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Virtual vs. traditional learning in higher education: A systematic review of comparative studies

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ABSTRACT

The evolving landscape of educational technologies has ushered Virtual Reality (VR) in the forefront of higher education. As the COVID-19 pandemic propelled a rapid shift toward e-learning, the demand for high-quality distance education has surged, prompting an exploration of VR as a viable solution. While existing research indicates that VR supports student engagement and learning experiences compared with traditional teaching methods, the lack of shared pedagogical frameworks and systematic analyses of its applications leaves a deeper investigation of VR's potentials and limitations in enhancing learning outcomes still unexplored. This paper presents a systematic literature review aimed at filling this gap by considering studies that evaluate VR-based teaching methods in comparison with traditional ones in higher education contexts in order to assess the strengths and weaknesses of this technology in improving students' learning outcomes and achieve inclusive education. The analysis focuses on a set of dimensions including the adopted research design, participants' characteristics, disciplinary field of application, VR technological features (i.e., immersivity, interactivity, operability, commercial availability, and presence of VR training), adopted teaching methodologies, assessed VR impact on learning outcomes and presence of studies involving students with disabilities or Specific Learning Disorders (SpLDs). Based on inclusion/exclusion criteria, a total of 71 studies of VR in higher education were analysed. Most of analysed studies employed quantitative methods (67%), while no qualitative studies were found. More than half of the studies were conducted with undergraduate students (61%). Most of the studies involved VR in STEM disciplines, with almost half of them concerning Health Sciences (45%). VR solutions were most frequently immersive (63%), predominantly using Oculus Rift and HTC Vive HMDs, interactive (59%), single-user (92%) and non-commercial (57%). Only a small portion of studies included a VR training in the research protocol (8%). Most of the studies compared lecture-based methodologies as control condition with active methodologies in the VR condition. Learning outcomes were positively influenced by immersivity, interactivity and active methodologies, although at different degrees. No study involved students with disabilities or SpLDs in the experimentation. By offering a multidimensional perspective on the application of VR in higher education contexts, the paper provides a valuable resource for educators, researchers, and policymakers navigating the dynamic intersection of VR and higher education.

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1. Introduction

The most recent technological advancements have been prompting a redesign of educational scenarios through innovative tools and learning opportunities in the direction of Virtual Reality-based learning. Virtual Reality can be defined as a multimedia technology that allows for the creation of three-dimensional computer-mediated environments (Abbas et al., 2023; Burdea & Coiffet, 2003; LaValle, 2023).

A growing number of scientific works focuses on the didactic use of VR in higher education specifically, investigating the application of this technology to improve the teaching-learning process in various disciplinary fields and assessing if and how VR can represent a useful resource to increase students' motivation, engagement and academic success (Parmaxi, 2023; Chen et al., 2021; Tilhou et al., 2020, pp. 169–184; Wu et al., 2022; Tsay, Kofinas, & Trivedi, 2018, July). Studies seem to suggest that VR technologies can provide multiple means of representation, expression and engagement, improving student's learning experience in comparison with traditional teaching methods (e.g., Campos et al., 2022; Krokos et al., 2019). Indeed, VR could offer innovative environments for the representation of the objects of knowledge through multiple levels of immersivity and sensory stimuli, as well as spatiality and movement features in an experiential learning perspective (Jensen & Konradsen, 2018; Dubovi et al., 2017). Furthermore, the price of immersive VR technologies, such as wearable devices, has seen a significant decrease over the past few years, thanks to the introduction of affordable devices, such as Meta Platforms' head mounted display (HMD) "Oculus" (Calvert & Abadia, 2020; Egliston & Carter, 2021). Big Tech Companies' investments on VR as a consumer good pave the way for an increasingly spread use of these tools. Such a scientific trajectory seems reasonable also in light of the COVID-19 pandemic's impact on everyday lives, with the breakthrough of e-learning technologies to face the transition of everyday activities into the virtual world. The response to an initial urgency is now becoming a habitus especially in higher education contexts (Flinspach et al., 2023; Maatuk et al., 2022; Aristovnik, Keržič, Ravšelj, Tomaževič, & Umek, 2020), with a growing demand of high-quality distance (or blended) education (Bashir et al., 2021).

Moreover, Metaverse for education appears as an emerging research field that is still in its early stages to this day. Although the scientific community has not reached a shared definition of the Metaverse's key features yet (Hennig-Thurau et al., 2023), it can be intended as a computer-mediated environment in which people can interact with each other, engaging in socially meaningful activities (Kye et al., 2021; Park & Kim, 2022). When considering the Metaverse as a dimension in which the physical and virtual realities can co-evolve and generate a space of significant social and cultural relationships and activities (Kye et al., 2021), its contribution to educational settings is foreseeable and already under early-stage scientific exploration (Lee et al., 2021; Pimentel et al., 2022; Rospigliosi, 2022; Suzuki et al., 2020; Tlili et al., 2022). If Metaverse-based environments could represent the future step for the growth of educational systems and communities, considering how they possess the potential to increase inclusion, personalisation, communication and network-based learning as well as space-time flexibility (Far & Rad, 2022; Park & Kim, 2022), Virtual Reality (VR) can constitute one of the best-fitting technologies to enable Metaverse environments for their technical implementation and hardware-software embodiment (Bhugaonkar et al., 2022; Cipresso et al., 2018; Iqbal & Campbell, 2023). Although VR can provide the technological infrastructure to establish Metaverse environments, it still does not represent its main and only possible support (Park & Kim, 2022).

An additional challenge consists in the use of VR for inclusive education, as a tool that can ensure equal learning opportunities (Ainscow et al., 2019), allowing for both individualisation and personalisation processes. As the number of students with special educational needs enrolling to higher education courses and pursuing an academic career has seen a significant increase over the past years (Kauffman et al., 2022; Mengoni et al., 2021), new challenges are posed for the elimination of barriers that impede equitable quality education. If the right to education must be guaranteed for all students, the application of VR in education must envision accessibility and usability issues, embracing students' diversity. Such a discourse underlines the necessity to carry out scientific studies aimed at assessing the validity of VR technologies in higher education contexts as inclusive education tools, that is to say tools that can reach out to all learners (UNESCO United Nations Educational Scientific and Cultural Organization, 2017) and provide equal opportunities of access to education (Chua & Bong, 2022), taking into consideration how ICTs can foster innovative trajectories for scholastic inclusion and development of personal talents (Beck, 2019; Giaconi & Del Bianco, 2018).

Although the latest advances of technologies in education are significant and are already affecting educational systems and approaches, one might consider how VR is still a developing technology that does not possess any shared or fixed pedagogical frameworks for its use in educational settings (Adurangba, 2023; Radianti et al., 2020; Johnston et al., 2018), lacking the instructive robustness that could orient systematic implementations in this area. Indeed, research's results on the application of VR in education are fragmentary and lack a wider vision on the topic. On one hand, a line of research in this field consists of qualitative studies that do not take into account learning outcomes produced by VR, aiming at collecting and analysing the attitudes and perceptions of students and teachers towards the use of these technologies applied to education and training through questionnaires, interviews and focus groups (e.g., Tarasova, Pozdeeva, & Baranova, 2022; Domingo & Bradley, 2018). On the other hand, another line of research focuses on illustrating the design and development of custom VR environments to support the learning of specific topics and subjects (e.g., Ha, 2021, pp. 64–68; Jang et al., 2021; Zhao et al., 2019, pp. 1–4). Such studies do not allow for comparisons or generalisation of results and therefore cannot provide the educational community with substantial indications on how to apply VR in teaching and learning processes. Furthermore, they mainly focus on illustrating the design and development of such solutions, including preliminary evaluations with limited samples of participants. Lastly, a discrete number of studies compare VR-based teaching solutions with traditional solutions in order to assess the impact of this technology on students' learning outcomes.

Given such a complex research scenario, acquiring more detailed and systematic knowledge about current VR application practices in higher education represents a crucial step in advancing the understanding of potential and limits of VR-based solutions in higher educational settings.

In this sense, a big picture analysis could provide the scientific and educational community with findings that might orient educational practices.

1.1. Motivation and novelty of the work

Given the established scientific interest towards VR technologies for educational purposes, we can observe the presence of several review studies that try to offer a comprehensive picture on the current application of VR in higher education contexts. However, such overviews, moving in the direction of providing systematised mappings on the topic, present features that might limit their impact for this scope. For instance, some reviews focus on specific VR technologies, such as immersive HMDs (Radianti et al., 2020) or 360° VR (Shadiev et al., 2022), excluding other solutions from their inquiry (e.g., Cave technologies, desktop VR, and so on). In contrast, other reviews are out of focus, including not only VR in the inquiry, but also other XR technologies, as well as Artificial Intelligence (Kaur et al., 2022; Rangel-de Lázaro & Duart, 2023) or considering also other educational contexts, such as K-12 (Luo et al., 2021). Additionally, some overviews are restricted to specific disciplinary fields, such as Engineering (Kaur et al., 2022) or Health Sciences related disciplines (Truong et al., 2020). Existing reviews also shed light on specific features of VR, such as the relationship between gamification and engagement (Das et al., 2022; Loureiro, Bilro, & de Aires Angelino, 2020), or specific types of VR applications, such as collaborative and multi-user VR (Li & Liu, 2022; Mystakidis et al., 2021), as well as specific issues, such as marketing (Loureiro et al., 2020), arts education (González-Zamar & Abad-Segura, 2020) or deep and meaningful learning (DML) (Mystakidis et al., 2021). Moreover, such reviews often do not focus on the analysis of learning outcomes emerging from the selected studies in detail (Ding & Li, 2022; Truong et al., 2020) and consider research trends through bibliometric analysis (González-Zamar & Abad-Segura, 2020; Rashid et al., 2021). Some of the reviews which aim at assessing the impact of VR do not consider the teaching methods that were implemented in the experimentations of selected studies (Sunardi et al., 2022, pp. 476–481). Furthermore, single database reviews can present partial results, limiting the number of potential studies to be included in their mapping (Loureiro et al., 2020), while other existing reviews are not up to date (Ghanbarzadeh & Ghapanchi, 2018). Lastly, to the best of our knowledge, no systematic review has provided a mapping of comparative studies on VR application to higher education contexts yet, that is to say studies which present a comparative analysis between experiencing traditional and VR-based teaching, considering both students' learning performance outcomes and/or their general learning experiences. As a result, there is still a limited provision of literature that offers an overview of studies that assess VR-based teaching solutions with reference to the benefits and weaknesses compared to traditional teaching methods, leaving a wider analysis on the possible fields of application and learning outcomes of VR still unexplored.

In this context, this paper provides a Systematic Literature Review (SLR) of studies that compare VR-based education approaches and traditional ones to deepen the understanding of VR's potential benefits and limits in higher education. Based on the analysis of the results of the considered papers, selected on the basis of specific inclusion/exclusion criteria, this SLR aims at providing an answer to the following research questions.

Q1. In which higher education disciplinary fields has VR been most widely analysed in comparison with traditional teaching solutions?

Q2. Which research designs methods were applied to assess the use of VR in comparison with traditional teaching solutions?

Q3. What features of VR technologies have been most widely assessed in comparison with traditional teaching solutions?

Q4. What teaching methodologies have been most widely used to evaluate VR solutions compared to traditional teaching solutions?

Q5. What is the impact of VR on learning outcomes emerging from the comparison with traditional teaching solutions?

Q6. What is the impact of VR in the achievement of inclusive education?

2. Methodology

The following section describes the research design adopted in this SLR. The different phases included to carry out the research follow the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Page et al., 2021). Additionally, this SLR includes a quality evaluation of selected studies to inform readers about their level of clarity and contextualise their results. Quality assessments were not used as inclusion/exclusion criteria. This choice is motivated by the selection of completely objective eligibility criteria, as illustrated in section 2.1. The quality assessment follows literature's considerations on the detection of possible biases, the acknowledgement of internal validity of studies and the involvement of at least two independent assessors (Assendelft et al., 1999; Bie, 1996).

2.1. Eligibility criteria

Based on the Research Questions, inclusion/exclusion criteria were defined to orient the data collection phase and select the articles that are relevant to the study's topic. Table 1 summarises the adopted inclusion/exclusion criteria. To assess the recent development of VR in the education field, the study covers peer-reviewed journal articles and conference papers written in English and published between 2018 and 2023. Concerning the research topic, we focused on the application of VR technologies only in higher education contexts. Articles and publications that analyse the use of such technologies at other levels of education or in other educational contexts (e.g., primary school and professional training) were not considered. Moreover, studies that focused on other eXtended Reality (XR) technologies, such as Augmented Reality (AR) and Mixed Reality (MR) technologies, were not included. Regarding the research method, we selected studies that carry out comparative researches. Therefore, literature reviews or qualitative studies that report students' and teachers' perceptions on VR environments exclusively were excluded. Moreover, studies that present VR applications for higher education without assessing their impact by means of a comparison with traditional methods were not considered, as well as studies that mainly focus on the design process of VR applications.

2.2. Search strategy

In accordance with the identified inclusion/exclusion criteria, literature collection was carried out through an extensive keywords-based search on multiple scientific databases. The keywords that would best support the proposed reconnaissance of studies were outlined, such as "Virtual Reality", "VR", "Metaverse", "Higher Education" or "University". Since we considered studies published between 2018 and 2023 exclusively, the publication time frame was applied as a filter to the search. The databases utilised for the search are the following: ACM Digital Library, Google Scholar, IEEE Xplore Digital Library, Scopus and SpringerLink. The logical expression used for searching in the considered databases was composed as it follows:

Title/Keywords/Abstract containing *["metaverse" OR "virtual environment*" OR "virtual reality" OR "VR"] AND ["learning" OR "virtual learning"] AND ["higher education" OR "university"]*

The search was carried out on articles titles, abstracts and keywords.

2.3. Selection process

Paper searching was carried out at the end of April 2023. Following the search strategy, a total amount of 3834 records was obtained. Table 2 displays the number of papers related to our issue acquired from the digital libraries that were consulted. Subsequently, an article selection process was carried out based on semi-automatic and manual methods.

Fig. 1 illustrates the selection process through a flow chart. Firstly, using a semi-automatic method (e.g., searching by keywords, applying filters), duplicated studies were excluded, as well as studies not published in English language. By eliminating duplicates and non-English language publications (432), a total of 3400 results were obtained. Subsequently, by excluding review studies (455) a total of 3348 studies was obtained. Secondly, the activity of selection was based on the defined inclusion/exclusion criteria to further select the publications relevant to our SLR through manual methods, consisting in an initial selection by title, followed by a selection by abstract and, lastly, by full paper. To enhance the reliability of the manual assessments, the method used in Radianti et al. (2020) was adopted: every title, abstract and full paper underwent review by a minimum of two researchers. In cases of disagreement, the remaining two authors would additionally evaluate the item to define its relevance.

Accordingly, the first step of this activity consisted in selecting the studies by their title and labelling those relevant to the SLR. This process led to the obtainment of 566 papers identified for further selection. Subsequently, a selection by abstract was carried out, leading to the obtainment of 178 papers. Lastly, such papers were fully analysed in order to ensure their compliance to the eligibility criteria and extract relevant data to the scope of the SLR. A total of 87 papers were excluded as non-comparative studies, 7 papers were excluded for not involving university students as participants and 13 papers were excluded because access to them was not allowed. Consequently, 71 studies were included in the Systematic Literature Review analysis.

2.4. Classification framework and data collection

To guide and organise the data collection phase of the SLR, a classification framework was adopted to identify the relevant features to be analysed in each selected study. To this scope, a set of dimensions was defined based on the research questions, which consists of the following: Research Design; Participants characteristics; Disciplinary Fields; Virtual Reality technology features and Teaching Methodologies. For each dimension, key aspects were considered through the definition of specific categories. The following

Table 1
Inclusion and Exclusion criteria.

Criteria	Item
Inclusion Criteria	Studies published between 2018 and 2023; Studies published in English language; Studies regarding VR technologies applied to higher education contexts; Comparative studies (VR-based solutions compared to traditional solutions).
Exclusion criteria	Studies published prior 2018; Studies published in languages other than English; Studies regarding VR technologies applied to other educational levels or fields; Review studies; Studies on teachers' and students' perceptions on the use of VR technologies in higher education contexts; Studies on the design of VR applications without comparative assessments; Studies that are focused on XR technologies other than VR (e.g., AR or MR); Access to paper denied.

Table 2
Initial search results.

Source	No. of publications
ACM Digital Library	379
IEEE Xplore	290
Google Scholar	766
Scopus	1454
Springer	945

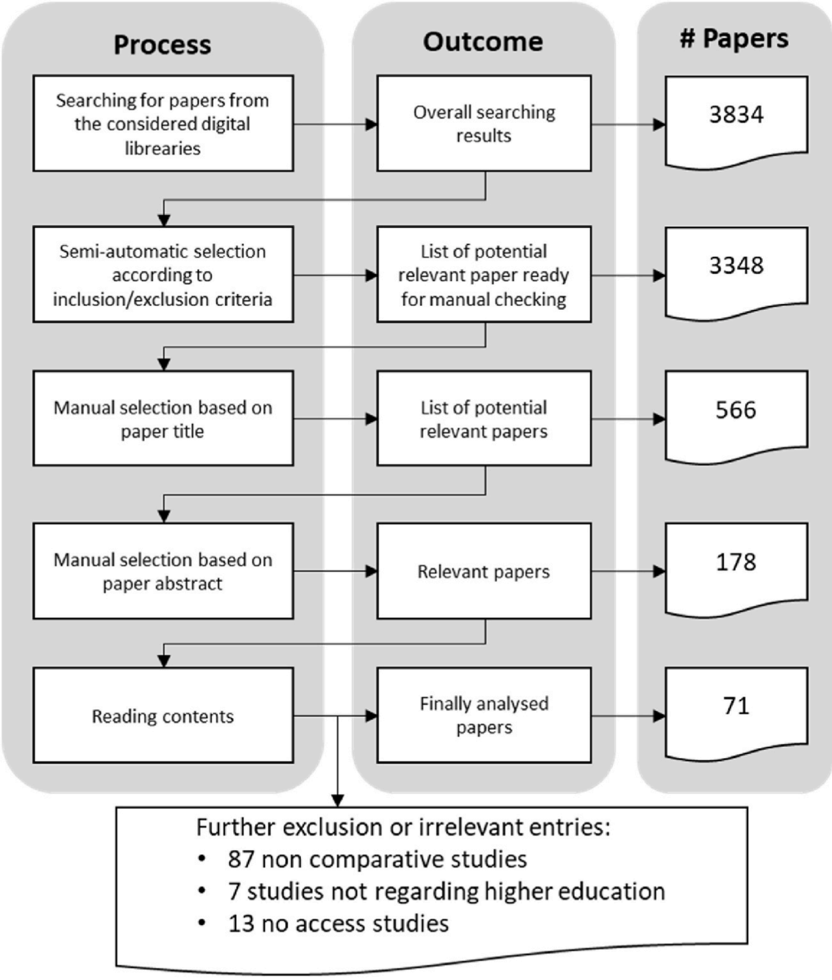

Fig. 1. Flow Chart of study selection process.

paragraphs illustrate the components of the developed classification framework.

2.4.1. Disciplinary fields analysis

Considering the Disciplinary fields analysis, this study proposes a classification of disciplines based on a primary distinction between Science, Technology, Engineering and Mathematics (STEM) disciplines and Humanities and Social Sciences (H&SS) disciplines based on an adaptation of the Higher Education Research Institute (HERIHigher Education Research Institute) comprehensive list of STEMdisciplines and the Australian Research Council Statement of Support for Interdisciplinary Research (ARCAustralian Research Council, 2016). Table 3 illustrates the categories identified for each disciplinary area.

2.4.2. Research design analysis

With reference to Research Design, the investigation focused on identifying the type of study design adopted by using existing categories, as well as participants' characteristics.

Following the categorisation of research design proposed in Creswell and Creswell (2017), the SLR identifies qualitative, quantitative and mixed-methods studies. Additionally, the data collection framework considers the distinction between experimental and quasi-experimental designs (Rogers & Révész, 2020) and the distinction between between-subjects and within-subjects designs (Charness, Gneezy, & Kuhn, 2012). Table 4 illustrates the definition of each category.

With reference to Participants' characteristics, this SLR reports the number of participants included in each study. The SLR analyses the type of participants involved (e.g., undergraduate, postgraduate), including studies that assessed teaching methodologies for specialisation courses too (for instance, medical residency) given they were conducted in a higher education context as well. Lastly, this SLR aimed at identifying the studies that involved students with physical, sensory, or intellectual disabilities or Specific Learning Disorders (SpLDs) in the sample of participants.

2.4.3. *Virtual reality technologies features analysis*

Scientific literature offers multiple frameworks to identify the key features of Virtual Reality. Heim (1993) considers immersion, interactivity, and information intensity as main characteristics of VR, while Bailenson (2018) finds its fundamental elements in Tracking, Rendering and Display. More commonly, immersion, presence, and interactivity are considered the core features of VR technologies (Radianti et al., 2020; Ryan, 2015; Walsh & Pawlowski, 2002).

Immersion can be understood from both technological and psychological perspectives. Based on a technological point of view, *immersion* can be considered as "a quantifiable description of a technology. It includes the extent to which the computer displays are extensive, surrounding, inclusive, vivid and matching" (Slater et al., 1996, p. 164). In this sense, the level of immersivity of a technology can be assessed on the basis of its technological attributes (Slater & Wilbur, 1997). From a psychological perspective, immersion should be viewed as a psychological state in which the user perceives an isolation of the senses from the real world (Witmer & Singer, 1998). This view emphasises how the perceived level of immersion varies between individuals, with technological attributes having partial influence on it (Mütterlein, 2018).

Presence can be interpreted as the psychological and cognitive sensation of "being in" the virtual environment (Slater et al., 1996, pp. 163–172), constituting the subjective ability to act within the virtual environment as if the sensory data it provides the user were real (Slater et al., 2009) or, in other words, "the subjective experience of being in one place or environment, even when one is physically situated in another" (Witmer & Singer, 1998).

Interactivity refers to the amount of freedom with which the user can control the VR experience, receiving feedback from the virtual environment (Wang et al., 2021). Interactivity features appear to influence *agency*, which can be defined as the users' perceived ability to control the VR experience (Piccione et al., 2019).

Given its scope, this SLR adopts a synthetic and broad classification model, in light of the variety of VR technologies implemented in the analysed studies, as well as the different levels of detail with which they are described. As the subjective experience of immersion can hardly be used as a classification criterion, this SLR distinguishes different types of VR technologies as immersive or non-immersive based on their technological attributes. Accordingly, this SLR does not consider *presence* as it is not related to technological features exclusively. The classification framework concerning VR technologies' features was oriented only towards the assessment of immersivity and interactivity of the solutions implemented in each study, which were shown to be impactful factors in VR-based learning (Liu et al., 2017; Petersen et al., 2022).

To identify and distinguish immersive VR technologies from non-immersive VR solutions, this SLR adopts Radianti et al.'s criteria (2020), assessing immersivity on the basis of objective system properties, considering only technological features' potential to create the illusion of reality by isolating the user from the surrounding environment (Slater & Wilbur, 1997).

Specifically, mobile VR, Head Mounted Displays and "enhanced VR" (defined as the integration of HMDs with haptic gloves or other technologies) were considered in the *Immersive* category. On the other hand, technologies such as desktop VR and Cave Automatic Virtual Environment (CAVE) systems were considered in the *Non-immersive* category, since they allow the user to recognise the surrounding physical space at different degrees.

Regarding *interactivity*, this SLR distinguishes a high level of interactivity from a low level of interactivity. In the first case, the user can actively prompt changes and initiate engagements, also through the active manipulation of elements in the VR environment (Makransky & Petersen, 2021) In the second case, the user is only allowed navigation (Moreno & Mayer, 2007), without considerable

Table 3
Categories of Disciplinary fields analysis framework.

Categories	Disciplinary fields
STEM disciplines	Biological, Chemical & Physical Sciences
	Computer Sciences
	Engineering, Architecture & Design
	Health Sciences
	Mathematics & Statistics
H&SS disciplines	Arts, Literature, History and Philosophy
	Economics & Tourism
	Education
	Law
	Language & Communication
	Social and Psychological Sciences

Table 4
Categories and explanations of Research Design analysis framework.

Categories	Explanation
Qualitative study	Studies that implement qualitative methodologies, that is to say research tools like interviews, narrative methods, observation and case studies, that aim at understanding a phenomenon and its variables through deductive approaches as well as application, assessment or generation of theories (Creswell & Creswell, 2017; Maxwell, 2009).
Quantitative study	Studies that implement quantitative methodologies, that is to say research tools that investigate the variables of interest by testing the research hypotheses through standardised methods and statistical criteria (Creswell & Creswell, 2017; Boeije, 2009).
Mixed-methods study	Studies that integrate both quantitative and qualitative methods (Creswell & Creswell, 2017; Tashakkori & Creswell, 2007)
Experimental study	Studies that aim at assessing the relationship between or among variables, maximising precision and objectivity. By controlling an independent variable, these studies can assess its impact on dependent variable(s) in terms of a causal relationship. They rely on random assignment (Rogers & Révész, 2020; Bell, 2009).
Quasi–experimental study	Studies that aim at assessing the relationship between or among variables but do not rely on random assignment, assigning participants to groups based on non–random criteria (Rogers & Révész, 2020).
Between-subjects study	Studies in which each participant is exposed to only one treatment (Charness et al., 2012).
Within-subjects study	Studies in which each participant is exposed to more than one of the treatments being tested (Charness et al., 2012).

control over the experience. VR environments in which the user has no control over their experience were considered in the Non-interactive category (Loreto-Quijada, Maldonado, Gutiérrez-Martínez, & Nieto-Luna, 2011).

The presence of single- or multi-user experiences in the VR solution was also assessed, given the relevance of social interaction in educational settings. With the concept of *operability*, this SLR distinguishes single-user systems (which allow access to the VR environment to only one user at a time) and multi-user systems (which allow access to the VR environment to more than one user at a time) (Birt & Vasilevski, 2021).

Additionally, this SLR aims at identifying the commercial availability of the VR environments implemented (VR *availability*) (Table 5). This dimension was added in order to understand the degree to which analysed VR-based solutions could be replicable and spread. This SLR identifies and distinguishes the studies that developed the VR environment from the ground up through 3D modelling software and cross-platform game engines (Custom), and studies that implemented existing, commercially available VR applications (Commercial) (see Table 6).

Lastly, studies that included a VR training phase on how to use the technology before the assessment were identified. The choice of assessing the presence of VR training is motivated by the need to consider possible novelty effects related to the application of VR as an unfamiliar technology (Clark, 1983; Miguel-Alonso et al., 2023; Rutten et al., 2020). Accordingly, such information can better contextualise the impact of VR features on learning outcomes.

2.4.4. Teaching methodologies analysis

The last dimension analysed in this SLR concerns the teaching methodologies implemented in the comparative studies. Considering the different levels of detail with which each study presents the control condition teaching method and the comparative assessment, in light of the scope of this study, the focus was put on the role of the learner, distinguishing studies that implemented active teaching methodologies from studies that considered lecture-based instructions (Willet, 2017; Michel et al., 2009). Additionally, studies that implemented mixed methodologies were recognised as part of a third category. Although scientific literature offers more detailed classifications of teaching methodologies (e.g., Akdeniz, 2016), the choice of analysing the studies on the basis of these three macro-categories was made to ensure that every study could be properly classified without making inaccurate inferences. This categorisation balances the need to systematise studies' information on teaching methodologies with the importance of operating an objective classification. In this sense, the macro-categories allowed researchers to rely on the explicit details each study provides. Active teaching methodologies include, for instance, case study based learning (McLean, 2016), simulation (Chernikova et al., 2020), role-playing (Van Ments, 1999), cooperative learning (Slavin, 1980), debate (Oros, 2007), flipped classroom (Bishop & Verleger, 2013), problem-based learning (Wood, 2003), game-based learning (Tobias et al., 2014), learning by doing (Schank et al., 2013) and self-regulated learning (Puustinen & Pulkkinen, 2001). Lecture-based methodologies include, for instance, theoretical lecture (Hodgson, 1997), observational learning (Bandura, 2008), as well as watching didactic video content or listening to didactic audio content. The categories were applied to both the control and the experimental conditions considered by each study.

Table 5
Categories and explanations of VR features analysis framework.

Feature	Categories	Disciplinary fields
Immersivity	Immersive	Allows seamlessness of VR environment, e.g., mobile VR, HMDs and enhanced VR (Radianti et al., 2020).
	Non-immersive	Allows recognition of surrounding physical space, e.g., desktop VR or CAVE technologies (Radianti et al., 2020).
Interactivity	High interactivity	Allows active manipulation of VR elements and change prompting (Makransky & Petersen, 2021).
	Low interactivity	Allows navigation and limited actions (Moreno & Mayer, 2007).
	Non-interactive	Allows no control over the VR experience (Loreto-Quijada et al., 2011).
Operability	Single-user	The system allows access to the VR environment to only one user at a time (Birt & Vasilevski, 2021).
	Multi-user	The system allows access to the VR environment to more than one user at a time (Birt & Vasilevski, 2021).
Availability	Commercial	Commercially available VR application.
	Custom	Self-made VR application.

Table 6
Categories and explanations of Teaching Methods analysis framework.

Categories	Explanation
Active methodologies	Teaching methodologies that allow students to learn through actions like reading, writing, discussing, reflecting, or carrying out specific actions (Michel et al., 2009).
Lecture-based methodologies	Teaching methodologies that allow students to learn by receiving information from external sources without interacting with them (Aliyari et al., 2019; Michel et al., 2009).
Mixed methodologies	Combination of both active and lecture-based teaching methods.

2.4.5. VR impact on learning outcomes analysis

With reference to VR impact on learning outcomes, this SLR reports the results of comparative studies that assessed whether learning outcomes in the experimental condition (i.e., VR based teaching) would be higher, lower or equal to those of the control condition (i.e., traditional teaching). Specifically, this SLR distinguishes positive impact (+), negative impact (−) or no significant difference (=) on observed learning outcomes based on each study's findings. Studies that did not assess learning outcomes in terms of acquisition of knowledge and/or skills, but focused on extrinsic factors (e.g., motivation, engagement, etc.) or learners' perceptions were not considered for this category. Studies that did not explicitly express the impact of VR or did not provide sufficient details for this dimension were not considered as well.

2.4.6. VR impact on inclusive education analysis

To investigate the role of VR technologies in the creation of inclusive educational settings and equal learning opportunities, this SLR aims at distinguishing positive impact (+), negative impact (−) or no significant difference (=) compared to traditional teaching methods. It is important to note that such dimension can only be analysed in presence of studies that included students with disabilities or SpLDs in the comparative assessments and that provided reflection upon this specific dimension.

2.5. Quality evaluation

This SLR identified specific guidelines to examine the robustness of the selected papers. A quality assessment checklist based on STROBE checklists (Von Elm et al., 2007) was defined following the method used in the study of (Marto et al., 2022). The established criteria are the following.

- Definition of study objectives;
- Description of technologies implemented;
- Description of participants sample;
- Description of research design;
- Declaration of adopted statistical methods;
- Presentation and discussion of results;
- Report of emerged insights;
- Discussion of study limits.

A set of predefined scores was created to evaluate the selected dimensions, i.e., score of 0 (the study does not meet the criterion), score of 0.5 (the study partially meets the criterion), weight of 1 (the study meets the criterion).

3. Results

The reconnaissance led to the selection of 71 studies. Table 7 offers a detailed overview of the papers' analysis, including research design, number of participants (P), VR features, disciplinary field, teaching methodologies adopted for control and experimental conditions, presence of VR training, reported VR impact, and quality score. Categories defined in the previous paragraph were applied to define these dimensions. To grant the objectivity of our analysis, categories were not applied in absence of sufficient details and information. These cases are labelled with a "Not Specified" (*NS*) indication.

Fig. 2 shows the distribution of the papers in the considered publication time frame. Fig. 3 reports the overall results of the quality evaluation, while Fig. 4 illustrates publications' quality trend for each disciplinary field.

3.1. Disciplinary field results

As shown in Fig. 5, most of the analysed studies focused on the application of VR in STEM disciplines (80,3%, k = 57), with a small number of studies investigating VR's potential in H&SS disciplines (19,7%, k = 14). The discipline that appeared in the highest number of studies was Health Sciences (k = 32) followed by Biological, Chemical & Physical Sciences (k = 12) and Engineering, Architecture & Design (k = 8). No comparative studies were found for the areas of Law and Social & Psychological Sciences.

Table 7
Articles included in the study.

#	Paper	Research Design	P	VR Features	Discipline	Teaching methodologies		VR Training	VR Impact	Q
						Control Condition	Experimental Condition			
1	Aeckersberg et al. (2019)	Quantitative Experimental Between-subject	50	Non-immersive Low interactive Single-user Commercial	Health Sciences	Lecture-based	Active	*NS*	=	5
2	Alfalah et al. (2019)	Mixed methods Experimental Within-subject	60	Non-immersive High interactive Single-user Non-commercial	Health Sciences	Active	Active	*NS*	+	3
3	Allcoat and von Mühlenen (2018)	Quantitative Experimental Between-subject	99	Immersive Low interactive Single-user Commercial	Biological Chemical & Physical Sciences	Lecture-based methods	Active methods	*NS*	+	6.5
4	Andersen et al. (2021)	Quantitative Experimental Between-subject	19	Immersive High interactive Single-user Commercial	Health Sciences	Lecture-based methods	Mixed methods	*NS*	+	6.5
5	Arif (2021)	Quantitative Experimental *NS*	69	Non-immersive High interactive Multi-user Non-commercial	Engineering Architecture & Design	Active methods	Active methods	*NS*	*NS*	3.5
6	Bakhos et al. (2020)	Quantitative Experimental Between-subject	29	Immersive High interactive Single-user Non-commercial	Health Sciences	Active methods	Active methods	*NS*	+	7.5
7	Ballinas-Gonzalez et al. (2022)	Quantitative Experimental Between-subject	*NS*	Non-immersive Low interactive Single-user Commercial	Engineering Architecture & Design	Active methods	Active methods	*NS*	+	4
8	Banerjee et al. (2023)	Quantitative Experimental Between-subject	12	Immersive Low interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Active methods	*NS*	=	6
9	Behmadi et al. (2022)	Quantitative Quasi-experimental. Between-subject	55	Immersive Non interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Lecture-based methods	*NS*	=	5.5
10	Cabrera et al., 2019, October	Quantitative Quasi-experimental Between subject	120	Immersive High interactive Single-user Commercial	Health Sciences	*NS*	Active methods	*NS*	+	5
11	Campos et al. (2022)	Mixed methods Experimental Between-subject	94	Immersive High interactive Single-user Commercial	Biological Chemical & Physical Sciences	Mixed methods	Mixed methods	*NS*	=/+	6.5
12	Castillo Reyna et al. (2022)	Mixed methods Quasi-experimental Between subject	94	Non-immersive Low interactive Single-user Non-commercial	Biological Chemical & Physical Sciences	Lecture-based methods	Active methods	*NS*	+	4
13	Chan et al. (2021)	Quantitative Experimental Between-subject	77	Non-immersive Low interactive Single-user Commercial	Health Sciences	Lecture-based methods	Active methods	*NS*	+	5.5
14	Chan et al. (2022)	Mixed Methods Experimental *NS*	125	Immersive Low interactive Single-user Non-commercial	Arts, Literature History & Philosophy	Lecture-based methods	Active methods	*NS*	*NS*	8

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Table 7 (*continued*)

#	Paper	Research Design	P	VR Features	Discipline	Teaching methodologies		VR Training	VR Impact	Q
						Control Condition	Experimental Condition			
15	Chang et al. (2022)	Quantitative Quasi-experimental Between subject	42	Non-immersive Low interactive Single-user Non-commercial	Health Sciences	Mixed methods	Mixed methods	*NS*	+	4
16	Chao et al. (2021)	Mixed methods Experimental Between-subject	32	Immersive Non-interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Lecture-based methods	*NS*	=	7
17	Checa and Bustillo (2020)	Quantitative Experimental Between-subject	100	Immersive Low interactive Single-user Non-commercial	Arts, Literature History & Philosophy	Lecture-based methods	Active methods	*NS*	+	5
18	Çoban and Göksu (2022)	Quantitative Quasi-experimental Between-subject	41	Non-immersive Low interactive Single-user Commercial	Computer Sciences	Lecture-based methods	Active methods	*NS*	*NS*	8
19	Christopoulos et al. (2023)	Quantitative Experimental Between-subject	50	Non-immersive High interactive Single-user Non-commercial	Biological Chemical & Physical Sciences	*NS*	Active	No	=	7
20	de Back et al. (2020)	Quantitative, Experimental Between-subject	40	Non-immersive High interactive Multi-user Non-commercial	Health Sciences	Lecture-based methods	Active methods	*NS*	+	7.5
21	Halabi (2020)	Mixed method Experimental Between-subject	67	Non-immersive Low interactive Multi-user Non-commercial	Engineering Architecture & Design	Active methods	Active methods	*NS*	+	6
22	Hu et al. (2020)	Quantitative Experimental Between-subject	101	Immersive High interactive Single-user Commercial	Health Sciences	Mixed methods	Mixed methods	*NS*	+	6.5
23	Huang et al. (2023)	Quantitative Experimental Between-subject	49	Immersive Low interactive Single-user Non-commercial	Education	Active	Active	*NS*	*NS*	7
24	Hu-Au and Okita (2021)	Mixed methods Experimental Between.subject	40	Immersive High interactive Single-user Non-commercial	Biological Chemical & Physical Sciences	Mixed methods	Mixed methods	Yes	+/−	6.5
25	Imai et al. (2022)	Mixed methods Experimental Between-subject	60	Immersive High interactive Single-user Non-commercial	Health Sciences	Active methods	Active methods	*NS*	+/ =	6
26	İsmailoğlu et al. (2020)	Quantitative Quasi-experimental Between-subject	60	Non-immersive High interactive Single-user Commercial	Health Sciences	Lecture-based methods	Active methods	*NS*	=	6
27	Jeong et al. (2022)	Quantitative Quasi-experimental Between-subject	65	Immersive High interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Mixed methods	*NS*	=	6
28	Jiménez et al. (2018)	Mixed methods Quasi-experimental Between subject	18	Immersive Non-interactive Single-user Commercial	Health Sciences	Lecture-based methods	Theoretical lectucre	*NS*	+	6
29	Kane et al. (2022)	Quantitative Experimental Between-subject	69	Immersive Low interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Active methods	*NS*	=	7.5

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Table 7 (*continued*)

#	Paper	Research Design	P	VR Features	Discipline	Teaching methodologies		VR Training	VR Impact	Q
						Control Condition	Experimental Condition			
30	Khodabandeh (2022)	Quantitative Quasi-experimental Between-subject	80	Immersive High interactive Single-user Non-commercial	Language & Communication	Mixed methods	Mixed methods	*NS*	+	7
31	Kim et al. (2022)	Mixed methods Experimental Within-subject	33	Immersive Non-interactive Single-user Non-commercial	Biological Chemical & Physical Sciences	Lecture-based methods	Lecture-based methods	Yes	*NS*	8
32	King et al. (2022)	Quantitative Experimental Between-subject	30	Immersive High interactive Single-user Non-commercial	Education	Theoretical lecture	Mixed methods	*NS*	+	7
33	Kolla et al. (2020)	Mixed methods Experimental *NS*	28	Immersive High interactive Single-user Commercial	Health Sciences	Mixed methods	Active methods	Yes	*NS*	5
34	Kurul et al. (2020)	Quantitative Quasi-experimental Between-subject	72	Immersive Low interactive Single-user Commercial	Health Sciences	Lecture-based methods	Active methods	*NS*	+	7.5
35	Lamb et al. (2019)	Quantitative Experimental Between-subject	79	Immersive High interactive Single-user Commercial	Language & Communication	Lecture-based methods	Mixed methods	*NS*	+	8
36	Lee (2022)	Quantitative Quasi-experimental Between-subject	40	Non-immersive High interactive Single-user Commercial	Health Sciences	Mixed methods	Mixed methods	*NS*	+	6.5
37	Liu et al., 2020	Quantitative Experimental Between-subject	38	*NS* *NS* NS Non-commercial	Economics & Tourism	Lecture-based methods	*NS*	*NS*	+	4
38	Lo et al. (2022)	Quantitative Experimental Between-subject	107	Immersive Non-interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Lecture-based methods	*NS*	=	7
39	Macnamara et al. (2021)	Mixed methods Experimental Within-subject	20	Immersive High interactive Single-user Commercial	Health Sciences	Active methods	Active methods	*NS*	–	6
40	Mansoory et al. (2021)	Quantitative Experimental Between subject	50	NS High interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Mixed methods	*NS*	+	6.5
41	Maresky et al. (2019)	Quantitative Experimental Between-subject	42	Immersive Low interactive Single-user Commercial	Health Sciences	Theoretical lecture	Active methods	*NS*	+	4
42	Moll-Khosrawi et al. (2022)	Quantitative Experimental Between-subject	97	Non-immersive High interactive Single-user Commercial	Health Sciences	Theoretical lecture	Mixed methods	Yes	+	6
43	Morales-Vadillo et al. (2019)	Quantitative Quasi-experimental Between-subject	130	Non-immersive Low interactive Single-user Non-commercial	Health Sciences	Mixed methods	Mixed methods	Yes	+	5.5
44	Nicolaidou, Pissas, & Boglou, 2023	Quantitative Quasi-experimental Between-subject	40	Immersive High interactive Single-user Commercial	Language & Communication	Active methods	Active methods	*NS*	=	7

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Table 7 (*continued*)

#	Paper	Research Design	P	VR Features	Discipline	Teaching methodologies		VR Training	VR Impact	Q
						Control Condition	Experimental Condition			
45	Özgen et al. (2021)	Quantitative Experimental Between-subject	20	Immersive High interactive Single-user Commercial	Engineering, Architecture & Design	Active methods	Active methods	*NS*	=	6.5
46	Pande et al. (2021)	Quantitative Experimental Between-subject	28	Immersive High interactive Single-user Commercial	Biological, Chemical & Physical Sciences	Lecture-based methods	Active methods	*NS*	+	6.5
47	Parong and Mayer (2021)	Quantitative Experimental Between-subject	80	Immersive Single-user High interactive Commercial	Arts, Literature, History & Philosophy	Lecture-based methods	Active methods	*NS*	–	8
48	Paxinou et al., 2022	Quantitative Quasi-experimental Between-subject	15	Non-immersive High interactive Single-user Commercial	Biological Chemical & Physical Sciences	Lecture-based methods	Active methods	*NS*	+	7.5
49	Pearl et al. (2019)	Mixed methods, Experimental, Between subject	26	Immersive High interactive Single-user Non-commercial	Mathematics & Statistics	Active methods	Active methods	*NS*	+	5
50	Pirker et al. (2021)	Mixed methods Experimental Within-subject	20	Immersive High interactive Single-user Non-commercial	Computer Sciences	Active methods	Active methods	*NS*	*NS*	7
51	Qorbani et al. (2021)	Quantitative Experimental Between-subject	36	Immersive & Non-immersive High interactive Commercial	Biological Chemical & Physical Sciences	Active methods	Active methods	*NS*	+	7
52	Richter et al. (2022)	Mixed methods, Quasi-experim. Between subjects	69	Immersive Low interactive, Single-user Non-commercial	Education	*NS*	Lecture-based methods	*NS*	***NS***	6.5
53	Rios et al. (2021)	Mixed methods Experimental Within-subject	*NS*	Immersive Non-interactive Single-user Non-commercial	Engineering, Architecture & Design	Active methods	Active methods	*NS*	+	3
54	Rodero and Larrea (2022)	Mixed methods Experimental Between-subject	100	Immersive Low interactive Single-user Commercial	Education	Active methods	Active methods	*NS*	+	6
55	Roehr et al. (2021)	Quantitative Experimental Between-subject	25	NS High interactive Single-user Commercial	Health Sciences	Active methods	Active methods	*NS*	–	7
56	Ruiz-Cantisani et al. (2020)	Mixed methods Experimental Within-subject	104	Immersive Non-interactive Single-user Non-commercial	Engineering, Architecture & Design	Lecture-based methods	Lecture-based methods	*NS*	*NS*	4.5
57	Sanzana et al. (2022)	Quantitative Experimental Between-subject	78	Immersive High interactive Single-user Non-commercial	Engineering, Architecture & Design	Lecture-based methods	Active methods	*NS*	+	6.5
58	Seufert et al. (2022)	Quantitative Quasi-experimental Between-subject	55	Immersive High interactive Single-user Commercial	Education	Active methods	Mixed methods	*NS*	=	6.5

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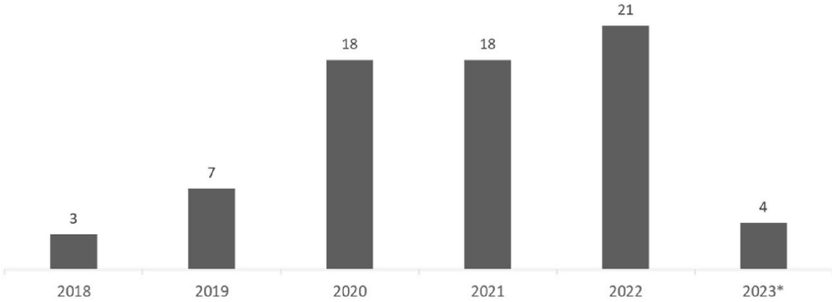
Table 7 (*continued*)

#	Paper	Research Design	P	VR Features	Discipline	Teaching methodologies		VR Training	VR Impact	Q
						Control Condition	Experimental Condition			
59	Singleton et al. (2022)	Mixed methods Experimental Between-subject	171	Non-immersive High interactive Single-user Non-commercial	Health Sciences	Active methods	Active methods	*NS*	+	6
60	Souza et al. (2020)	Mixed methods Experimental Between-subject	23	Immersive Non-immersive High interactive Single-user Non-commercial	Health Sciences	Active methods	Active methods	*NS*	=	8
61	Srinivasa et al. (2021)	Quantitative Experimental Within-subject	118	Immersive High interactive Single-user Non-commercial	Engineering, Architecture & Design	Active methods	Active methods	*NS*	+	5.5
62	Stavroulia et al. (2018)	Quantitative Experimental Between subject	33	Immersive High interactive Single-user Non-commercial	Education	Active methods	Active methods	*NS*	*NS*	7.5
63	Sultan et al. (2019)	Mixed methods Experimental Between-subject	169	*NS* Non-interactive Single-user *NS*	Health Sciences	Active methods	Mixed methods	*NS*	+	6
64	Veneruso et al. (2020)	Quantitative Experimental, Between subject	40	Immersive High interactive Single-user Non-commercial	Computer Sciences	Lecture-based methods	Active methods	*NS*	=	7
65	Wu et al. (2022)	Quantitative Quasi-experim. Between-subject	105	Immersive High interactive Single-user Non-commercial	Health Sciences	Lecture-based methods	Mixed methods	*NS*	+	7.5
66	Yu & Lin, 2020	Quantitative Experimental Between-subject	52	Immersive Non-interactive Single-user Commercial	Biological, Chemical & Physical Sciences	Lecture-based methods	Lecture-based methods	*NS*	+	5
67	Zable et al. (2020)	Mixed methods Experimental Between subject	24	Immersive High interactive Single-user Non-commercial	Biological Chemical & Physical Sciences	Active methods	Active methods	*NS*	+/=	8
68	Zhang, Chen, and Yin (2020)	Quantitative Experimental Between-subject	50	*NS NS* *NS* *NS*	Arts Literature, History & Philosophy	*NS*	*NS*	*NS*	*NS*	2.5
69	Zhang, Li, et al. (2020)	Quantitative Experimental Between-subject	80	Non-immersive High interactive Single-user Non-commercial	Health Sciences	Active methods	Active methods	*NS*	=	5
70	Zhao et al. (2020)	Quantitative Experimental Between-subject	52	Immersive Non-immersive Low interactive Single-user Non-commercial	Biological Chemical & Physical Sciences	Active methods	Active methods	*NS*	*NS*	7.5
71	Zhong & Liu, 2021, March	Quantitative Experimental Between-subject	50	Immersive High interactive Single-user Non-commercial	Computer Sciences	Lecture-based methods	Active methods	*NS*	+	3.5



*Paper searching was carried out at the end of April 2023.

Fig. 2. Distribution of the studies according to publication year.

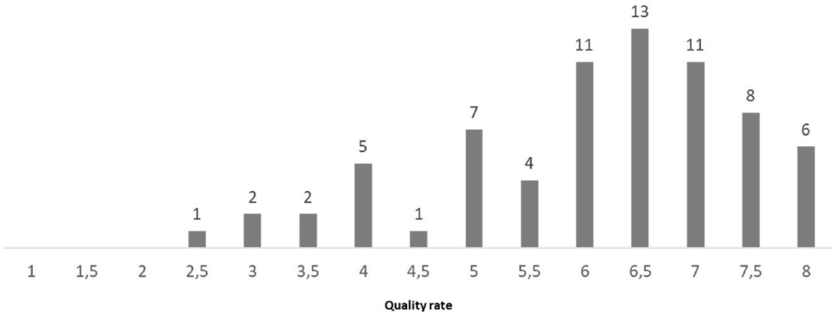


Fig. 3. Overall results of papers' quality evaluation.

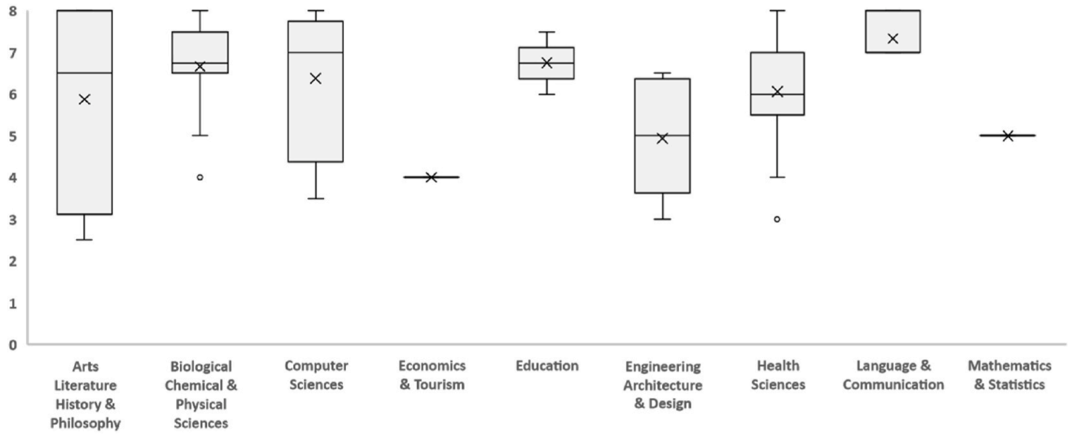


Fig. 4. Publications' quality trend for each disciplinary field.

3.2. Research design results

Regarding Research Design results, Fig. 6 shows the distribution of Experimental and Quasi-experimental design methods, as well as Between-subjects and Within-subjects assessments, in relation to qualitative, quantitative and mixed methods studies. Results show how most of analysed studies ($k = 51$) conducted experimental assessments. Among these, most of studies ($k = 44$) adopted between-subject designs, mainly implementing quantitative methods ($k = 33$). Only a small minority adopted within-subject designs ($k = 7$), the majority of which implemented mixed methods ($k = 6$). 17 studies conducted quasi-experimental assessments, implementing between-subject designs and quantitative methods. No study adopted qualitative methods exclusively. Three studies were excluded from the Figure since they do not sufficiently specify the Research Design.

With reference to participants' characteristics, Fig. 7 illustrates the distribution of the studies according to sample size. The majority of studies (33) included between 30 and 75 students, while only 14 studies had fewer than 30 participants. Notably, 12 studies

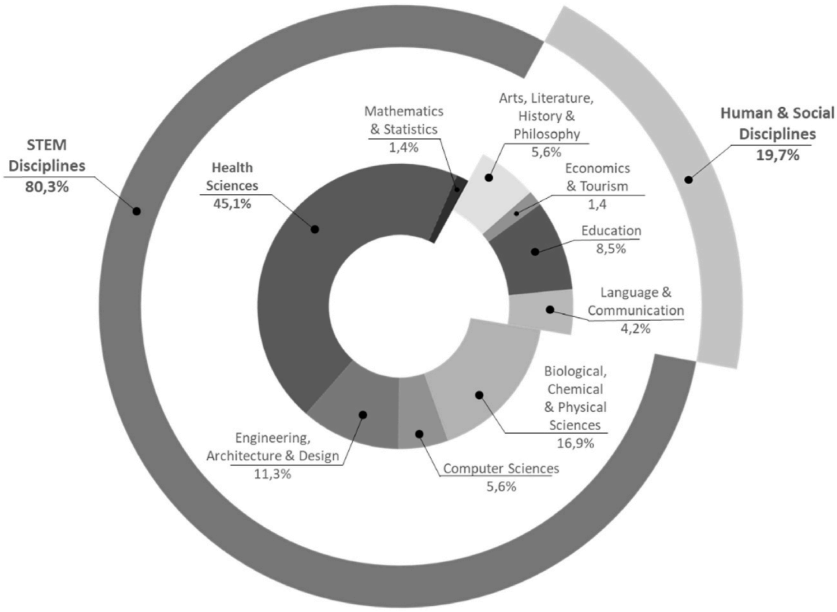


Fig. 5. Distribution of the studies based on the disciplinary field.

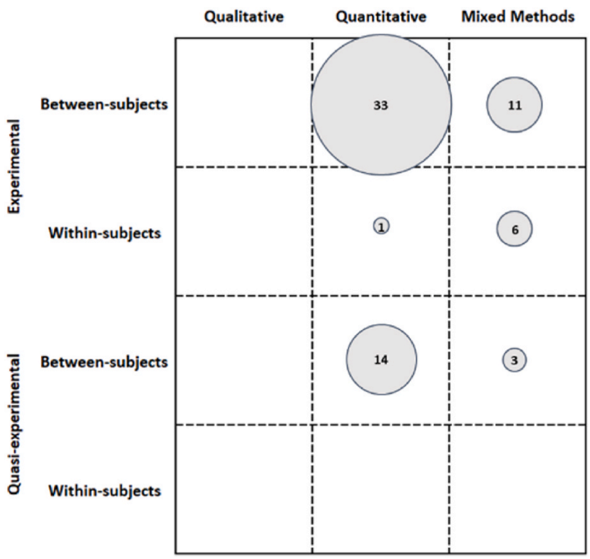


Fig. 6. Distribution of the studies based on the research design method.

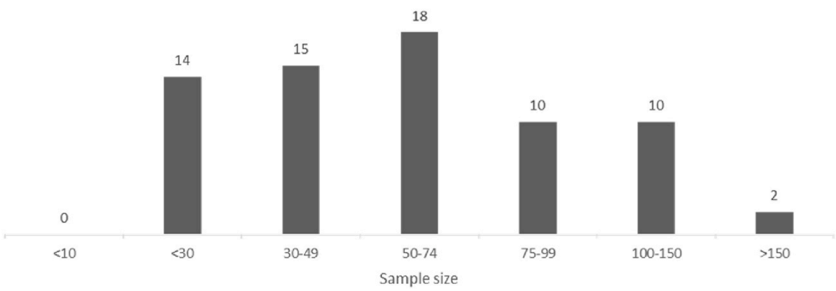


Fig. 7. Distribution of the studies based on sample size.

involved more than 100 students, with only 2 of those exceeding 150 participants. Fig. 8 shows the distribution of study sample size based on the disciplinary field. Concerning students' year of enrolment, a total of 44 studies involved students from different undergraduate courses as participants, while a minority of studies either involved postgraduate students or both groups (respectively, 7 and 4 studies). The rest of the studies (k = 16) do not specify whether the assessment involved undergraduate or postgraduate students. None of the analysed studies involved students with disabilities or SpLDs in the experimentation.

3.3. Virtual reality technologies features

This section illustrates the features of the VR technologies implemented in the comparative studies. Only 6 studies mention the conduction of training and familiarisation with VR technology as a part of their experimental procedure.

3.3.1. Virtual reality immersivity

Regarding VR immersivity, more than half of the studies included immersive VR solutions in the comparative assessment (k = 45), while 18 studies assessed non-immersive VR (Fig. 9). Three studies assessed both immersive VR and non-immersive VR in comparison with traditional teaching methods. Five studies do not present information concerning immersivity of implemented VR.

In detail, the technological devices implemented in the immersive and non-immersive VR solutions were analysed. As Fig. 10 shows, most of the studies that assessed immersive VR implemented Oculus Rift and HT C Vive HMDs (k = 38). Only 3 studies considered VR headset based on mobile devices, such as Cardboard or Samsung VR gear. A total of 4 studies assessed other types of VR headsets (e.g., VR glasses). Three studies do not specify the type of immersive technology implemented in the assessment. Regarding non-immersive VR applications, most of the studies implemented desktop interfaces (k = 7). Five studies used projection systems, screen projection, multiple wall projections or CAVE. Only 2 studies considered mobile devices such as smartphones and tablets. Seven studies do not specify the type of non-immersive technology implemented in the assessment.

3.3.2. Virtual reality interactivity

With regards to interactivity, more than half of the analysed studies implemented VR solutions that allowed a high level of interactivity (k = 42). A smaller portion of studies implemented low-interactivity VR solutions (k = 19). High interactivity solutions included virtual simulations that would allow 3D objects manipulation, whereas low interactivity solutions mainly consisted in virtual tours. Non-interactive solutions (k = 8) consisted in participants watching 360° videos with no control over the learning experience. Two studies do not specify if the VR solutions would present interactivity features or not.

Fig. 11 shows the distribution of high, low and non-interactive features in both immersive and non-immersive tested VR solutions. Fig. 12 shows the number of studies that assessed immersive, non-immersive, interactive or non-interactive VR solutions in relation to disciplinary fields (e.g., the assessed VR solutions for each disciplinary field). Studies that assessed both immersive and non-immersive VR solutions in the comparative study were counted for each categories, while studies that do not specify such features of VR technology were excluded from the Figure.

3.3.3. Virtual reality operability

With reference to VR operability, most experimentations assessed single-user VR environments in which learning is experienced individually (k = 66). Only 3 studies assessed a multi-user VR solution, implementing CAVE systems (i.e., Arif, 2021; de Back et al., 2020; Halabi, 2020).

3.3.4. Virtual reality availability

With regards to the availability of the VR applications, most of the studies (59%) implemented non-commercial VR software solutions developed using 3D modelling and animating software such as Blender and cross-platform game engines such as Unity (Fig. 13). For instance, Hu et al.'s study (2020) implements a VR chemistry lab built in Unity. Two studies do not specify the type of VR environment implemented in the assessment. All the studies adopted commercially available VR hardware equipment.

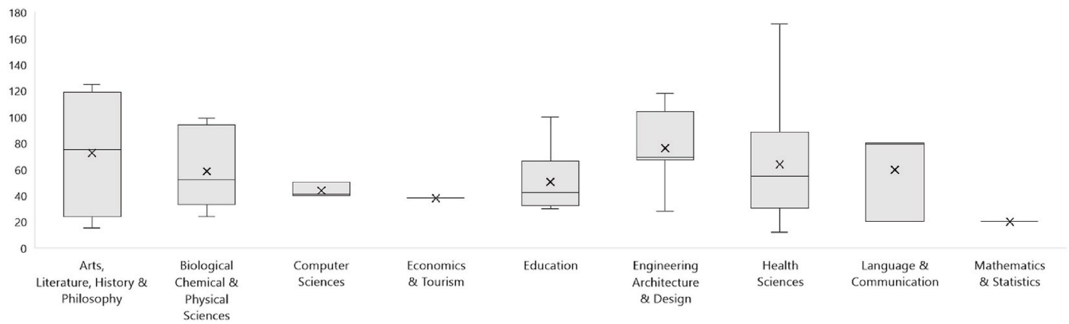


Fig. 8. Distribution of study sample size based on the disciplinary field.

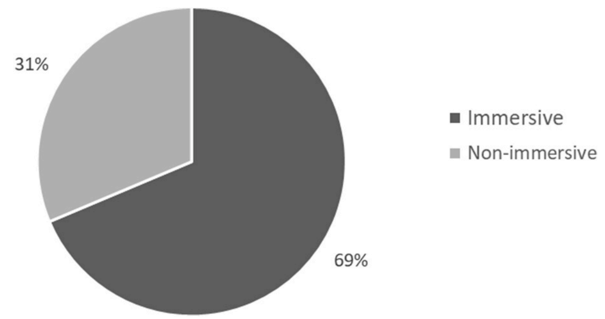


Fig. 9. Distribution of level of immersivity of VR solutions analysed by the considered studies.

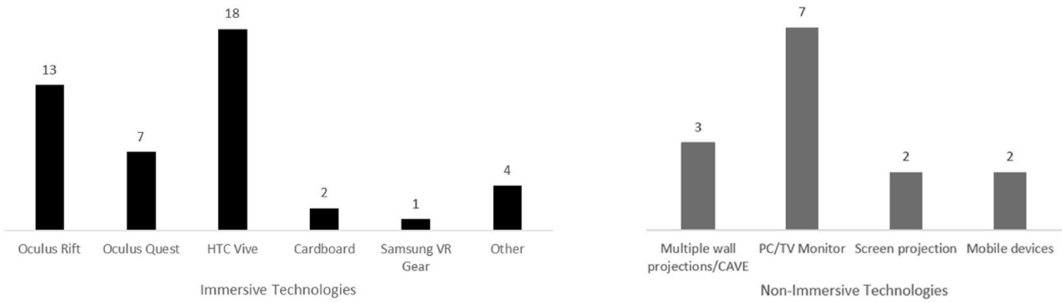


Fig. 10. Immersive technologies and non-immersive technologies implemented.

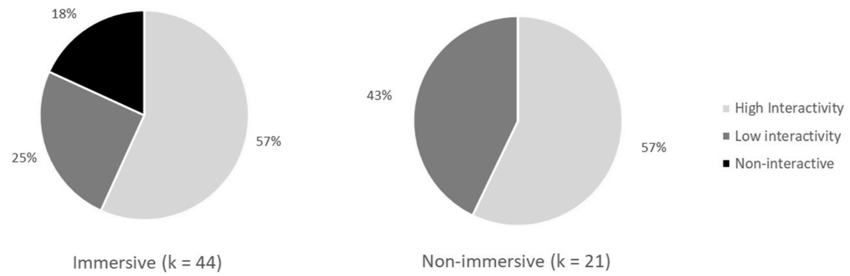


Fig. 11. VR immersivity and interactivity.

3.4. Teaching methodologies results

The SLR included an analysis of the teaching methodologies adopted in the comparative assessments of the studies. Fig. 14 shows the distribution of active, lecture-based and mixed teaching methodologies for both the control and the experimental conditions. In the case of control condition, half of the studies adopted lecture-based teaching methodologies, such as theoretical lectures. Active learning methodologies included real-life hands-on experiences, simulations, case studies or cooperative learning activities. 38% of studies implemented active methodologies for the control condition, while 12% of the studies assessed mixed methodologies. On the other hand, most of teaching methodologies adopted for the experimental condition consisted in active learning methodologies (65%): these included multiple types of simulation training and practice, empirical case studies, experiential learning activities, serious games, interactive exercises and situated learning. Lecture-based methodologies with VR (12%) included watching demonstrations or videos. 23% of studies assessed mixed methodologies in the experimental condition.

3.5. VR impact on learning outcomes results

With reference to VR impact, the relationship between specific VR features and impact on learning outcomes was analysed. Fig. 15 shows VR impact rates with reference to immersive and non-immersive technologies. Given that extrinsic dimensions like learner's engagement and self-confidence were not considered in the VR impact, the studies that did not assess the learning efficacy of VR were excluded from the Figure. With reference to immersive VR solutions, 62% were found to have a positive impact on learning outcomes, 31% were found to make no difference compared to traditional methods and 7% negatively impacted learning outcomes. With

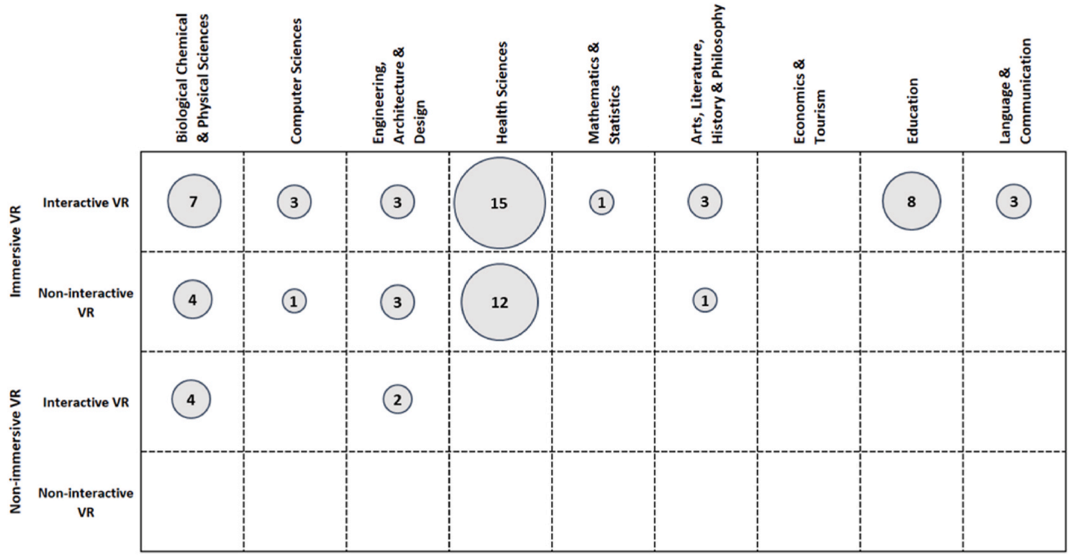


Fig. 12. Distribution of VR solutions based on disciplinary fields.

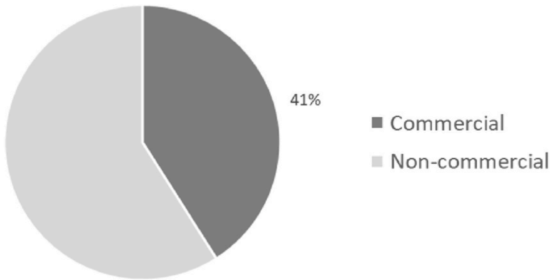


Fig. 13. Distribution of the studies based on VR applications availability (k = 69).

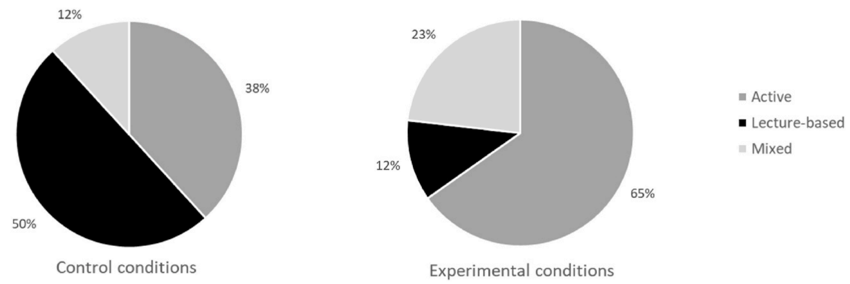


Fig. 14. Distribution of studies based on teaching methods assessed (k = 66).

reference to non-immersive VR solutions, 72% of them provided a positive impact, while 28% of them were shown to make no difference.

Fig. 16 shows the VR impact rates with reference to high, low and non-interactive solutions. The studies that did not assess the learning efficacy of VR were excluded from the Figure. With reference to interactive VR solutions, 68% played a positive impact on learning outcomes, 26% were found to produce no differences and 6% negatively impacted learning outcomes. In the context of non-interactive VR solutions, 57% of them provided a positive impact, while 43% of them were shown to make no difference.

Fig. 17 reports collected results regarding the impact of VR depending on teaching methodologies. The studies that did not assess the learning efficacy of VR were excluded from the Figure. Most of the studies that compared Active methodologies in the control condition with Active methodologies in the experimental condition found VR to have a positive impact on learning outcomes (k = 12). Six of them found no differences and 2 of them assessed a negative impact. Most of the studies that compared Lecture-based methodologies in the control condition with Active methodologies in the experimental condition found VR to have a positive impact (k =

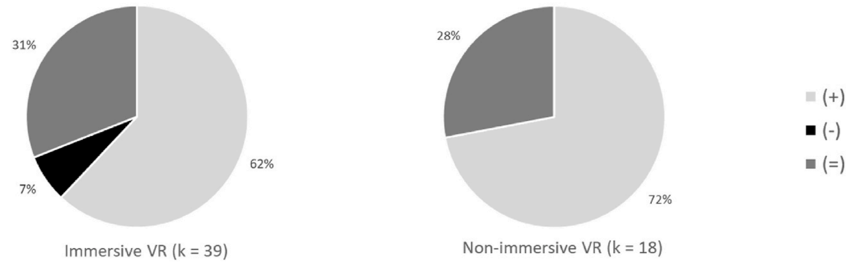


Fig. 15. VR impact rates with reference to immersive and non-immersive technologies.

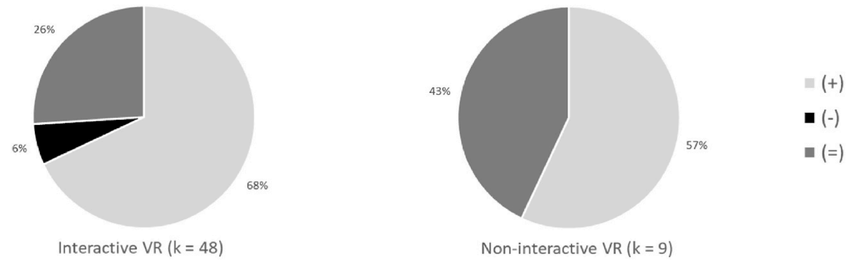


Fig. 16. VR impact rates with reference to interactive and non-interactive technologies.

11). Five of them found no differences and 1 assessed a negative impact. The few studies that compared Lecture-based control condition and Lecture-based experimental condition found a positive impact of VR (k = 2) or no differences (k = 3). The study that compared Active methodologies in the control condition with Mixed methodologies in the experimental condition assessed a positive impact of VR. In the comparison of Lecture-based methodologies in the control condition and Mixed in the experimental condition, 5 studies found a positive impact of VR and 2 studies found no differences. Most of the studies that compared Mixed methodologies both in the control and experimental conditions found a positive impact of VR (k = 8). One of them found no differences and 1 of them assessed a negative impact.

Fig. 18 shows the VR impact rates with reference to active, lecture-based or mixed teaching methodologies used to implement VR-based solutions. 60% of active VR methodologies had positive learning outcomes, while 32 made no difference with the control condition and 8% had a negative impact. Lecture-based VR solutions made no difference with the control condition in most cases (60%), while a smaller portion had a positive impact (40%). 78% of Mixed VR solutions had a positive impact on learning outcomes, while 17% of them made no difference and 5% of them had a negative impact.

3.6. VR impact on inclusive education results

Due to the absence of studies that involved students with disabilities or SpLDs in the comparative assessments, it was not possible to collect data on the impact of VR on inclusive education.

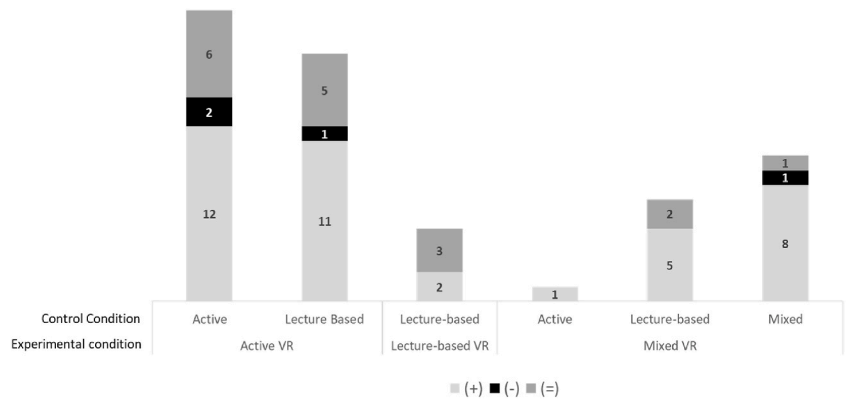


Fig. 17. VR impact rates with reference to teaching methods comparison.

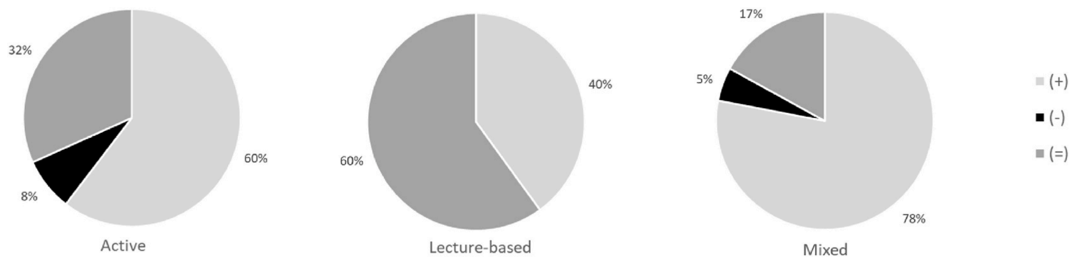


Fig. 18. VR impact on learning outcome, depending on teaching methods.

4. Discussion

The results obtained from this SLR offer multiple insights to discuss VR's application scenarios, potentials and limits in the context of higher education.

The review of 71 papers on the use of VR in higher education highlighted several key trends. Most of the studies (67%) employed quantitative research methods, and no exclusively qualitative studies were found. Over half of the studies involved undergraduate students (61%), and most of the studies focused on STEM disciplines, particularly Health Sciences (45%). The VR solutions assessed were predominantly immersive (63%), interactive (59%), designed for single users (92%), and non-commercial (57%). Only a small portion of the studies (8%) included VR training in their protocols. In terms of teaching methods, most studies compared traditional lecture-based approaches in the control group with active learning methods in the VR group. Overall, VR applications had a positive effect on learning outcomes. None of the studies included students with disabilities or SpLDs as participants. This section presents a discussion of the systematic mapping results according to the research questions.

4.1. In which higher education disciplinary fields has VR been most widely analysed in comparison with traditional teaching solutions?

With regards to the disciplinary fields considered as case scenarios in the comparative assessments, most of the studies analysed VR's impact in the context of STEM disciplines. Still to this day, Health Sciences undoubtedly represents the most explored field in this topic, presenting the greatest body of studies regarding VR's opportunities and limitations in the teaching of its disciplines in comparison with traditional methods. The other disciplinary fields that were most present are Biological, Chemical & Physical Sciences and Engineering, Architecture & Design, as Fig. 5 illustrates. This distribution was not unexpected, although the results of a recent review study identified the Engineering and Computer Sciences areas as the most explored disciplinary fields for immersive VR application in higher education (Radianti et al., 2020). Traditionally, the aforementioned areas those in which XR technologies (and VR in particular) are generally designed and developed. However, considering how comparative studies would require more robust and reliable VR applications to be tested, the greater availability of commercial VR applications for Health Sciences can explain this difference in our findings. This demonstrates how the research line of comparative studies in medical areas appears to be more mature and developed compared to other disciplinary fields. When questioning the reason of this greater availability, one might consider how the area of Health Sciences presents critical needs with regards to teaching and training, especially in light of the applicative nature of its disciplines or the scarce availability of specific didactic resources, e.g., trainings on cadaveric dissection (Kolla et al., 2020).

Accordingly, in human role-play simulations, the implementation of VR can reduce the costs of health sciences education without compromising its quality level (Figols Pedrosa et al., 2023; Pottle, 2019). Another reason motivating the high number of comparative studies belonging to this area and published in the last years of the considered time frame could be the result of the challenges emerging from the COVID-19 emergency, giving push to research on VR for educational purposes as an effective solution to support distance learning (Javaid et al., 2020; Singh et al., 2020). Indeed, VR for medical teaching and training can provide information close to real-life situations (Javaid & Haleem, 2020; Pottle, 2019) offering multiple means of visualisation and analysis (Alfalah et al., 2019; Campos et al., 2022; Zable et al., 2020) and providing learners with a safe training environment to acquire specific skills and competences (Conges et al., 2020; Hu-Au & Okita, 2021; Li et al., 2017) in alternative to real-life contexts. These assets can explain how VR represents a unique didactic resource also for Biological, Chemical and Physical Sciences in lab safety procedures training (Paxinou, Georgiou, Kakkos, Kalles, & Galani, 2022). On the other hand, VR represents a suitable teaching tool in the fields of Engineering, Architecture & Design when considering the opportunities it offers for visualisation and 3D object manipulation (Halabi, 2020; Oje et al., 2023). Regarding H&SS disciplines, as evidenced in Radianti et al. (2020), VR technologies have not spread with consistency, leaving the field of comparative assessments in these disciplines mostly unexplored. In the category of Arts, Literature, History & Philosophy, comparative studies were found in relation to history teaching, exploiting the visualisation potential of VR to transport students into different 3D reproductions of historical contexts (Chan et al., 2022). With reference to Language & Communication, VR was applied to foster vocabulary proficiency and contextualised learning (Cheng et al., 2017). The opportunities connected to simulation environments were also explored in the Education area, specifically to support pre-service teacher training (Seufert et al., 2022). However, this line of research appears to be far from being fully developed. This situation could be also due to barriers to VR design and development, since researchers of H&SS disciplines might lack technological skills. Indeed, in the absence of commercially available technologies, the creation of custom software solutions would require specific competences that are more frequently present in researchers of STEM areas.

4.2. Which research designs methods were applied to assess the use of VR in comparison with traditional teaching solutions?

The Research Design analysis, as shown in Fig. 6, illustrates how most of the studies implemented quantitative methods in the assessment (k = 48), while fewer studies implemented mixed methods (k = 20). No studies operating qualitative evaluations exclusively were found. Moreover, most of the considered studies (k = 44) implemented experimental and between-subject designs. The predominant use of quantitative methods and experimental designs indicates a strong focus on measuring the effectiveness of VR in a controlled, empirical manner. However, the lack of qualitative-only studies and the restricted use of mixed methods limit possible insights on the nuanced experiences of students, including their engagement, motivation, and deeper learning processes (Rana et al., 2023). This suggests a need for future research to incorporate more diverse research designs, particularly qualitative approaches, to capture the full range of VR's educational impact.

With regards to participants, most of the analysed studies involved students from undergraduate courses, with a small minority including postgraduate students or both groups. Since the potential benefits of VR would mainly depend on the specific subject matter (e.g., acquisition of specific technical skills) rather than the year of enrolment (Ma et al., 2022), we can assume that one of the reasons why most studies involved undergraduate students could be linked to recruitment opportunities. Indeed, undergraduate courses generally welcome a broader student population compared to postgraduate ones.

4.3. What features of VR technologies have been most widely assessed in comparison with traditional teaching solutions?

Regarding VR equipment utilised in the comparative assessments, the study found multiple combinations of immersive, non-immersive, interactive, non-interactive, single-user, multi-user, commercial and non-commercial solutions.

As Fig. 10 shows, most of the studies implemented immersive VR solutions that consisted in the use of head-mounted displays. Most of the implemented headsets were Oculus Rift and HTC Vive devices. These results might seem unexpected, given the widespread availability of more affordable immersive technologies (e.g., Meta Oculus Quest, commercially available from 2019). However, it appears understandable when considering the high levels of VR technology robustness required to successfully evaluate their use in educational settings (Al-Ansi et al., 2023). Moreover, newer VR technologies require the acquisition of new technical skills and knowledge to successfully develop educational applications (Ashtari et al., 2020). Such reasons help explain why well-established technologies, such as Oculus Rift and HTC Vive, were used more often. Lower price visualisation technologies, e.g., cardboard, were scarcely considered and implemented (k = 3).

With reference to non-immersive technologies, the majority of the studies implemented PC or TV desktop-based VR. The application of CAVE technologies was almost restricted to the Engineering, Architecture & Design disciplinary field. The prevalence of immersive technologies appears to address researchers' interest in investigating the interrelation between the sense of presence and the quality of the learning experience, assessing if and how it can trigger the same feelings, sensations and learning outcomes of a real scenario. VR technologies with interactivity features were found to be more frequent compared to non-interactive VR. As noted in scientific literature (Petersen et al., 2022; Wang et al., 2021), interactivity is one of the key affordances of VR and plays a central role in the user experience. As illustrated in Fig. 11, VR with high interactivity features was the most assessed solution in the analysed studies. Studies exploited the interactivity potential of VR by designing learning scenarios that would allow change prompting and active manipulation of VR elements, such as simulations in 3D environments, with high degrees of freedom in navigation. Low interaction solutions, such as virtual tours with basic navigation controls, were generally less implemented. These features are directly connected to the learning experience designed in the assessment: in this sense, many of the studies exploited the opportunities of VR to create active learning experiences that would engage the user in first person. Activities like problem solving, serious games and simulation training were proved to be effectively deliverable through VR, allowing for embodied and experiential learning (Henriksen et al., 2023). Although interactivity is a feature which is not exclusively specific to VR, studies seem to agree upon the fact that a higher level of user interaction with VR elements can increase learning efficacy (Yang et al., 2023; Zhang et al., 2019). Fewer studies implemented Non-interactive VR (30%), mainly consisting in learners watching 360° videos, with no control over the VR experience. All Non-interactive VR cases counterbalanced the absence of interactivity with the presence of immersivity, proving to rely on immersion as the main affordance to be investigated in the assessment. As illustrated in Fig. 12, non-interactive VR was mostly utilised in Health Sciences and Biological, Chemical & Physical Sciences, in both cases to support learning through visualisation features. No study assessed both non-interactive and non-immersive VR solutions.

The nearly total absence of multi-user VR solutions in the analysed studies raises important questions regarding the advancement of research on VR technologies for learning. Indeed, even though such technologies offer the possibility of engaging in virtual interactions, it appears that most of the experimentations conceptualised VR learning as an individual experience. Although the expertise and resources needed to build multi-user VR systems can be significantly higher than those needed for single-user applications, the lack of comparative studies assessing collaborative learning experiences in VR environments appears peculiar and leaves a significant research gap. Indeed, given the benefits of cooperative learning (Laal & Ghodsi, 2012; Vuopala et al., 2016), as well as the potential support of virtual technology to collaboration in educational settings (Drey et al., 2022; Herrera-Pavo, 2021; Scavarelli et al., 2021), it would seem reasonable to explore VR as a social learning space in comparison with traditional methods. It is also significant to note that the CAVE technology implemented in the multi-user VR solutions only allowed the simultaneous visualisation of the VR environment, without offering possibilities of simultaneous interaction with it. As this research gap questions the role of VR in supporting Metaverse educational applications in the future, which are considered to be intrinsically social (Hennig-Thurau et al., 2023; Hwang &

Chien, 2022), the conduction of comparative assessments on the use of VR for collaborative learning appears to be a fundamental step to gain deeper knowledge on the relationship between education, VR and the Metaverse.

With reference to VR availability, as illustrated in Fig. 13, the results show a balance between commercial and non-commercial solutions, leaning towards the prevalence of the latter category. Non-commercial VR solutions consisted in self-developed and self-programmed native VR applications, requiring the use of 3D modelling and cross-platform game engines (e.g., SketchUp, 3ds Max, Blender, Unity, Unreal Engine) to develop VR environments. Going further into detail, while commercial solutions were mostly present in H&SS disciplines assessments and Health Sciences, non-commercial solutions appeared to be the most frequent case in the Engineering, Architecture & Design and Computer Science disciplinary fields. These findings appear to confirm how healthcare, representing an early adopter of this technology, benefits from a deeper knowledge on its application. In fact, Smutny's mapping of educational VR applications (2023) revealed that users' best-rated applications for immersive VR belong to areas connected to nature, space, medicine, art and history, underlining how the availability of applications for nature, art and psychology significantly increased between 2019 and 2021. However, the choice between commercial or custom VR systems seems to depend on researchers' skills and time resources, rather than on budget. Indeed, developing self-made VR is more time-consuming compared to purchasing an application from the marketplace (Smutny, 2022). Furthermore, even though commercially available VR applications are ready-made, they require the purchase of computationally adequate equipment if immersive (Smutny, 2022) which can equal the cost of developing VR systems (Kamińska et al., 2019).

However, it should be noted that the choice of software and hardware equipment and their respective technical limitations can affect the overall impact of VR on learning outcomes, as discussed in sub-section 4.4. Lastly, it is important to note how, among the self-developed VR applications, only two studies mention a usability assessment as part of the research protocol.

4.4. What teaching methodologies have been most widely used to evaluate VR solutions compared to traditional teaching solutions?

As illustrated in Fig. 14, VR-based teaching settings mostly included active learning methodologies or, in a smaller portion of studies, mixed methodologies. This result meets the researchers' expectations: indeed, studies proved to be assessing the potentials and limits of VR-based teaching solutions by investigating the opportunities they provide through their original features of immersivity and interactivity. Among active learning methodologies, the most common scenario in the analysed studies consists in active simulation-based learning, which involves direct interactions and experiential learning (Frasson & Blanchard, 2012). Such scenario represents an effective pathway to provide practice opportunities in higher education, especially with reference to technical, manual or procedure-related skills (Chernikova et al., 2020). This finding further explains the prevalence of experimentations in STEM disciplines, in which learning objectives are often related to the acquisition of operational skills. Simulation-based learning appears to specifically fit the needs of these disciplines, providing risk-free and realistic learning environments. However, simulation was proved to represent a useful resource also for the acquisition of social skills (Stavroulia et al., 2018). In this sense, VR solutions offer opportunities of situated learning (Schott & Marshall, 2018). Simulation-based learning appeared to rely on both immersivity and interactivity features. Another active learning methodology implemented in the analysed studies consisted in the use of serious games. As stated in Arias-Calderón et al. (2022) and Mansoory et al. (2021), serious games can increase intrinsic and extrinsic motivation, confidence and engagement, relying on goal setting dynamics and flow theories. However, using gamification as a part of the learning experience rather than as exclusive didactic mediator appears to be a more viable solution to ensure positive learning outcomes (Sanzana et al., 2022). Lastly, problem-solving activities, such as project-based learning, were found to be suitable for VR applications. In this case, VR technology can provide innovative tools to foster problem solving skills (Halabi, 2020; Ruiz-Cantisani et al., 2020) and field-specific competencies (Chang et al., 2022). With reference to lecture-based teaching methodologies, although constituting the smallest portion of analysed studies, 360° immersive videos were used as teaching material. Such a solution allows for the reproduction of 3D environments which can provide the user a sense of immersion, without giving them the opportunity to interact with or within it (Rosendahl & Wagner, 2023). According to the methodologies applied to VR-based teaching solutions, it also appears that VR has been most widely used to create individual learning experiences, even though scientific literature has also investigated the role of VR in supporting cooperative learning (van der Meer et al., 2023).

4.5. What is the impact of VR on learning outcomes emerging from the comparison with traditional teaching solutions?

Findings suggest that VR-based teaching solutions generally improve learning outcomes regardless of the teaching methodology considered as a baseline (Fig. 17). However, this result should be considered in light of the limitations of the analysed studies. Firstly, results of the comparative assessments might be biassed by the "novelty" effect introduced by the VR technologies. Indeed, such technologies are typically unfamiliar to people, especially if immersive. As observed in some studies (Jiménez et al., 2018; Zhao et al., 2020; Çoban & Göksu, 2022) this effect can increase student's motivation and engagement, improving learning experience and, consequently, learning outcomes (Kahu et al., 2015). In this sense, the novelty of the medium could translate into higher levels of attention or effort and lead to temporary higher learning gains (Huang et al., 2021).

On the other hand, unfamiliarity with technology could produce negative effects, resulting in high cognitive load (Chao et al., 2021; Frederiksen et al., 2020; Lo et al., 2022), which is often more related to immersive VR technologies (Juliano et al., 2022). The amount of information to handle during the VR experience, alongside the multiple sensory stimulations, can lead the students to poorer learning performances, distracting them from the achievement of the learning tasks (Frederiksen et al., 2020). Moreover, as shown in Fig. 15, the few cases in which VR-based solutions produced negative outcomes were registered within immersive VR technologies. In general, based on reported results, non-immersive VR seems to improve learning outcomes more than immersive VR. Despite it is well known how a preliminary training can eliminate or mitigate "novelty" effects (Miguel-Alonso et al., 2023), only 6 of the analysed studies mentioned the conduction of a VR training phase as part of the research protocol. Additionally, only 4 out of 71 studies carried out a longitudinal assessment to verify the long-term effect of the VR-based intervention on students' knowledge and skills acquisition and retention. The possibility of lower positive effects of VR connected to students' familiarisation with it remains mostly unexplored, while the body of works analysed seem to lean towards a bias connected to positive "novelty" effects, making it difficult to conclude whether VR has an overall positive or negative impact as a tool to be implemented consistently throughout extended periods of time (such as the time frame of a semester).

When considering VR's impact on learning outcomes based on immersivity and interactivity features, our findings appear to be consistent with those from Petersen et al. (2022), highlighting how such features have the potential to facilitate learning via presence and agency.

However, the comparison of Figs. 15 and 16 (learning impact of immersivity and interactivity) can suggest another hypothesis: interactive VR seems to be more successful in providing positive impacts compared to non-interactive VR (Fig. 16), while immersive VR and non-immersive VR show the opposite tendency (Fig. 15). As research illustrates the positive effects of students' active engagement n the learning experience (Deslauriers et al., 2019), VR interactive solutions were shown to be connected to better learning performances, in line with existing literature (Makransky & Petersen, 2021). Immersivity, although providing opportunities for embodied learning and realistic situated learning, might not always constitute an essential and decisive feature to ensure VR teaching success in terms of learning outcomes. Additionally, users are generally more familiar with non-immersive VR technologies (which mainly consist in traditional desktop or mobile based interfaces). This could result in a higher focus on learning tasks (with higher chances of positive learning outcomes) rather than on the exploration or enjoyment of the novel technology. Even though this assumption cannot be statistically supported considering the collected data, it seems that interactivity could have a greater impact on positive learning outcomes compared to immersivity.

The only cases in which VR methods appear to be less successful than traditional methods belong to the adoption of lecture-based learning methodologies, e.g., watching 360° videos (Fig. 17). However, given the scarce number of studies that experimented with VR teaching through this teaching solution, there is not sufficient evidence to fully understand VR's impact on learning in this application scenario. However, within the context of this study, this aspect can illustrate how relying solely on immersion without creating an active learning experience through VR can translate into a missed opportunity on exploiting VR's educational potential. Essentially, allowing the learner to have an active role appears to represent a priority in VR-driven education even when VR is being used for its visualisation opportunities, considering how "interactivity-triggered concept visualisation and animation are more effective for learning than automated visualisation and animation" (Zhang et al., 2019, p. 7). If, on one hand, the use of active, lecture-based or mixed methodologies to assess VR might be biassed from the "novelty" effect related to immersivity features, on the other, when isolating the variable of interactivity, its deeper connection to positive learning outcomes can be assessed with ease. Interactivity seems to increase learning outcomes regardless of the presence or absence of immersivity features (te.g., regardless of possible "novelty" effects). In conclusion, studies' results appear to indicate that interactivity - allowing for active learning experiences – represents a determining factor for VR teaching efficacy and a key affordance for its specificity. Immersivity, on the other hand, in addition to being less impactful on VR teaching efficacy according to the studies' findings, could sometimes represent a source of distraction or excessive cognitive load. The use of immersive virtual applications must also be carefully considered, as students may find interaction with such technologies unpleasant, experiencing known symptoms of motion-sickness, such as dizziness and nausea, during their use (Ruiz-Cantisani et al., 2020; Wilkerson et al., 2022).

Although most of the studies reported positive outcomes in the application of VR technologies to support learning - both in terms of learning performance and students' satisfaction - many studies highlight how current VR applications cannot efficiently replace traditional teaching. While current simulated environments seems to support the acquisition of declarative and procedural knowledge (e.g., Chan et al., 2021; Maresky et al., 2019; Morales-Vadillo et al., 2019), they can limit the acquisition of important skills and psychosocial aspects that are currently obtainable only through traditional teaching activities, e.g., cadaveric dissection (Kolla et al., 2020), laboratory activities (Hu-Au & Okita, 2021; Wilkerson et al., 2022), clinical training (Lee, 2022; Mcnamara et al., 2021). Finally, the adoption of VR technologies to support learning entails active teaching methodologies. This not only requires more lecture preparation time: it also demands more knowledge and skills from teachers (Liu, Zhang, & Zhou, 2020).

4.6. What is the impact of VR in the achievement of inclusive education?

None of the analysed studies involved students with special educational needs in the experimentation, such as people with disabilities or Specific Learning Disorders (SpLDs), leaving a comparative assessment on VR technology's potentials and limits as an inclusive educational tool in higher education contexts fully unexplored. In general, the application of VR in educational contexts to support equal learning opportunities is not an extraneous topic to scientific literature (Chițu et al., 2023). For instance, studies considered the relationship between VR and accessibility (Fromm et al., 2021) or its opportunities in increasing equality (Yildirim et al., 2018). In this context, VR can represent an opportunity to support people with disabilities in a self-determination perspective, allowing for empowerment processes (Nosek et al., 2016). However, research has also highlighted how these technologies can generate exclusion phenomena with reference to people with disability because of accessibility issues. If, on one hand, the presence of physical impairments could impede VR system configuration, proper equipment setup or efficient use of control functions, people with intellectual disabilities could experience sensory overload and other challenges, while people with visual or hearing impairments have more specific needs in order to successfully interact with a VR system. Essentially, the current barriers of VR can be considered as accessibility and usability challenges that, still to this day, have not been properly addressed by scientific research (Creed et al., 2023b). Not surprisingly, in line with these considerations, only 2 of the 71 analysed studies included a usability assessment on the implemented VR system. As highlighted in Creed et al. (2023a), technical, societal and economical barriers must be addressed by scientific literature as they are directly connected to the full participation of all people in VR environments, not only those with disabilities or special needs. As VR is being increasingly and consistently integrated within educational paths, the joint action of educational institutions, technical specialists, associations advocating for people with disabilities and other stakeholders is required to promote inclusive processes. Indeed, the introduction of such technologies raises important questions regarding the degree to which they can welcome students' diversity and meet their specific needs in an inclusive perspective, which appear to be still unanswered. In conclusion, the scientific and educational community must reflect deeply upon the inclusion perspectives arising from the introduction of these technologies.

5. Study limitations

Due to the nature of the review, selection, and filtering process, this work has several limitations. First, we limited our search to publications that appeared between 2018 and the first half of 2023, considering this time frame as a period in which virtual reality technologies, particularly HMDs, experienced a rapid diffusion driven by the availability of low-cost devices on the market. However, in doing so, we may have missed many studies that were published outside the time frame, possibly implementing less advanced or different VR technologies. This might have had an impact on the proportion between comparative studies assessing immersive VR and comparative studies assessing non-immersive VR solutions. Secondly, the choice of keywords composing the search string to collect the studies, as the considered digital libraries, could influence the breadth and representativeness of the results of this review: assuming to have captured the totality of studies related to this topic would be unrealistic. Another limitation of this study concerns the categories adopted for the qualitative analysis of the studies. Taking into consideration how each study presents different levels of detail concerning the description of VR features, study design and teaching methodologies, this SLR adopted broader categories to classify the selected studies objectively, relying on the information each study provides. If, on one hand, such a classification responds to the scope of this research, providing a systematic mapping, on the other it limits the depth of the analysis of each considered dimension. In this sense, this SLR could not include comparisons based on task design and learning experiences, even if such aspects could be relevant for further reflections as evidenced in other review studies (e.g., Won et al., 2023; Hamilton, McKechnie, Edgerton, & Wilson, 2021). This is due to the fact that the analysed studies are structured in different and multiple ways, describing their research method with different levels of detail and focusing on specific aspects on VR impact on education. Such an in-depth investigation would be a proper aim for a meta-analysis, which could certainly be conducted as a follow up to this research.

Furthermore, results of collected comparative studies may have limited generalisability due to variations in study designs, methodologies, and contexts. Additionally, in the comparison of learning impacts depending on VR features, we did not consider the actual sizes of the analysed studies. This implies the risk of producing biased results compared to those that would have been obtained through a meta-analysis. It is still important to note that the relationship between studies' sample size and the reliability of their results is not deterministic, given the diverse levels of quality that were assessed in this SLR. This highlights how we could not make broad implications on studies' quality and reliability based on sample size variances: for instance, some studies with large sample sizes were still assigned a low level of quality based on the adopted evaluation criteria. This should be carefully considered when making broader claims about the effectiveness of VR in higher education. For this reason, it was only possible to qualitatively analyse the collected findings, while the discussion was deepened only with reference to the aspects in which the studies were more closely aligned.

6. Conclusions and perspectives

The presented Systematic Literature Review explores the potentials and limits of VR technologies application within higher education contexts throughout the analysis of studies that assessed VR-based teaching solutions in comparison with traditional teaching solutions. Given the well-established scientific interest towards VR technologies for educational purposes, the aim of this study was to deepen the understanding on the potential and limits of such technologies by offering a comprehensive mapping. Such an endeavour opened reflections on several dimensions concerning VR application in higher educational contexts. Specifically, this SLR focused on analysing the disciplinary fields, the features of VR technologies and the teaching methodologies most widely assessed in comparison with traditional teaching methods. Additionally, this SLR focused on analysing the potentials and limits of VR in enhancing learning outcomes and achieving inclusive education based on the results of the analysed comparative studies. Results provide a comprehensive overview of the application scenarios, potentials and limitations of Virtual Reality in higher education contexts. While most studies report positive outcomes from the implementation of VR in higher education, specifically in terms of learning performance and students' engagement and satisfaction, Virtual Reality appeared to not represent a viable replacement of traditional teaching methods. The absence of assessments on its long-term effects, the limited acquisition of specific skills that can be achieved only through real-life situations, as well as related psychosocial aspects, high development costs and the need to design active learning experiences pose multiple challenges for its widespread adoption. However, a change of perspective on the role of VR in educational contexts appears to be reasonable. Indeed, instead of considering VR as a potential comprehensive learning environment to fully replace traditional real-life settings, the results of this SLR hint at how, in order to make the most out of this novel technology, VR might rather be interpreted and applied as a new didactic mediator to be thoughtfully implemented in an organic perspective: VR could be integrated alongside traditional mediators and methodologies, complementing them with the unique opportunities for learning it can provide. Therefore, VR could be considered as a means rather than an end, avoiding deterministic conclusions on its potentials and relating its use to the added value it offers (e.g., practice-oriented contexts, need for enhanced visualisation, integration to distance learning, possibility of training in safe environments). It appears that this context-related application represents a viable pathway to exploit VR's potential in creating original learning experiences in higher education contexts. This review also draws attention to the unexplored terrain of inclusive education within the application of VR technologies. Notably, the absence of studies involving students with special educational needs in the comparative assessments leaves a significant gap regarding the potentials and challenges of VR in contributing to inclusive learning environments. Accessibility and usability issues, alongside the design of tailored solutions to meet students' diversity, underscore the urgent need for further research in this crucial area.

Overall, this SLR offers a multidimensional perspective on the application of VR in higher education contexts, providing researchers and higher education institutions with crucial information on disciplinary fields scenarios, VR features and teaching methodologies that were assessed in comparison with traditional teaching by the most up to date scientific literature. In this sense, the findings of this SLR can serve as a guidance for the future application and integration of VR in education paths within the academic context, offering a bigger picture that aims at counterbalancing the multiple aspects connected to this specific topic.

In conclusion, there are many directions that further research could take. Firstly, future works should carry out longitudinal comparative studies to assess the actual impact of VR in higher education contexts eliminating or reducing "novelty" effects. With reference to disciplinary fields of application, comparative studies should be expanded beyond the realm of STEM disciplines, investigating the application of VR in H&SS fields, providing stronger evidence on the benefits and challenges of this technology in diverse academic domains. Moreover, the potential and limits of in achieving inclusive education should be properly assessed throughout the conduction of comparative studies involving students with special needs to understand the degree to which these technologies can be tailored to support different learning styles and needs. Currently, there are no accessibility guidelines on virtual environments, especially with reference to people with sensory or intellectual disabilities and SpLDs (Caldarelli et al., 2022, December). Such a gap highlights the need for studies that will provide the background for the creation of guidelines supporting the development of accessible virtual content.

Moreover, when considering the resources needed to implement VR solutions in higher education, on one hand, future works could investigate the impact of teachers' preparedness and training on the successful implementation of VR in education, unveiling how educators' skills, training and familiarity with VR technologies can influence the effectiveness of VR-integrated teaching. On the other hand, research could focus on the economic aspects of VR technologies application in education, comparing costs and benefits between self-made VR application and commercially available application with reference to budgetary constraints and long-term sustainability. The role of cultural and contextual factors could be influencing the effectiveness of VR-based education: in this sense, scientific literature could explore whether the impact of VR technologies in higher education is subject to variation across different cultural and educational contexts. Additionally, if VR appears to represent a viable didactic mediator to be integrated within educational paths, research should identify the proper approaches and strategies to operate an efficient incorporation of VR-based activities into traditional curricula without disrupting established teaching methods, identifying proper topics and contexts. Lastly, conducting a meta-analysis or systematic review that aggregates findings from multiple literature reviews in this domain could provide an even more comprehensive overview of the cumulative evidence on the topic and allow for the identification of consistent patterns across different studies.

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CRediT authorship contribution statement

Tommaso Santilli: Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Silvia Ceccacci:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Conceptualization. **Maura Mengoni:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis. **Catia Giaconi:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis.

Declarations of competing interes

None.

Data availability

No data was used for the research described in the article.

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