International Journal of Sustainable Development and Planning
Vol. 21, No. 9, September, 2026, pp. 4433-4446
Journal homepage: http://iieta.org/journals/ijsdp

Virtual Reality-Based Learning for Sustainable Education: A Systematic Review of Learning Outcomes, Research Gaps, and Alignment with SDG 4

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https://doi.org/10.18280/ijsdp.210938

Received: 2 June 2026
Revised: 17 August 2026
Accepted: 26 August 2026
Available online: 30 September 2026

Keywords:
Virtual Reality, learning outcomes, systematic literature review, sustainable education, SDG 4, immersive learning

ABSTRACT

Virtual Reality (VR) has gained increasing attention as a tool for advancing inclusive and equitable quality education in line with SDG 4; however, evidence on its effectiveness in improving learning outcomes remains fragmented across educational contexts. This study synthesizes evidence on VR-based learning by examining its effects on learning outcomes, identifying research gaps, and assessing its alignment with sustainable education agendas. A systematic literature review (SLR) was conducted following the PRISMA 2020 guidelines, drawing on four databases (Scopus, Web of Science, IEEE Xplore, and Google Scholar) and analyzing 43 peer-reviewed documents published between 2014 and 2025. Selected studies were examined through thematic analysis to map publication trends, conceptualizations, research themes, and reported effects. Two-thirds of the corpus (29 of 43 studies; 67.4%) were published in 2024–2025, indicating an accelerating field. Affective outcomes were the most consistently reported benefit (18 of 37 primary studies; 48.6%), followed by cognitive (64.9%), skill-based (21.6%), behavioral-attitudinal (10.8%), and pedagogical (8.1%) outcomes. Six review-type documents were analyzed separately and excluded from these domain counts. Evidence on higher-order cognition and long-term retention remains limited and inconclusive. The review identifies persistent gaps, including the dominance of higher-education contexts, the scarcity of longitudinal studies, weak theoretical grounding, and the near-absence of explicit alignment with the SDGs. The study offers directions for researchers, educators, and policymakers seeking to embed immersive learning within pedagogically effective, equitable, and sustainable education systems.

1. INTRODUCTION

The integration of Virtual Reality (VR) into education has become a focal point in the digital learning era, as immersive technologies reshape how knowledge is constructed, retained, and applied. VR enables learners to engage actively with simulated environments that resemble real-world situations, and recent studies report that its interactive and immersive nature enhances students' understanding, retention, and engagement, particularly in STEM and higher education [1, 2]. It also promotes motivation and active participation across diverse disciplines, including medicine, agriculture, and special education [3, 4]. Within the broader agenda of sustainable development, these capabilities position VR as a potential instrument for advancing SDG 4—ensuring inclusive, equitable, and quality education—by extending access to experiential learning that is otherwise constrained by cost, safety, or geography.

Systematic literature reviews (SLRs) play a crucial role in consolidating this rapidly expanding evidence base. They map trends, methodologies, and underexplored areas, thereby identifying research gaps and guiding future directions. Darvishinia et al. [2] highlighted the limited focus on English language learners and the scarcity of longitudinal studies examining the sustained effects of VR on learning outcomes, while other reviews report persistent challenges such as high implementation costs, limited hardware access, and insufficiently developed educational software [5]. The rapid growth of VR-related publications has produced a fragmented body of knowledge, making it difficult for educators and researchers to identify consistent patterns, effective instructional designs, and evidence-based best practices. Without systematic synthesis, findings remain scattered across disciplines and educational levels, limiting the scalability and transferability of VR-based innovations [6, 7].

Beyond consolidation, SLRs enable the evaluation of pedagogical models, revealing that immersive simulations and gamified environments can enhance both cognitive and psychomotor outcomes relative to traditional methods [6, 7]. This aligns with contemporary learning theories—

constructivism and experiential learning—that emphasize active knowledge construction through experience and reflection [8]. Reviews also show that integrating VR with artificial intelligence supports personalized learning pathways that adapt to individual needs [9], and that low-cost solutions such as cardboard VR can reduce digital inequality in public institutions [10], directly supporting the equity dimension of sustainable education.

Despite these contributions, existing reviews remain fragmented. Ghanbaripour et al. [11] reviewed the impact of emerging technologies on student learning, engagement, and employability in built environment education; Marougkas et al. [12] examined the personalization and effectiveness of immersive VR over the last decade; Cabrera-Duffaut et al. [1] focused on competence development in higher education; and Lampropoulos [6] synthesized AR, VR, and intelligent tutoring systems. However, these reviews tend to concentrate on specific domains, technologies, or learner populations, and none has simultaneously examined publication trends, conceptual definitions, research themes, and learning-outcome domains while explicitly assessing alignment with the SDGs. This study addresses that gap by providing an integrative synthesis that links VR learning outcomes to the sustainability agenda, offering a perspective that is both pedagogically and policy-relevant.

Accordingly, this study systematically reviews the application of VR in education following the PRISMA 2020 guidelines to ensure methodological rigor, transparency, and reproducibility. The review pursues four objectives: (a) to identify publication trends by year, country, subject area, and authorship; (b) to examine how VR is conceptualized within educational contexts; (c) to map the key research themes linking VR to students' learning outcomes; and (d) to analyze the reported effects of VR on learning outcomes, identify research gaps, and assess alignment with SDG 4.

2. LITERATURE REVIEW

2.1 Virtual Reality in education

VR has emerged as an innovative educational technology because of its capacity to create immersive, interactive, and contextual learning experiences. Unlike traditional approaches that position students as passive recipients of information, VR allows learners to actively engage with simulated environments that resemble real-world situations, making learning more meaningful and experience-based [13, 14]. A primary motivation for adopting VR lies in its ability to enhance engagement and motivation: immersive environments capture attention and sustain focus, especially for abstract or complex subject matter [15, 16], and encourage active participation in authentic communicative situations [17].

Increased engagement also supports comprehension and retention. By emphasizing experiential learning, VR enables direct exploration of content, leading to deeper conceptual understanding and longer-lasting memory [18]; in human-computer interaction education, for instance, VR has outperformed traditional methods [19]. VR further supports personalized and adaptive learning, allowing students to control their pace and explore content according to individual needs [20], consistent with the learner-centered demands of 21st-century education [21]. It is particularly effective for developing practical skills through simulation-based learning in engineering and vocational education, where learners practice safely without real-world risk [22-24], and it facilitates collaborative learning across physical distance [25].

Nevertheless, implementation faces challenges. High hardware and content-development costs remain significant barriers [16, 26]; technical issues such as motion sickness and device limitations may hinder the user experience [27]; and effective integration requires adequate teacher training and pedagogical adaptation [27]. Addressing these barriers requires high-quality content, improved accessibility, and sustained professional development [26], while integration with emerging technologies such as artificial intelligence offers opportunities for more adaptive and personalized environments [28]. These limitations should therefore be read not as obstacles but as directions for future development.

2.2 Virtual Reality and sustainable education (SDG 4)

The 2030 Agenda for sustainable development frames quality education (SDG 4) as a foundation for inclusive and equitable development [29], and education for sustainable development emphasizes learner-centered, experiential, and transformative pedagogies [30]. VR aligns with this agenda along three dimensions. First, it advances inclusivity and equity by extending immersive experiences to learners who lack access to physical laboratories, field sites, or specialized equipment; low-cost solutions such as cardboard VR demonstrate that immersive learning need not be confined to well-resourced institutions [10]. Second, it supports resource efficiency and resilience by reducing dependence on physical materials, enabling virtual laboratories, and sustaining remote education during disruptions, which contributes to economically sustainable provision over time [31]. Third, it strengthens the experiential and competence-based learning that education for sustainability requires, allowing learners to rehearse complex, real-world scenarios safely [22, 24].

Despite this conceptual fit, the explicit use of the SDGs as an analytical or design framework remains rare in VR research. Few studies position immersive learning within sustainability targets or evaluate outcomes against equity and access criteria. This review therefore treats SDG alignment not as a peripheral concern but as an organizing lens for interpreting learning outcomes and research gaps, thereby connecting immersive pedagogy to the planning and policy priorities central to sustainable development.

Table A1 operationalizes the alignment of the 37 primary studies with SDG 4 (Quality Education) by mapping the educational context reported in each study to the most relevant SDG 4 targets. Specifically, Target 4.1 was mapped to studies conducted at the school and early-childhood levels, reflecting its emphasis on equitable access to quality primary and secondary education; Target 4.3 was mapped to studies addressing vocational and higher education, consistent with its focus on equal access to technical, vocational, and tertiary education; and Target 4.4 was applied to studies emphasizing vocational or technical skills relevant to employment. Target 4.5 was associated with studies addressing gifted learners or inclusive education, particularly where the focus involved reducing educational disparities, whereas Target 4.c was mapped to studies focused on pre-service teacher education and teacher preparation.

To distinguish the strength of this alignment, studies were classified as Direct only when their substantive content

explicitly addressed a theme that could be linked to an SDG 4 target beyond educational level alone, such as environmental sustainability or other clearly articulated educational priorities. Studies that did not explicitly address SDG 4-related themes were classified as Indirect, even when their educational context was consistent with a particular SDG 4 target. This approach provides a structured and transparent first-pass assessment of SDG 4 alignment based on the available extraction data. Nevertheless, because SDG 4 was not necessarily an explicit analytical framework in the original studies, the Direct/Indirect classifications should be interpreted cautiously. A full-text assessment of the 37 primary studies would provide a stronger basis for validating these classifications and identifying additional dimensions of equity, inclusion, and educational access that may not have been captured in the current extraction framework.

2.3 Positioning against existing systematic reviews

Several systematic reviews have already examined VR in education, yet each adopts a narrower lens than the present study. Table 1 contrasts six recent reviews with the current work across primary focus, explicit alignment with SDG 4, and whether the review delivers an integrative four-part synthesis—simultaneously addressing publication trends, conceptualizations, research themes, and learning—outcome domains. Prior reviews typically privilege a single dimension (e.g., competence development, effectiveness, or challenges) within a specific population, and none foregrounds the SDGs as an analytical frame. The present review addresses this gap by integrating all four analytical dimensions and explicitly mapping VR learning outcomes to SDG 4.

Table 1. Comparison of the present review with existing systematic reviews

Prior Review	Primary Focus and Scope	SDG 4 Lens	Integrative Four-Part Synthesis†
Cabrera-Duffaut et al. [1]	Competence development in higher education	No	Partial
Darvishinia et al. [2]	VR for English language learners in STEM	No	Partial
Ndjama and Van Der Westhuizen [5]	Challenges and limitations of VR in education	No	Partial
Lampropoulos [6]	AR, VR, and intelligent tutoring in education and training	No	Partial
Vásquez-Carbonell and Torres [7]	How VR effectiveness is evaluated and resulting outcomes	No	Partial
Marougkas et al. [12]	Personalization and effectiveness of immersive VR (last decade)	No	Partial
This study (2026)	Learning outcomes, research gaps, and SDG alignment across all educational levels	Yes	Full

Note: †: Integrative four-part synthesis = simultaneous analysis of publication trends, conceptualizations, research themes, and learning-outcome domains.

3. METHODOLOGY

This study employs a SLR following the PRISMA 2020 guidelines [32, 33], selected for their rigorous reporting structure and demonstrated validity across multiple fields [34, 35]. The approach aligns with the aim of synthesizing empirical, conceptual, and prototype-based studies on the use of VR in education.

3.1 Research questions

Consistent with the study objectives, the review is guided by four research questions (RQs):

RQ1. What are the publication trends in VR-based education research by year, country, subject area, and authorship?

RQ2. How is VR conceptualized within educational contexts?

RQ3. What are the dominant research themes linking VR to students' learning outcomes?

RQ4. What effects does VR have on learning outcomes, and what research gaps-including alignment with SDG 4-remain?

3.2 Research design and search strategy

The review process consisted of collecting candidate documents from multiple databases, removing duplicates and clearly irrelevant records by title and abstract, evaluating full texts against the inclusion criteria, selecting the final corpus, and synthesizing the included studies to answer the research questions. To ensure comprehensive coverage of this interdisciplinary field, the search drew on four databases-Scopus, Web of Science (WoS), IEEE Xplore, and Google Scholar-conducted in October 2025 (final search executed on 28 October 2025 at 23:30 Western Indonesian Time). A broad identification search using ("Virtual Reality" OR "VR") AND Education in titles, abstracts, and keywords returned 230,274 records. The search was then refined using the string ("Virtual Reality" OR "VR") AND Education AND "learning outcomes" AND School, yielding 11,505 records for screening. No restriction was imposed on publication year to capture the full developmental trajectory of the field. The use of "School" as the primary population term reflects the review's intended focus on school-level education, encompassing early childhood through secondary education. Nevertheless, a small number of studies situated in higher-education contexts were also retrieved through the broader keyword combinations and retained in the final corpus because their reported learning outcomes were considered relevant to the review's objectives. Table 2 reflects this scope boundary by specifying that a minority of the included studies were conducted in higher-education contexts. This scope boundary is acknowledged as a limitation in Section 5.4, as future reviews could expand the search strategy by incorporating terms such as "University" and "Higher Education" to provide a more comprehensive mapping of VR learning outcomes across the full educational continuum.

3.3 Inclusion and exclusion criteria

Studies were assessed against predefined inclusion and exclusion criteria to ensure relevance and methodological

adequacy.

Table 2. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Topic relevance	Addresses VR-based learning and its effect on learning outcomes in educational settings	Not focused on VR in education or on learning outcomes
Population/ context	School and formal education contexts (early childhood to secondary/school level, with a non-trivial minority of higher-education studies 10 of 37 primary studies; 27.0% captured incidentally through the search process)	Non-school populations or non-educational training only
Publication type	Journal articles, review papers, conference papers, short surveys	Editorials, abstracts only, non-peer-reviewed material
Period	2014–2025	Published before 2014
Language	English	Languages other than English
Access/outcome	Open access with a reported or measurable learning outcome	No learning-outcome measurement; full text unavailable

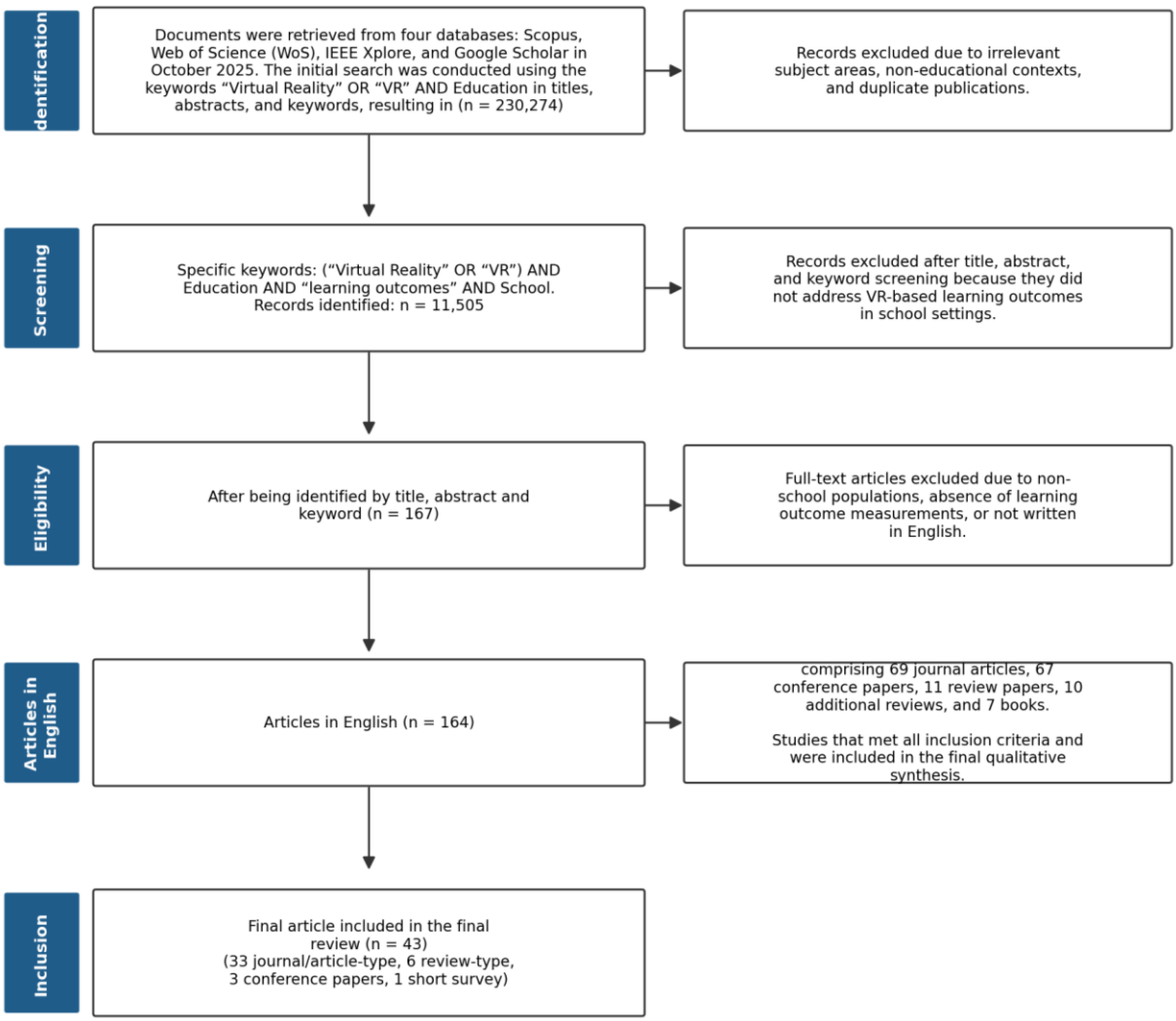


Figure 1. PRISMA flow diagram illustrating the study selection process

3.4 Study selection process

Document selection followed the five PRISMA stages (identification, screening, eligibility, inclusion, and synthesis), as illustrated in Figure 1. From the 11,505 screened records, title-, abstract-, and keyword-based identification reduced the set to 167 documents. Restricting the records to English-language publications yielded 164 documents, comprising 69 journal articles, 67 conference papers, 11 review papers, 10 additional reviews, and 7 books. Full-text records were subsequently assessed for eligibility, with studies excluded when they involved non-school populations, lacked measurable learning outcomes, or did not meet the language criterion. Applying the open-access criterion and the predefined inclusion rules resulted in a final corpus of 43 documents. Based on Scopus' official Document Type

classification, this corpus comprised 33 Article-type documents, 6 Review-type documents, 3 Conference Paper-type documents, and 1 Short Survey-type document. This classification supersedes the earlier categorization of seven review papers, which was found to be inconsistent with the Scopus extraction data. The final corpus spans research across education, computer science, social sciences, and multidisciplinary fields. To ensure consistency and transparency in reporting, Figure 1 and all downstream percentage calculations were updated to reflect the reconciled Scopus records and the confirmed corpus composition.

The assessments were conducted independently by two reviewers, with disagreements resolved through discussion until consensus was reached. Inter-rater agreement was assessed using Cohen's κ, with the final coefficient reported accordingly. A standardized data-extraction form was used to systematically record the author, publication year, country, educational level, VR type, sample characteristics, learning-outcome domain, assessment method, and reported effects. The final corpus comprised 37 primary studies. Review-type documents were excluded from the analysis because they synthesize evidence from previously published primary studies and their inclusion alongside primary research could result in double-counting of evidence. Accordingly, all analyses were restricted to the primary-study corpus. All tables, figures, and associated percentages reported in Section 4 were recalculated based on the 37 primary studies using the complete study-level extraction data, including domain and outcome classifications. This approach ensures that the findings are derived exclusively from primary empirical evidence and provides a consistent basis for the subsequent analysis.

3.5 Quality appraisal and synthesis

The methodological quality of included studies was appraised using the Mixed Methods Appraisal Tool (MMAT), which accommodates quantitative, qualitative, and mixed-methods designs. Each study was assessed against criteria for clarity of research questions, appropriateness of design, adequacy of sampling and measurement, and coherence between data and interpretation; studies with serious methodological limitations were retained but interpreted with caution. The included corpus was then analyzed through thematic analysis to derive publication patterns, conceptualizations, research themes, and outcome domains, complemented by performance analysis, science mapping, and network analysis using VOSviewer.

4. RESULTS

4.1 Publication trends (RQ1)

The 43 eligible documents were published between 2014 and 2025 across social sciences, computer science, psychology, engineering, education, environmental science, and health sciences, reflecting the interdisciplinary nature of VR research. Three complementary analyses—performance analysis, science mapping, and network analysis—are reported below.

Figure 2 illustrates the annual publication output from 2014 to 2025. Publication activity remained limited and relatively stable during 2014–2020, with one to two documents published per year, followed by a modest increase in 2021–2022. The number of publications then increased to five in 2023 and rose substantially to 12 in 2024 and 17 in 2025. Across the study period, the annual distribution sums to 43 documents, consistent with the total corpus. Notably, 29 of the 43 studies (67.4%) were published during 2024–2025, indicating a pronounced recent acceleration in research activity. This pattern suggests growing scholarly interest in VR-based education and may reflect the field's transition toward a more established and increasingly dynamic area of research, in parallel with broader developments in digital transformation and learning technologies [9].

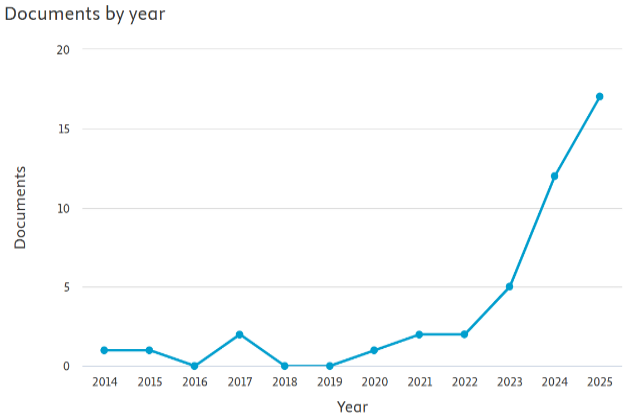


Figure 2. Document productivity on Virtual Reality (VR) in education, 2014–2025

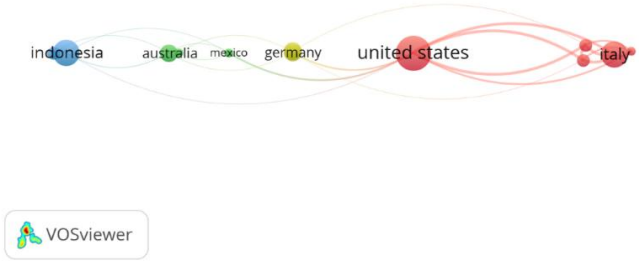


Figure 3. International collaboration network in Virtual Reality (VR) education research

Figure 3 visualizes the international collaboration network generated with VOSviewer. The United States occupies a central position, reflected in its larger node and strong links—particularly with Italy—indicating high productivity and intensive cooperation. Countries such as Indonesia, Australia, Mexico, and Germany appear in smaller, less connected clusters, suggesting that research remains concentrated in a limited number of countries and highlighting opportunities to broaden global participation, especially among under-represented regions central to equitable sustainable development.

Figure 4 presents the distribution by subject area. Social Sciences account for the largest share (27.8%), indicating a predominantly pedagogical and policy-oriented framing, followed by Computer Science (20.0%), reflecting attention to system design and technological development. Psychology (8.9%) and Engineering (7.8%) contribute substantially, while Arts and Humanities (5.6%), Health Professions (4.4%), Medicine (4.4%), Business and Management (3.3%), Decision Sciences (3.3%), and Nursing (3.3%) represent smaller but meaningful shares; the "Other" category (11.1%) underscores

the spread of VR across emerging fields.

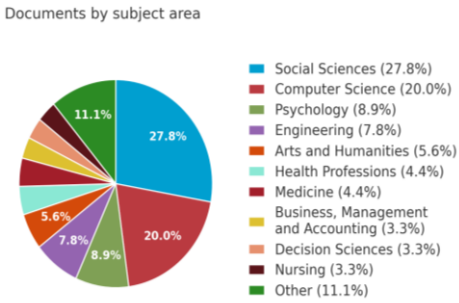


Figure 4. Distribution of Virtual Reality (VR) in education research by subject area

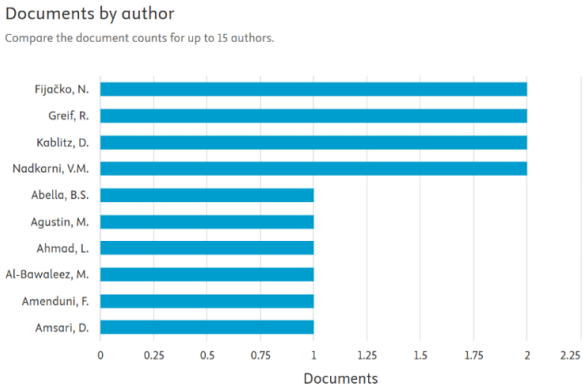


Figure 5. Most prolific authors in Virtual Reality (VR) in education research

Figure 5 shows the most prolific authors. Fijačko, N.; Greif, R.; Kablitz, D.; and Nadkarni, V.M. record the highest output, while a broader group—including Abella, B.S.; Agustin, M.; Ahmad, L.; Al-Bawaleez, M.; Amenduni, F.; and Amsari, D.—contribute consistently. Representative works from these core contributors [36-41] illustrate their sustained engagement with VR in education. The pattern reflects both a concentration of activity among a few productive authors and a diverse base of contributors.

4.2 Conceptualizations of Virtual Reality (RQ2)

Across the corpus, VR is conceptualized as an immersive technology that generates simulated environments, enabling learners to experience situations otherwise inaccessible in the real world [42]. Its immersive and interactive nature facilitates active learning and deeper comprehension [43], sustains engagement and motivation [44], and strengthens knowledge retention through multisensory experiences [45]. VR is further framed as a means of developing practical and technical skills through experiential simulation [46], enabling personalized and adaptive learning [47], and fostering inclusivity for learners with diverse abilities [48]. Additional defining features include enhanced visualization of abstract concepts [49], collaborative learning in shared virtual spaces [50], reduced performance anxiety in low-pressure settings [51], real-time feedback [52], and safe exploration of hazardous scenarios [53]. While initial setup costs are high, VR is increasingly conceptualized as economically sustainable over time [31], and ongoing advances in hardware, graphics, and haptics are expected to expand its applications further [52]. Table 3 summarizes the defining elements of VR in education.

4.3 Research themes (RQ3)

Figure 6 presents a keyword co-occurrence network generated with VOSviewer, mapping the main research themes linking VR to students' learning outcomes. Learning-related constructs—learning, immersive learning, teaching, students, and learning outcomes—form closely connected clusters, indicating strong conceptual integration between VR technology and educational effectiveness.

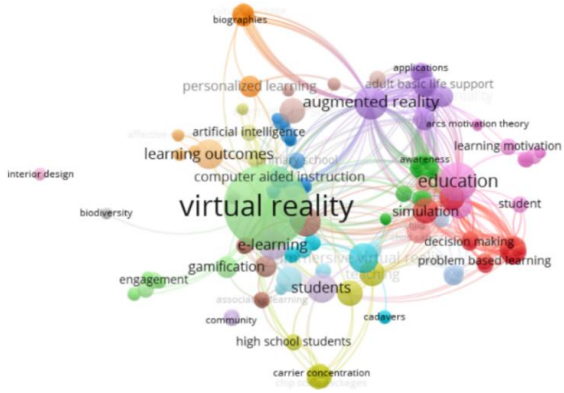


Figure 6. Keyword co-occurrence map of Virtual Reality (VR) research in educational contexts

Table 3. Defining elements of Virtual Reality (VR) in education

No.	Defining Factor of Virtual Reality in Education	Ref.
1	VR is an immersive technology that creates simulated environments, allowing learners to experience scenarios otherwise inaccessible in the real world	[42]
2	VR facilitates interactive learning, enabling direct engagement with content and fostering active participation and deeper understanding	[43]
3	It enhances engagement through novel and stimulating experiences that capture learners' attention	[44]
4	VR improves knowledge retention via multisensory experiences that aid memory more effectively than traditional methods	[45]
5	It promotes practical and technical skills through experiential simulations of real-world activities	[46]
6	VR supports personalized learning by adapting pace and complexity to individual needs	[47]
7	It fosters inclusivity, making learning more accessible to students with diverse abilities and preferences	[48]
8	It enhances visualization, rendering abstract concepts as tangible three-dimensional experiences	[49]
9	VR encourages collaborative learning through shared virtual spaces	[50]
10	By providing controlled, low-pressure contexts, VR reduces performance and testing anxiety	[51]
11	VR enables safe exploration of dangerous or complex scenarios without real-world risk	[53]
12	Despite high initial costs, VR can be economically sustainable over time, supporting remote education	[31]
13	Continual advances in hardware, graphics, and haptic feedback expand VR's educational potential	[52]

Table 4. Most frequent keywords and their total link strength in Virtual Reality (VR)-based educational research

No.	Keyword	Total Link Strength
1	Virtual Reality	361
2	Education	163
3	Augmented Reality	118
4	Students	109
5	Virtual Environment	102
6	Learning	101
7	Teaching	96
8	Immersive Learning	93
9	Learning Outcome	93
10	Personnel Training	77

Table 4 quantifies these patterns through total link strength. Virtual Reality is the most dominant keyword, followed by Education and Augmented Reality, reinforcing VR's central role in educational research. The substantial link strength of Learning Outcome (93) shows that outcome-oriented perspectives are a core focus rather than a peripheral concern, while Immersive Learning (93) highlights the emphasis on experiential, engagement-driven environments. Taken together, Figure 6 and Table 4 indicate that VR research in school settings is primarily oriented toward improving learning outcomes through immersive, pedagogically grounded experiences—treating VR not as a technological novelty but as an instructional medium strategically linked to learning effectiveness.

4.4 Effects on learning outcomes and research gaps (RQ4)

Table 5 summarizes the effects of VR on learning outcomes across the 37 primary studies, organized into five domains: cognitive, affective, skill-based, pedagogical, and behavioral-attitudinal. Because individual studies frequently report outcomes across multiple domains, these categories are not mutually exclusive.

Affective outcomes are the most consistently reported benefit (18 of 37 primary studies; 48.6%): VR enhances motivation, engagement, interest, satisfaction, and immersion across contexts [54]. Cognitive benefits are also substantial (24; 64.9%), with immersive environments supporting concrete, experiential processing of abstract content; however, several studies report mixed or non-significant cognitive effects when instructional design fails to manage task complexity or cognitive load. Skill-based outcomes (8; 21.6%) include spatial reasoning and applied competence, particularly in vocational and technical contexts [55], though this domain remains comparatively under-represented. Pedagogical outcomes (3; 8.1%) suggest VR can support instructional practice through scenario-based activities, but the evidence is limited and fragmented, concentrated in pre-service teacher training [56]. Behavioral and attitudinal outcomes (4; 10.8%) include more positive attitudes, greater participation, and learner autonomy.

Synthesizing findings across the 37 primary studies, six recurrent research gaps emerge (Table 6). VR research remains concentrated in higher education, with 10 of the 37 primary studies (27.0%) conducted at the higher-education level, while evidence from school-level and early-childhood contexts remains comparatively limited. Interventions are predominantly short-term, constraining conclusions regarding knowledge retention and transfer over time. Affective outcomes are more frequently examined than higher-order cognitive outcomes, while instructional designs are often insufficiently grounded in established learning theories and may be susceptible to cognitive overload. Assessment practices also rely heavily on self-reported measures rather than objective or performance-based indicators. Finally, cultural, contextual, and sustainability dimensions including explicit alignment with the SDGs remain underexplored, highlighting important opportunities for future research.

Table 5. Effects of Virtual Reality (VR) on learning outcomes

Learning Outcome Domain	Specific Effects	No. of Studies
Cognitive	Improved conceptual understanding, knowledge acquisition, retention, and procedural knowledge	24 (64.9%)
Affective	Increased motivation, engagement, interest, satisfaction, and immersion	18 (48.6%)
Skill-based	Enhanced spatial ability, problem-solving, collaboration, and 21st-century skills	8 (21.6%)
Pedagogical	Improved teaching competence, instructional confidence, and classroom readiness (mainly pre-service teachers)	3 (8.1%)
Behavioral & attitudinal	Positive learning attitudes, increased participation, and self-directed learning	4 (10.8%)
Mixed/ inconclusive	Mixed or non-significant effects, often linked to cognitive load or instructional-design issues	*Not determinable**

Table 6. Research gaps identified in Virtual Reality (VR)-based learning studies

Research Gap	Key Evidence	Future Research Direction
Limited educational levels	Most studies focus on higher education [39, 57, 58]	VR research in early-childhood and primary education
Short-term interventions	Predominantly short-term, experimental designs [59, 60]	Longitudinal studies on sustained outcomes
Focus on affective outcomes	Motivation, engagement, and immersion dominate [57, 58]	Higher-order cognition and learning-transfer studies
Instructional-design issues	Weak theoretical grounding and cognitive overload [36, 59]	Theory-based VR instructional-design models
Assessment methods	Heavy reliance on self-report questionnaires [60]	Objective, performance-based assessment
Weak SDG alignment	SDGs rarely used as an analytical or design framework [36, 59]	VR studies explicitly supporting SDG 4 and equity

5. DISCUSSION

5.1 Comparison with prior reviews

As positioned in Table 1, the dominance of affective outcomes observed here is consistent with Marougkas et al. [12], who reported strong engagement and motivation effects across a decade of immersive VR research, and with Cabrera-Duffaut et al. [1], who emphasized competence development in higher education. However, the present review extends these findings by quantifying the relative weight of each outcome domain and by exposing the imbalance between affective gains (48.6%) and higher-order cognitive evidence. It also corroborates Vásquez-Carbonell and Torres [7], who found that many studies evaluate VR effectiveness with limited methodological rigor, and aligns with Lampropoulos [6] in noting the fragmentation of instructional approaches. Unlike these reviews, and unlike level-specific syntheses focused on higher education [61] or primary education [62], this study integrates publication, conceptual, thematic, and outcome analyses within a single synthesis and foregrounds sustainability alignment as an evaluative criterion.

5.2 Theoretical implications

The findings reinforce constructivist and experiential learning theory: VR's strongest and most consistent effects—engagement, motivation, and conceptual understanding—arise precisely where learners actively construct knowledge through immersive experience and reflection [8, 43]. Yet the prevalence of mixed cognitive effects under poor design conditions points to cognitive load theory as a necessary complement; immersive richness can overwhelm working memory when scaffolding is absent [37]. A theoretically robust VR pedagogy therefore requires integrating experiential design with deliberate cognitive-load management, an alignment that current studies achieve only inconsistently.

5.3 Implications for sustainable development planning

Read through the lens of SDG 4, the evidence indicates that VR can advance inclusive and equitable quality education by widening access to experiential learning and reducing reliance on costly physical infrastructure [10, 31]. The concentration of research in a few high-income countries, however, mirrors a broader equity gap: if immersive learning is to support sustainable development globally, investment and research capacity must extend to under-represented regions. For educational planners and policymakers, the practical implications are threefold: prioritize teacher professional development to ensure pedagogically sound integration; adopt low-cost, scalable VR solutions to mitigate digital inequality; and embed sustainability criteria—equity, accessibility, and long-term viability—into VR procurement and curriculum design. Framing VR investment within sustainable development planning thus shifts the question from whether VR engages learners to whether it does so equitably and durably.

5.4 Limitations

Several limitations should be acknowledged. First, although four databases were searched, the inclusion of only open-access, English-language publications may introduce language and access bias and exclude relevant grey literature. Second, the refined search strategy employed "School" as the primary population term rather than broader terms such as "University" or "Higher Education." Although the search was designed to prioritize school-level education, 10 of the 37 primary studies (27.0%) were conducted in higher-education contexts. These studies were identified through the broader keyword combinations and database retrieval process rather than through a systematic search specifically targeting higher-education literature. Accordingly, the resulting corpus should be interpreted as predominantly school-oriented but not exclusively limited to school-level education, with a substantive higher-education component. This scope characteristic should be considered when interpreting the findings and their generalizability across educational levels. Readers should therefore not interpret this review as a comprehensive account of VR in higher education, and future reviews using an expanded string covering both school and higher-education terms are needed for that purpose. A supplementary Scopus search incorporating "university" and "higher education" indicated that broader population terms would likely retrieve additional relevant studies. Third, the corpus of 43 studies, while systematically derived, reflects a still-emerging field, and the predominance of recent publications limits longitudinal interpretation. Fourth, the synthesis is qualitative and thematic rather than meta-analytic, so effect magnitudes are not statistically pooled. Finally, heterogeneity in study designs and outcome measures constrains direct comparability. These limitations define the boundaries of the present conclusions and motivate the future directions outlined below.

6. CONCLUSION

This systematic review synthesized 37 primary studies (2014–2025) on VR-based learning, following PRISMA 2020 and drawing on four databases. Six review-type documents identified in the corpus were analyzed separately and excluded from this primary-research synthesis. The evidence shows that VR most consistently enhances affective outcomes-motivation, engagement, and immersion (48.6% of studies)-while also supporting cognitive (64.9%) and skill-based (21.6%) learning. Evidence on higher-order cognition and long-term retention, however, remains limited and inconclusive, frequently constrained by short interventions, weak theoretical grounding, and reliance on self-report assessment.

Theoretically, the review clarifies how immersive learning operationalizes constructivist and experiential principles while underscoring the need to manage cognitive load. Practically, it offers planners and educators a sustainability-oriented agenda: invest in teacher training, adopt scalable low-cost VR, and embed equity and durability into design. Its principal contribution is an integrative synthesis that, for the first time within this corpus, connects VR learning outcomes to the SDG 4 agenda.

Future research should prioritize: (1) longitudinal designs measuring retention and transfer; (2) studies in early-childhood and primary education; (3) higher-order cognitive and skill outcomes; (4) theory-driven instructional-design models that balance immersion with cognitive load; (5) objective, performance-based assessment; (6) culturally

responsive VR for under-represented regions; and (7) explicit alignment of VR research with SDG 4 and broader sustainability targets. Pursuing these directions will help ensure that immersive learning technologies are pedagogically effective, equitable, and sustainable.

AUTHOR CONTRIBUTIONS

Conceptualization and methodology: A.F. and S.S.; literature search, screening, and data extraction: A.F. and H.; formal analysis and visualization: A.F. and S.; writing—original draft: A.F.; writing—review and editing, and supervision: S.S., H., S., and N.Y. All authors have read and approved the final manuscript.

FUNDING

This research was supported by BIMA, Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, through the Doctoral Dissertation Research Scheme 2026 under Contract Number 267/C3/DT.05.00/PL-BARU/2026.

DATA AVAILABILITY

The data supporting the findings of this study—comprising the list of included studies and the extraction matrix—are available from the corresponding author upon reasonable request.

ACKNOWLEDGEMENTS

The authors thank BIMA for the financial support that enabled the completion of this research.

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APPENDIX

Appendix A. SDG 4 Target Alignment Coding

Table A1 presents the coding used to map each of the 37 primary studies to the most relevant SDG 4 targets, as

described in Section 2.2.

Table A1. SDG 4 target alignment coding (n = 37 primary studies)

No.	Reference	Level	SDG 4 Target(s)	Alignment	Equity/Access Basis
1	Kablitz, D.	Vocational (VET)	4.3, 4.4	Indirect	Vocational-level access/skills (level-based)
2	Baldassa, A.	Primary (aged 9–11)	4.1	Indirect	Primary-level access (level-based)
3	Keller, C.	Vocational (VET)	4.3, 4.4	Indirect	Vocational-level access/skills (level-based)
4	Mulders, M.	Lower secondary	4.1, 4.7	Direct (4.7)	Explicit biodiversity/sustainability content
5	Somadayo, S.	Primary	4.1	Indirect	Primary-level access (level-based)
6	Wu, S.-H. (2025)	Primary	4.1	Indirect	Primary-level access (level-based)
7	Fijacko, N. (2025) - BLS	Adults (BLS)	4.4	Indirect	Adult skills training (level-based)
10	Spangenberger, P. (2025)	Vocational (VET)	4.3, 4.4	Indirect	Vocational-level access/skills (level-based)
11	McGivney, E. (2025)	Upper secondary	4.1	Indirect	Secondary-level access (level-based)
12	Shabir, A. (2025)	Primary (Grade 5)	4.1	Indirect	Primary-level access (level-based)
13	Hermansyah, N.	Vocational (Grade 11)	4.3, 4.4	Indirect	Vocational-level access/skills (level-based)
14	Al-Bawaleez, M. (2025)	K-12 (gifted)	4.5	Indirect	Gifted-education inclusion (equity-based)
15	Žnideršič, K. (2025)	Upper secondary	4.1	Indirect	Secondary-level access (level-based)
16	Scippo, S. (2025)*	Primary (Grade 4)	4.1	Indirect	Primary-level access (level-based); *limited immersive-VR alignment (see Appendix B)
17	Huang, X. (2025)	Mixed	4.1 (partial)	Indirect	Mixed student/public audience (level-based, partial)
18	Lai, C.-J. (2024)	Primary (Grade 4)	4.1	Indirect	Primary-level access (level-based)
19	Tarng, W. (2024)	Upper secondary/University	4.1, 4.3	Indirect	Secondary+tertiary access (level-based)
20	Arifin, A.	Vocational (VET)	4.3, 4.4	Indirect	Vocational-level access/skills (level-based)
21	Topalska, R. (2024)	Preschool & primary (teachers)	4.c	Indirect	Teacher-training focus, not direct student outcome
23	Daghriri, I. (2024)	Primary	4.1	Indirect	Primary-level access (level-based)
24	Sulisworo, D. (2024)	Primary (Grades 4–5)	4.1	Indirect	Primary-level access (level-based)
25	Christopoulos, A. (2024)	Lower secondary	4.1	Indirect	Secondary-level access (level-based)
26	Neuwirth, L.S. (2024)	Medical students (HE)	4.3	Indirect	Tertiary/medical education access (level-based)
28	Lin, X.P.	Lower secondary	4.1	Indirect	Secondary-level access (level-based)
29	Corrales, M. (2024)	Pre-service primary teachers (HE)	4.c	Indirect	Teacher-training focus, not direct student outcome
30	Cárdenas-Sainz, B.A. (2023)	University students (HE)	4.3	Indirect	Tertiary access (level-based)
31	Kablitz, D.	Vocational (VET)	4.3, 4.4	Indirect	Vocational-level access/skills (level-based)
33	Goudarzi, N. (2023)	Postgraduate students (HE)	4.3	Indirect	Tertiary access (level-based)
34	Henriksen, A.H. (2023)	Preschool (aged 6–7)	4.1	Indirect	Early-childhood/primary access (level-based)
35	Cullinane, A. (2022)*	Doctoral students (HE)	4.3	Indirect	Tertiary access (level-based); *limited immersive-VR alignment (see Appendix B)
36	Globa, A. (2022)	Higher education (HE)	4.3	Indirect	Tertiary access (level-based)
37	Hsiao, P.-W. (2021)	School (general)	4.1	Indirect	School-level access (level-based)
38	Espitia, N.F. (2021)	Veterinary students (HE)	4.3	Indirect	Tertiary/veterinary education access (level-based)
39	Ahmad, L. (2020)*	Interior design students (HE)	4.3	Indirect	Tertiary access (level-based); *limited immersive-VR alignment (see Appendix B)
40	Baud-Bovy, G. (2017)	Primary	4.1	Indirect	Primary-level access (level-based)
41	Birt, J. (2017)	Distance-learning paramedic students (HE)	4.3, 4.4	Indirect	Tertiary/distance-education access + skills (level-based)
42	Badilla, M.G. (2015)	Pre-service teachers (HE)	4.c	Indirect	Teacher-training focus, not direct student outcome

Appendix B. List of Officially Included Studies

Table B1 presents the 43 documents comprising the final corpus identified through the Scopus bibliographic export and cross-checked against the study-level data extraction records. Document types are reported according to Scopus's official classification, including Article, Review, Conference Paper, and Short Survey. Of these 43 documents, 37 primary studies constitute the analytical corpus, whereas six review-type documents were excluded from the substantive analyses to avoid potential double-counting of evidence.

Studies marked with an asterisk (*) in the Cognitive & Affective column were identified during the data-extraction process as potentially having limited alignment with the

review's operational definition of immersive VR. In these cases, VR was either discussed as a potential direction for future research or represented through non-immersive online media rather than as an implemented immersive VR intervention. These studies were nevertheless retained because they report learning outcomes relevant to virtual learning environments; their limited alignment with immersive VR is taken into account when interpreting the findings.

Table B1. List of officially included studies (n = 43)

No.	Reference (Author, Year)	Doc. Type	Country	Level	VR Type	Sample	Cognitive & Affective
1	Kablitz, D. (2025)	Article	Germany	Vocational (VET)	IVR (HMD)	141	Cognitive & affective
2	Baldassa, A. (2025)	Article	Italy	Primary (aged 9–11)	VR full-immersive (HMD)	74	Psychomotor/behavioral
3	Keller, C. (2025)	Article	Switzerland	Vocational (VET)	VR HMD vs desktop	81	Cognitive
4	Mulders, M. (2025)	Article	Germany	Lower secondary	XR/VR application	172	Cognitive & affective
5	Somadayo, S. (2025)	Article	Indonesia	Primary	VR (online)	Not reported	Cognitive (literacy)
6	Wu, S.-H. (2025)	Article	Taiwan/Hong Kong	Primary	Spherical Video-based VR	841 students; 33 teachers	Affective/behavioral
7	Fijacko, N. (2025)	Article	Multinational	Adults (BLS)	VR & AR (recommendations)	N/A (review)	Cognitive/behavioral
8	Fijacko, N. (2025)	Review	Multinational	Laypeople & health workers	VR & AR (scoping review)	N/A (review)	Affective, behavioral, cognitive
9	Agustin, M. (2025)	Review	Indonesia/Brunei	Biology (general)	Immersive VR & virtual labs	N/A (review)	Cognitive, affective, psychomotor
10	Spangenberger, P. (2025)	Article	Germany	Vocational (VET)	iVR (HMD)	29	Cognitive
11	McGivney, E. (2025)	Article	USA	Upper secondary	VR (immersive video)	30	Affective (agency)
12	Shabir, A. (2025)	Article	Indonesia	Primary (Grade 5)	VR + AI	Not reported	Cognitive
13	Hermansyah, N. (2025)	Article	Indonesia	Vocational (Grade 11)	AR mobile	420	Cognitive & psychomotor
14	Al-Bawaleez, M. (2025)	Article	Jordan	K-12 (gifted)	VR/AR (qualitative)	6 teachers	Teacher perceptions
15	Žnideršič, K. (2025)	Conference paper	Slovenia	Upper secondary	VR game	Not reported	Cognitive & affective
16	Scippo, S. (2025)	Article	Italy	Primary (Grade 4)	Non-VR (3D printer/GeoGebra)*	Not reported	Cognitive*
17	Huang, X. (2025)	Article	China	Mixed	AR/MR/PC-IVM	42	Affective
18	Lai, C.-J. (2024)	Article	Taiwan	Primary (Grade 4)	VR game	81 (EG40/CG41)	Cognitive & communication
19	Tarng, W. (2024)	Article	Taiwan	Upper secondary/University	VR (immersive modules)	Not reported	Cognitive & affective
20	Arifin, A. (2024)	Article	Malaysia	Vocational (VET)	VR welding kit	N/A (review)	Psychomotor
21	Topalska, R. (2024)	Article	Bulgaria	Preschool & primary	VR & AR (teacher survey)	205 teachers	Teacher literacy
22	van der Want, A.C. (2024)	Review	Netherlands	Pre-service teachers (HE)	VR (various)	N/A (review of 24 studies)	Affective & teaching skills
23	Daghriri, I. (2024)	Conference paper	Australia/Saudi Arabia	Primary	VR/AR	N/A (review)	Cognitive & affective
24	Sulisworo, D. (2024)	Article	Indonesia	Primary (Grades 4–5)	Immersive VR	85	Cognitive & affective
25	Christopoulos, A. (2024)	Article	Greece	Lower secondary	VR 360	52	Cognitive & affective
26	Neuwirth, L.S. (2024)	Article	USA/France	Medical students (HE)	Immersive VR (POV)	Pilot (small N)	Psychomotor
27	Erita, Y. (2024)	Review	Indonesia/Malaysia	Primary	VR (review)	N/A (review)	Cognitive, affective, creativity
28	Lin, X.P. (2024)	Short survey	Thailand/others	Lower secondary	VR (critical review)	N/A (review)	Affective & behavioral
29	Corrales, M. (2024)	Article	Spain	Pre-service primary teachers (HE)	VR virtual tour	51	Affective & cognitive
30	Cárdenas-Sainz, B.A. (2023)	Article	Mexico	University students (HE)	XR (VR & AR)	99	Affective & cognitive
31	Kablitz, D. (2023)	Article	Germany	Vocational (VET)	IVR	79	Cognitive & wellbeing
32	Carlos, C.A. (2023)	Review	Mexico	Primary	VR (tethered & mobile)	N/A (meta-analysis)	Cognitive
33	Goudarzi, N. (2023)	Article	USA	Postgraduate students (HE)	VR (3D modeling)	Not reported	Cognitive
34	Henriksen, A.H. (2023)	Article	Denmark	Preschool (aged 6–7)	VR headset	RCT protocol	Cognitive & attention
35	Cullinane, A. (2022)	Article	UK	Doctoral students (HE)	Non-VR (online)*	Not reported	Affective*

36	Globa, A. (2022)	Article	Australia	Higher education	VR (hybrid)	Not reported	Affective
37	Hsiao, P.-W. (2021)	Article	Taiwan/Macau	School (general)	VR (STEAM)	Not reported	Affective & cognitive
38	Espitia, N.F. (2021)	Article	USA	Veterinary students (HE)	VR multi-user	Not reported	Cognitive & psychomotor
39	Ahmad, L. (2020)	Article	UAE	Interior design students (HE)	Non-VR (online exhibition)*	Not reported	Cognitive*
40	Baud-Bovy, G. (2017)	Conference paper	Italy	Primary	Haptic/force-feedback	N/A (review)	Cognitive/psychomotor
41	Birt, J. (2017)	Article	Australia	Distance-learning paramedic students (HE)	Mixed reality mobile	Not reported	Psychomotor
42	Badilla, M.G. (2015)	Article	Chile	Pre-service teachers (HE)	Immersive Virtual World	Not reported	Affective/teaching skills
43	Ricciardi, F. (2014)	Review	Italy	Health professions (HE)	VR/Serious games	N/A (review)	Cognitive & skills