript has to be written in English.	
The findings of the study may have an impact on education.	

Table 3 Exclusion criteria based on the abstract and on the full text

Exclusion criteria based on abstract	Exclusion criteria based on full text
Activities irrelevant to VR	There were no evaluation methodologies used
Non immersive VR	Studies related to vocational training
Not In-class use	No student outcomes or achievements reported
Studies related to physical activities or neurological treatments, as well as surgical procedures and medical training.	No evaluation of students' relevance, efficacy, or impact as a result of VR implementation
	Not having an experimental group that underwent VR treatment
	The research not providing a descriptive report
	Studies did not give a context for instructional design employing VR

outcomes, these studies mostly focus on motor skills or neurological treatments that target specific functions, symptoms and/or the user's well-being. Furthermore, because surgical procedures and medical training constituted the majority of the studies related to VR and education identified in the repository, they were excluded. The main rationale for this exclusion was because they would have an impact on the review's results by shifting the attention away from education and toward medical sciences in particular, with the bulk of the studies being in surgical domains [66].

After eliminating 44 duplicates from the remaining 295 studies, the 251 papers that matched the specific inclusion criteria (Table 3) by thoroughly reviewing their contents were screened. The remaining 182 studies were excluded based on the exclusion criteria by reading their full text (Table 3) such as there were no evaluation methodologies used, studies related to vocational training, no student outcomes or achievements reported, no evaluation of students' relevance, efficacy, or impact as a result of VR implementation, not having an experimental group that underwent VR treatment, the research not providing a descriptive report and studies did not give a context for instructional design employing VR, 69 studies were left to move on to the next step. An Excel matrix was utilized to apply a coding scheme based on the study questions for data processing.

The guidelines and instructions regarding the *PRISMA* statement [77], as well as the recommended flow chart, will assist in dynamically documenting and projecting any changes as evidence to provide method transparency [84].

A 27-item checklist and a four-phase flow diagram comprise the PRISMA Statement. The PRISMA Statement's objective is to assist researchers in strengthening the reporting of systematic reviews and meta-analyses. PRISMA may also be beneficial for appraising published systematic reviews. It should be mentioned that the PRISMA checklist is not a methodology for evaluating the quality of a systematic review. [77].

There are three phases in the flow diagram. The initial step is to find the records that were considered to be relevant to the study. The use of *Boolean* types is employed in this phase to create a more comprehensive query that will result in a semi-manual record exclusion.

The screening process is the next phase. It involves a manual screening procedure to decide the number of records that will be retained after a comprehensive review of the titles, abstracts, keywords and body of each manuscript to determine whether they meet the criteria. Moreover, during the same phase, a screening within the body of each publication resulted in the identification and exclusion of all duplicate entries, as well as the identification of personalization aspects within the study and gamification techniques as a means of personalization.

A rigorous identification and categorization of studies that included the element of personalization (RQ1) in their design and implementation was also carried out. Personalization strategies that were possibly identified focused on cognitive diversity and mindset of each student, incorporating elements such as students' interests, abilities, competencies, learning styles, preferences, learning requirements, and prior knowledge incorporated in VR settings.

During the same phase, when screening the body of each manuscript, an interesting observation was made about the employment of various types of gamification approaches as a means of personalization (RQ2) for educational purposes. As a result, in the dimension of personalization, gamification strategies that may aid students throughout the VR learning process were explored and assessed. Among these were live regular updates on information about students' scores, ongoing state, progress status, and milestones reached in each level, as well as awards for game-like achievements and scoreboards as a representation of position based on their scores.

Seeking personalization and gamification approaches within the body of each publication was carefully evaluated, with the studies that offered techniques linked to customization being excluded from this systematic review. A customized learning environment differs from a customizable environment in that the former is an adaptive automated system based on individualization, whilst the latter requires manual adjustments before it can be employed for any educational intervention [69].

The third phase projects the remaining studies that were included in this systematic review Fig. 2.

4 Reporting the review

This section is devoted to reporting the findings from the selected studies in relation to the research questions. The sample demographics, educational topics, contemporary HMDs and systems, personalization aspects, advantages and limitations, development characteristics of the applications used as part of the experimental process of the studies and the variations of Virtual Reality as a term are described.

Since new VR devices such as the Meta's *Oculus Quest*, *HTC Vive* and *Sony's PlayStation VR* entered the market during this time period, the last decade was considered for study selection. Figure 3 illustrates how the selected studies are arranged by year, and it is apparent that no studies were published in 2012, while one study was published in 2013. It's worth mentioning that no linked studies were found throughout 2012 and 2014 that were relevant to the inclusion criteria of this systematic review. As VR gained again commercial and academic interest, there has been a progressive increase in research linked to this systematic literature review in the years following 2015 through 2018 and during 2019. Additionally, there's an 100% increase in studies from 2019 to 2020, indicating that academics are becoming more interested in the field.

There are 33 countries of origin among the 69 publications in our systematic review (Fig. 4). The two countries with the most studies are the United States of America and Indonesia, with 8 studies each. Apart from the United States of America and Indonesia, which together account for about a third of the total volume (23% of 69 studies), Taiwan has 4 studies,

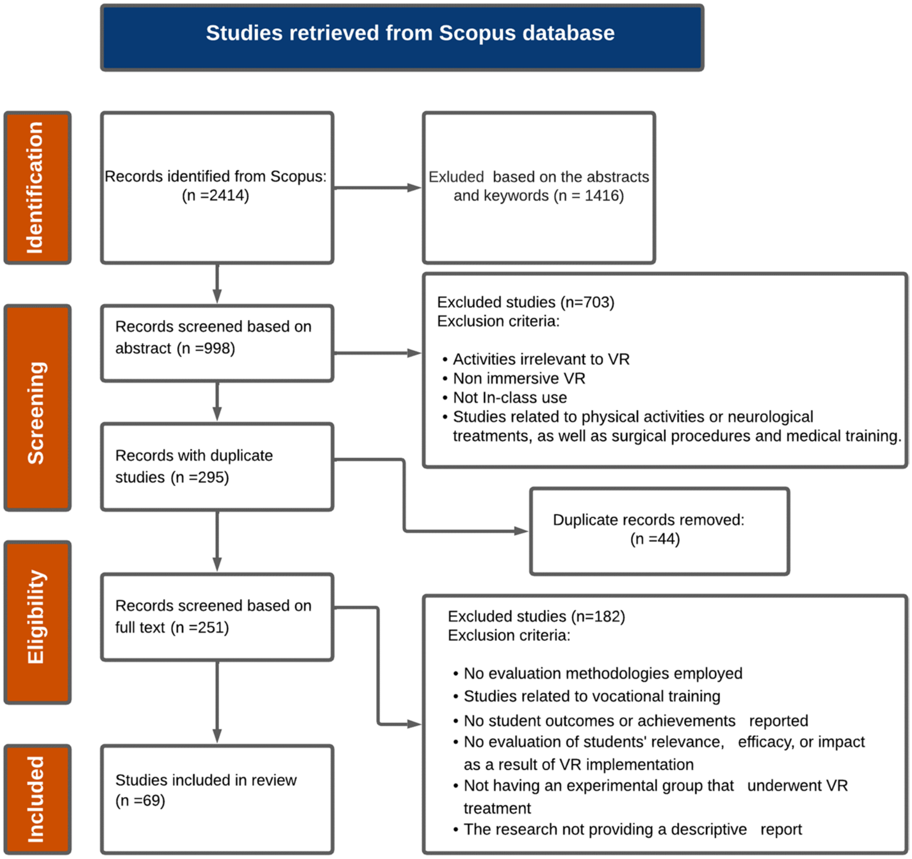

Fig. 2 The PRISMA flow diagram projecting all the phases and steps of selection procedure

China contributes five studies, while Taiwan and Spain both contribute four. Denmark, the United Kingdom, Australia, and Malaysia each contributed three studies. Switzerland, Turkey, the Netherlands, and the Czech Republic each contribute two studies to the included studies in this systematic review. Austria, Colombia, France, Germany, Greece, Hong Kong, India, and Australia, Italy, Kuwait, Peru, Poland, Russia, Sweden, Slovakia, Kirgizstan, Jordan, Iran, Belgium, Hungary, and Malta are also represented by one study each. There is also one study in the field of history that is being conducted as part of an international collaboration with students from India and Australia [21].

The inclusion and exclusion criteria resulted in two different types of publications in the 69 studies. The overall amount of research is 50 articles and 19 conference papers.

4.1 Sample demographics

A diverse group of people made up the sample demography for the VR educational applications that were analyzed (see Table 15 in the Appendix). The majority of the studies were conducted on university undergraduates accounting for 45% of all studies, with primary school students accounting for 13% and secondary school students

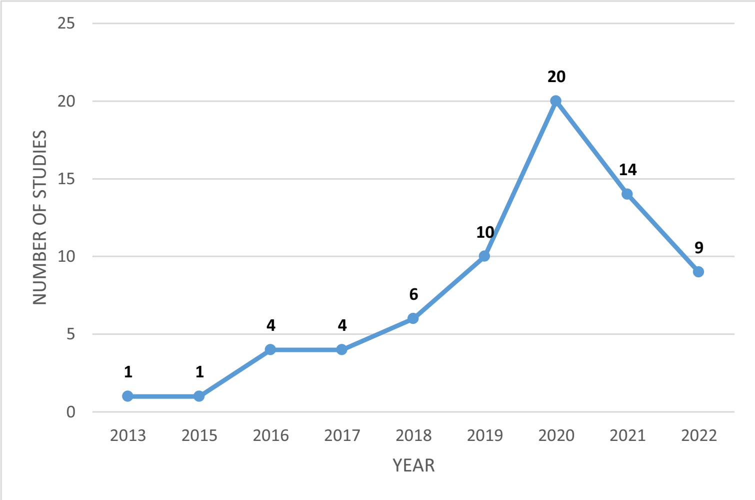

Fig. 3 Number of studies per year

accounting for 9%. A total of 20% is made up of university undergraduate students combined with other demographics such as graduates, academics, professionals and conference participants. In two studies, the demographics of secondary and university undergraduate students were mixed. Another study used graduate students as the sample demographic, while another used university teachers as the sample demographic. Additionally, a study's sample demography defined as postsecondary education included college students. Aside from academics, one study was carried out on video game developers and designers. In the appendix, the table named "Educational background of sample participated in studies" illustrates all of the studies' demographics in detail.

4.2 Educational topics

VR in education can be used in a spectrum of areas and subjects (Table 4). Chemistry and engineering are the most popular subjects in this systematic review, with seven studies each focusing on these fields. VR is a valuable supplement to traditional instructional methodologies for visualizing and interacting with complex structural representations at the molecular level in three dimensions [10] (Table 5).

Three studies focused on physics models [13, 90, 91] astronomy planetary representations in two studies [62, 78] all use the approach of interaction with artificial structures.

Biology is a natural science field that stands out above the others in our review, with five studies integrating VR capabilities to allow students to engage in a more life-like experience, such as interacting with real organisms [48]. History was also a frequent topic appeared in four studies [21, 94, 95]. Also, four times the topic of environment is observed in the studies ([8, 64, 82]; environmental [93]). Language also was a topic explored three times in the selected studies [2, 14, 119]. Furthermore, with two research stand out on the topics of geology [23, 35], geography [47, 101], software engineering [71, 120] and industrial engineering [54, 98].

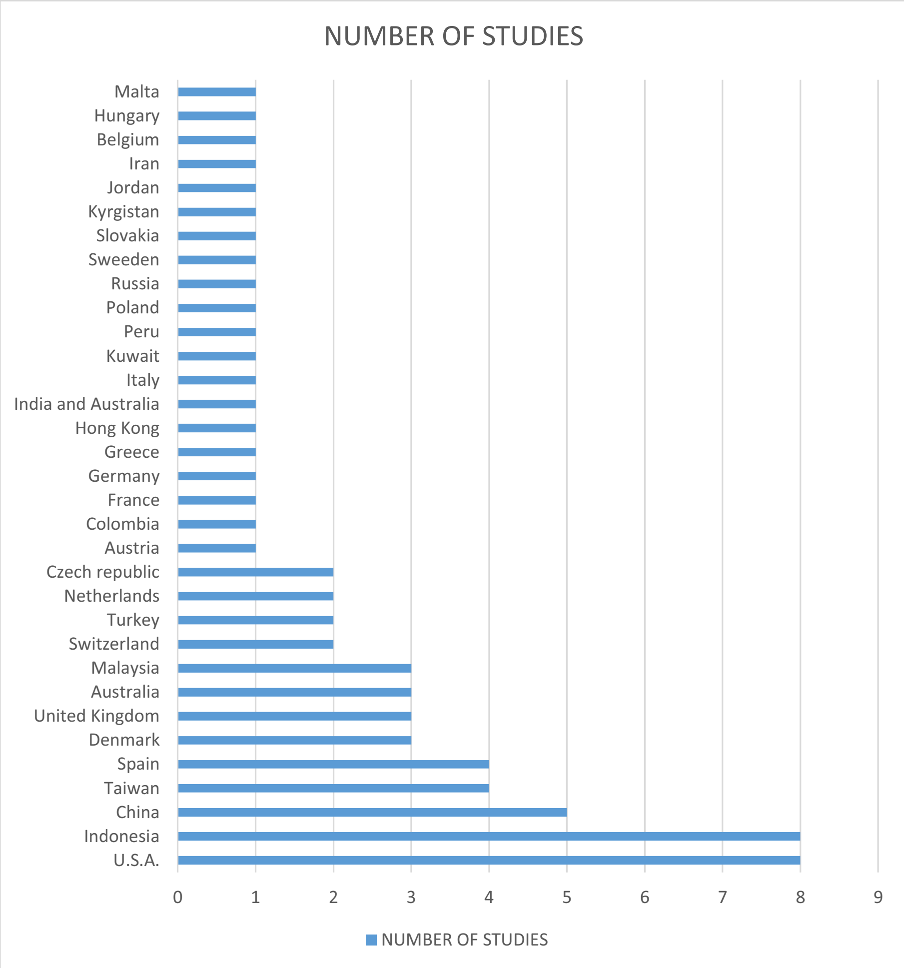

Fig. 4 Number of studies per country

Agriculture [108], architecture [99], attentional memory [99], construction engineering [123], educational consultancy [17], electrostatics [91], field engineering [18], field trips / social studies [27], Geospatial Information Science [12], lab machinery [25], materials science [111], mechanical and electrical engineering [50], music education [45], religion [6], health science [68], electrical engineering [87], safety education [125], sustainability [106], video game development [110], education [104], spatial ability [36], cultural heritage [79], and manufacturing [7] are among the remaining research, with one study for each topic.

It's worth noting that Al Kork and Beyrouthy's [4] study is categorized into three fields since it focuses on three unique areas: chemistry, biology, and physics, whereas Li et al.,'s [58] study is divided into two categories: language and geography.

Table 4 Topics regarding use of VR in education

Topic	Frequency	Study
Chemistry	7	Bakar et al. [10], Barrett and Hegarty [11], Bennie et al. [15], Ikhsan et al. [44], Megat et al. [74], Renganis et al. [96], Rychkova et al. [97]
Engineering (General)	7	Brown et al. [20], Häfner et al. [38], Krajčovič et al. [54], Valentine et al. [115], Zhao et al. [126], Seybold and Mantwill [102], Triviño-Tarradas et al. [112]
Biology	5	García-Bonete et al. [33], Johnson-Glenberg et al. [48], Meyer et al. [75], Johnston et al. [49], Pande et al. [85]
History	4	Calvert and Abadia [21], Ramansyah et al. [94], Liu et al. [59], Remolar et al. [95]
Languages	3	Adnan et al. [2], Bendeck Soto et al. [14], Wang et al. [119]
Physics	3	Becerra et al. [13], Pirker et al. [90], Porter et al. [91]
Environment	3	Makransky and Mayer [64], Asish et al. [8], Ou K-L et al. [82], Ramansyah et al. [93].
Astronomy	2	Madden et al. [62], Monita and Ikshan [78]
Geography	2	Jochecová et al. [47], Sedlak et al. [101]
Software Engineering	2	Mayor et al. [71], Wee et al. [120]
Math	2	Akman and Çakır [3], Xu and Ke [124]

Table 5 Personalization techniques employed in the studies

Personalization technique	Frequency	Paper
Real time object manipulation	17	Abuhammad et al. [1], Antoniou et al. [7], Barrett and Hegarty [11], Bennie et al. [15], Guzsvinecz et al. [36], Kamińska et al. [50], Liu et al. [59], Madden et al. [62], Monita and Ikshan [78], Ou et al. [82], Porter et al. [91], Remolar et al. [95], Sanchez-Sepulveda et al. [99], Seybold and Mantwill [102], Smit et al. [106], Triviño-Tarradas et al. [112], Valentine et al. [115]
Intuitive navigation	11	Bolkas et al. [18], Calvert and Abadia [21], Jochecová et al. [47], Johnston et al. [49], Krajčovič et al. [54], Mayor et al. [71], Pirker et al. [90], Remolar et al. [95], Tarng et al. [111], Wee et al. [120], Xu and Ke [124]
Personalized feedback system	8	Al Kork and Beyrouthy [4], Bendeck Soto et al. [14], Boetje and Van Ginkel [17], Parmar et al. [87], Bazargani et al. [12], Surer et al. [110], Wee et al. [120], Zhang et al. [125]
Guidance assistance	4	Al Kork and Beyrouthy [4], Pande et al. [85], Bazargani et al. [12], Zhang et al. [125]

4.3 Contemporary HMDs and systems

The findings addressing the hardware utilized for the development and usage of VR applications, as stated in the studies, led to two modern immersive VR hardware systems. Head Mounted Displays are the first, while the incorporation of smartphone devices onto smartphone-based VR headsets is the second. The controlling methods, degrees of freedom and graphical fidelity that affect the overall experience are the key distinctions between these two approaches.

Advanced controllers are used in HMDs to represent hand movement in the virtual environment, giving the user the feeling of presence and embodiment, as well as a more natural interaction with artificial objects. Contemporary headsets also include hand tracking movement, thanks to front-facing cameras that capture and transfer hand movement within the virtual environment, allowing for more intuitive interactions without the use of hardware controllers. Furthermore, HMDs provide intuitive flexibility of movement due to their *six degrees of freedom (6-DoF)*, which allows users to wander around and inspect a virtual object within the simulation as if they were in the real world. HMDs provide a high graphic fidelity since the device's two screens (one for each eye) produce high-quality images due to high resolution and frequency, resulting in a high refresh rate, which allows for more natural virtual object movement. However, HMDs have a few drawbacks, including the expensive cost of operating them in groups of students at the same time due to the need for several devices, as well as the fact that they require the purchase of a new device.

Smartphone-based VR headsets, on the other hand, do not require the purchase of expensive equipment and are accessible to anybody with a smartphone, making them ideal for big groups such as classrooms. Because it was not specifically designed for VR and is not their primary usage, it offers inferior visual fidelity when compared to hardware HMDs. Moreover, *Bluetooth* controllers [13] employed for player interaction with the virtual environment through the use of a smartphone device are not as precise and advanced as those used by HMDs, limiting the perception of natural interactions within the virtual environment. In certain circumstances, researchers such as Innocenti et al. [45] developed gaze-based navigation systems for cardboard VR headset applications that, while successful, eliminate the use of controllers, therefore removing the use of hands-on interaction with the artificial environment.

Figure 5 shows that 35 of the 72 systems in the 69 studies chosen for further analysis of our systematic literature review use hardware HMDs, 28 use a cardboard VR headset

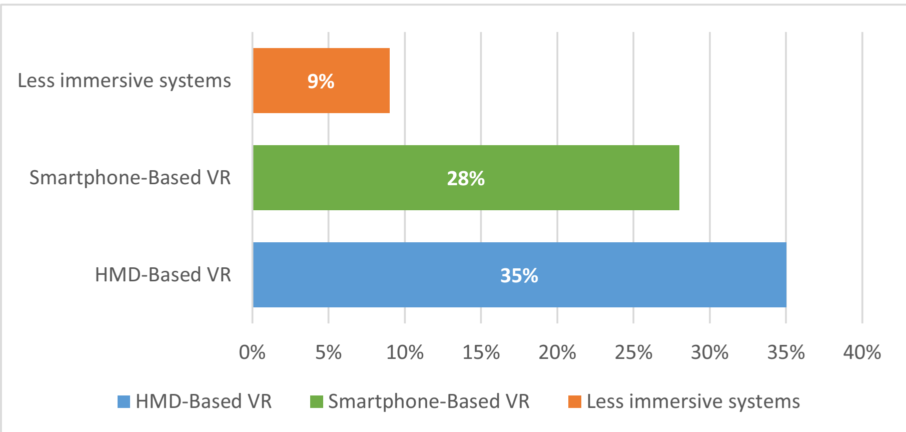

Fig. 5 VR Equipment used

unit that integrates a smartphone device and in comparison to both HMD and cardboard VR headset-based systems, the remaining 9 systems provide less immersive experiences. For example, the system used in Barrett and Hegarty's [11] study, which utilizes Nvidia 3D Vision Wireless Glasses, provides a less immersive experience than modern HMD's since it delivers a stereoscopic vision of a monitor with a limited field of view rather than a six degrees of freedom (6-DoF) capability like modern HMD's. It is worth mentioning that, despite the fact that there are 69 included studies in this systematic review, the hardware systems identified within the studies number 72. This is mostly due to the fact that several research used multiple systems. Pirker et al. [90], for example, use both HMD-based VR (HTC Vive) and Smartphone-based VR (Samsung Gear).

4.4 Personalization

Designing and implementing personalization approaches into the virtual learning environments that students utilize is a very effective strategy to help them learn more efficiently. Students' interests, abilities, competencies, learning styles, preferences, learning needs and prior knowledge of the subject will indeed be considered while developing a tailored experience for them. This will result in an efficient and result-oriented educational process that focuses on content knowledge, learning outcomes, academic achievements, cognition, memory retention, learning experience and more while removing the frustrations that traditional learning approaches or non-personalized virtual environments might cause. Troussas et al. [113] for instance, provided a methodology for learning analytics into learning environments which includes multiple modules such as students' cognitive state, behavior prediction, identification of targeted educational material, curriculum development and personalization. The study's authors developed and tested a web-based application based on the previously mentioned qualities, which yielded highly promising results.

Meacham et al. [73] created an Adaptive Virtual Learning Environment framework that interdisciplinary educators can use to deliver instructional materials that are adapted to students' needs. Overall, the study demonstrated that the proposed approach received positive response. According to the findings of a study undertaken by Troussas et al. [114], personalized learning environments play a key role in effective learning activities that are embedded into the system and aid in the development of higher-order thinking skills. Personalization strategies can effectively promote students' decision to employ Bloom's taxonomy (learning at six levels: knowledge, comprehension, application, analysis, synthesis and evaluation) in the construction of activities with cognitive objectives, according to the same study.

In 50 out of the 69 studies selected to conduct this systematic review, the element of personalization was observed and presented.

To differentiate between the personalization techniques employed in the selected studies and the gamification techniques used in the form of personalization approaches, the "personalization" section is divided into two parts.

4.4.1 Personalization techniques in virtual reality in education (RQ1)

Real time object manipulation The manipulation of virtual objects was another personalization method used in seventeen studies. VR controllers allow learners to interact with virtual objects and modify them according to their requirements and preferences. Learners are given the capacity to change the viewing perspective and other properties of artificial objects within the virtual space in the context of learning.

García-Bonete et al. [33], used VR in conjunction with the Technological Pedagogical Content Knowledge Framework (TPACK) to provide students with a holistic educational approach to biomolecular structure, allowing them to observe things in real-time from a different angle. This allowed students to control the artificial components according to their preferences.

Bennie et al. [15] also developed and exhibited *iMD-VR*, a VR application that allowed undergraduate students to interact with virtual objects that were displayed as molecular dynamics models of biological processes. The software allowed users to perform real-time alterations based on their preferences and educational requirements.

Similarly, Monita and Ikshan [78] created an application that allows users to manipulate and modify virtual items in a variety of forms, depending on their preferences and needs. In the study of Porter et al. [91], university undergraduate students used smartphone devices connected with cardboard VR headsets to manipulate projected objects, in this case, electric field vectors, to investigate them from multiple angles in the context of the electrostatics curriculum.

Brown et al. [20], introduced an engineering visuospatial course application to assist freshmen students in improving their visuospatial skills and reasoning. Students had the option of selecting a 2D shape from a pre-made list or designing their own in one of the application's modes. They then used this shape to create a three-dimensional virtual object by selecting factors such as the amount of rotation, the axis around which the item could be turned and the object's distance from the axis.

In the study of Sanchez-Sepulveda et al. [99], users could use VR headsets and controllers to manipulate artificial objects within the virtual space to transform a real-life urban public space. This enabled participants to observe in real-time how their adjustments affected the virtual world.

Madden et al. [62] used a VR simulation of the solar system that featured the sun, the earth and the moon to allow students to manipulate and control the flow of time, their perspective and the moon's orbital position. The authors were able to teach their students about the lunar phases as a result of this.

To aid inexperienced users in comprehending and exploring the application's artificial surroundings, Johnston et al. [49] included the ability to virtually touch and interact with virtual items using the controllers in their study. This capacity to interact with artificial items activates voice-over-instruction-based and visual information about each object individually.

Students were able to virtually manipulate artificial surveying equipment in order to complete objectives, according to Bolkas et al. [18]. They could also use the program to virtually fill out forms with virtual measurements and save them as PDF files.

Intuitive navigation Learners experience a real-life sense of freedom when they can intuitively navigate freely within the virtual environment. Pirker et al. [90], presented two VR approaches to the same subject, one using mobile VR and the other using a fully immersive hardware HMD. Students reported that the second experience allowed them to have a free-roaming experience within the artificial environment rather than a linear one, which allowed them to gain a deeper comprehension of the subject. Since users were given the ability to teleport inside the artificial environment using hardware controllers, navigation within the virtual environment became more intuitive and personalized as a result of this experience.

Personalized feedback system Providing feedback during or after a VR experience is a great approach to aid learners in learning procedures by providing a personalized experience based on their needs and preferences. Within the relevant studies, this approach is employed eight times. Parmar et al. [87], developed an application to instruct students on electrical circuitry by exploring psychophysical skills education. The authors included a training module at the start of the application so that students may become familiar with the application's functions and learn how to operate virtual objects. Students could receive visual input in the form of shifting colors and highlights, as well as audio feedback in the form of sound effects produced by interactions with virtual objects, through the training module.

In a guided practice module, the same functions were used with the addition of a pseudo-haptic function that offered feedback when the user interacted with a virtual object. Boetje and Van Ginkel [17] developed and tested an application to see if an extra VR practice session could help with oral presentation skills (OPS). After use, the application provided feedback in the form of reports for each individual student on the pitch, volume and the quantity and length of pauses. As a result, the intervention's outcomes gained a personalized perspective, allowing each user to get tailored feedback that would aid towards future improvement.

Al Kork and Beyrouthy [4], developed a virtual instructor to assist students in conducting virtual experiments by offering immediate feedback and instructions. The students who took part in the study were able to construct their knowledge by exploring the virtual world and interacting with virtual items at their convenience.

Guidance assistance Providing guidance is another personalized technique to aid learners in completing assigned tasks within the virtual simulation and facilitating the flow of the learning process. Pande et al. [85], used VR to create hands-on interactive experiences by recreating a field course that covers three areas in environmental biology, allowing students to form a link between experiential learning and theoretical materials. The student follows a linear simulation, which frequently includes a brief story and leads back to a virtual lab. The participant is guided audibly by an inside simulation drone and by text by a virtual text-pad throughout the encounter to produce a well-structured sequence in the method. In a VR application created by Sagnier et al. [98], users followed written instructions to learn how to operate assembly procedures as an in-application training module in the context of aeronautical training where the user is immersed in a VR environment that represents an aircraft manufacturing workshop.

Gaze-based navigation / movement [3, 45], in- application training instructions on how to proceed to virtual operations to complete the tasks [25, 98] design and assembly virtual models according to guidelines [126], design of virtual object and it's attributes [20], information regarding in- application progress [25], intrinsic body movement modeling using real-time motion capture instead of controls [35], instant and summative feedback mechanisms [48], personalized realistic controlling mechanism [38], real time observation of virtual objects from different perspectives [33], users could design their own project [23], users can design their own virtual objects and later on to explore them [123], users can design personalized objects in the form of sketches [102], user can build personalized virtual environment [95], visual hints system [25], voice guidance system providing direction feedback [3] are the rest of the personalization approaches used in the reviewed studies.

4.4.2 Gamification techniques as personalization approaches (RQ2)

Virtual Reality is an emerging technology that offers students immersive and interactive experiences that can help them comprehend a wide range of educational programs. Incorporating VR technology into education may give learners unique hands-on experiences, improve retention rates, and increase levels of engagement.

VR may be used to promote constructivist learning, in which learners actively construct their knowledge via their experiences. For example, to develop their own knowledge, learners can explore virtual worlds, manipulate virtual objects, and interact with virtual characters. This method stimulates critical thinking abilities and greater comprehension of the subject matter.

To boost motivation and engagement, gamification elements may be incorporated into VR learning experiences. Gamification components like points, badges, and leaderboards can stimulate a feeling of competition in learners, motivating them to accomplish their learning objectives [25]. Furthermore, game-like environments can provide a secure and enjoyable environment for learners to practice skills, receive feedback, and overcome challenges.

The utilization of VR with gamification features can provide several benefits to students. For starters, it can create a safe and low-risk environment in which learners can investigate difficult or hazardous problems. Medical students, for example, are able to practice surgical procedures in a virtual environment before performing them on actual patients. Second, it may deliver a more interesting and dynamic learning experience, increasing student motivation and retention [40]. Third, it may deliver personalized learning experiences that are tailored to the requirements and preferences of the learners, allowing them to acquire knowledge at their own pace. This strategy can stimulate a learner's interest to generate motives that may lead to an engaging and exciting experience [26, 125].

However, there are potential challenges and limitations to integrating VR in education with gamification. For instance, the cost of developing and implementing VR technology might be prohibitively expensive, restricting access to these tools for some learners and organizations. Second, in order for educators to effectively integrate VR into their teaching techniques, it might require special training. Third, VR experiences may not be appropriate for all learners, particularly those who suffer from motion sickness or other sensory disorders [70].

VR with gamification elements has the potential to fundamentally change education by delivering immersive and engaging learning experiences to students. However, the educational approach, cost, and accessibility must all be carefully considered in order to ensure that the benefits of this technology are achieved.

Online cooperative capability Southgate et al. [108] used a commercial application, in this case, a video game based on a version of *Minecraft* that is quite popular among secondary school students. The game's unique architecture allowed up to three students to work together at the same time to build a model of a plant while studying respiration and photosynthesis in different sociocultural situations. This cooperative mode also delivered students a more personalized experience, as they were able to adapt their play styles to the learning material and make decisions through active participation and collaboration.

Gaming support system The authors in the study of Parmar et al. [87] included performance reviews after each stage was successfully completed, in addition to gamification techniques that also serve as personalization techniques. Virtual awards that helped to inform and assist users' progress across task completion, a scoring system as a product from knowledge quiz and an awarding system were amongst these techniques. Johnson-Glenberg et al. [48] created an interactive VR game to teach students about mimicry and natural selection in biology. The software used controllers to capture butterflies at different scoring levels. The scoring mechanism provided immediate information as well as summative feedback at the end of each level, both of which projected points based on the number of butterflies captured. Furthermore, the authors used an assessment in which participants manually filled virtual bars using VR controllers to understand the subject matter. If a user fills in a bar incorrectly, the system displays the correct answer with animations as part of an evaluation.

Students in the work of Zhang et al. [125] can interact freely with virtual items while exploring the virtual environment, making it possible to create their knowledge. Individuals can also obtain informative support on learning faults from the system through interactions, allowing for a more effective learning experience. Gamification combined with a learning environment scan piques students' interest and one of its key features is the use of reward strategies to make the procedure more demanding and engaging to learners. The authors developed a gamified educational simulation in the subject of fire safety for university students. While displaying relevant information through media, the students could walk around several locations on campus and interact with fire safety signs and equipment. They could also go to places where they could take knowledge quizzes and watch presentations, as well as locations where they could engage in fire drills, complete the module and obtain awards.

Surer et al. [110] provide users with the opportunity to switch between *"Non-Playable Characters" (NPCs)* within the game in real-time. This technique allows users to experience the simulation from a different perspective by using game scenarios. As part of a personalized experience, gamification tactics such as informative support from system, scoring and health points are also delivered.

Rewarding system Another personalization technique that is useful in the case of VR Learning Environments with gaming characteristics is reward systems. VR learning environments can be much more effective when integrated with rewards systems as a gaming feature.

Reward systems can enhance motivation and engagement, which is one of their key benefits when used in VR learning environments [13]. Students are encouraged to keep learning and growing by providing rewards for completing tasks or achieving particular learning goals. The rewards may come in the form of virtual badges, points, or even the unlocking of new levels in the virtual environment.

The reinforcement of learning is another advantage of including systems for rewards in VR learning environments. Rewarding learners for finishing assignments or proving that they comprehend a concept might aid in embedding that information in their memory. Better retention and recall of knowledge may result through this.

Reward systems can also increase the amusement and enjoyment of learning. Students are more likely to remain motivated in their studies by gamifying the learning process [120]. This may result in a more enthusiastic attitude towards learning and a higher motivation to learn even outside of the traditional physical classroom setting.

According to Wang et al. [118], in video games, there are eight different types of reward systems. Score systems, experience points, virtual item rewards, in-game resources, achievements, feedback messaging, plot-related visualizations and media, as well as restricted access aspects, are all available. Each of them has a unique set of capabilities. All of these types can be used individually or in combination to add a new perspective to the overall learning process, giving the user a sense of accomplishment.

Becerra et al. [13] established a reward system based on the user's performance, which the user could exchange for virtual things or utilize as a means of progressing through the application.

Navigation assistance system A valuable feature to assist virtual learning environments is the live navigation system that provides useful directions, or recommendations, for those who face difficulties on their way to task completion, as it can transform the learning procedure into a less time-consuming, less stressful and less, unnecessarily, difficult experience. As such, the systems automatically provide information and assistance whenever they deem it necessary, based on the user's performance status and needs.

Because the users can easily be disoriented or distracted by virtual objects, surroundings and the level of realism within the artificial space, features like the ones mentioned above may become a significant aid in VR Learning Environments so they can have an effortless progression, focus entirely on the learning process and reduce the cognitive load.

Akman and Çakır [3] created a navigation help system in the form of a person's voice to keep students from becoming disoriented and disrupting their flow experience in the VR environment, which students found realistic and satisfying. Table 6 illustrates the rest of the gamification techniques used in the studies.

Level of difficulty The ability to choose between different levels of difficulty is a feature frequently been met in commercial video games as a personalized technique and it is usually the first parameter that the user is asked to customize to have a pleasant and enjoyable experience while playing the game. In learning environments, two parameters that can influence the learning process are the student's learning ability and the difficulty of the teaching material. As a result, it would be advantageous if the system could take the initiative to change through various levels of difficulty and be automatically change to the educational requirements and learning abilities of the learners to avoid creating a state in which they lose interest or lead to poor educational outcomes when the teaching material becomes too easy or too difficult to cope with [26]. The capacity to tailor the learning experience for individual students is one of the most important benefits of gamification via VR educational systems. Artificial intelligence algorithms that monitor the student's progress and modify the game's difficulty level as necessary can be used to personalize learning experiences. For instance, if a student is having trouble conceptualizing a particular concept, the system may adapt the game to offer extra guidance and support until the student has mastered the subject. Similarly to this, if a student considers the game to be too easy, the system can make it harder to keep them motivated and engaged [65].

The advantages of this adaptive gamification approach are numerous. A student's motivation and enthusiasm in their studies are first and foremost reinforced [86]. Students are more likely to stay engaged and dedicated to their studies when learning experiences are matched to their specific requirements and abilities. By delivering students a rigorous and satisfying learning experience that helps to reinforce their comprehension of key concepts, it can also aid to improve educational outcomes [42].

In general, an intriguing and promising method of teaching is through gamification utilizing VR educational systems that automatically adapt the level of difficulty to the students' learning needs and skills. It can enhance educational outcomes and support students in cultivating a lifetime interest of learning by offering a personalized and effective

Table 6 Gamification techniques employed in the studies

Gamification Technique	Frequency	Research
Controllers tutorial	8	Chen [25], Jochecová et al. [47], Kamińska et al. [50], Krajčovič et al. [54], Safari Bazargani et al. [12], Sagnier et al. [98], Seybold and Mantwill [102], Wee et al. [120]
Gamified scenarios	7	Akman and Çakır [3], Bendeck Soto et al. [14], Mayor et al. [71], Bazargani et al. [12], Surer et al. [110], Xu and Ke [124], Zhao et al. [126]
Rewarding system	6	Becerra et al. [13], Chen [25], Jochecová et al. [47], Wee et al. [120], Xu and Ke [124], Zhang et al. [125]
Scoring system	5	Antoniou et al. [7], Al Kork and Beyrouthy [4], Becerra et al. [13], Bendeck Soto et al. [14], Surer et al. [110]
Gaming levels	5	Al Kork and Beyrouthy [4], Chen [25], Johnson-Glenberg et al. [48], Ou K-L et al. [82], Varela-Aldás et al. [116]
Game scenario	3	Calvert and Abadia [21], Krajčovič et al. [54], Rychkova et al. [97]
Multiplayer mode	3	Akman and Çakır [3], Sedlak et al. [101], Rychkova et al. [97]
Different level of difficulty	3	Bendeck Soto et al. [14], Johnson-Glenberg et al. [48], Ramansyah et al. [94]
In- application virtual guidance assistant	2	Al Kork and Beyrouthy [4], Pande et al. [85]
Item inventory	2	Akman and Çakır [3], Xu and Ke [124]
Countdown timer	2	Abuhammad et al. [1], Liu et al. [59]
Health points	2	Liu et al. [59], Surer et al. [110]
User can interact with non-playable characters (NPC's)	2	Remolar et al. [95], Sedlak et al. [101]

learning experience. To prevent a situation where students lose interest or receive subpar educational results, it is crucial to make sure the adaptive approach to gamification is implemented successfully.

Chen [25] designed, developed and evaluated a virtual training laboratory for a power binding machine simulation. An interactive guiding mechanism design that incorporated visual hints, a workflow chart that provided information about the activities' order and a training map that projected the content of the training scheme were all part of the first development phase. Due to the lack of students' motivation and despite the overall positive feedback towards the application, the authors decided to include a gamification design to address this issue. As a result, gamification design was used in the middle of the development phase to make the application more appealing. Gamified approaches such as player status, levels, progress, leaderboards and badges all added to the overall project's personalization.

Mariscal et al. [68] employed the "*RCSI Medical Training Sim program*", a commercial application that replicates a real-life scenario of first aid in a traffic emergency. The application allowed university students to actively participate in the simulation to prioritize the necessary actions, engaging them in decision-making procedures regarding the implementation of suitable treatment to the patient while attempting to maintain self-control in the face of a stressful situation. To accomplish this, the application incorporated gamification features such as tasks in the form of questions that could be answered using multiple choices, allowing the user to progress to the next activity. Additionally, false responses could result in the patient's death, hence procedures would be terminated. The application also featured scenarios and event scenes similar to those found in commercial video games to immerse the user in the simulation.

Bendeck Soto et al. [14] used a platform (*ImmerseMe*) to provide students with a personalized experience that incorporates English language tutoring into everyday real-life scenarios to improve their speaking and pronunciation skills through interaction with objects in a VR environment. Students can experience a virtual environment that can be adjusted according to their educational needs and professional careers and that includes speaking activities and procedures. Real-life scenarios, various levels of difficulty and points gathered after each completed level were all included in the platform's gamified features as well as various real-life scenarios and different levels of difficulty.

Zhao et al. [126] created a VR application for undergraduate engineering students that simulates a setting where the user utilizes *LEGO* bricks to design a product, such as a car, based on consumer demands and specifications. The study's goal was to provide students with an environment where they could practice and develop their skills by completing specific tasks in a set amount of time as part of the application's gamified aspects. The authors intend to expand on their current work and include AI technology into the existing application to improve the educational experience even further. As this application is already a gamified simulation, integrating a player modeling technique with AI technology will enable students to have a more effective learning experience because the software will adapt to the user's needs and behavior, resulting in a more engaged and effective learning experience.

Furthermore, each of the following gamification strategies appears once in the selected studies: Within the simulation, the user is represented by an avatar [35], in game enemies [82], commercial game [108], puzzle type gameplay [1], control mechanism similar to that used in video game car simulators [38], users can build personalized virtual locations based on their needs and preferences [104], player status information [25], Leaderboard [25], user has the ability to shift through non-playable characters within the game while the simulation continues for the NPC' [110].

Table 7 Sample size distribution

Sample Size	Frequency
5 to 50	37
51 to 100	18
101 to 150	8
151+	5
Undefined	1

4.5 Limitations using VR in education (RQ3)

Small sample size As indicated in Table 7, almost half of the studies included in this systematic review feature small sample sizes (5 to 50 participants), which is the most prevalent limitation among the studies. The sample size variation is shown in four levels in Table 7, with the first and second levels (5 to 50 and 51 to 100 participants) accounting for the great majority (79%) of the research sample volume (totaling 55 studies). It's worth noting that 64 of the studies mentioned the methodologies they employed, with 16% using qualitative methods, 39% using quantitative methods and 45% using combined qualitative and quantitative approaches (as in Table 16 in the Appendix).

No control groups Lack of a control group is the second most common limitation. The authors of 19 of the 69 studies investigate VR's educational potential, but the experimental group is not compared to a control group. Comparing AR [33] and even traditional hands-on experience [62] with VR, as we've shown in previous sections, can highlight the importance of VR in the learning process. As a result, the presence of a control group in a study appears to be critical for exporting valuable and unambiguous data.

Virtual content of 360° images and videos Another common limitation is that the authors of six studies developed applications that project virtual content in the form of 360-degree videos or images. This approach differs from most other studies in that the majority of them are about applications that provide users with more immersive content based on VR, which allows for interactivity and immersion with interactive artificial objects and realistic virtual surroundings.

Limited data analyzed and presented In addition, four studies analyzed and reported limited quantities of data acquired during and after the experimental stage. In order to have a critical perspective, it is vital to have a comprehensive picture of the methodology, data and findings of the studies in the form of statistics. This will make it easier for academics to assess studies and export meaningful and constructive conclusions.

Limited movement within VR simulation Another limitation is that two of the studies [48, 85] allow limited movement within the VR artificial world since they only provide *three degrees of freedom (3-DoF)*, although contemporary HMDs (Head Mounted Displays) can provide *six degrees of freedom (6-DoF)*. With 6 degrees of freedom, the user may explore the virtual space in a more natural and intuitive manner.

Table 8 shows the remaining limitations that were mentioned multiple times in the included studies. The rest of the limitations that appear one time each within the reviewed literature are as follows:

Table 8 Limitations using VR in education

Limitation	Frequency	Author
Small sample size	37	Akman and Çakır [3], Antoniou et al. [7], Bakar et al. [10], Bennie et al. [15], Bolkas et al. [18], Chang et al. [23], Cheng and Tsai [27], García-Bonete et al. [33], Häfner et al. [38], Innocenti et al. [45], Johnston et al. [49], Mariscal et al. [68], Megat et al. [74], Pande et al. [85], Pirker et al. [90], Ramansyah et al. [93], Rengganis et al. [96], Surer et al. [110], Rychkova et al. [97], Sagnier et al. [98], Varela-Aldás et al. [116], Wizaka et al. [123], Xu and Ke [124], Zhao et al. [126], Sims et al. [104], Liu et al. [59], Jochecová et al. [47], Smit et al. [106], Mayor et al. [71], Seybold and Mantwill [102], Ramansyah et al. [94], Li et al. [58], Bazargani et al. [12], Abuhammad et al. [1], Asish et al. [8], Montusiewicz et al. [79], Remolar et al. [95]
No control group	19	Adnan et al. [2], Akman and Çakır [3], Al Kork and Beyrouthy [4], Bendeck Soto et al. [14], Bolkas et al. [18], Cheng and Tsai [27], Chen [25], Kamińska et al. [50], Megat et al. [74], Ramansyah et al. [93], Rengganis et al. [96], Wizaka et al. [123], Zhao et al. [126], Wee et al. [120], Guzsvinecz et al. [36], Sedlak et al. [101], Ou K-L et al. [82], Wang et al. [119], Krajčovič et al. [54]
Virtual content of 360° images and videos and not real-time 3D interactive environment	6	Adnan et al. [2], Bendeck Soto et al. [14], Chang et al. [23], Cheng and Tsai [27], Megat et al. [74], Wang et al. [119]
Limited data analyzed and presented	4	Anamisa et al. [6], Becerra et al. [13], Bolkas et al. [18], Wizaka et al. [123]
No audio	3	Bennie et al. [15], Ikhsan et al. [44], Wizaka et al. [123]
Expensive system	2	Antoniou et al. [7], Häfner et al. [38]
Limited movement within VR simulation (only 3 degrees of freedom)	2	Johnson-Glenberg et al. [48], Pande et al. [85]
No cognitive elements presented	2	Adnan et al. [2], Cheng and Tsai [27]
No use of controllers	2	Adnan et al. [2], Cheng and Tsai [27]
The software development was outsourced	2	Bendeck Soto et al. [14], Pande et al. [85]
No interaction using VR controllers	2	Akman and Çakır [3], Innocenti et al. [45]
Use of commercial game as an application	2	Mariscal et al. [68], Southgate et al. [108]
Application needs to be further developed	2	Rengganis et al. [96], Xu and Ke [124]
No information about the application development	2	Antoniou et al. [7], Bakar et al. [10]

Data collected for further processing contained only one question [49], depth perception was impacted by the lack of stereoscopic vision [87], distractions caused by virtual in-application elements [17], distractive audio narrative [33], field of view was limited [87], further investigation needed regarding issues of gender equity [108], inability to teleport to multiple locations within the virtual space in a non-intuitive manner [33], issues in rendering virtual objects (Megat et al. [74], lack of realism [50], limited evaluation methods [97], low resolution of HMD [87], low sound quality [2], no info about apparatus used [14], no interaction with the VR environment [78], no locomotion or free roaming, user stands in one place [48], no significant differences between VR approach (experimental group) and the traditional approach (control group) [62], only teachers' perspectives are examined, not students' [13], presence of research assistant during the practice sessions that might affected result negatively [17], scarcity of research on the impact of PSVT: R on both males and females [20], sensor (Leap Motion) controller needs some practice in order to get used to it [4], experiment with a short duration [116], the number of participants in the experimental group is nearly double that of the control group [20], the simulation lacked of representing user's body [33], VR gyroscopic controller provides unintuitive movement in the VR environment [33], unintuitive control and interaction interface [124] and users have a higher educational level than the application's targeted population (Xu and Ke [124].

4.6 Advantages using VR in education (RQ3)

VR learning environments can assist students in having a more effective learning experience. The advantages of employing VR in the classroom have been identified, retrieved, and divided into four categories (didactic aspects, student mental perceptions, VR stimuli, VR system features) based on which classification they corresponded to, as seen in Tables 9, 10, 11, 12 and 13.

4.6.1 Didactic aspects

Didactic aspects take into account a range of actions connected to learning objectives, educational outcomes and learner cognitive features. The advantages related to didactic aspects delivered by VR Learning Environments are described in this section and tabulated in Table 9.

Enhances content knowledge The most frequent advantage connected to didactic features is that it enhances content knowledge, which is reported sixteen times in the studies. Students use VR to practice and revise foreign language curriculum before tests, according to Adnan et al. [2], leading to the enhancement of content knowledge. The preceding study supports the findings of Parmar et al. [87]. Students in this study considered the VR application to be enjoyable and effective in terms of content knowledge, allowing them to expand their learning and absorb related facts from the subject's educational material while also giving them a sense of natural learning. Tarng et al. [111] established a VR environment simulating experiments in the "Shaping Memory Alloys" curriculum for University Undergraduate Students in Taiwan, which not only provided students with an effective means of learning but also a positive outlook and enhanced content knowledge.

Content knowledge enhancement was also observed in the studies of Zhang et al. [125] with a VR application related to fire safety, Johnson-Glenberg et al. [48] with a VR

Table 9 The advantages of VR in education focused on didactic aspects

Advantage	Frequency	Author
Enhances content knowledge	16	Adnan et al. [2], Anamisa et al. [6], Barrett and Hegarty [11], Bendeck Soto et al. [14], Brown et al. [20], Calvert and Abadia [21], Chang et al. [23], Johnson-Glenberg et al. [48], Krajčovič et al. [54], Meyer et al. [75], Parmar et al. [87], Pirker et al. [90], Porter et al. [91], Sedlak et al. [101], Wizaka et al. [123], Zhang et al. [125]
Improves perceived educational outcomes	9	Bennie et al. [15], Bolkas et al. [18], Monita and Ikshan [78], Montusiewicz et al. [79], Pande et al. [85], Rychkova et al. [97], Sims et al. [104], Zhang et al. [125], Bendeck Soto et al. [14]
Enhances learning effectiveness	8	Anamisa et al. [6], Brown et al. [20], Ou K-L et al. [82], Ramansyah et al. [93], Ramansyah et al. [94], Wizaka et al. [123], Bazargani et al. [12], Valentine et al. [115]
Increases students' understanding	6	Becerra et al. [13], Kamińska et al. [50], Monita and Ikshan [78], Rengganis et al. [96], Wee et al. [120], Wizaka et al. [123]
Improves students' academic achievement	5	Ikhsan et al. [44], Johnston et al. [49], Mariscal et al. [68], Parmar et al. [87], Tarng et al. [111]
Improves memory retention	4	Kamińska et al. [50], Megat et al. [74], Varela-Aldás et al. [116], Zhang et al. [125]
Increases students' perception about subject	3	Calvert and Abadia [21], Johnston et al. [49], Madden et al. [62]
Improves learning experience	3	Innocenti et al. [45], Megat et al. [74], Rychkova et al. [97]
Promotes student's creativity in learning	2	Bakar et al. [10], Ikhsan et al. [44]
Enhances learning efficiency	2	[93], Ramansyah et al. [94]

Table 10 The advantages of VR in education focused on student mental perceptions

Advantage	Frequency	Author
Attracts Students' Interest	13	Bakar et al. [10], Bennie et al. [15], Ikhsan et al. [44], Jochecová et al. [47], Makransky and Mayer [64], Monita and Ikshan [78], Montusiewicz et al. [79], Ou K-L et al. [82], Pande et al. [85], Ramansyah et al. [93], Ramansyah et al. [94], Sims et al. [104], Wizaka et al. [123]
Enhances motivation	11	Becerra et al. [13], Bendeck Soto et al. [14], Cheng and Tsai [27], Mariscal et al. [68], Mayor et al. [71], Monita and Ikshan [78], Ou K-L et al. [82], Tarng et al. [111], Triviño-Tarradas et al. [112], Wang et al. [119], Wee et al. [120]
Increases engagement	10	Abuhammad et al. [1], Antoniou et al. [7], Calvert and Abadia [21], Liu et al. [59], Madden et al. [62], Megat et al. [74], Parmar et al. [87], Pirker et al. [90], Sims et al. [104], Xu and Ke [124]
Enhances enjoyment	10	Abuhammad et al. [1], Akman and Çakır [3], Innocenti et al. [45], Makransky and Mayer [64], Monita and Ikshan [78], Liu et al. [59], Pande et al. [85], Mariscal et al. [68], Remolar and Rebollo [95], Wizaka et al. [123]
Promotes knowledge acquisition	3	Antoniou et al. [7], Mayor et al. [71], Li et al. [58]
Enhances confidence on learning subject	2	Bendeck Soto et al. [14], Megat et al. [74]
Reduces anxiety	2	Boetje and Van Ginkel [17], Cheng and Tsai [27]
Provides student's active participation	2	Bakar et al. [10], Monita and Ikshan [78]
Promotes self-efficacy	2	Boetje and Van Ginkel [17], Meyer et al. [75]

Table 11 VR's advantages in terms of stimulation

Advantage	Frequency	Author
Enhances immersion	10	Calvert and Abadia [21], Guzsvinecz et al. [36], Johnson-Glenberg et al. [48], Madden et al. [62], Monita and Ikshan [78], Ou K-L et al. [82], Pirker et al. [90], Ramansyah et al. [93], Rengganis et al. [96], Surer et al. [110]
Creates sense of presence	4	Akman and Çakır [3], Calvert and Abadia [21], Makransky and Mayer [64], Pirker et al. [90]
Provides a sense of reality	3	García-Bonete et al. [33], Madden et al. [62], Monita and Ikshan [78]
Improves spatial perception	3	Cheng and Tsai [27], Guzsvinecz et al. [36], Sanchez-Sepulveda et al. [99]
Provides effective embodiment	1	Johnson-Glenberg et al. [48]

application related to biology, Calvert and Abadia [21] with a VR application related to history education to Australian University and High school students and Brown et al. [20] with a VR application related to visuospatial skills course. Even though most studies refer to VR as an excellent tool for assisting students in understanding subject content, Porter et al. [91] found that there was no clear evidence to support this claim.

Improves perceived educational outcomes One of the most frequently mentioned advantages of employing VR is that it improves educational outcomes and it appears nine times in the literature. [78]) presented a VR application to secondary school students that allowed them to learn about planetary functions and their connections with one another. They improved their perceived educational outcomes by using the application to properly understand the concept of the subject. This advantage of VR is also mentioned in Bennie et al. [15].

Improves of students' academic achievement VR also improves students' academic achievement, which has been observed in five different studies. Mariscal et al. [68] investigated the impact of VR on undergraduate university students' learning and satisfaction by incorporating a virtual simulation of a potential real-life scenario into

Table 12 The advantages of VR in education related to VR system features

Advantage	Frequency	Author
Cost effective	5	Al Kork and Beyrouthy [4], Bakar et al. [10], Chen [25], Tarng et al. [111], Gong et al. [35]
Easy to use	2	Monita and Ikshan [78], Rengganis et al. [96]
Enhances Perceived Usefulness	2	Kamińska et al. [50], Sagnier et al. [98]
Improves usability	2	Pirker et al. [90], Surer et al. [110]
Creates interaction	2	Pirker et al. [90], Zhao et al. [126]
Provides safety (performs hazardous experiments virtually)	2	Al Kork and Beyrouthy [4], Chen [25]
Improves problem-solving	1	Chang et al. [23]
Enables students to communicate the content easily	1	Megat et al. [74]

Table 13 VR viewing method

Apparatus	Frequency	Paper
Cardboard VR headset mounted with smartphone	23	Abuhammad et al. [1], Adnan et al. [2], Akman and Çakır [3], Anamisa et al. [6], Becerra et al. [13], Bendeck Soto et al. [14], Boetje and Van Ginkel [17], Brown et al. [20], Chang et al. [23], Cheng and Tsai [27], García-Bonete et al. [33], Ikhsan et al. [44], Innocenti et al. [45], Johnston et al. [49], Mayor et al. (2021), Megat et al. [74], Monita and Ikshan [78], Montusiewicz et al. [79], Porter et al. [91], Ramansyah et al. [93], Ramansyah et al. [94], Sims et al. [104], Wizaka et al. [123]
HTC Vive	14	Bennie et al. [15], Calvert and Abadia [21], Chen [25], Kamińska et al. [50], Ou K-L et al. [82], Pirker et al. [90], Sagnier et al. [98], Sanchez-Sepulveda et al. [99], Seybold and Mantwill [102], Smit et al. [106], Surer et al. [110], Valentine et al. [115], Zhang et al. [125], Zhao et al. [126]
Oculus Rift	6	Al Kork and Beyrouthy [4], Bolkas et al. [18], Madden et al. [62], Remolar et al. [95], Southgate et al. [108], Wee et al. [120]
Samsung Gear VR	5	Guzsvinecz et al. [36], Makransky and Mayer [64], Mariscal et al. [68], Meyer et al. [75], Pirker et al. [90]
Oculus Go	3	Johnson-Glenberg et al. [48], Varela-Aldás et al. [116], Rychkova et al. [97]
HTC Vive Pro	3	Krajčovič et al. [54], Bazargani et al. [12], Sedlak et al. [101]
Undefined	3	Bakar et al. [10], Tarng et al. [111], Xu and Ke [124]
CAVE	2	Antoniou et al. [7], Häfner et al. [38]
DPVR M2 Pro	1	Wang et al. [119]
Vive Pro Eye	1	Asish et al. [8]
Oculus Rift S	1	Liu et al. [59]
Oculus Quest	1	Triviño-Tarradas et al. [112]
Oculus Quest 2	1	Jochecová et al. [47]
HTC Vive Pro2	1	Li et al. [58]
Powerwall monitor	1	Häfner et al. [38]
eMagin HMD	1	Parmar et al. [87]
Lenovo Mirage Solo HMD	1	Pande et al. [85]
Nvidia 3D Vision Wireless Glasses	1	Barrett and Hegarty [11]
Oculus Rift DK2	1	Rengganis et al. [96]
VUZIX Wrap 1200 HMD	1	Gong et al. [35]

the first year Laboratory Techniques course at the Universidad Europea de Madrid's "Advanced Diploma in Pathological Anatomy and Cytology Diagnosis" program. In the experimental group, the authors utilized a commercial, free VR application called "*RCSI Medical Training Sim application*", in which the students actively participated by performing necessary actions on the patient, while on the control group, they used a master class on the subject. In their study, the authors found that the experimental group of VR treatment students performed better academically than the control group.

Improves learning experience By comparing it to regular classroom learning, Innocenti et al. [45] developed an educational experience using VR as a medium to improve music learning in primary school students. According to the authors, VR is an effective learning approach because it improves the learning experience for students with Certified Special Education Needs who also took part in the study and overcame their learning challenges. Combining VR with game-based settings can also produce optimal learning results [97].

In contrast to the previous studies, Madden et al. [62], conducted a study in which no improvements in students' learning outcomes were observed based on their approach to VR for educational reasons.

Table 9 displays the advantages that emerged several times in the selected studies. Improves learning experience for students with certified special needs [45], prepares students for real life education environment [18], provides a more natural learning approach [87], provides high didactic utility [13], yields new knowledge [108], improves understanding of academic methods [18], improves presentation skills [17], enhances oral presentation competence [17] are advantages that can be identified once in each of the selected studies.

4.6.2 Student mental perceptions

Students' perceptions include their thoughts, feelings and impressions about the learning process, activities and conditions associated to Virtual Reality as an educational tool.

Increases engagement VR is proven to be also an engaging experience. In the study of Parmar et al. [87], students found the VR application satisfying and effective in terms of engagement. According to Pirker et al. [90], VR gives a more engaging and exciting learning experience to university undergraduate students. The authors also demonstrate how students prefer this learning method to traditional learning methods, which they believe are less effective than Virtual Environments. Future adaptation as a supplement to established learning methods is also being considered by the authors.

Megat et al. [74] used VR in chemistry for Malaysian primary school children, applying the *Technology Acceptance Model* theory as a foundation for their research, to address the problem that students lose interest in the subject when they learn in conventional ways. The authors employed questionnaires to measure the mean values of each question after applying relevant subject content to students. Perceived convenience [22], as well as the authors' introductions of facileness and gratification, were merged into an extended version of TAM. The authors utilized the *Google Expedition* application through the learning process, applying VR as a medium. Perceived convenience refers to how convenient the student perceives the system is for completing a task. The degree to which the learner believes the system is user-friendly is referred to as facileness. The degree to which a learner is satisfied after utilizing the system is referred to as user gratification. After the analysis, the perceived convenience had the highest mean value and the approach was regarded as a good way to teach and engage students in general.

Attracts students' interest and promotes curiosity Students also find VR to be an interesting mode of learning that piques their curiosity [15]. Ramansyah et al. [93] developed and tested a VR experience for primary school. The application targeted the topic of environmental pollution and offered users the capability to wander around the artificial environment and the experience of being within the artificial environment. Users were given an experience that contrasted a clean and unpolluted environment with a contaminated one. The study's feedback from students revealed that the experience was not only generally successful and efficient, but it also attracted students' interest, thanks to immersive music and three-dimensional objects depicting waste or environmental items. This demonstrates VR's ability to deliver immersive experiences that can turn a theoretical subject into an attractive environment experience for students.

Enhances motivation VR is a technological approach that encourages and motivates learners to participate in learning activities [111]. The topic of motivation enhancement was addressed in eleven of the 69 studies. Cheng and Tsai [27] used a VR approach to investigate students' learning in immersive VR field trips for elementary school social studies. Students completed a Chinese version of the *Motivated Strategies for Learning Questionnaire (MSLQ)* [89] following the intervention, which provided a clear image of motivation and learning technique, demonstrating that motivation was significantly increased.

Enhances enjoyment The use of VR in the classroom can enhance students' enjoyment of the learning process. This is something that can be found in the literature ten times. Pande et al. [85] contrasted an interactive condition using VR as a medium to a passive and non-interactive treatment using video for learning tasks linked to environmental biology. The VR condition was considered "enjoyable" by the students, whereas the video condition was considered "boring."

Monita and Ikshan [78] found similar results, with students in a VR planetary simulation rating the whole experience as enjoyable. The same pattern has been observed in topics such as construction engineering, where VR can enhance enjoyability as students find it appealing [123]. Although, this is not always the case, as Bendeck Soto et al. [14] discovered that students' experiences with VR were adversely appraised as a result of a survey filled out by students. This is primarily due to the fact that not all students were familiar to this new learning method, but rather to traditional ones, demonstrating that not all students have the same perspectives on new learning methods.

Even though some studies claim that VR aids students' learning, Chang et al. [23] revealed evidence to the contrary in their study. For the subject of natural science, the authors conducted an experiment with Hong Kong Primary School Students, using a VR 360 video design in the experimental group and a traditional VR Environment (Desktop version) in the control group. They discovered that learning achievement, learning motivation, self-efficacy and cognitive load were not significantly better in the experimental group than in the control group.

Aside from the Table 10 representation of VR's potential advantages connected to student mental perceptions; the following advantages can be identified one time in each of the selected studies:

Delivers unique experiences to students [108], reduces cognitive load [75], increases awareness towards the subject [7], improves self-esteem [14], improves metacognitive skills [23], improves concentration in cognitive rehabilitation [116], generates held positive attitudes towards the teaching module [111], impacts behavior [106], enhances learning attractiveness [93], enhances empathy [21], enables faster processing [102].

4.6.3 VR Stimuli

This section describes the advantages related to arousals, behaviors and impulses that are produced by interventions generated by VR systems.

The enhancement of immersion, the creation of presence, the improvement of spatial perceptions, the sense of reality delivered and the effective embodiment of users are the most prominent advantages associated with the stimulations produced by VR applications that are met in this systematic review.

Enhances immersion and creates a sense of presence According to students who participated in Pirker et al.'s (2017) study, VR delivers higher levels of immersion when combined with the usage of controllers and it delivers an engaging experience. Johnson-Glenberg et al. [48] report that high levels of immersion and embodiment, obtained using a VR headset and real-time control of the virtual environment's actions, can be used to help students enhance their knowledge. In the lack of student participation and interaction, passive learning becomes a disadvantage. Calvert and Abadia [21] used statistical analysis to compare two conditions of immersive VR and 360 videos in tutoring a history subject to Australian university and high school students. They discovered that the VR condition performed better because the students experienced high levels of immersion and felt present within the simulation. Students in the educational application designed and developed in Akman and Çakır's [3] study felt physically present in the virtual environment. This is because VR not only gives the user the feeling of being there but the virtual environment was also designed to interact with and enhance their sense of awareness, resulting in a rewarding experience and mental transfer.

While Sagnier et al. [98] believed that presence is an important aspect of VR, they found that it only had a minimal impact on the intention to use, indicating it needs to be investigated more.

Table 11 exhibits all the advantages listed in this systematic review's research that are related to VR environments.

4.6.4 VR system features

The advantages of VR system features, as well as how they can contribute to the educational process as a technological approach, are discussed in this section.

Provides safety When compared to traditional labs, virtual labs represented in VR provide solutions to challenges such as wear and tear maintenance and repair expenses. VR laboratories also provide a solution for the production of hazardous derivatives that are directly discarded from the machines. In their studies on lab equipment training, Chen [25] and Al Kork and Beyrouthy [4] highlight the aforementioned solutions.

Cost effective According to the aforementioned studies, another advantage of virtual labs is that the consumable materials required to deliver the experiments for training purposes are costly. Since every function is artificially controlled, VR seems to be a cost-effective alternative. Furthermore, because universities cannot afford a large amount of lab equipment, the number of students who may be served at the same time increases, resulting in crowded places and increased training time.

Enables students to communicate the content easily Students also see the usage of VR in education as an easy way to learn [78, 96].

According to Kamińska et al. [50] in a study related to mechanical and electrical engineering education, students considered the VR application to be a useful learning approach in transferring knowledge. Moreover, the vast majority of students expressed an interest in seeing this approach used in their classes Table 12.

4.7 Apparatus (RQ4)

The apparatus that the authors of the studies utilized during the development phase of the included studies are listed in the following paragraphs. To deliver VR applications to learners, a range of hardware devices were used.

Incorporating smartphone devices into systems known as *"Cardboard VR headsets "*, such as *Google Cardboard*, was the most widely utilized method for delivering VR simulations to users. That might be because this method is convenient to incorporate into classroom-scale instructional approaches and is a cost-effective solution because most students in a class own a smartphone device [5]. HMD hardware devices, on the other hand, increase costs because purchasing a new device for each student is costly.

Five of the studies made use of the *Samsung Gear VR*, a smartphone-based device that was discontinued by *Samsung* in 2020. *Samsung* collaborated with *Oculus* to develop a smartphone-based solution that was compatible with Samsung's flagship smartphones. This distinguishes the system from cardboard VR systems like *Google Cardboard*, because *Samsung Gear VR* combines high-end Samsung smartphones with head tracking technology, but *Google Cardboard* works with any smartphone. Furthermore, *Samsung Gear VR* took advantage of *Oculus* optics, including *Oculus* lenses that enhanced the user's field of view, as well as an advanced controller designed specifically for the device. *Google Cardboard* and *Samsung Gear VR* cost $20 and 129 dollars, respectively, with the majority of cardboard variations costing roughly the same as *Google Cardboard* did. 28 of the 71 systems employed in the 69 studies used smartphone-based VR, while another 36 use HMDs.

HTC Vive is the second most widely utilized device, accounting for 20% of all systems. Oculus devices are next on the list, with five different versions available. The *Oculus Rift* was assessed in six experiments, the *Oculus Go* in three and the *Oculus Rift CV1* and *Oculus Rift DK2* in one study each. Three studies also addressed the

CAVE VR system [28]. In addition, three studies do not specify which VR apparatus was used. One study used the *Mirage Solo* HMD, another used the *eMagin* HMD and yet another used the *VUZIX Wrap 1200* HMD, all of which have been discontinued by their manufacturers. Additionally, a *PowerWall* monitor was employed in two further studies. DPVR M2 Pro [119], Vive Pro Eye [8], Oculus Rift S [59], Oculus Quest [112], HTC Vive Pro2 [58] and Nvidia 3D Vision Wireless Glasses [11] are also devices used by researchers and appear once each in the included studies in this systematic review. Meta's Oculus Quest 2 is also used in one study, which is a device with unique characteristics such as haptic control and stand-alone use without the need for a computer connection. Haptic control, which offers sensations of touch to the user, may improve the immersive experience and help students acquire and recall knowledge better. For example, haptic feedback may be utilized to imitate the sensation of touching items in the virtual environment, which can aid students in understanding and remembering the distinct characteristics of such objects. Since it was launched in the fall of 2020, it has only been utilized once in the chosen studies [47].

4.8 Different uses of the terms of "Virtual Reality" and "Immersive"

One of the most noteworthy results revealed during the extensive analysis of the articles to extract data to our matrix database was the range of apparatus used by the researchers. Furthermore, within the chosen decade of our systematic review, from 2012 to 2021, a distinction in the use of the phrases *"Virtual Reality"* and *"Fully immersive Virtual Reality"* was observed. To avoid any misconceptions, the term Virtual Reality was given a whole new meaning during the last decade and it is now an interwoven meaning to the device known as Head Mounted Displays (HMDs), which has gained widespread recognition from researchers and the tech industry.

Low refresh rates and low resolution in the hardware displays, limited graphics projection that hindered visual depth and realism and a limited range of color reproduction, were all connected with oculomotor disturbances like headaches and simulation sickness [51] in previous VR technology implementations. Even though that their Head Mounted Display systems were released, firms like *SEGA* and *Nintendo* for instance, who were prominent and influential in the video game and entertainment industries, stopped backing their VR-related projects *Sega VR*, *Virtual Boy* due to the aforementioned issues. Additionally, there were multiple references to VR from the 1990s to the mid-2010s regarding various devices and systems that were significantly less immersive than what is now accessible.

With headsets like the *Oculus Rift*, *PlayStation VR* and *HTC Vive*, manufacturers like *Oculus*, *Sony* and *HTC* have given HMDs and VR a whole new meaning since 2016. This was made possible by hardware advances in screen resolution, refresh rate, color range, advanced controlling hardware and gesture recognition. Support from software developers who provide cross-platform 3D engines like *Unreal Engine* and *Unity3D*, as well as online stores that supply rich content in available applications, were other essential aspects in VR's breakthrough. Developers and researchers were given the opportunity to produce high-quality content, which aided VR's adoption and introduced a variety of solutions for developing VR, AR and XR applications.

Term variations of virtual reality According to Witmer et al. [122], a virtual environment must properly isolate the learner from the actual world in order to minimize physical environment stimulations and allow the user to attain high levels of immersion. This is something that a head-mounted display (HMD) can accomplish for the user. As Witmer et al. [122] points out, traditional media-based approaches generate a sensation of being outside the artificial world and observing from outside, leading to a loss of the sense of being there.

Between 2012 and 2016, technologies such as *CAVE* VR [7], VR with stereoscopic glasses [11] delivered limited immersion and embodiment experiences that adopted the term "Virtual Reality".

Even though four of the studies used the terminology "Virtual Reality", none of them used contemporary immersive VR HMDs that provide optimal interaction and immersion, as shown in Table 14.

In one study [38], *PowerWall* monitors were used as a viewing method, providing limited immersion and visual field due to their proximity to traditional monitor displays. Additionally, the authors of one study [11] employed a desktop computer connected to a conventional monitor to project stereoscopic graphics captured by stereoscopic wireless glasses *(Nvidia 3D Vision Wireless Glasses)*. Although this custom-built system provided a sense of depth and three-dimensional visuals, the viewing field of the conventional monitor was limited in comparison to the capabilities of today's current HMDs, leading in a different interpretation of how the term "Virtual Reality" is perceived today.

The *CAVE* system was another technological approach utilized in two of these four studies [7, 38]. CAVE VR technology is a viable option for a group of individuals who want to interact, collaborate and participate in the same physical space while interacting with a virtual one [9]. CAVE system can vary from three-sided to six-sided installations [30, 76]. Additionally, when compared to modern HMDs, one downside of a *CAVE* system is that it requires a physical room with three or six projection surfaces and 3D stereoscopic glasses to replicate a three-dimensional environment, making it more complicated and expensive to install. Even though the *CAVE* system delivers an immersive experience [52], it only allows for limited embodiment because the user cannot see his or her hands represented within the virtual world as in VR applications supported by modern HMDs. Instead, they can view them in a real-world context while using the *CAVE*'s controllers and stereoscopic glasses. In contrast to CAVE, which is not supported at that scale, modern development platforms give developers with a wide range of features for HMDs so they can create novel applications [117]. As a result, *CAVE* is more of a Mixed Reality approach, merging the real environment with projections in flat displays using a stereoscopic viewing methodology, rather than a VR experience like HMDs.

One study [35] did, however, use a *VUZIX Wrap 1200* HMD, which was different from recent ones. This type of HMD was designed to provide a low-resolution two-dimensional or anaglyph three-dimensional view of a larger display, similar to a large television. It was less immersive than modern HMDs due to its low visual fidelity. In addition, the system did not support VR compatible controllers, resulting in no intuitive control and limited interaction with the virtual environment.

Table 14 illustrates the features of the 4 papers stated above, out of a total of 69, that were chosen for inclusion in the current systematic review. The studies are characterized and displayed according to the year they were published, the equipment utilized, the controlling hardware and the software used.

Table 14 VR apparatus been utilized in research from 2012 to 2016, as well as one study in 2019

Article	Year	Apparatus	Controllers	Software
Häfner et al.	2013	PowerWall monitor with an Advanced Realtime Tracking system and, CAVE, passive technology TV	Commercial video game racing wheel set, Microsoft Kinect, Flystick2	3DVIA Virtools, Poly VR, Matlab/SimulinK
Gong et al.	2015	VUZIX Wrap 1200 HMD, Microsoft Kinect	Microsoft Kinect	SIGVerse, Autodesk Maya
Antoniou et al.	2016	CAVE	Undefined	Undefined
Barrett and Hegarty	2016	Nvidia 3D Vision Wireless Glasses	Cylinder shaped hand-held interaction device	WorldViz Vizard

5 Conclusions

This systematic review aims to serve as a future reference for academics, students and professionals interested in VR as an educational approach that incorporates personalization techniques. As a result of performing this comprehensive review, key aspects of the studies, such as sample demographics, educational topics, advantages of using VR in education, study limitations and characteristics related to the software development stage of each study were examined. Furthermore, because VR has evolved over the last five years and has become a technology that is interwoven with modern immersive HMDs, an analysis of the discrepancies between studies that used fully immersive hardware (HMDs and cardboard VR headsets) and studies that used less immersive approaches (such CAVE VR, stereoscopic glasses-based VR, etc.) within the chosen decade was undertaken. The most important element of this review, which fills a gap identified in the relevant literature, is that the personalization mechanisms of the developed VR applications are presented, thereby forming the novelty of this research. Gamification strategies are also highlighted as methods of producing personalized experiences in the studies reviewed.

None of the reviewed studies employed adaptive learning methodologies tailored to individual learners' educational needs [55] for in-class use, which is a significant gap. VR blended with gamified design and adaptive techniques [31, 34, 41, 107] has the potential to deliver effective educational experiences that not only attract but also motivate learners and provide a tailored experience based on skills, learning gaps, personal preferences, cognitive characteristics, prior knowledge and other factors [63].

Researchers and academics started paying more attention to VR around 2016, with the majority of papers coming out in 2019 and 2020. The United States of America and Indonesia have the most studies, demonstrating that these countries exploit VR potential more than the rest of the world, with Africa being the only continent that is not represented in any of the studies in this systematic review. A total of 69 studies were published, with 50 articles and 19 conference papers accounting for 72% and 28% of the total.

University undergraduate students participated in 31 studies during the experimental stage as a stand-alone group, accounting for 45% of the 69 studies and 19 total sample demographics and 9 times when combined with other sample demographics. As a result, university undergraduate students were involved 40 times in total, accounting for 58% of the overall sample demographics. This suggests that university undergraduate students were the researchers' most popular target group for acquiring their conclusions.

Chemistry and engineering were the most frequent topics amongst the studies indicating that these areas are more appealing to researchers in employing VR in education as a medium. This also suggests that academics regard VR as a practical way for creating artificial objects and settings in the domains of chemistry and engineering, as these fields can use VR to portray subject-related themes.

In studies after interventions, the most frequently positively evaluated component of VR is the enhancement of content knowledge, as VR is a valid method of facilitating and transferring knowledge from the artificial world to the learners. In addition, the studies all had two significant limitations. To begin with, 19 of the studies did not include a control group to compare findings to those of an experimental group, therefore conclusions were based only on the data gathered by the students who participated in a VR treatment. This is a key issue since the conclusions drawn by both the experimental and control groups would provide the intervention phase a new dimension regarding various features of VR. The most commonly encountered limitation among the studies was the small sample size, which accounted for nearly half of the studies and may have limited the statistical quality of the conclusions.

Regarding the VR systems used throughout the studies, 35% of them used cardboard VR headset-based VR employing smartphone devices. This is mostly because this type of system simply requires a smartphone device, which almost everyone has, making it simple and cost-efficient to employ in classroom scale interventions.

The personalization mechanisms used throughout the research are the most important findings of this systematic review. In order to provide a more personalized experience to the learners, 50 of the 69 articles considered in this review included at least one personalization mechanism. The manipulation of artificial objects within virtual space was the most extensively used technique, allowing learners to view them from a different perspective that would otherwise be impossible, expensive, or dangerous to perform. Additionally, another category of personalization approaches was discovered and it was linked to gamified characteristics. VR can provide the technological hardware and software components to develop gamified experiences due to its complex nature. To spark students' interest and generate their learning engagement, several researchers integrated gamified elements into the learning process. The most frequently utilized mechanisms found in the selected studies were tutorials on how to use the controllers, gamified scenarios and rewarding systems, all of which are common in commercial video games. All three techniques strive to personalize the learning experience, making it more interesting and engaging.

This systematic review summarizes the current state of research on virtual reality (VR) as an educational approach, specifically focusing on the use of personalization techniques. The review examines key aspects of 69 studies, including sample demographics, educational topics, advantages of using VR in education, study limitations, and characteristics related to the software development stage. The most important finding of the review is the presentation of personalization mechanisms used in the development of VR applications, with gamification strategies highlighted as methods of producing personalized experiences. The review also notes the potential for VR blended with gamified design and adaptive techniques to provide effective educational experiences.

The advantages, limitations and effectiveness of virtual reality as a learning method, as well as the development features incorporated in the chosen studies, will be apparent to the readers of this study. The novelty of this study lies in its in-depth investigation of VR personalization strategies that have been used for educational purposes, as well as how gamification approaches have been used in VR for educational purposes as a means of personalization.

The methods of the studies, as well as the statistical outcomes of the studies that used quantitative approaches, will be the focus of future research (Table 15 and 16).

Appendix

Table 15 Educational background of sample participated in studies

Sample Demographic	Freequency	Percentage (%)	Study
University Undergraduate Students	31	45	Abuhammad et al. [123], Adnan et al. [2], Asish et al. [8], Bazargani et al. [12], Bendeck Soto et al. [14], Bennie et al. [15], Bolkas et al. [18], Brown et al. [20], Chen [25], Johnson-Glenberg et al. [48], Guzsvinecz et al. [36], Johnston et al. [49], Krajčovič et al. [54], Li et al. [58], Liu et al. [59], Madden et al. [62], Mariscal et al. [68], Meyer et al. [75], Ou K-L et al. [82], Pande et al. [85], Parmar et al. [87], Pirker et al. [90], Porter et al. [91], Rychkova et al. [97], Sedlak et al. [101], Sims et al. [104], Smit et al. [106], Tarng et al. [111], Ramansyah et al. [94], Wee et al. [120], Wizaka et al. [123], Zhang et al. [125], Zhao et al. [126]
Primary School Students	9	13	Akman and Çakır [3], Anamisa et al. [6], Chang et al. [23], Cheng and Tsai [27], Innocenti et al. [45], Megat et al. [74], Ramansyah et al. [93], Ramansyah et al. [94], Smit et al. [106]
Secondary School Students	6	9	Antoniou et al. [7], Ikhsan et al. [44], Monita and Ikshan [78], Remolar et al. [95], Rengganis et al. [96], Southgate et al. [108]
University Graduate and Undergraduate Students	4	6	Häfner et al. [38], Sagnier et al. [98], Triviño-Tarradas et al. [127], Xu and Ke [124]
Secondary and University Undergraduate Students	2	4	Bakar et al. [10], Calvert and Abadia [21]
University Undergraduate, Academics	2	4	García-Bonete et al. [33], Kamińska et al. [50]
University Postgraduate Students	2	4	Valentine et al. [115], Seybold and Mantwill [125]
University Teachers	2	4	Becerra et al. [13], Jochecová et al. [47]
Game Developers and Game Designers	1	1	Surer et al. [110]
University Graduate Students	1	1	Boetje & Van Ginkel [17]
University Undergraduate Students, University Instructors and Various Conference Attendees	1	1	Al Kork and Beyrouthy [4]
University Undergraduate Students and Professionals	1	1	Sanchez-Sepulveda et al. [99]
University Undergraduate Students and Various Conference Attendees	1	1	Varela-Aldás et al. [116]

Table 15 (continued)

Sample Demographic	Freequency	Percentage (%)	Study
University graduate and undergraduate students and faculty members	1	1	Gong et al. [35]
Middle School Students	1	1	Makransky and Mayer [64]
University Undergraduate Students and University Teachers	1	1	Mayor et al. [71]
University Undergraduate Students, Doctoral Students and Academic Teachers	1	1	Montusiewicz et al. [79]
College Students	1	1	Wang et al. [119]
Postsecondary Education Students (College)	1	1	Barrett and Hegarty [11]

Table 16 Qualitative and quantitative approaches

Method	Frequency	Percentage (%)	Paper
Qualitative	10	16	Anamisa et al. [6], Ramansyah et al. [93], Southgate et al. [108], Calvert and Abadia [21], Al Kork and Beyrouthy [4], Meyer et al. [75], Akman and Çakır [3], Chang et al. [23], Jochecová et al. [47], Smit et al. [106]
Quantitative	25	39	Zhang et al. [125], Mariscal et al. [68], Bakar et al. [10], Johnson-Glenberg et al. [48], Becerra et al. [13], Ikhsan et al. [44], Varela-Aldás et al. [116], Pande et al. [85], Sanchez-Sepulveda et al. [99], Boetje & Van Ginkel [17], Chen [25], Wizaka et al. [123], Sagnier et al. [98], Megat et al. [74], Kamińska et al. [50], Liu et al. [59], Ramansyah et al. [94], Abuhammad et al. [123], Asish et al. [8], Wee et al. [120], Sedlak et al. [101], Ou K-L et al. [82], Wang et al. [119], Krajčovič et al. [54], Makransky and Mayer [64]
Qualitative and quantitative	29	45	Adnan et al. [2], Cheng and Tsai [27], Parmar et al. [87], García-Bonete et al. [33], Pirker et al. [90], Tarng et al. [111], Bolkas et al. [18], Surer et al. [110], Zhao et al. [126], Monita and Ikshan [78], Brown et al. [20], Rengganis et al. [96], Johnston et al. [49], Innocenti et al. [45], Rychkova et al. [97], Bendeck Soto et al. [14], Madden et al. [62], Bennie et al. [15], Porter et al. [91], Sims et al. [104], Mayor et al. [71], Seybold and Mantwill [125], Li et al. [58], Bazargani et al. [12], Montusiewicz et al. [79], Remolar et al. [95], Guzsvinecz et al. [36], Valentine et al. [115], Triviño-Tarradas et al. [127]

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Declarations

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