Virtual Reality and Augmented Reality in Education: A Systematic Review

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Abstract

Virtual Reality (VR) and Augmented Reality (AR) together often termed extended reality (XR) have matured rapidly over the past decade and are increasingly deployed across K–12, higher education, and professional training. This systematic review synthesizes recent meta-analyses, scoping and umbrella reviews (2019–2025) to examine learning effectiveness, design considerations, challenges, and emerging trends in VR/AR for education. Evidence from multiple meta-analyses indicates that immersive VR (IVR) generally improves academic achievement and practical skills compared to traditional methods, with stronger effects when tasks require high interactivity, psychomotor performance, or experiential learning (e.g., medicine, STEM labs, complex spatial reasoning). Effects on higher-order thinking are mixed and may depend on instructional design and assessment alignment. AR shows consistent benefits for engagement, motivation, and conceptual understanding by overlaying digital content on real contexts, particularly in higher education and discipline-specific tasks (e.g., anatomy, mathematics manipulatives). Healthcare education remains the most studied domain, with recent umbrella and domain-specific reviews supporting VR/AR for skills acquisition and (emerging) assessment use.Key challenges persist: motion sickness and cognitive load management, accessibility and inclusion, teacher preparation, cost and scalability, data privacy/ethics, and evaluation rigor. Standards and guidance for XR accessibility are developing (e.g., W3C XAUR), yet gaps remain in procurement, policy, and universal design. Emerging trends include mobile/low-cost VR, spatial computing headsets, AI-enabled adaptive XR, multimodal haptics, digital twins, and competency-based assessments. We provide a comparative analysis of VR vs AR affordances, summarize applications across disciplines, and outline design-for-learning principles and implementation roadmaps. The review concludes with future directions: (1) stronger theory-driven instructional design; (2) accessibility-first development and policy; (3) robust, longitudinal, and equity-aware evaluation; (4) interoperable content and analytics standards; and (5) teacher professional learning at scale. Overall, VR/AR can add significant value when used purposefully for tasks that exploit their unique affordances and when integrated with inclusive pedagogy and sound assessment

Keywords: virtual reality; augmented reality; extended reality; immersive learning

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1. Introduction

Education is undergoing a profound transformation through the integration of immersive technologies, particularly VR and AR. Traditional teaching methods, while effective for knowledge transfer, often struggle to engage students or provide authentic experiential learning opportunities. VR and AR have emerged as solutions to bridge this gap by offering interactive, learner-centered experiences that foster deeper understanding and engagement (Radianti et al., 2020).

Virtual Reality immerses learners in entirely computer-generated environments, enabling them to interact with simulated worlds. For instance, medical students can practice surgeries in a risk-free environment, while engineering students can manipulate 3D models of machines (Jensen & Konradsen, 2018). Augmented Reality, on the other hand, overlays digital content on the physical world, enhancing real-world learning. Examples include AR-based anatomy applications or AR-supported language learning tools that contextualize vocabulary in everyday settings (Akçayır & Akçayır, 2017).

The relevance of VR and AR in education is amplified by advances in hardware and software technologies, alongside growing affordability and accessibility. Devices such as Oculus Rift, Microsoft HoloLens, and smartphone-based AR applications have lowered entry barriers for educational institutions (Bailenson, 2018). Furthermore, the COVID-19 pandemic accelerated the adoption of digital tools, further positioning VR and AR as critical components of future learning ecosystems (Merchant et al., 2014).

Despite these promising developments, challenges persist. Implementation requires significant financial investment, teacher training, and curriculum integration. Furthermore, equity issues arise, as not all institutions or learners have equal access to VR/AR devices and infrastructure (Zhao et al., 2020). From a pedagogical perspective, while immersive experiences can enhance learning outcomes, without clear instructional design frameworks their use risks becoming superficial (Parong & Mayer, 2018).

This systematic review examines how VR and AR are applied in education, the pedagogical benefits they bring, challenges encountered in adoption, and the emerging trends shaping future directions. By consolidating research across multiple domains, the paper aims to provide insights into how VR and AR can be systematically integrated to advance educational practices.

2. Literature Review

2.1. Evidence of learning effectiveness

Recent meta-analyses find that immersive VR yields small-to-moderate positive effects on academic achievement and skill performance across K–12 and higher education, with stronger effects for practice-intensive and spatial tasks. Moderator analyses often identify interactivity level, feedback, and task authenticity as key drivers; results for critical thinking are mixed without deliberate scaffolds.

In healthcare education, systematic and umbrella reviews indicate that VR/AR training improves knowledge and psychomotor performance and can be at least as effective as conventional simulation, while the use of VR for assessment is nascent but growing. Nursing education meta-analysis shows gains in knowledge and practical aptitude but limited effects on critical thinking, suggesting design-assessment misalignment (Moro et al., 2017).

For AR, a comprehensive review of higher education (2000–2023) reports consistent benefits in engagement, conceptual understanding, and performance, moderated by task type, technology features, and instructional design. Discipline-specific reviews (e.g., mathematics) corroborate these advantages and highlight teacher training and technical readiness as determinants of success (Jensen & Konradsen, 2018; Radianti et al., 2020).

Teacher education is an emerging focus: a 2014–2024 synthesis found positive overall effects for VR-supported instruction in teacher preparation but emphasized fragmentation and the need for theory-driven designs.

Table 1: Representative recent reviews and meta-analyses

Study (Year)	Scope & Sample	Key Findings
Makransky & Petersen et al. (var.; e.g., 2022/2024)	Meta-analyses of immersive VR in K–12/higher ed	Positive effects on learning; stronger for active/practical tasks; design moderates outcomes.
MDPI AR in Higher Education (2024)	237 studies (2000–2023)	AR supports engagement and learning; effects moderated by discipline/technology; included meta-analysis.
Umbrella Review—Medical Education (2024)	VR/AR across health professions	Improves competencies vs. traditional/no intervention; heterogeneity and quality issues noted.
BMC Med Educ (2025)	VR as assessment in nursing/medicine	Assessment use increasing; frameworks still evolving.
IEEE Access—IVR in STEM (2024)	Systematic review (STEM focus)	Affordances align with hands-on STEM; recommendations for design and tools.

3. Applications

- **STEM & Laboratory Learning.** IVR supports safe practice of hazardous procedures and complex spatial understanding (e.g., molecular structures, engineering visualization); AR enhances lab authenticity by overlaying steps/instrument data (Fonseca et al., 2014).
- **Healthcare & Allied Professions.** Widely used for anatomy, clinical skills, and increasingly assessment; evidence supports gains in knowledge and performance relative to conventional training (Moro et al., 2017).
- **Teacher Education.** Classroom management and practicum simulations help preservice teachers rehearse decision-making in safe environments, with promising effect sizes but need for coherent frameworks (Fonseca et al., 2014).
- **K–6 & Secondary.** VR shows positive effects on achievement; AR boosts motivation and conceptual understanding with manipulatives and context-aware overlays.
- **Emerging Spatial Computing & Mobile VR.** New headsets and mobile platforms are expanding classroom use cases; early education resources and procurement guidance are appearing, though empirical evaluation remains limited.

Table 2: Examples of applications by discipline

Discipline	Typical VR Use	Typical AR Use	Evidence snapshot
Medicine/Nursing	Procedural skills, anatomy, scenario-based training	Anatomy overlays, equipment guidance	Positive knowledge/skill gains; assessment emerging.
STEM (HE)	Virtual labs, simulations, spatial visualization	Lab steps, data overlays	Strong alignment with hands-on tasks
K–12	Explorations/field trips, science demos	Manipulatives, context-based tasks	Achievement/motivation benefits
Teacher Education	Classroom scenarios	In-situ guidance	Positive but fragmented evidence

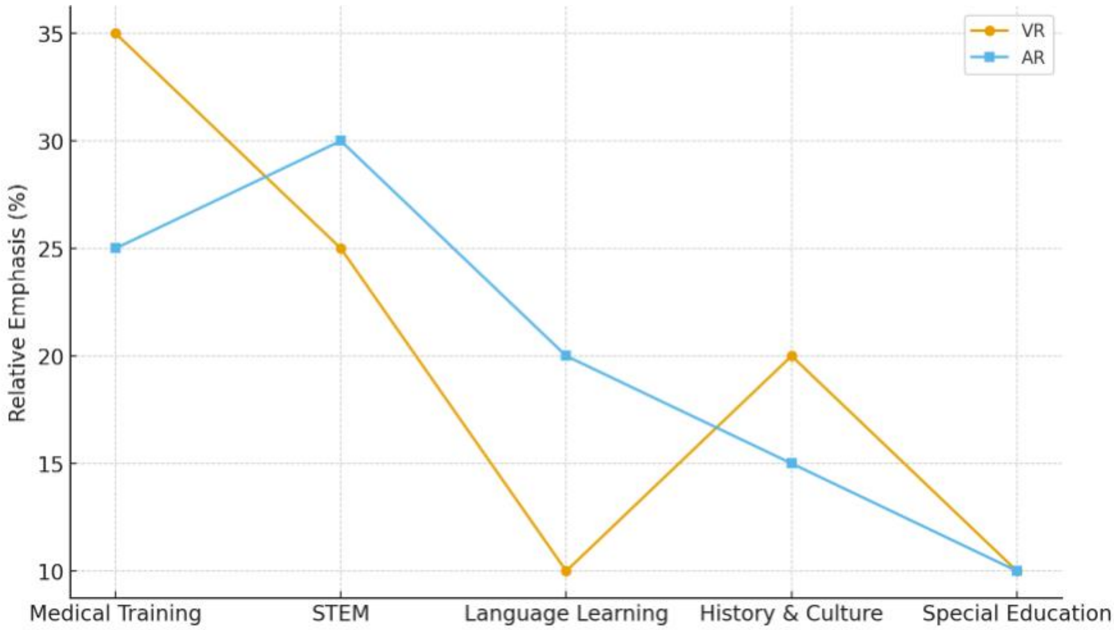

Figure 1: Application of VR and AR in education

4. Emerging Trends

- **AI-enabled XR** for adaptive feedback, analytics, and semi-automatic content authoring—an active area but under-evaluated in classrooms.
- **Spatial computing headsets & mobile VR** lowering barriers; vendors publish education resources, yet independent
- **Haptics and multi-sensory interfaces** to enhance procedural fidelity especially in healthcare and engineering.research is still catching up.
- **XR for assessment** (simulation-based and performance-based), with initial frameworks and validity studies emerging.
- **Accessibility-first XR** guided by XAUR and sector initiatives; tooling and practice are evolving.
- **Policy & procurement guidance** in higher education around privacy, safety, and compliance.

5. Challenges

Despite the proven benefits of VR and AR in education, their widespread adoption continues to be hindered by several significant challenges. One of the foremost barriers relates to cost and accessibility. High-quality VR headsets, AR-enabled devices, and supporting infrastructure remain prohibitively expensive for many institutions, limiting opportunities for equitable adoption across different educational contexts (Zhao et al., 2020). In addition to financial constraints, technical limitations further restrict usability. Common issues include motion sickness, hardware requirements, and limited battery life, all of which reduce the reliability and consistency of immersive learning experiences (Parong & Mayer, 2018).

Another challenge lies in pedagogical integration, as VR and AR are often introduced as novelty tools without being embedded into well-structured instructional frameworks. Without clear alignment to curriculum objectives, these technologies risk being underutilized or producing only superficial engagement rather than meaningful learning outcomes (Radianti et al., 2020). Furthermore, equity and inclusion concerns persist, with students from underprivileged backgrounds facing reduced access to devices, stable internet connectivity, and institutional support. This digital divide exacerbates existing educational inequalities and raises questions about the fairness of immersive technology deployment in classrooms (Bailenson, 2018).

Finally, the success of VR and AR integration depends heavily on teacher training and professional development. Many educators lack the technical expertise and confidence to incorporate immersive tools effectively into their lessons, which often results in fragmented or inconsistent implementation. Teacher readiness, therefore, is as crucial as infrastructure investment in ensuring that VR and AR move beyond pilot projects to become sustainable elements of modern pedagogy (Akçayır & Akçayır, 2017).

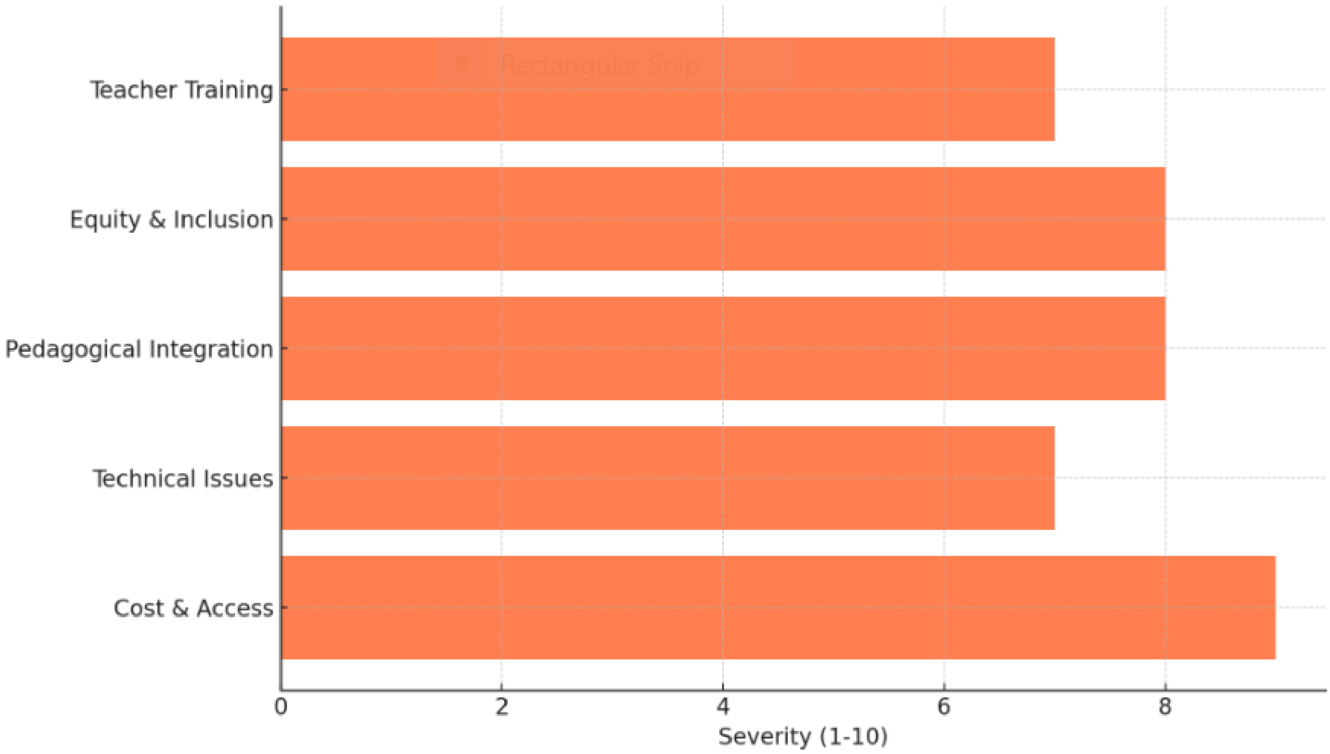

Figure 2: Challenges of VR and AR in education

Table 3: Mitigations

Challenge	Why it matters	Mitigation strategies
Cybersickness & cognitive load	Discomfort reduces time-on-task; overload harms learning	Comfort-first design, session limits, navigation aids, gradual immersion, instructional scaffolding
Accessibility & inclusion	Diverse sensory/motor/cognitive needs; risk of exclusion	Follow W3C **XAUR**, provide multimodal alternatives, adjustable input/output, seated modes, captions/voice.
Teacher capacity	Effective integration requires pedagogical/technical fluency	Professional learning tied to curriculum; co-design with instructors; reusable lesson templates
Cost & scalability	Devices, licenses, sanitation, support	TCO planning; mobile/low-cost options; device carts; shared content repositories
Privacy, safety, and ethics	Biometric/behavioral data; student safety	Risk-aware procurement, data minimization, clear policies, vendor compliance checks
Evaluation quality	Heterogeneous measures, small samples	Use validated outcomes, theory-aligned designs, replication, longitudinal tracking

6. Comparative Analysis

VR offers unparalleled immersion, making it ideal for disciplines requiring simulation, such as medicine and engineering. However, its cost and infrastructure requirements limit widespread adoption. AR, while less immersive, is more practical for everyday classrooms due to its reliance on mobile devices and ease of integration into curricula (Radianti et al., 2020; Jensen & Konradsen, 2018).

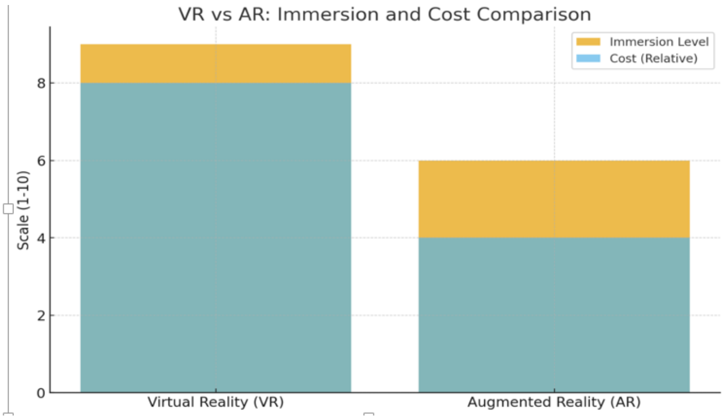

Figure 3: Immersion and cost comparison

Figure 2 shows that VR offers deeper immersion but is more costly, while AR balances affordability with moderate immersion.

Table 4: Comparative Analysis

Dimension	VR (Fully immersive)	AR (Overlay on real world)	When to prefer
Task type	High-risk practice, spatial/3D manipulation, scenario rehearsal	Contextual augmentation, situated tasks, real-world equipment	VR for safe simulation; AR for in-situ guidance
Cognitive load	Higher if poorly designed; can focus attention by removing distractions	Lower baseline; real-world distractions persist	AR for light overlays; VR for focused practice
Equipment & cost	HMDs with controllers/haptics; higher TCO	Mobile devices/tablets or lightweight headsets	AR for quick wins and scale; VR for specialized labs
Accessibility	More barriers (locomotion, motion sickness)	Broader device access; fewer motion constraints	AR often more inclusive initially; both need XAUR-aligned design
Assessment	Rich performance capture; validity work emerging	In-situ performance prompts; easier classroom deployment	Choose based on assessment context and fidelity needs

7. Future Directions

- **Theory-driven design.** Align XR affordances with learning theories (embodied cognition, cognitive load, deliberate practice) and assessment types; report design rationales and fidelity decisions.
- **Accessibility-first ecosystems.** Operationalize XAUR in procurement and course design; co-design with disabled learners; build institutional playbooks and audits.
- **Robust evaluation.** Prioritize randomized/controlled studies where feasible, standardized outcome measures, and longitudinal effects (transfer, retention, equity impacts).
- **Interoperability & analytics.** Advance standards for content portability and privacy-preserving learning analytics in XR; integrate with LMS and credentialing systems
- **Teacher professional learning at scale.** Scaffolded PD, micro-credentials, and communities of practice to translate research into classroom practice.

8. Conclusion

VR and AR can meaningfully enhance learning when applied to problems that benefit from immersion, spatial interaction, and real-time feedback. The strongest evidence lies in healthcare and STEM contexts for knowledge and skills acquisition, with AR adding situated support and motivation across disciplines. However, impact is contingent on instructional design, accessibility, teacher capacity, and policy-aware implementation. The field now needs accessibility-first, standards-aligned, and theory-grounded deployments evaluated with rigorous, longitudinal methods. With these guardrails, XR can shift from isolated pilots to sustainable, equitable educational innovation.

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