ISSN: 1130-3743 - e-ISSN: 2386-5660
DOI: https://doi.org/10.14201/teri.31921

A SYSTEMATIC REVIEW OF COLLABORATIVE LEARNING THROUGH VIRTUAL REALITY, AUGMENTED REALITY AND MIXED REALITY

Revisión sistemática sobre aprendizaje colaborativo mediante realidad virtual, realidad aumentada y realidad mixta

Joel Manuel PRIETO ANDREU
Universidad Internacional de La Rioja. Spain.
joelmanuel.prieto@unir.net
https://orcid.org/0000-0002-2981-0782

Date received: 26/03/2024
Date accepted: 16/05/2024
Online publication date: 01/01/2025

How to cite this article / Cómo citar este artículo: Prieto Andreu, J. M. (2025). Systematic Review of Collaborative Learning in Virtual Reality, Augmented Reality and Mixed Reality [Revisión sistemática sobre aprendizaje colaborativo mediante realidad virtual, realidad aumentada y realidad mixta]. *Teoría de la Educación. Revista Interuniversitaria*, 37(1), 151-186. https://doi.org/10.14201/teri.31921

ABSTRACT

The integration of augmented reality (AR), virtual reality (VR), and mixed reality (MR) in education holds great promise for advancing teaching and learning models that cater to the needs of 21st-century students. AR- and VR-based learning offer efficiency and total immersion, while MR merges the real world with the virtual world for overlapping experiences. However, there is a lack of studies that examine the pedagogical factors and potential benefits of collaborative learning in these environments. This work aims to conduct a systematic literature review to explore the impact of collaborative experiences facilitated by AR, VR, and MR. The rapid systematic review was prepared following the protocols of the PRISMA 2020 declaration in the selection of studies. This review analysed 62 studies centred on collaborative learning through AR, VR or MR, comprising 7 theoretical reviews, 21 experimental studies, and 34 observational studies. The criteria set out in the Guidance for Quality Assessment Tool of the National Heart, Lung, and Blood Institute (NHLBI, 2020) were followed. Technical limitations and a lack of instructional design hinder the usability of virtual reality and augmented reality in education. Real-world sessions and adequate interaction are suggested for monitoring and manipulating virtual content. Integrating MR technologies into higher education can enhance educational practice, but challenges remain. Further research is needed to assess their effectiveness in collaborative learning. By understanding the challenges and opportunities presented by these technologies in teaching scientific subjects, policymakers and educators can develop effective strategies to leverage current trends and foster meaningful educational change.

Keywords: augmented reality; virtual reality; mixed reality; collaboration; education; learning.

RESUMEN

La integración de la realidad aumentada (RA), la realidad virtual (RV) y la realidad mixta (RM) en la educación es muy prometedora para el avance de modelos de enseñanza y aprendizaje que satisfagan las necesidades de los estudiantes del siglo XXI. El aprendizaje basado en RA y RV ofrecen eficacia y total inmersión, mientras la RM fusiona el mundo real con el virtual para tener experiencias superpuestas. Sin embargo, son escasos los estudios que examinen los factores pedagógicos y los beneficios potenciales del aprendizaje colaborativo en estos entornos. Este trabajo tiene como objetivo realizar una revisión sistemática de la literatura para explorar el impacto de las experiencias colaborativas facilitadas por AR, VR y MR. Para la selección de estudios se ha elaborado la revisión sistemática rápida siguiendo los protocolos de la declaración PRISMA 2020. En esta revisión, se analizaron 62 estudios centrados en el aprendizaje colaborativo a través de AR, VR o MR, comprendiendo 7 revisiones teóricas, 21 estudios experimentales y 34 estudios observacionales. Se han seguido los criterios expuestos en la Guía para la Evaluación de Criterios de Calidad del Instituto Nacional del Corazón, los Pulmones y la Sangre (NHLBI, 2020). Las limitaciones técnicas y la falta de diseño instruccional obstaculizan la usabilidad de la realidad virtual y la realidad aumentada en la educación. Se sugieren sesiones del mundo real y una interacción adecuada para monitorear y manipular contenido virtual. La integración de tecnologías de RM en la educación superior puede mejorar la práctica educativa, pero persisten desafíos. Se necesitan más investigaciones para evaluar su eficacia en el aprendizaje colaborativo. Al comprender los desafíos y oportunidades que presentan estas tecnologías en la enseñanza de materias científicas, los formuladores de políticas y los educadores pueden desarrollar estrategias efectivas para aprovechar las tendencias actuales y fomentar un cambio educativo significativo.

Palabras clave: realidad aumentada; realidad virtual; realidad mixta; colaboración; educación; aprendizaje.

1. Introduction

Use of augmented reality (AR), virtual reality (VR), and mixed reality (MR) in education promises new teaching and learning models that cater to the needs of 21st-century students. There has been a striking growth in electronic learning, as distance education based on digital platforms has become popularised. Thanks to this, there has been a large increase in innovation in the educational sector. There is clearly growing interest in the use of AR, VR, and MR in education, backed by studies that have demonstrated their effectiveness for improving information retention, facilitating active learning, and providing immersive contextualised experiences (Ke & Hsu, 2015; Lindgren *et al.*, 2016; Mosher & Carreon, 2021; Vasilevski & Birt, 2020; Veer *et al.*, 2022; Wang *et al.*, 2021; Watson & Livingstone, 2018; Webb *et al.*, 2022). However, despite these advances, there are gaps in the understanding of how these technologies can be exploited effectively in collaborative learning environments. Consolidation of existing knowledge about the impact of collaborative experiences using AR, VR, and MR in education is needed. Furthermore, the importance of analysing and critically assessing the quality of the available studies – experimental and observational – to provide a complete and rigorous overview of the current state of the art in this area is apparent.

The technique of AR-based learning is an active-learning method as it can quickly and efficiently turn the information acquired into long-term memory (Santos *et al.*, 2014). Learning materials in the form of videos or as part of a simulation or a game are available for use by instructors to involve the students. According to Wanis (2019), AR combines real and virtual objects in its own environment and it is known as a technology that has the capacity to superimpose virtual objects in our real world in real time. Virtual reality, in turn, is generally known as a totally immersive computer technology that enables the user to interact with the digital working space in a unique way. By comparison, MR combines elements of the real and virtual worlds to create an immersive experience. It uses technologies such as AR and VR to superimpose digital objects in the physical environment.

According to Webb *et al.* (2022), many previous pieces of research have suggested that computer simulations can support the learning of difficult concepts by secondary students. Elmqaddem (2019) argues that, in the sector of education and training, it permits engineers, for example, to learn new procedures in real conditions. When encountering a new device, the learner can discover the disassembly procedure step-by-step, seeing the instructions appear in real time. *HoloLens*, for example, enables medical students to manipulate and visualise the human body with unprecedented precision. In the cultural sphere, augmented reality applications enable tourists or visitors to museums to discover the history of places or works just by pointing their smartphone's camera in its direction. According to Ke and Hsu (2015), *Wikitude*, a location-based mobile AR application, uses the GPS incorporated into mobile devices to track users' real locations and present contextually relevant virtual information about surrounding points of interest (for example, buildings, parks and shops). AR applications can also function without location restrictions and use images and objects from the real world as "triggers" to activate the superimposition of digital information to support learning. For example, the *Aurasma* application enables its users to see "Aura", multimedia artefacts that can be animations or video clips, by pointing their mobile devices at a designated trigger in the real world.

With regards to collaborative learning, mobile computer supported collaborative learning (MCSCL) is the practice of groups of individuals creating meaning in the context of a joint activity mediated through mobile computing (Ke & Hsu, 2015). In a recent review of empirical studies of MCSCL, Hsu and Ching (2013) found multiple ways in which mobile information mediated the creation of meaning in a joint activity.

In particular, wirelessly connected mobile devices can: 1) facilitate the exchange of information and the provision of instant commentaries; and 2) provide people with different parts of a group learning task and coordinate the interaction orientated towards the task. However, although Webb *et al.* (2022) suggest that virtual reality has benefits for learning, they conclude that there are insufficient studies examining what pedagogical factors can be important, or whether collaborative learning in these settings can be beneficial (Merchant *et al.*, 2014). Whewell *et al.* (2022) explored different combinations of immersive digital technologies through a connected community, noting that both connectivism and constructionism underline the importance of constructing social relations between students in a learning context. Alalwan *et al.* (2020) indicate that understanding the challenges posed by use of virtual reality and augmented reality in teaching science subjects would provide the means for educational policymakers to support the necessary measures to reflect effectively on current trends and thus bring about educational change.

The main aim of the present work is to carry out a systematic review of literature on the impact of collaborative experiences through the use of AR, VR, and MR. This review proposes a discussion of the objectives and contributions of the studies included in the review, as well as the limitations and challenges facing the implementation of these technologies in collaborative learning environments.

Likewise, the specific objectives of the review are to provide an umbrella review that establishes the current state of the art of the topic, to analyse and assess separately the quality of the experimental and observational studies included in the review, and to discuss the objectives and principal contributions of the studies included in the review and the limitations of the use of AR and VR in collaborative settings.

2. Method

The systematic review followed the protocols of the PRISMA 2020 declaration (Page *et al.*, 2021) in the selection of studies.

2.1. *Eligibility criteria*

The following inclusion criteria were used: studies written in Spanish and English; peer-reviewed manuscripts; works with full-text access. As exclusion criteria, doctoral theses and manuscripts from unreliable sources were rejected. The sample for the systematic review comprises studies that have used VR, AR or MR in collaborative teaching experiences, and studies that have theorised about their possibilities in the educational setting.

2.2. *Information sources and search strategy*

The search for studies was done on 23 May 2023 in two of the most important online databases in the areas of social sciences and health sciences: ISI Web of Science and SCOPUS. By editorial decision, the search for studies was updated for the final time on 13 May 2024. Table 1 shows the details of the searches in JCR and in SCOPUS, using the following search term: [collaborative learning AND VR OR virtual reality OR AR OR augmented reality OR MR OR mixed reality]. The search in SCOPUS was filtered by title, abstract and keywords, and in ISI Web of Science by TOPIC, since 2009. A quantitative ad-hoc table was prepared, ordered by year and assigning a record number to the studies that permitted their subsequent selection in the classification phase.

2.3. *Selection of studies and data extraction process*

During the review of the full text, the reviewer assessed the eligibility of the studies in accordance with the predefined inclusion and exclusion criteria. In this case, as one single person carried out the selection process in the study, it was important to ensure that the process was impartial and exhaustive. This was achieved by having a second reviewer independently examine a randomly selected subset of the studies to guarantee consistency in the selection process. With regards to the data extraction process, the data were extracted using a standardised form to guarantee consistency and precision. In this case, the data extraction was done by one single person and recorded in an Excel spreadsheet, which included information about the design of each study, the characteristics of the participants, the interventions, the results and the risk of bias, among other relevant aspects, helping ensure that the data would be complied in a consistent and precise way and thus improving the quality and reliability of the systematic review.

Moreover, to analyse the scientific production, the Guidance for Quality Assessment Tool for Systematic Reviews and Meta-Analyses of the National Heart, Lungs and Blood Institute (NHLBI, 2020) was used. The NHLBI guidance is a well-established and widely recognised tool in the field of health and medicine. Its use provides credibility and reliability to the assessment of the quality of the systematic review.

It also provides a standardised and systematic framework to assess the quality of scientific evidence, including considerations on the methodology of the studies included and the clarity and coherence in the presentation of the results among other relevant aspects for the thematic area of the present review.

The *Quality Assessment of Controlled Intervention Studies* scale was also used to assess the original experimental studies in which an intervention or treatment is implemented and is compared with a control group. This scale centres on various key methodological quality domains, such as study design, random allocation, allocation concealment, blinding of participants and assessors, comparability of the groups at the start of the study, handling of deviations from the protocol and the attrition rate, among others. Each domain is assessed against a series of specific criteria, and a score is assigned to each study according to whether these criteria are fulfilled. This allows a quantitative assessment of the quality of the studies included in the review.

Finally, the *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies* scale was used to assess the original observational studies, such as cohort studies and cross-sectional studies, that did not involve experimental interventions. Like the scale for experimental studies, this tool centres on various domains of methodological quality that are relevant to observational studies, such as study design, the size and representativeness of the sample, the validity and reliability of the measurements, the handling of confounding factors and biases, and the follow-up of participants. Each domain is assessed by means of specific criteria, and a score is assigned to each study according to its fulfilment, which allows a quantitative assessment of its quality.

Both tools are designed to be used by systematic reviewers as part of the process of critical assessment of scientific literature. They allow a standardised and rigorous assessment of the methodological quality of the studies included in the review, something that contributes to the validity and reliability of the findings of the review. To measure the quality of the experimental studies and of the controlled intervention or observational and transversal cohort studies, the quality criteria from the NHLBI (2020) quality assessment tools were followed, using cutoff points that define a quality scale of 1 to 4 stars depending on the number of criteria that were fulfilled [1 star, ★☆☆☆ (<3), 2 stars, ★★☆☆ (3–6), 3 stars, ★★★☆ (7–10), 4 stars, ★★★★ (11–14)]. The NHLBI quality assessment tools are not designed to assess the quality of articles in the field of education. However, responses provided above are based on the sections of the tool that are applicable to this review.

3. Results

The search gave 3227 results in SCOPUS (1656 conference proceedings, 978 journal articles, and 455 books), resulting in 36 reviews, 610 articles, 142 book chapters, and the rest unspecified. The search in WoS with the same search string, seeking words in the search fields by "title", gave 75963 results, leaving 2497 for the

TABLE 1
IDENTIFICATION AND CLASSIFICATION PHASES IN THE SYSTEMATIC REVIEW

Year	**Identification**		**Classification**	
	JCR	**SCOPUS**	**JCR**	**SCOPUS**
2024	210	183	63	47
2023	410	496	157	110
2022	420	487	116	78
2021	378	351	139	73
2020	316	287	114	57
2019	230	228	82	46
2018	123	164	44	32
2017	128	140	46	22
2016	82	109	22	17
2015	55	97	6	20
2014	28	117	6	12
2013	39	125	4	17
2012	27	108	8	13
2011	17	114	3	8
2010	16	100	3	15
2009	18	121	2	13

Source: Own elaboration, based on data extracted from WoS and SCOPUS

area of Educational Research in Education. In total, in the first phase of the identification, 5724 registers were identified. Table 1 shows the details of the searches in JCR and in SCOPUS.

In the second phase of classification, the search for articles was filtered by open access, and registers that did not comply with the inclusion and exclusion criteria were eliminated, giving a total of 696 results in SCOPUS and 815 results in WoS, leaving a total of 1511 registers. In the eligibility phase, and after reading the abstract, 1274 studies were rejected because they did not fulfil the inclusion criteria and were not related to the thematic line of the systematic review, resulting in 237 studies. Finally, in the article selection for review phase, 62 works were selected. Figure 1 is a flow chart of the article selection process.

This review analysed 62 studies centred on collaborative learning through AR, VR, and MR, including 7 theoretical reviews (Table 2, Annexe 1), 55 original studies, 21 experimental studies (5 VR, 8 AR, and 8 MR) (Table 3, Annexe 2) and 34 observational studies (10 VR, 5 AR, and 19 MR) (Table 4, Annexe 3). Taking the matrix of the 55 original studies included in the review, 15 studies (28 %) analyse the impact of collaborative work through VR, 13 studies (23 %) analyse the impact of collaborative work through AR, and 27 studies (49 %) analyse the impact of collaborative work through MR.

FIGURE 1
FLOWCHART OF THE ARTICLE SELECTION PROCESS

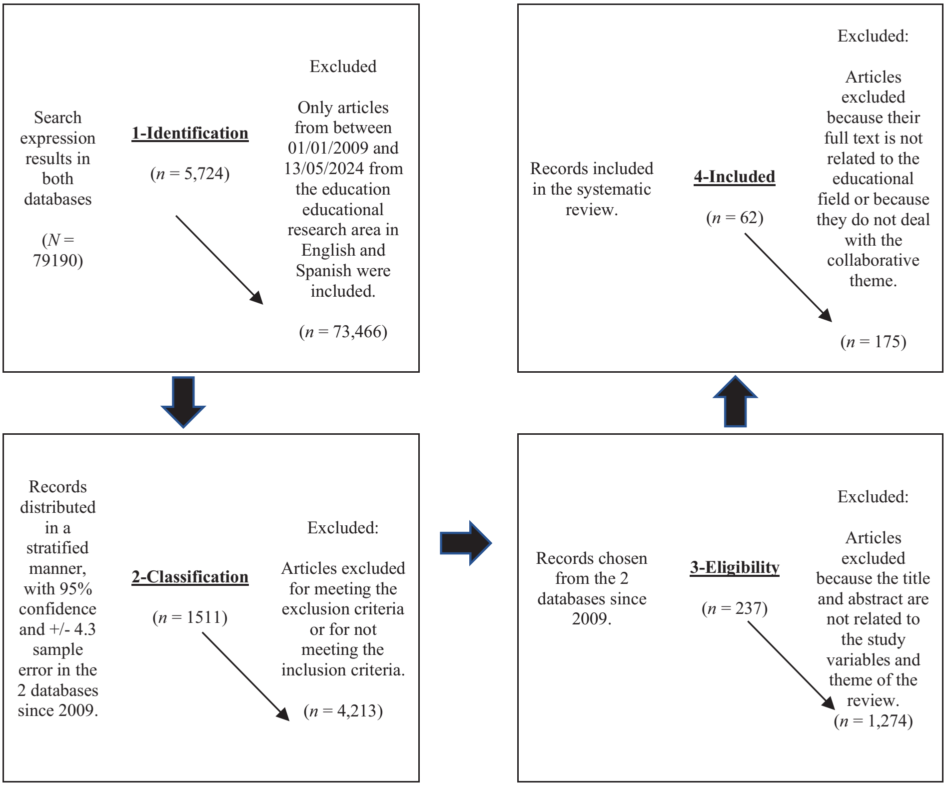


Figure 2 compares the percentages of fulfilment of each of the 14 assessment criteria from the *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies* to assess original observational studies on the one hand and, on the other, from the *Quality Assessment of Controlled Intervention Studies* to assess the original experimental studies.

Figure 3 compares the quality of the observational and experimental studies included in the systematic review.

It is apparent that the observational studies displayed greater quality than the experimental studies, taking into account the 14 assessment criteria from the two NHLBI tools. In decreasing order, 52 % of the observational studies scored 3 stars, 33 % scored 4 stars, 9 % scored 2 stars, and 6 % scored 1 star. On the other hand, 63 % of the experimental studies obtained 1, 26 % scored 2 stars, 11 % scored 3 stars, and 0 % scored 4 stars.

FIGURE 2
FULFILLMENT OF THE ASSESSMENT CRITERIA FROM THE NHLBI (2020) TOOLS

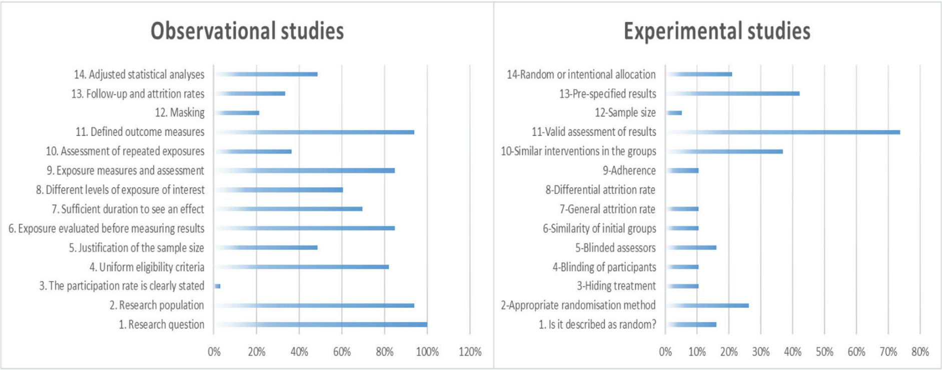
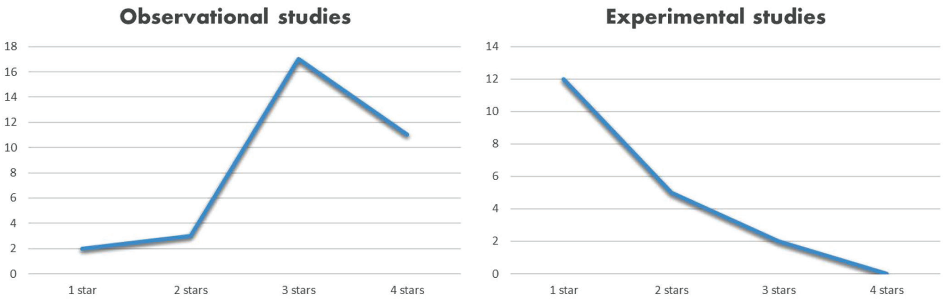


FIGURE 3
QUALITY OF THE OBSERVATIONAL AND EXPERIMENTAL STUDIES INCLUDED IN THE REVIEW



4. DISCUSSION

4.1. *Objectives and principal contributions of the studies included in the review*

The studies are centred on exploring the benefits and applications of AR and VR in education, as well as in collaborative learning. Many of them also seek to comprehend how these technologies can improve social interaction, creativity and the idea creation in collaborative learning (Rodríguez *et al.*, 2018; Sanabria & Lizárraga, 2017). Some of the studies included in the systematic review have the aim of exploring, developing and validating the effectiveness of VR and AR in collaborative learning (Ke & Hsu, 2015; Lindgren *et al.*, 2016; Veer *et al.*, 2022; Watson & Livingstone, 2018). These studies seek to investigate the ways these technologies can improve learning experiences, foster collaboration and improve academic performance in different areas, such as biology, technological education, geography and engineering, focussing on different age groups.

The studies also centre on the development of collaborative interfaces in VR and AR environments, as well as on identifying the effects of haptic systems and 3D models on learning (Kucukyilmaz & Issak, 2019; Webb *et al.*, 2022). Furthermore, some studies have compared the results of collaborative learning in virtual reality and augmented reality environments with traditional text books. Some studies have sought to compare the performance of students in virtual settings with the use of conventional text books (de Back *et al.*, 2020). Others seek to develop improved tools with AR and VR and assess their effectiveness in learning (Sanabria & Lizárraga, 2017), and others explore how technical limitations can be overcome to improve the experience of collaborative learning in AR and VR environments (Alhumaidan *et al.*, 2018; Ahsen *et al.*, 2019; Bekele *et al.*, 2021; Jovanović & Milosavljević, 2022; Rusli *et al.*, 2023)

Although some of the objectives of the studies that are centred on AR and VR can complement one another, there are some notable differences. Studies that centre on AR generally seek to examine how AR technology can improve the learning experience, for example, how AR can be used to improve comprehension of abstract concepts or to improve interaction between students and learning materials. Studies have also explored how AR can improve creativity and collaboration in class (Chung *et al.*, 2021; Matcha & Rambli, 2013; Sanabria & Lizárraga, 2017; Strada *et al.*, 2023).

In contrast, the studies that centre on virtual reality generally seek to examine how virtual reality technology can improve the immersive learning experience and provide students with a simulated environment for experiencing real-life situations (de Back *et al.*, 2020; Lindgren *et al.*, 2016; McArdle *et al.*, 2011). Studies have also been done to explore how virtual reality can improve collaboration and problem solving among students (Wang *et al.*, 2021; Webb *et al.*, 2022).

In summary, augmented-reality studies centre on how the technology can improve comprehension and interaction, while virtual-reality studies centre on providing an immersive simulated learning experience. In conclusion, these studies underline the importance of mixed reality in collaborative learning and they suggest that these technologies have the potential to improve collaborative learning and students' academic performance significantly. They also show that technologies can improve social interaction and creativity, significantly improving learning and collaboration in a close future.

With regards to the principal contributions of the articles reviewed, AR and VR are technologies with great potential in different areas of application, such as entertainment, tourism, architecture, medicine, education and industry. In particular, immersive virtual reality improves collaborative learning, especially in spatial awareness and navigation, and it can improve the participation of students in a collaborative problem-solving task and improve collaborative group communication (de Back *et al.*, 2020). It is also worth mentioning the potential of collaborative virtual environments (CVE) for supporting socio-communicative interactions in people with autism spectrum disorder (ASD) (Wallace *et al.*, 2017). Moreover, technological pedagogical content knowledge (TPACK) is important for teachers and students in designing and implementing educational technologies. In this sense, the design of mobile augmented reality devices tended to be better at promoting technological knowledge competences, while the visualisation on mobile phones with AR technology appeared to be better at supporting the development of content knowledge, in both cases increasing students' scientific interest and collaboration skills (Ke & Hsu, 2015).

AR and VR technologies have great potential to improve collaborative learning and socio-communicative interaction in different areas of application, but it is necessary to continue researching the use of these technologies in real educational environments and to assess their efficacy for improving learning and group collaboration (Wallace *et al.*, 2017). AR and VR are also effective tools for improving the education and understanding of the sciences, transforming passive learning into attractive interaction with 3D objects and improving students' motivation for the intervention (McArdle *et al.*, 2011; Stromberga *et al.*, 2021; Tüzün *et al.*, 2019; Watson & Livingstone, 2018; Webb *et al.*, 2022)

As for learning social skills, intervention through AR/VR has proven to be effective in the majority of the studies, which suggests that combining these technologies can provide a more effective intervention (Mosher & Carreon, 2021). In the field of medicine, AR and VR also improve learning of practical skills and comprehension of anatomy. In particular, MR has shown value for facilitating meaningful learning opportunities and improving students' knowledge of dynamic systems and control concepts (Richards, 2023). Likewise, VR and AR technologies are valuable tools that complement traditional teaching methods, providing an attractive and motivational educational experience. Nonetheless, their efficacy depends on various factors and requires more research.

4.2. *Limitations of the use of AR and VR in collaborative settings*

According to Fu and Liu (2018), because of the specific nature of construction projects, the use of AR/VR (for example, investing in hardware and simulation of construction) can result in a high cost and time spend. For virtual reality, the main drawbacks are an effect of limited immersion, inadequate sensory feedback (that is, the virtual sense predominates with less presence of the sense of hearing, haptic sense and others), lack of comfort for users (motion sickness, difficulties with the body), and the cost or accessibility of this technology. On this line, according to Elmqaddem (2019), better accessibility of VR and AR is the primary element that should help to popularise these technologies. Google was the pioneer in proposing low-cost virtual reality platforms and headsets, starting with Google Cardboard in 2014 (the first virtual reality platform and virtual reality headsets). In 2016, Google presented a new virtual reality platform and headset called *Daydream* (which costs under 50 euros). Given that the high importance of accessibility of virtual reality, *Oculus* has been working on a project for new displays. To benefit from higher quality virtual reality headsets such as *Oculus Rift*, an expensive computer is needed (that meets the needs of *Oculus Rift*). And *Oculus Rift* itself, cost 700 euros. According to Miller *et al*. (2020) portable headsets, like *Microsoft HoloLens*, are increasingly common and are an example of new technologies that are mature for further research from an educational research perspective. *Microsoft HoloLens* is a portable computer running Windows 11 that allows interaction with MR. The head-mounted display (HMD) superimposes three-dimensional (3D) virtual images on the real world, enabling users to interact with these holographic projections through voice commands and gestures. According to Sonntag and Bodensiek (2022), most of the research in this field is still limited to tablet-based augmented reality (AR), although MR through HMDs offers advanced possibilities to support students in laboratory-based learning activities: use of an HMD allows experimentation with the hands free, virtual representations or simulations can be shown and perceived three-dimensionally and superimposed on the physical environment more naturally, and intuitive gesture-based interaction with the virtual elements. Therefore, MR-HMD is able to combine laboratory learning with the advantages of interactive computer simulations such as *PheT*. The few studies that explicitly use MR-HMD indicate a positive impact on conceptual knowledge (Scaravetti & Doroszewski, 2019; Sonntag *et al*., 2019). The MR-HMDs recently available on the market, such as *Microsoft HoloLens 2*, which are used in the study by Sonntag and Bodensiek (2022), feature integrated eye tracking functions.

On the other hand, McArdle *et al*. (2011) suggested that while CLEV-R provides asynchronous access to reading material through the library, synchronous reading is where most learning occurs. As it offers both forms of e-learning, students can decide which they find more beneficial. CLEV-R also offers few opportunities for asynchronous online communication, such as message boards, email and forums. These can easily be incorporated into the design and form the focus of future studies to determine how they compare with the real-time communication that CLEV-R currently offers, and, ultimately, improve the students' learning experience. However, there are technical limitations on the use of MR technologies, especially in the AR subcategory, such as response time in collaborative environments. There will also be difficulties replicating MR experiments in real educational environments and scenarios, and an absence of assessment processes in collaborative educational environments that incorporate technologies in the continuum of virtuality with the introduction of new optical head-mounted displays (OHMD), such as *HoloLens*, *Oculus Rift*, and *HTC Vive*.

As for the difficulties of applying these technologies in an educational context, Jovanović and Milosavljević (2022) suggest that the educational aspects and problem solving through 3D avatars aspects could be a good way of personalising the experience and attracting users so that they support the platform. Nonetheless, monitoring students' activities is difficult because attention is centred on the virtual environment. It is suggested that real world class sessions are more reliable for the activities of the students. Alalwan *et al*. (2020) indicate that there is a shortage of guidelines for VR, with a lack of long-term participation in AR, a lack of instructional design, a lack of competence, and a lack of focussed attention in VR and AR being the most important factors to address to ensure its usability in the educational system.

As for interaction, according to Wanis (2019), VR technology is centred on replacing reality with a complete virtual environment. To manipulate virtual content in the AR and VR work space, adequate interaction is needed. Interaction is one of the most studied topics in research into virtual reality and augmented reality. Interaction with AR should work well when it is a case of using real objects to manipulate virtual objects.

The integration of MR technologies and mobile visualisation in higher education is an important contribution that can improve educational practice. AR, VR, and MR have the potential to improve scientific comprehension and education, and the combination of these technologies can provide a more effective intervention in the teaching of social skills. Although use of these emerging technologies in education has benefits, there are also challenges that must be faced, such as the lack of competence, limited instructional design, the lack of focussed attention, the lack of time, and limited environmental resources.

5. Conclusions

Augmented reality (AR) and virtual reality (VR) technologies have emerged as powerful tools in the field of education, especially for fostering collaborative learning. The studies reviewed reflect a varied focus, from exploring their benefits and applications to development of collaborative interfaces and comparison with traditional teaching methods. The following conclusions stand out in this review:

- The studies reviewed centre on exploring how AR and VR can improve the experience of collaborative learning and foster social interaction, creativity, and generation of ideas. Furthermore, the effectiveness of these technologies in various academic and age groups is investigated. VR is oriented towards the creation of simulated environments for immersive experiences, while AR is focussed on improving comprehension and interaction. Both technologies display significant potential to improve academic performance and group collaboration.
- Despite their potential, the use of AR and VR in collaborative environments faces significant challenges. These include high implementation costs, technological limitations such as inadequate sensory feedback, and limited accessibility. Furthermore, the lack of competence and appropriate instructional design, along

with the lack of high quality research works, represent barriers to their effective adoption in educational environments.

- Although the studies reviewed display promising results, further research is needed to fully understand the impact of these technologies on collaborative learning. It is crucial to consider the limitations identified and develop effective strategies for their implementation in real educational environments. This includes improving competence in the use of these technologies, designing effective pedagogical interventions and assessing their long-term efficacy.
- In light of the results, greater quality is needed in the experimental studies that consider collaborative experiences through the use of AR, VR, and MR. Moreover, further research is needed to determine the effectiveness of these technologies in collaborative learning in comparison with other teaching tools.

6. Limitations and potential lines for future research

Possible selection bias stands out as a potential limitation of the review, as this was done by a single reviewer, which could introduce biases. Furthermore, although an exhaustive search strategy in two major databases was used, the breadth of the sample of studies included might have been limited by restricting the language to Spanish and English and excluding doctoral theses. Moreover, despite the efforts to guarantee the exhaustiveness of the search, it is possible that some relevant studies were not identified and so are not included in the review. This could be because of limitations in the search terms used or lack of access to particular databases or information sources. Finally, there might be limitations in the assessment of the methodological quality, as, even though established tools were used to assess the quality of the studies included, such as the NHLBI quality assessment guidance, these tools might not be fully applicable to the field of education. This could limit the validity of assessments of methodological quality and, so, the reliability of the findings of the review. Despite these limitations, the systematic review provides an exhaustive overview of the current state of literature on the use of AR, VR, and MR in collaborative experiences in the educational context. Nonetheless, caution is recommended when interpreting the results and considering these limitations when applying the conclusions in educational practice or when designing future research in this field.

Regarding future lines of research, more research is needed to assess the effectiveness of AR and VR technologies in collaborative learning in comparison with other teaching tools. This includes studies that examine the impact on students' academic performance, social interaction and creativity. It is also crucial to investigate strategies to improve competence and training in the use of AR and VR technologies among educators and students. This could include the development of specific training programmes and the creation of clear guidelines for the design and implementation of educational activities based on these technologies. Finally, research into how to design effective educational settings that appropriately integrate AR and VR technologies is recommended. This includes exploring different pedagogical focuses and assessment methods that make the most of the potential of these technologies to improve collaborative learning. As a corollary, while AR and VR offer exciting opportunities to transform collaborative learning, it is necessary to tackle key challenges and continue researching to exploit fully their potential in the educational environment.

Funding

This work was funded under the 2022–2023 Call for Grants for Foreign Research Visits of the Universidad Internacional de La Rioja (UNIR).

References

Ahsen, T., Dogar, F. R., & Gardony, A. L. (2019). *Exploring the impact of network impairments on remote collaborative augmented reality applications*. In Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (pp. 1-6). https://doi.org/10.1145/3290607.3312774

Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Alzahrani, A. I., & Sarsam, S. M. (2020). Challenges and prospects of virtual reality and augmented reality utilization among primary school teachers: A developing country perspective. *Studies in Educational Evaluation, 66,* 100876. https://doi.org/10.1016/j.stueduc.2020.100876

Alhumaidan, H., Lo, K. P. Y., & Selby, A. (2018). Co-designing with children a collaborative augmented reality book based on a primary school textbook. *International Journal of Child-Computer Interaction, 15*, 24-36. https://doi.org/10.1016/j.ijcci.2017.11.005

Ali, A. A., Dafoulas, G. A., & Augusto, J. C. (2019). Collaborative educational environments incorporating mixed reality technologies: A systematic mapping study. *IEEE Transactions on Learning Technologies, 12(*3), 321-332. http://dx.doi.org/10.1109/tlt.2019.2926727

Baratz, G., Sridharan, P. S., Yong, V., Tatsuoka, C., Griswold, M. A., & Wish-Baratz, S. (2022). Comparing learning retention in medical students using mixed-reality to supplement dissection: a preliminary study. *International Journal of Medical Education, 13,* 107. https://doi.org/10.5116/ijme.6250.0af8

Bekele, M. K., Champion, E., McMeekin, D. A., & Rahaman, H. (2021). The Influence of Collaborative and Multi-Modal Mixed Reality: Cultural Learning in Virtual Heritage. *Multimodal Technologies and Interaction, 5*(12), 79. https://doi.org/10.3390/mti5120079

Birt, J., Moore, E., & Cowling, M. (2017). Improving paramedic distance education through mobile mixed reality simulation. *Australasian Journal of Educational Technology, 33*(6). https://doi.org/10.14742/ajet.3596

Bölek, K. A., De Jong, G., Van der Zee, C. E., van Cappellen van Walsum, A. M., & Henssen, D. J. (2022). Mixed–methods exploration of students' motivation in using augmented reality in neuroanatomy education with prosected specimens. *Anatomical Sciences Education, 15*(5), 839-849. https://doi.org/10.1002/ase.2116

Bonnat, C., & Sanchez, E. (2022). Toward a Digital Companion to Monitor a Mixed Reality Game. *International Journal of Serious Games, 9*(3), 5-21. https://doi.org/10.17083/ijsg.v9i3.504

Bork, F., Lehner, A., Eck, U., Navab, N., Waschke, J., & Kugelmann, D. (2021). The effectiveness of collaborative augmented reality in gross anatomy teaching: a quantitative and qualitative pilot study. *Anatomical Sciences Education, 14*(5), 590-604. https://doi.org/10.1002/ase.2016

Chung, C. Y., Awad, N., & Hsiao, I. H. (2021). Collaborative programming problem-solving in augmented reality: Multimodal analysis of effectiveness and group collaboration. *Australasian Journal of Educational Technology, 37*(5), 17-31. https://doi.org/10.14742/ajet.7059

de Back, T. T., Tinga, A. M., Nguyen, P., & Louwerse, M. M. (2020). Benefits of immersive collaborative learning in CAVE-based virtual reality. *International Journal of Educational Technology in Higher Education, 17*(1), 1-18. https://doi.org/10.1186/s41239-020-00228-9

Dolezal, M., Chmelik, J., & Liarokapis, F. (2020). *An immersive virtual environment for collaborative geovisualization*. arXiv preprint arXiv:2010.06279. https://doi.org/10.1109/vs-games.2017.8056613

Doumanis, I., Economou, D., Sim, G. R., & Porter, S. (2019). The impact of multimodal collaborative virtual environments on learning: A gamified online debate. *Computers & Education,* 130, 121-138. https://doi.org/10.1016/j.compedu.2018.09.017

Du, J., & DeWitt, D. (2023). Technology acceptance of a wearable collaborative augmented reality system in learning chemistry among junior high school students. *Journal of Pedagogical Research, 8*(1), 106-119. https://doi.org/10.33902/jpr.202425282

Elmqaddem, N. (2019). Augmented reality and virtual reality in education. Myth or reality?. *International journal of emerging technologies in learning, 14*(3). https://doi.org/10.3991/ijet.v14i03.9289

Essmiller, K., Asino, T. I., Ibukun, A., Alvarado-Albertorio, F., Chaivisit, S., Do, T., & Kim, Y. (2020). Exploring mixed reality based on self-efficacy and motivation of users. *Research in Learning Technology, 28,* 1-14. https://doi.org/10.25304/rlt.v28.2331

Frank, J. A., & Kapila, V. (2017). Mixed-reality learning environments: Integrating mobile interfaces with laboratory test-beds. *Computers & Education, 110,* 88-104. https://doi.org/10.1016/j.compedu.2017.02.009

Fu, M., & Liu, R. (2018). *The application of virtual reality and augmented reality in dealing with project schedule risks*. In Proceedings of the Construction Research Congress (pp. 429-438). https://doi.org/10.1061/9780784481264.042

Ghobadi, M., Shirowzhan, S., Ghiai, M. M., Mohammad Ebrahimzadeh, F., & Tahmasebinia, F. (2022). Augmented reality applications in education and examining key factors affecting the users' behaviors. *Education Sciences, 13*(1), 10. https://doi.org/10.3390/educsci13010010

Hamzah, F., Abdullah, A. H., & Ma, W. (2024). Advancing Education through Technology Integration, Innovative Pedagogies and Emerging Trends: A Systematic Literature Review. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 41*(1), 44-63. https://doi.org/10.37934/araset.41.1.4463

Hsu, Y. C., & Ching, Y. H. (2013). Mobile app design for teaching and learning: Educators' experiences in an online graduate course. *International Review of Research in Open and Distributed Learning, 14(*4), 117-139. https://doi.org/10.19173/irrodl.v14i4.1542

Jovanović, A., & Milosavljević, A. (2022). VoRtex Metaverse platform for gamified collaborative learning. *Electronics, 11*(3), 317. https://doi.org/10.3390/electronics11030317

Ke, F., & Hsu, Y. C. (2015). Mobile augmented-reality artifact creation as a component of mobile computer-supported collaborative learning. *The Internet and Higher Education, 26*, 33-41. https://doi.org/10.1016/j.iheduc.2015.04.003

Kucukyilmaz, A., & Issak, I. (2019). Online identification of interaction behaviors from haptic data during collaborative object transfer. *IEEE Robotics and Automation Letters, 5*(1), 96-102. https://doi.org/10.1109/lra.2019.2945261

Leonard, S. N., & Fitzgerald, R. N. (2018). Holographic learning: A mixed reality trial of Microsoft HoloLens in an Australian secondary school. *Research in Learning Technology, 26*. https://doi.org/10.25304/rlt.v26.2160

Li, C., Jiang, Y., Ng, P. H., Dai, Y., Cheung, F., Chan, H. C., & Li, P. (2024). *Collaborative Learning in the Edu-Metaverse Era: An Empirical Study on the Enabling Technologies*. IEEE Transactions on Learning Technologies. https://doi.org/10.1109/tlt.2024.3352743

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education, 95*, 174-187. https://doi.org/10.1016/j.compedu.2016.01.001

Lu, S. J., Lin, Y. C., Tan, K. H., & Liu, Y. C. (2022). Revolutionizing elementary disaster prevention education and training via augmented reality-enhanced collaborative learning. *International Journal of Engineering Business Management, 14,* 1-11. https://doi.org/10.1177/18479790211067345

Matcha, W., & Rambli, D. R. A. (2013). Exploratory study on collaborative interaction through the use of augmented reality in science learning. *Procedia computer science, 25,* 144-153. https://doi.org/10.1016/j.procs.2013.11.018

McArdle, G., Schön, B., & Bertolotto, M. (2011). *Assessing the application of 3D collaborative interfaces within an immersive virtual university*. In Virtual Immersive and 3D Learning Spaces: Emerging Technologies and Trends (pp. 1-24). IGI Global. https://doi.org/10.4018/978-1-61692-825-4.ch001

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education, 70,* 29-40. https://doi.org/10.1016/j.compedu.2013.07.033

Miller, J., Hoover, M., & Winer, E. (2020). Mitigation of the Microsoft HoloLens' hardware limitations for a controlled product assembly process. *The International Journal of Advanced Manufacturing Technology, 109,* 1741-1754. https://doi.org/10.1007/s00170-020-05768-y

Minty, I., Lawson, J., Guha, P., Luo, X., Malik, R., Cerneviciute, R., ... & Martin, G. (2022). The use of mixed reality technology for the objective assessment of clinical skills: a validation study. *BMC Medical Education, 22*(1), 639. https://doi.org/10.1186/s12909-022-03701-3

Mosher, M. A., & Carreon, A. C. (2021). Teaching social skills to students with autism spectrum disorder through augmented, virtual and mixed reality. *Research in Learning Technology, 29*. https://doi.org/10.25304/rlt.v29.2626

Motejlek, J., & Alpay, E. (2021). Taxonomy of virtual and augmented reality applications in education. *IEEE transactions on learning technologies, 14*(3), 415-429. https://doi.org/10.1109/tlt.2021.3092964

National Heart, Lung, and Blood Institute (NHLBI) (2020). *Study quality assessment tools.*

Niculescu, A., & Thorsteinsson, G. (2011). Enabling idea generation through computer-assisted collaborative learning. *Studies in Informatics and Control, 20*(4), 403-410. https://doi.org/10.24846/v20i4y201108

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Alonso-Fernández, S. (2021). Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas. *Revista Española de Cardiología, 74*(9), 790-799. https://doi.org/10.1016/j.recesp.2021.10.020

Pan, X., Zheng, M., Xu, X., & Campbell, A. G. (2021). Knowing your student: targeted teaching decision support through asymmetric mixed reality collaborative learning. *IEEE Access, 9,* 164742-164751. https://doi.org/10.1109/access.2021.3134589

Peramunugamage, A., Ratnayake, U. W., & Karunanayaka, S. P. (2022). Systematic review on mobile collaborative learning for engineering education. *Journal of Computers in Education, 10*(1), 83-106. https://doi.org/10.1007/s40692-022-00223-1

Pickering, J. D., Panagiotis, A., Ntakakis, G., Athanassiou, A., Babatsikos, E., & Bamidis, P. D. (2022). Assessing the difference in learning gain between a mixed reality application and drawing screencasts in neuroanatomy. *Anatomical Sciences Education, 15*(3), 628-635. https://doi.org/10.1002/ase.2113

Radu, I., Tu, E., & Schneider, B. (2020). *Relationships between body postures and collaborative learning states in an augmented reality study.* En Artificial Intelligence in Education: 21st International Conference, AIED 2020, Ifrane, Morocco, July 6–10, 2020, Proceedings, Part II 21 (pp. 257-262). Springer International Publishing. https://doi.org/10.1007/978-3-030-52240-7_47

Richards, S. (2023). Student Engagement Using HoloLens Mixed-Reality Technology in Human Anatomy Laboratories for Osteopathic Medical Students: an Instructional Model. *Medical Science Educator*, 1-9. https://doi.org/10.1007/s40670-023-01728-9

Robinson, B. L., Mitchell, T. R., & Brenseke, B. M. (2020). Evaluating the use of mixed reality to teach gross and microscopic respiratory anatomy. *Medical Science Educator, 30*(4), 1745-1748. https://doi.org/10.1007/s40670-020-01064-2

Rodriguez, C., Hudson, R., & Niblock, C. (2018). Collaborative learning in architectural education: Benefits of combining conventional studio, virtual design studio and live projects. *British Journal of Educational Technology, 49*(3), 337-353. https://doi.org/10.1111/bjet.12535

Rusli, K. D. B., Lau, S. T., Tan, J. Z., & Liaw, S. Y. (2023). Academic-Practice Collaboration Using Virtual Telesimulation to Support Students' Clinical Practice. *Nurse Educator, 48(*1), E6-E10. https://doi.org/10.1097/nne.0000000000001243

Sanabria, J. C., & Lizárraga, J. (2017). Enhancing 21st century skills with AR: Using the gradual immersion method to develop collaborative creativity. *Eurasia Journal of Mathematics, Science and Technology Education, 1*3(2), 487-501. https://doi.org/10.12973/eurasia.2017.00627a

Santos, M. E. C., Chen, A., Taketomi, T., Yamamoto, G., Miyazaki, J., & Kato, H. (2014). Augmented reality learning experiences: survey of prototype design and evaluation. *IEEE Transactions on Learning Technologies, 7,* 38–56. https://doi.org/10.1109/tlt.2013.37

Scaravetti & D. Doroszewski (2019). Augmented reality experiment in higher education, for complex system appropriation in mechanical design, *Procedia CIRP, 84,* 197. https://doi.org/10.1016/j.procir.2019.04.284

Schaffernak, H., Moesl, B., Vorraber, W., Holy, M., Herzog, E. M., Novak, R., & Koglbauer, I. V. (2022). Novel mixed reality use cases for pilot training. *Education Sciences, 12*(5), 345. https://doi.org/10.3390/educsci12050345

Shore, J., Ravindran, A. V., Gonzalez, V. A., & Giacaman, N. (2023). Using augmented reality in aec tertiary education: a collaborative design case. *Journal of Civil Engineering Education, 149*(1), 04022009. https://doi.org/10.1061/(asce)ei.2643-9115.0000069

Silseth, K., Steier, R., & Arnseth, H. C. (2024). Exploring students' immersive VR experiences as resources for collaborative meaning making and learning. *International Journal of Computer-Supported Collaborative Learning,* 1-26. https://doi.org/10.1007/s11412-023-09413-0

Simone, M., Galati, R., Barile, G., Grasso, E., De Luca, R., Cartanese, C., ... & Grassi, G. (2021). Remote mentoring in laparotomic and laparoscopic cancer surgery during Covid-19 pandemic: an experimental setup based on mixed reality. *Medical Education Online, 26*(1), 1996923. https://doi.org/10.1080/10872981.2021.1996923

Sofianidis, A. (2022). Why do students prefer augmented reality: A mixed-method study on preschool teacher students' perceptions on self-assessment AR quizzes in science education. *Education sciences, 12*(5), 329. https://doi.org/10.3390/educsci12050329

Sonntag, G. Albuquerque, M. Magnor, & O. Bodensiek (2019). Hybrid learning environments by data-driven augmented reality. *Procedia Manuf., 31*, 32. https://doi.org/10.1016/j.promfg.2019.03.006

Sonntag, D., & Bodensiek, O. (2022). How mixed reality shifts visual attention and success in experimental problem solving. *Physical Review Physics Education Research, 18*(2), 023101. https://doi.org/10.1103/physrevphyseducres.18.023101

Stojanovska, M., Tingle, G., Tan, L., Ulrey, L., Simonson-Shick, S., Mlakar, J., ... & Wish-Baratz, S. (2020). Mixed reality anatomy using Microsoft HoloLens and cadaveric dissection: a comparative effectiveness study. *Medical science educator, 30,* 173-178. https://doi.org/10.1007/s40670-019-00834-x

Strada, F., Lopez, M. X., Fabricatore, C., dos Santos, A. D., Gyaurov, D., Battegazzorre, E., & Bottino, A. (2023). Leveraging a collaborative augmented reality serious game to promote sustainability awareness, commitment and adaptive problem-management. *International Journal of Human-Computer Studies, 172,* 102984. https://doi.org/10.1016/j.ijhcs.2022.102984

Stromberga, Z., Phelps, C., Smith, J., & Moro, C. (2021). *Teaching with disruptive technology: the use of augmented, virtual, and mixed reality (HoloLens) for disease education.* In Biomedical Visualisation (pp. 147-162). Springer, Cham. https://doi.org/10.1007/978-3-030-61125-5_8

Tüzün, H., Bilgiç, H. G., & Elçi, S. Y. (2019). The effects of 3D multi-user virtual environments on collaborative learning and social presence. International Electronic *Journal of Elementary Education, 11*(3), 221-231. https://doi.org/10.26822/iejee.2019349247

Vasilevski, N., & Birt, J. (2020). Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments. *Research in Learning Technology, 28*. https://doi.org/10.25304/rlt.v28.2329

Veer, V., Phelps, C., & Moro, C. (2022). Incorporating mixed reality for knowledge retention in physiology, anatomy, pathology, and pharmacology interdisciplinary education: a randomized controlled trial. *Medical Science Educator,* 1-8. https://doi.org/10.1007/s40670-022-01635-5

Wallace, S., Parsons, S., & Bailey, A. (2017). Self-reported sense of presence and responses to social stimuli by adolescents with autism spectrum disorder in a collaborative virtual reality environment. *Journal of Intellectual & Developmental Disability, 42*(2), 131-141. https://doi.org/10.3109/13668250.2016.1234032

Wang, A., Thompson, M., Uz-Bilgin, C., & Klopfer, E. (2021). Authenticity, interactivity, and collaboration in virtual reality games: Best practices and lessons learned. *Frontiers in Virtual Reality, 130.* https://doi.org/10.3389/frvir.2021.734083

Wanis, I. A. (2019). *A review on collaborative learning environment across virtual and augmented reality technology*. In IOP Conference Series: Materials Science and Engineering (Vol. 551, No. 1, p. 012050). IOP Publishing. https://doi.org/10.1088/1757-899x/551/1/012050

Watson, P., & Livingstone, D. (2018). Using mixed reality displays for observational learning of motor skills: A design research approach enhancing memory recall and usability. *Research in Learning Technology, 26.* https://doi.org/10.25304/rlt.v26.2129

Webb, M., Tracey, M., Harwin, W., Tokatli, O., Hwang, F., Johnson, R., ... & Jones, C. (2022). Haptic-enabled collaborative learning in virtual reality for schools. *Education and Information Technologies, 27(*1), 937-960. https://doi.org/10.1007/s10639-021-10639-4

Whewell, E., Caldwell, H., Frydenberg, M., & Andone, D. (2022). Changemakers as digital makers: Connecting and co-creating. *Education and Information Technologies, 27*(5), 6691-6713. https://doi.org/10.1007/s10639-022-10892-1

Xefteris, S., & Palaigeorgiou, G. (2019). Mixing educational robotics, tangibles and mixed reality environments for the interdisciplinary learning of geography and history. International Journal of Engineering Pedagogy, 9(2), 82-98. https://doi.org/10.3991/ijep.v9i2.9950

Annexe 1

Table 2 presents an analysis of 7 literature reviews to establish the current state of the art relating to the topic, setting out the objective, the questions raised in the search process and the contribution of each review, as well as the 8 criteria set out in the Guidance for Quality Assessment Tool for Systematic Reviews and Meta-Analyses.

Although the reviews have some strengths, such as well-defined research questions and clear presentation of the studies included, they lack transparency in the methodology used to carry out the literature search and assess the quality of the studies and they do not report on the assessment of publication bias. The majority of the reviews include a high-quality systematic mapping study that complies with most of the criteria for quality assessment, including having a clear research question, an exhaustive literature search, an independent second review of the studies for their inclusion and exclusion, and an independent assessment of the quality of the studies included. Nonetheless, the majority of the reviews did not report whether publication bias was assessed.

TABLE 2

7 REVIEWS INCLUDED IN THE SYSTEMATIC REVIEW

Authors	Objective	Questions	Principal contributions	Quality Assessment Tool for Systematic Reviews and Meta-Analyses (NHLBI)							
				1	2	3	4	5	6	7	8
Elmqaddem (2019). Augmented reality and virtual reality in education. Myth or reality?	To explain the reasons behind the new surge in AR and VR and why their adoption will be a reality in education in the near future.	1- What means that augmented reality and virtual reality are no longer just a myth? 2- Why are AR and VR a real new improvement to teaching and learning? 3- What makes them more suitable for the student of the 21st century than the different learning methods we have known up to now?	The principal areas of application of augmented reality (AR) are listed, such as entertainment, tourism, architecture, medicine, education and industry.	Y	Y	NR	NR	NR	Y	NR	NA
Ali *et al*. (2019). Collaborative educational environments incorporating mixed reality technologies: A systematic mapping study.	To review the literature from 2007 to 2017 on collaborative educational environments that incorporate VR.	1- What are the different types, benefits and challenges of the use of virtual and augmented reality technologies in education? 2- How can virtual and augmented reality be integrated into teaching practices to improve students' results? 3- What are the types, benefits, challenges and integration of virtual and augmented reality in education for better student results?	The results underlined the lack of result in all of the spectrum of MR, especially in AR, as well as technical limitations such as the response time and the absence of assessment processes in collaborative educational environments.	Y	Y	Y	Y	Y	Y	NR	NA

Authors	**Objective**	**Questions**	**Principal contributions**	**Quality Assessment Tool for Systematic Reviews and Meta-Analyses (NHLBI)**							
				1	2	3	4	5	6	7	8
Peramunugamage *et al*. (2022). Systematic review on mobile collaborative learning for engineering education.	To determine the extent to which research was carried out on mobile collaborative learning in the field of education in engineering between 2010 and 2020.	1- What is the efficacy of mobile collaborative learning to improve education in engineering? 2- What are the benefits and challenges of implementing collaborative mobile learning in education in engineering?	Forty-eight articles were reviewed to determine research methodologies and study areas for collaborative mobile applications in education and engineering. AR was principally used in computing and electronic engineering, with potential for collaborative virtual laboratories in engineering study plans.	Y	Y	Y	Y	Y	Y	NR	ND
Wang *et al*. (2021). Authenticity, interactivity, and collaboration in virtual reality games: best practices and lessons learned.	To review how collaborative learning environments in virtual reality (CLEVR) influence learning.	1- How can virtual reality games be designed to promote authentic learning experiences? 2- What are the key elements of collaboration that should be incorporated into virtual reality games to improve learning outcomes?	Collaborative learning in virtual reality practices was reviewed. It was found that authentic representations improve learning but require more time and resources. Interactive experiences help learn spatial relations better than 2D ones.	Y	NA	NA	NA	NA	NA	NA	NA

(*continued*)

Table 2

7 reviews included in the systematic review (*continued*)

Authors	**Objective**	**Questions**	**Principal contributions**	**Quality Assessment Tool for Systematic Reviews and Meta-Analyses (NHLBI)**							
				1	2	3	4	5	6	7	8
Pan *et al*. (2021). Knowing your student: targeted teaching decision support through asymmetric mixed reality collaborative learning.	To understand the functioning of collaborative virtual environments (CVE) created through mixed reality (MR) technologies.	1- How can collaborative mixed reality learning be used to support the taking of specific teaching decisions? 2- What is the role of collaborative learning by asymmetric MR in improving teacher–student interactions? 3- What are the characteristics and key benefits of the use of mixed reality collaborative learning for specific teaching in education?	The classification of mixed reality CVEs as symmetrical/asymmetrical, with LFD for auto-stereoscopic visualisation in asymmetrical CVEs is presented. LFD used in MR based veterinary training to reduce the costs of the devices.	Y	NA	NA	NA	NA	NA	NA	NA
Motejlek & Alpay (2021). Taxonomy of virtual and augmented reality applications in education.	To analyse existing taxonomies of virtual and augmented reality.	1- What are the different types of virtual and augmented reality applications that have been used in education? 2- How have virtual and augmented reality technologies been used to improve teaching and learning in diverse educational settings?	Existing of virtual- and augmented-reality taxonomies are analysed, showing gaps in knowledge and inconsistent terminology that causes confusion. It centres on technology, content, gamification and operation.	Y	Y	Y	Y	N	Y	N	NA

Authors	Objective	Questions	Principal contributions	Quality Assessment Tool for Systematic Reviews and Meta-Analyses (NHLBI)							
				1	2	3	4	5	6	7	8
Hamzah, F., Abdullah, A. H., & Ma, W. (2024). Advancing Education through Technology Integration, Innovative Pedagogies and Emerging Trends: A Systematic Literature Review.	To review the advance of education through integration of technology, pedagogical innovation, and emerging trends, to improve student participation, their critical thinking skills and access to resources.	1-How has the advance of education through the integration of technology, innovative pedagogies and emerging trends become a driving force to transform the learning panorama?	Technology in education improves learning, but it presents challenges such as security and inequality. Online supervision and better infrastructure are recommended. Trends such as gamification promise advances, with attention to socio-economic disparities and sustainability. Virtual reality platforms offer immersive and personalised educational experiences, and augmented reality provides a magic lantern view of physical objects that simplifies and facilitates the learning process.	Y	Y	Y	ND	ND	Y	ND	ND

*Y, yes; N, no; ND, not determined; NA, not applicable; NR, not reported

Annexe 2

Table 3 shows the objectives and contributions of the 21 experimental studies included in the review, as well as the assessment of their quality in view of the assessment of the quality of the controlled intervention studies.

Most of these studies have a design that does not involve randomisation, their groups were similar at the start of the study in important characteristics that could affect the results, and they did not report the general attrition rate of the study nor the differential attrition rate between the treatment groups at the end of the study. On the other hand, some studies did not involve interventions, and so fulfilment of the intervention protocols or the similarity of the background treatments is not applicable. There is no information on the differential attrition rate between groups (there is no information on the number of participants who withdrew). It is also not clear whether the differential attrition rate was 15 percentage points or less. There is no information on the use of other interventions or treatments. There is no information on the sample size required to detect a significant difference between the groups of 80% in the principal result, and there is no information on whether intentional analyses were done (in some studies, the authors did not report whether it was a randomised trial). It is unclear whether the method of random assignment was adequate or whether the assignment to the treatment was hidden. The authors did not mention whether the participants and study providers were blinded in the assignment of the treatment group, but it is unlikely given that some studies involved a virtual reality or augmented reality game.

Table 3

1 experimental articles included in the review

Title	M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	C
Webb *et al*. (2022). Haptic-enabled collaborative learning in virtual reality for schools.	VR	Y	Y	Y	Y	Y	NR	NR	NR	NR	NR	Y	NR	NR	NR	★★☆☆
de Back *et al*. (2020). Benefits of immersive collaborative learning in CAVE-based virtual reality.	VR	NR	CD	CD	NR	NR	CD	CD	CD	CD	CD	Y	CD	Y	Y	★★☆☆
Niculescu & Thorsteinsson (2011). Enabling idea generation through computer-assisted collaborative learning.	VR	*N*	Y	*N*	CD	CD	CD	CD	CD	CD	Y	Y	CD	Y	Y	★★☆☆
Jovanović & Milosavljević (2022). VoRtex Metaverse platform for gamified collaborative learning.	VR	NR	NA	NA	NA	NA	NR	NR	NR	NA	Y	Y	NR	NR	NA	★☆☆☆
Ke & Hsu (2015). Mobile augmented-reality artifact creation as a component of mobile computer-supported collaborative learning.	AR	Y	Y	CD	CD	CD	CD	Y	CD	Y	Y	Y	Y	Y	Y	★★★☆
Chung *et al*. (2021). Collaborative programming problem-solving in augmented reality: Multimodal analysis of effectiveness and group collaboration.	AR	CD	Y	CD	Y	CD	CD	NA	NA	CD	Y	Y	CD	Y	CD	★★☆☆
Bork *et al*. (2021). The effectiveness of collaborative augmented reality in gross anatomy teaching: A quantitative and qualitative pilot study.	AR	NR	NR	*N*	NR	NR	Y	NR	NR	NR	NA	CD	CD	CD	CD	★☆☆☆

(*continued*)

Table 3
1 experimental articles included in the review (*continued*)

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Matcha & Rambli (2013). Exploratory study on collaborative interaction through the use of augmented reality in science learning.	AR	NR	NA	NA	NA	NA	CD	NA	CD	CD	Y	CD	CD	*N*	NA	★☆☆☆
Alhumaidan *et al*. (2018). Co-designing with children a collaborative augmented reality book based on a primary school textbook.	AR	CD	CD	CD	NA	NA	NA	NA	NA	NA	CD	CD	CD	CD	CD	★☆☆☆
Lu *et al*. (2022). Revolutionizing elementary disaster prevention education and training via augmented reality-enhanced collaborative learning.	AR	NR	NA	NA	NA	NA	NR	NR	NR	NA	Y	Y	NR	CD	CD	★☆☆☆
Sofianidis (2022). Why Do Students Prefer Augmented Reality: A Mixed-Method Study on Preschool Teacher Students' Perceptions on Self-Assessment AR	AR	*N*	NA	NA	NA	NA	NA	NA	NA	NA	NA	Y	*N*	NR	NA	★☆☆☆
Stromberga *et al*. (2021). Teaching with disruptive technology: the use of augmented, virtual, and mixed reality (HoloLens) for disease education.	MR	*N*	NA	NA	NA	NA	*N*	NA	NA	NA	NA	Y	NA	Y	NA	★☆☆☆
Schaffernak *et al*. (2022). Novel Mixed Reality Use Cases for Pilot Training.	MR	CD	CD	CD	NR	NR	CD	NA	CD	CD	CD	CD	CD	CD	CD	★☆☆☆

Title	M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	C
Birt *et al*. (2017). Improving paramedic distance education through mobile mixed reality simulation.	MR	*N*	NA	NA	NA	NA	NA	NA	NA	NA	NA	Y	NR	NR	NA	★☆☆☆
Minty *et al*. (2022). The use of mixed reality technology for the objective assessment of clinical skills: a validation study	MR	*N*	NA	NA	NA	Y	*N*	*N*	NA	Y	*N*	Y	*N*	Y	NA	★★☆☆
Pickering *et al*. (2022). Assessing the difference in learning gain between a mixed reality application and drawing screencasts in neuroanatomy.	MR	NR	NR	NR	NR	NR	NR	CD	CD	NR	CD	Y	CD	Y	CD	★☆☆☆
Veer *et al*. (2022). Incorporating mixed reality for knowledge retention in physiology, anatomy, pathology, and pharmacology interdisciplinary education: a randomized controlled trial.	MR	Y	Y	Y	CD	Y	Y	Y	NA	CD	Y	Y	NR	Y	Y	★★★☆
Richards (2023). Student Engagement Using HoloLens Mixed-Reality Technology in Human Anatomy Laboratories for Osteopathic Medical Students: an Instructional Model.	MR	NR	NR	NR	NR	NR	NR	NR	NA	NA	NR	Y	NR	NR	NR	★☆☆☆
Fu & Liu (2018). The application of virtual reality and augmented reality in dealing with project schedule risks.	MR	NA	NA	NA	NA	NA	NR	NR	NR	NA	NA	Y	NR	NR	NA	★☆☆☆

(*continued*)

Table 3

1 experimental articles included in the review (*continued*)

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Li, C., Jiang, Y., Ng, P. H., Dai, Y., Cheung, F., Chan, H. C., & Li, P. (2024). Collaborative Learning in the Edu-Metaverse Era: An Empirical Study on the Enabling Technologies. IEEE Transactions on Learning Technologies.	VR	CD	Y	Y	CD	CD	Y	*N*	CD	CD	Y	Y	CD	Y	Y	★★★☆
Du, J., & DeWitt, D. (2023). Technology acceptance of a wearable collaborative augmented reality system in learning chemistry among junior high school students. Journal of Pedagogical Research, 8(1), 106-119.	AR	CD	NA	NA	NA	NA	Y	*N*	CD	Y	Y	Y	CD	Y	Y	★★☆☆

* *Y, yes; N, no; CD, cannot determine; NA, not applicable; NR, not reported; M, methodology.

Annexe 3

Table 4 lists the aims and contributions of the 34 observational studies included in the review, as well as the assessment of their quality in view of the *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies*.

All of the articles clearly stated their aim and the majority clearly specified the population, the participants and inclusion and exclusion criteria. Exposures of interest were measured before measuring the results, there was sufficient time to see the associations between the statement and the result, different exposure levels in relation to the result and the measures of exposure were defined clearly, and they were implemented consistently. Likewise, the measures of the result were clearly defined, valid, reliable and consistently implemented in all of the study participants.

A minority of articles did not provide a justification for the sample size, a description of the statistical power or estimates of the variance and the effect. In addition, exposures were not assessed more than once over time, and the possible key confounding variables were not measured nor was their impact on the relationship between the exposure(s) and the result(s) adjusted statistically.

TABLE 4
34 OBSERVATIONAL ARTICLES INCLUDED IN THE REVIEW

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Wallace *et al*. (2017). Self-reported sense of presence and responses to social stimuli by adolescents with autism spectrum disorder in a collaborative virtual reality environment.	VR	Y	Y	NR	Y	*N*	Y	CD	NA	Y	*N*	Y	CD	Y	*N*	★★★☆
Kucukyilmaz & Issak (2019). Online identification of interaction behaviors from haptic data during collaborative object transfer.	VR	Y	Y	NA	Y	Y	Y	Y	Y	Y	Y	Y	CD	NA	Y	★★★★
Radu *et al*. (2020). Relationships between body postures and collaborative learning states in an augmented reality study.	VR	Y	Y	NA	Y	CD	Y	Y	Y	Y	Y	Y	CD	Y	Y	★★★★
Tüzün *et al*. (2019). The effects of 3D multi-user virtual environments on collaborative learning and social presence.	VR	Y	Y	Y	Y	*N*	Y	Y	Y	Y	Y	Y	CD	Y	Y	★★★★
Rodriguez *et al*. (2018). Collaborative learning in architectural education: Benefits of combining conventional studio, virtual design studio and live projects.	VR	Y	Y	NA	Y	Y	NR	NR	NR	NR	Y	Y	CD	NA	Y	★★★☆
Dolezal *et al*. (2020). An immersive virtual environment for collaborative geovisualization.	VR	Y	Y	NA	NA	NR	NA	NA	NA	NA	NA	NA	NA	NA	NA	★☆☆☆
McArdle *et al*. (2011). Assessing the application of 3D collaborative interfaces within an immersive virtual university.	VR	Y	Y	NA	Y	*N*	NA	NA	NA	Y	NA	Y	NA	NA	Y	★★☆☆

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Doumanis *et al*. (2019). The impact of multimodal collaborative virtual environments on learning: A gamified online debate.	VR	Y	Y	NA	Y	Y	Y	CD	*N*	Y	*N*	Y	*N*	NA	Y	★★★☆
Rusli *et al*. (2023). Academic-Practice Collaboration Using Virtual Telesimulation to Support Students' Clinical Practice.	VR	Y	Y	NA	Y	Y	NA	NA	NA	NA	NA	Y	NA	NA	NA	★★☆☆
Bölek *et al*. (2022). Mixed–methods exploration of students' motivation in using augmented reality in neuroanatomy education with prosected specimens.	AR	Y	Y	NA	Y	Y	Y	CD	Y	Y	Y	Y	CD	Y	Y	★★★★
Strada *et al*. (2023). Leveraging a collaborative augmented reality serious game to promote sustainability awareness, commitment and adaptive problem-management.	AR	Y	Y	NR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	★★★★
Ahsen *et al*. (2019). Exploring the impact of network impairments on remote collaborative augmented reality applications.	AR	Y	Y	NR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	★★★★
Ghobadi *et al*. (2022). Augmented Reality Applications in Education and Examining Key Factors Affecting the Users' Behaviors.	AR	Y	Y	NR	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NA	*N*	★★★☆
Shore *et al*. (2023). Using augmented reality in AEC tertiary education: a collaborative design case.	AR	Y	Y	NA	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NA	*N*	★★★☆
Vasilevski, & Birt (2020). Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments.	MR	Y	Y	NR	Y	Y	Y	Y	Y	Y	Y	Y	NR	*N*	Y	★★★★

(*continued*)

TABLE 4

34 OBSERVATIONAL ARTICLES INCLUDED IN THE REVIEW (*continued*)

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Mosher, & Carreon (2021). Teaching social skills to students with autism spectrum disorder through augmented, virtual and mixed reality.	MR	Y	Y	NA	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NA	*N*	★★★☆
Alalwan *et al*. (2020). Challenges and prospects of virtual reality and augmented reality utilization among primary school teachers: A developing country perspective.	MR	Y	Y	NR	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NR	*N*	★★★☆
Bonnat & Sanchez (2022). Toward a Digital Companion to Monitor a Mixed Reality Game.	MR	Y	Y	NA	Y	*N*	Y	Y	Y	Y	NA	Y	NR	NA	NA	★★★☆
Xefteris, & Palaigeorgiou (2019). Mixing educational robotics, tangibles and mixed reality environments for the interdisciplinary learning of geography and history.	MR	Y	Y	NA	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NA	*N*	★★★☆
Essmiller *et al*. (2020). Exploring mixed reality based on self-efficacy and motivation of users.	MR	Y	Y	NA	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NR	*N*	★★★☆
Frank, & Kapila (2017). Mixed-reality learning environments: Integrating mobile interfaces with laboratory test-beds.	MR	Y	Y	NA	Y	*N*	Y	Y	Y	Y	*N*	Y	NR	NR	Y	★★★☆
Lindgren *et al*. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation.	MR	Y	Y	NA	Y	Y	Y	Y	Y	Y	*N*	Y	NR	Y	Y	★★★★

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Sonntag, & Bodensiek (2022). How mixed reality shifts visual attention and success in experimental problem solving.	MR	Y	Y	NR	Y	Y	Y	Y	Y	Y	*N*	Y	Y	Y	Y	★★★★
Stojanovska *et al*. (2020). Mixed reality anatomy using Microsoft HoloLens and cadaveric dissection: a comparative effectiveness study.	MR	Y	Y	NR	Y	*N*	Y	Y	NR	Y	*N*	Y	Y	Y	*N*	★★★☆
Robinson *et al*. (2020). Evaluating the use of mixed reality to teach gross and microscopic respiratory anatomy.	MR	Y	Y	NR	Y	*N*	Y	Y	NR	Y	*N*	Y	Y	Y	*N*	★★★☆
Leonard & Fitzgerald (2018). Holographic learning: A mixed reality trial of Microsoft HoloLens in an Australian secondary school.	MR	Y	Y	NR	Y	*N*	Y	Y	NR	Y	*N*	Y	NR	NR	*N*	★★★☆
Baratz *et al*. (2022). Comparing learning retention in medical students using mixed-reality to supplement dissection: a preliminary study.	MR	Y	Y	NR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	★★★★
Watson & Livingstone (2018). Using mixed reality displays for observational learning of motor skills: A design research approach enhancing memory recall and usability.	MR	Y	Y	NR	NR	Y	Y	Y	Y	Y	Y	Y	Y	NR	Y	★★★★
Simone *et al*. (2021). Remote mentoring in laparotomic and laparoscopic cancer surgery during Covid-19 pandemic: an experimental setup based on mixed reality.	MR	Y	Y	NA	NA	Y	Y	Y	NA	Y	Y	Y	NA	NA	Y	★★★☆
Vasilevski & Birt (2020). Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments.	MR	Y	Y	NA	Y	Y	Y	NA	Y	Y	Y	Y	NR	NR	Y	★★★☆

(*continued*)

Table 4
34 observational articles included in the review (*continued*)

Title	**M**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**C**
Wanis (2019). A review on collaborative learning environment across virtual and augmented reality technology.	MR	Y	*N*	NA	NA	*N*	NA	NA	NA	NA	NA	NA	NA	NA	*N*	★☆☆☆
Fu, & Liu (2018). The application of virtual reality and augmented reality in dealing with project schedule risks.	MR	Y	*N*	NA	NA	Y	Y	Y	*N*	*N*	NA	Y	NA	NA	*N*	★★☆☆
Bekele *et al.* (2021). The Influence of Collaborative and Multi-Modal Mixed Reality: Cultural Learning in Virtual Heritage.	MR	Y	Y	NA	*N*	Y	Y	Y	NA	Y	NA	Y	NA	NA	*N*	★★★☆
Silseth, K., Steier, R., & Arnseth, H. C. (2024). Exploring students' immersive VR experiences as resources for collaborative meaning making and learning. International Journal of Computer-Supported Collaborative Learning, 1-26.	VR	*N*	NA	NA	NA	NA	NA	NA	NA	Y	NA	Y	NA	NA	Y	★★☆☆

*Y, yes; N, no; CD, cannot determine; NA, not applicable; NR, not reported; M, methodology.