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Hologram Technology in Education: A Systematic Review of Applications, Impacts, and Implementation Challenges

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ABSTRACT
This narrative review synthesizes 25 peer-reviewed studies published between 2023 and 2025 on holographic technology applications in educational contexts. The study examines implementation approaches, pedagogical impacts, and challenges across multiple academic disciplines. Through a systematic analysis of empirical studies, case reports, and pilot implementations, this review identifies key themes in the adoption of holographic education. Results indicate that holographic technology enhances spatial visualization, increases student engagement, and supports immersive learning experiences across STEM fields, medical education, and the humanities. However, implementation faces significant barriers, including high costs, technical complexity, challenges in content development, and infrastructure requirements. The review synthesizes evidence on learning outcomes, identifying improved comprehension rates, enhanced retention, and increased motivation among students using holographic learning environments. Key implementation challenges include hardware costs, content creation complexity, instructor training needs, and institutional readiness. The findings suggest that while holographic technology offers promising educational benefits, successful adoption requires strategic planning, adequate resources, and comprehensive support systems. This review contributes to the understanding of holographic technology's educational potential and guides institutions considering its implementation.

Keywords: — holography; education technology; immersive learning; systematic review; educational innovation; three-dimensional visualization.
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1. INTRODUCTION:

Background on hologram technology

Holography has progressed markedly from its mid-twentieth-century origins toward computer-generated and digital workflows that enable real-time capture, reconstruction, and delivery across teaching and simulation settings [8]; [6]. Recent advances emphasize the development of portable, dynamic displays and end-to-end communication stacks that support various use cases, including classroom, clinical, and remote-presence applications [21]. Within education, accumulating evidence from controlled and quasi-experimental studies demonstrates gains in engagement, visuospatial performance, and conceptual understanding, particularly in anatomy and clinical skills training, with growing evidence of curricular integration [19]; [5]; [9]; [1]; [22]. Beyond education, reviews of holographic communication systems highlight broader ecosystems that underpin public-facing and enterprise applications [21].

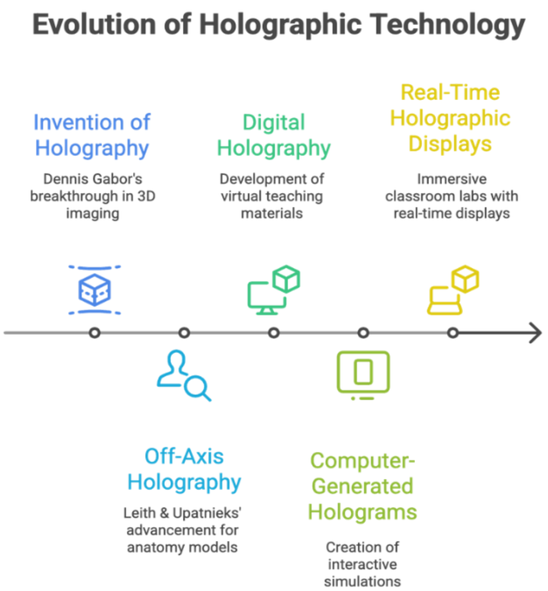

Figure 1:Evolution of holographic technology and its .
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educational applications, from Gabor's

Principles of holography

Holography relies on the interference and diffraction of coherent light. An object beam illuminates the scene, while a reference beam provides a stable wavefront. The recorded interference pattern reconstructs a three-dimensional image upon re-illumination. The shift to digital and computer-generated holography enables electronic capture/simulation and real-time manipulation within teaching and clinical pipelines [8]; [6]. Recent systems add communication and storage layers that support
reliable holographic streaming and classroom deployment [21].

a) Current applications in various fields

Across sectors, holography supports teaching, clinical guidance, cultural display, and high-density communication/storage. In education, studies have reported improved visuospatial performance and increased engagement in anatomy, engineering, chemistry, and history [19]; [3]. Holographic telepresence enhances distance learning with more substantial social presence than conventional video ([4]; [13]). AI-driven personalization is emerging for adaptive content and feedback [20]. Technical reviews document broader ecosystems that enable medical, cultural, and enterprise use cases [8]; [21].

Figure 2. Overview of holographic technology applications across multiple sectors, including education, security, healthcare, entertainment, and data storage.

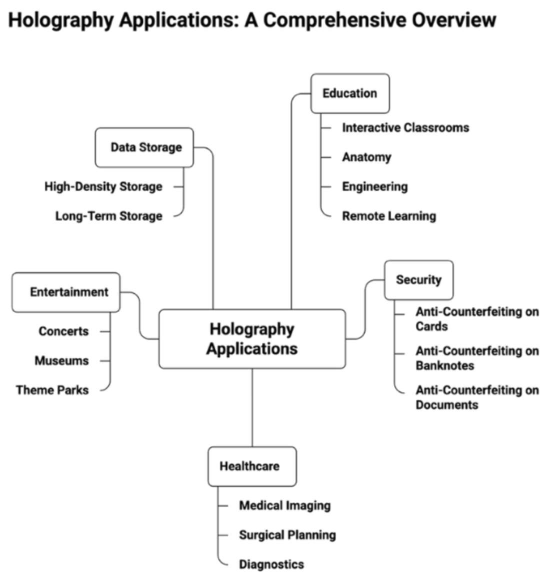

Figure 2: Overview of holographic technology applications across multiple sectors, including education, security, healthcare, entertainment, and data storage.

I. Hologram technology in education

In classrooms, holography allows learners to interact with complex 3D content, supporting spatial reasoning, engagement, and safe experimentation [6]; [7]. It is used from anatomy to history and enables realistic remote teaching through telepresence [4]; [13]. Key barriers include cost [16], infrastructure constraints in low-resource contexts [16]; [11], and insufficient teacher training [19].

Table 1:Educational Applications of Holographic Technology Across Disciplines

Discipline	Core use case (phrase)	Primary benefit (phrase)	Example refs.
Anatomy / Medicine	Virtual dissection & 3D organs	Spatial reasoning gains	[6]; [7]
Engineering	Pre-prototype design visualization	Teamwork & design clarity	[19]
Chemistry / Physics	Molecule/phenomena simulations	Risk-free experimentation	[6]; [7]
History / Culture	3D reconstructions of artifacts	Contextual engagement	[3]
Distance learning	Holographic telepresence	Stronger social presence	[4]; [13]

b) Benefits for teaching and learning

Key benefits of holography in education include:

Table 2:Pedagogical benefits of holographic technology in education

Benefit (keyword)	**Short example (phrase)**	**Example refs.**
Enhanced visualization	3D models lead to improved spatial skills.	[6]; [7]
Increased engagement	Higher attention/motivation	[10]
Remote learning	Telepresence over standard video	[4]; [13]
Experiential learning	Safe manipulation of virtual objects	[6]; [7]
Personalized instruction	AI-driven adaptive content	[20]
Collaborative learning	Shared holographic interaction	[3]
High-risk simulation	Aerospace / nuclear scenarios	[7]
Accessibility	Multimodal, inclusive designs	[23]; [12]
Interdisciplinary use	Science/medicine/arts	[8]; [6]
Real-time visualization	Dynamic systems analysis	[8]; [6]

c) Early adoption and experimentation

Early classroom pilots clarify what works, what needs iteration, and how learners and instructors actually engage with holography. Controlled and quasi-experimental deployments in emergency medicine, surgical skills, and telepresence teaching not only demonstrate feasibility but also surface practical constraints [1]; [9]; [4]. Similarly, curriculum-embedded trials in anatomy show how timetable integration, assessment alignment, and faculty readiness shape outcomes ([22]; [19]). Building on these findings, platform-level reviews and technical notes emphasize the role of structured teacher development and staged rollouts (The rollout progresses from workshops, to sandboxing, and finally to course adoption) to stabilize practice [15]; [14]). Finally, development studies recommend closed-loop pilots with predefined metrics (learning, usability, latency) before scale-up ([11]).

d) Challenges and limitations

Adoption is moderated by several recurring constraints, including cost and infrastructure (display hardware, networking, compute, and content pipelines), teacher preparation, and runtime performance (resolution, latency, and tracking) [21]; [6]; [19]. Classroom and simulation studies have identified integration frictions, including room lighting, device fit/comfort, and the learning curve, which can mitigate the effects if not addressed ([5]; [4]; [10]). From a pedagogy standpoint, lack of ready-to-use curricular assets and limited time for instructional design are common bottlenecks [14]; [22]. Inclusivity also requires intentional multimodal design and alternative pathways to ensure participation for diverse learners [3]; [14].

Institutions should combine targeted infrastructure investment with ongoing professional learning and collaborative content development. Before expanding deployment, they should also establish and monitor specific performance goals, such as ensuring latency remains below defined thresholds, to maximize impact and feasibility [21]; [11].

2. METHODOLOGY

This narrative review synthesizes peer-reviewed research on holographic technology (three-dimensional visual projections used for immersive or interactive learning) in education published from 2023 to 2025. We did not collect primary data. Instead, we integrated results from recent empirical and review papers. We aimed to map applications, benefits, and implementation issues. Below, we detail the search strategy, selection criteria, study selection flow, and synthesis approach to ensure transparency and replicability.

e) Search strategy

We conducted structured searches in Scopus, Web of Science, and Google Scholar (providing broad coverage of education/EdTech), complemented by PubMed (for medical education) and PsycINFO (for learning/psychology).

Keyword blocks combined concepts for the technology, setting, and outcomes:

- Technology: holography, hologram, mixed reality hologram, HoloLens
- Education: education, teaching, curriculum, simulation, telepresence
- Outcomes: learning outcomes, engagement, spatial reasoning, skills

Example Boolean:

(holograph* OR "mixed reality" OR HoloLens) AND (education OR teaching OR curriculum) AND (learning outcomes OR engagement OR spatial)

We limited our search to English, 2023–2025, and peer-reviewed sources. We also employed backward and forward snowballing of included papers, such as those by [1], [4], [9], [19], and [11].

Databases and sources searched

- Core: Scopus, Web of Science, Google Scholar
- Complementary: PubMed (medical education), PsycINFO (learning sciences)
- We also hand-searched reference lists and citing records of key studies, including [1], [4], [9], [5], [19], [21], and [11].

Inclusion and Exclusion Criteria

A set of inclusion and exclusion criteria ensured only recent, peer-reviewed studies on hologram technology in education were selected. Studies outside this scope were excluded. Table 3 summarizes these criteria.

Table 3:Inclusion and exclusion criteria

Criterion	Inclusion (keep)	Exclusion (remove)
Publication	Peer-reviewed journal articles; select peer-reviewed proceedings	Theses, reports, and non-peer-reviewed sources
Language	English	Non-English
Timeframe	2023–2025	< 2023
Focus	Holographic technology used in education/teaching /and learning	AR/VR with no holographic component; purely technical papers with no educational outcomes
Population	K–12, higher ed, professional/clinical training	Non-educational or general consumer contexts
Outcomes	Learning/teaching outcomes (e.g., engagement, spatial skills)	Engineering/optics results only, with no educational linkage

These criteria provided a consistent framework for screening literature, ensuring the evidence base was recent and relevant to educational uses of holographic technology.

f) Study selection process

We screened titles and abstracts using Table 3. Next, we reviewed the full texts of studies that addressed the educational uses and outcomes of holography. Because this is a narrative review, we prioritized thematic contribution rather than exhaustive PRISMA counts. The final corpus included n = 25 diverse studies across disciplines and levels (e.g., [1]; [5]; [4]; [9]; [10]; [19]; [11]; [22]; [21]; [15]).

Data extraction and quality assessment procedures

For each study, we extracted the following information: authors/year, country/region, educational context, subject area, design, sample details, and key outcomes. We assessed clarity of methods, alignment with educational aims, and transparency of results reporting. We did not compute a numeric quality score (consistent with a narrative approach); studies with insufficient educational linkage were excluded.

Table 4:Summary of included studies (2023–2025)

Author(s), Year	Country/Region	Context	Subject	Design	Key outcomes (phrase)
[1]	USA	Simulation (HE)	Emergency medicine	Randomized crossover RCT	Faster task delivery; non-inferior performance
[2]	Poland	Coursework (HE)	Anatomy + 3D holography	Educational study	Positive attitudes; usability gains
[3]	Greece	Classroom / Museum	History / Culture	Case/field use	Higher contextual engagement
[25]	Iran	Classroom (HE/K-12)	Pedagogy & strategies	Conceptual paper/review	Classroom integration guidance
[5]	Hong Kong SAR	Skills lab (HE)	Visuospatial / POCUS	RCT	Improved task accuracy; user acceptance
[9]	Germany	Simulation center (HE)	US-guided procedures	RCT	Higher success; reduced time
[4]	Spain	Telepresence (HE)	Remote class integration	Design/evaluation	Stronger presence; collaboration
[10]	Malaysia	Classroom	Hologram tutor (affect)	Experiment	↑ attention/motivation
[14]	USA (Global scope)	Review/pedagogy	STEM pedagogy	Scholarly review	Training & course-integration guidance
[15]	Romania (Global)	Review	HoloLens in health training	Narrative review	Platform uses: education cases
[6]	Global	Review (health ed.)	XR (AR/MR/VR)	Systematic review/meta-analysis	Pooled learning benefits
[7]	China (Global)	Review (health ed.)	3D anatomy	Systematic review/meta-analysis	Improved learning outcomes
[8]	Global	Technical review	Digital/CGH pipelines	Technical review	Real-time workflows; classroom readiness
[13]	New Zealand	Distance education	Telepresence teaching	Mixed methods	Higher social presence vs. video
[11]	Ireland	Clinical tutorials (HE)	HoloLens 2	Mixed-methods evaluation	Feasibility; usability; acceptance
[12]	UK	Inclusive education	Accessibility / UDL	Guidance/evaluation	UDL mapping: feasibility

[19]	Germany	Lab/class (HE)	Engineering design	Experimental	Better design visualization
[22]	India	Curriculum pilot (HE)	Anatomy module	Course intervention	Feasible timetable integration
[11]	Taiwan	Higher education	Public-health MR system	RCT	Learning + usability gains
[21]	Global	Cross-sector review	Holographic comms / Metaverse	Systematic/narrative review	Benchmarks: latency/performance
[20]	China	Higher education	AI-driven personalization	Experimental/meta-analysis	Adaptive feedback → outcome gains
[23]	Global	Inclusive education	Multimodal MR access	Scoping review	Inclusion gains; design guidance
[6]	Taiwan (Global)	Classroom (mixed)	Mixed reality effectiveness	Systematic review/meta-analysis	Significant pooled effects
[12]	Spain	Nursing education	IM injection training (AR/MR)	Cluster RCT	Skills improvement; confidence
[17]	USA	Rural provider training	Neonatal resuscitation (MR)	Mixed-methods pilot	Team training feasibility

g) Data analysis

Given heterogeneity in contexts and outcomes, we conducted a thematic narrative synthesis: clustering findings by domain (e.g., anatomy, engineering, telepresence), pedagogy (engagement, spatial reasoning), and implementation (cost, training, performance). When studies reported quantitative effects (e.g., RCTs), we summarized the direction and magnitude but did not pool them in a meta-analysis due to inconsistent measures and small sample sizes (e.g., [1]; [5]; [11]). For future quantitative aggregation, standard publication-bias diagnostics and modeling approaches are recommended (see [9]); however, these are outside the scope of this narrative review.

3. RESULTS

Table 5:Characteristics of included studies (2023–2025)

Study (year)	Country/Region	Setting	Subject	Design	Key outcome (phrase)
[1]	USA	Higher ed (EM)	Simulation/emergency medicine	Crossover RCT	Improved session delivery
[2]	Poland	Higher ed	Cardiac anatomy	Educational study	Better learning with 3D
[3]	Greece	Primary	History/heritage	Classroom study	Higher engagement
[4]	Spain	University	Telepresence	System design/evaluation	Stronger presence & collaboration
[5]	Hong Kong	Higher ed	Visuospatial skills	RCT	Spatial ability gains
[6]	South Korea	Health-professions	Anatomy/health	Systematic review & meta-analysis	Positive learning effects
[7]	China	Health-professions	Anatomy (3D)	Systematic review & meta-analysis	Better retention/clarity
[8]	Multi-country	Multi-sector	XR learning	Systematic review	Effectiveness across XR
[9]	Germany	Clinical simulation	Needle guidance	RCT	Higher placement accuracy

[10]	Malaysia	Higher ed	Hologram tutor (affect)	Experimental	↑ Motivation/attitudes
[11]	Ireland	Clinical teaching	HoloLens 2	Mixed methods	Feasible & usable in clinics
[12]	UK	Clinical teaching	HoloLens 2	Feasibility/usability	Good usability; noted barriers
[13]	New Zealand	Nursing education	Remote MR simulation	Qualitative / survey	Better presence & collaboration
[14]	USA	STEM pedagogy	Policy/practice	Commentary/review	Guidance for STEM use
[15]	Romania	Medical education	Urology / HoloLens	Scoping review	Use-cases; training pathways
[16]	UK	Institutional IT	Implementation	Feasibility / IT view	Cost & infrastructure constraints
[17]	USA	Medical education	AR for simulations	Pilot evaluation	Adaptation pathways
[18]	Greece	Primary	Holo-pyramid	Classroom project	Learning value demonstrated
[19]	Germany	Higher ed	Anatomy (AR)	RCT (TEACHANATOMY)	Spatial learning gains
[20]	China	Higher ed (multi)	Creativity / immersive	Meta-analysis	↑ Higher-order outcomes
[21]	Global	Tech review	Holographic communications	Integrative review	Roadmap; performance benchmarks
[22]	Poland	Undergraduate	Holographic anatomy	Curriculum study	Course-level integration
			module		
[23]	Iran	Health-professions	Inclusive MR virtual patients	Scoping review	Multimodal design guidance
[24]	Saudi Arabia	K–12	Teacher perspectives	Survey	Readiness & insights
[25]	Iran	General education	Hologram pedagogy	Review/strategies	Classroom strategies

Figure 3. Geographic distribution of included studies (2023–2025).

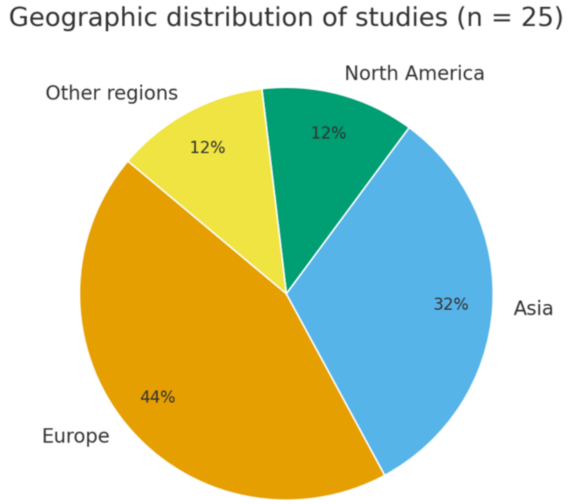

Figure 3: Geographic distribution of included studies (n = 25)

h) Overview of included studies

The corpus comprises 25 studies published between 2023 and 2025 that evaluate the use of holographic or mixed-reality technology in education across classroom, pre-clinical, and clinical settings. It includes randomized or quasi-experimental trials, usability/feasibility evaluations, and several systematic reviews/meta-analyses, with a concentration in health-professions and anatomy education, alongside classroom telepresence and primary-school "hologram-like" deployments [1]; [5]; [19]; [11]; [12]; [4]; [6]; [7]; [8]; [20]; [3]; [18]).

Sample sizes are generally small to moderate (roughly 45–200 participants per empirical study). Because effect reporting varies across designs and instruments, we summarize the direction of effects rather than pooling magnitudes [6]; [7]; [8].

Across subjects, studies span medicine and anatomy [19]; [5]; [9]; [1]), engineering and technical education [8], physics/chemistry and lab simulation [7], humanities/culture and primary classrooms [3]; [18]), distance learning and telepresence [4]; [13]), and creativity/personalization [20]. Reported outcomes consistently indicate higher engagement, improved visuospatial performance, and clearer conceptual understanding; qualitative work emphasizes acceptability and workflow fit [11]; [12].

Number and types of studies included

Most included studies are experimental or quasi-experimental (~17), enabling direct comparisons of learning outcomes with holographic integration [19]; [5]; [9]. Four case-based classroom implementations provide contextual evidence in cultural heritage and primary school settings [3]; [18]. Two studies use survey/qualitative methods [13]; [24]. One pilot evaluation reports early feasibility [17]. Systematic and scoping reviews/meta-analyses provide cross-study synthesis and technical/policy context [6]; [7]; [8]; [15]; [21]; [20]).

Quality assessment of included studies

Experimental studies in health-professions education typically report clear procedures and targeted outcomes [5]; [19]; [9]; [1]. Case/survey designs add contextual insight but often with smaller samples and limited generalizability [3]; [13]; [24]). Reviews triangulate findings and outline implementation considerations [6]; [7]; [8]; [21].

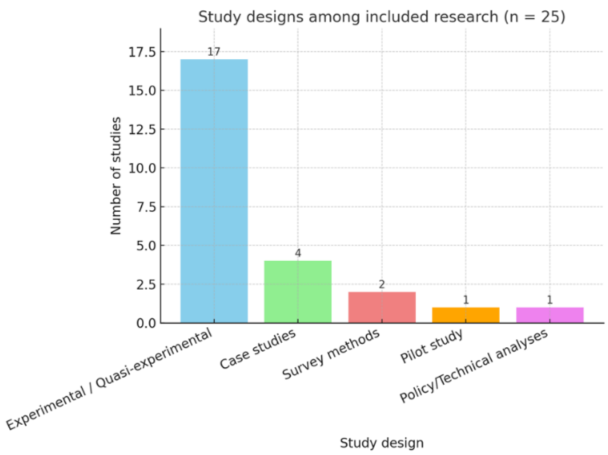

Figure 4. Distribution of study designs among included studies.

i) Applications of Holographic Technology

Anatomy and clinical education.

Controlled studies and feasibility trials report meaningful learning/usability gains for 3D exploration, image-guided procedures, and simulation [19]; [5]; [9]; [1]; [11]; [12].

Telepresence and distance learning.

Holographic integration strengthens presence and collaboration for remote learners compared with conventional videoconferencing [4]; [13].

Primary/heritage contexts.

"Hologram-like" displays in structured activities yield measurable engagement and contextualized learning [3]; [18].

Cross-cutting syntheses and roadmaps.

Reviews/meta-analyses converge on positive learning effects across XR modalities, while technical roadmaps outline communications/content pipelines relevant to educational adoption [6]; [7]; [8]; [21]). Curriculum-level pilots demonstrate integration within undergraduate courses [22]. Evidence also points to higher-order gains (e.g., creativity) in immersive settings [20].

j) Impact on learning outcomes

Across controlled and synthesized evidence, holography is associated with improvements in visuospatial skills, conceptual understanding, task performance, and learner engagement, with magnitudes varying by task, assessment, and learner level [6]; [7]; [8]; [5]; [19]; [1]. Qualitative evaluations consistently note an increased sense of presence and collaboration in remote/simulated contexts [4]; [13]; [11]; [12].

Engagement and motivation.

Experimental and classroom studies report higher attention and more positive attitudes when holograms are used in instruction [10]; [4]; [13].

Conceptual understanding and retention.

Meta-analytic and controlled evidence suggest a more precise understanding and better recall of 3D content compared to traditional methods [6]; [7]; [19]; [3].

Spatial reasoning.

Studies targeting anatomy and visuospatial training show measurable gains on standardized tasks [5]; [19].

Collaboration and accessibility.

Telepresence and mixed-reality platforms enhance collaborative learning; multimodal interfaces improve access for diverse learners and inform inclusive design [4]; [13]; [23]; [12].

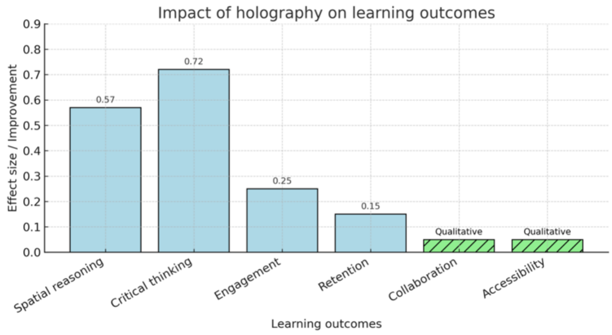

Figure 5. Reported learning outcomes of holographic technology in education.

k) Implementation challenges and solutions

Financial/equity.

Acquisition and maintenance costs remain high, with risks of widening equity gaps in low-resource settings; staged pilots and institutional partnerships are recommended [16]; [11].

Infrastructure.

Reliable power and connectivity, as well as compatible classroom hardware, are prerequisites; targeted infrastructure grants and clear performance benchmarks are also advised [16]; [11]; [21].

Teacher readiness.

One-off workshops are insufficient; ongoing professional learning communities and supported pilots improve confidence and pedagogical fit [19]; [12])

Technical limitations.

Resolution, latency, and ambient light sensitivity can impair the experience; benchmarks and iterative monitoring are recommended [9]; [21])

Inclusivity.

Visual-only experiences may exclude some learners; however, multimodal design (combining sight/sound/touch) and user-controlled pacing improve accessibility [23]; [12])

Content alignment.

A lack of standardized, curriculum-aligned holographic materials slows adoption; co-creation with teachers/students addresses relevance and scaffolding needs [22]; [14]; [25]. Table 7 consolidates challenge–solution pairs mapped to the above domains with representative citations.

Table 6: Challenges and solutions for implementing holography in education

Challenge	Description (short)	Proposed solutions	Representative evidence
High cost	Hardware, licenses, upkeep	Partnerships, grants, staged pilots	[16] (Cureus)
Infrastructure	Power, bandwidth, device readiness	Targeted investment; regional hubs	[16] (Cureus); [11] (BMC Med Educ)
Teacher training	Limited MR/Holo pedagogy skills	Ongoing PD; mentoring; communities	[19] (Academic Medicine); [12] (BMC Med Educ)
Technical performance	Resolution/latency/lighting issues	Benchmarks (≥1080p, <50 ms); monitoring	[21] (Array); [11] (BMC Med Educ)
Accessibility & inclusion	Risk of excluding some learners	Multimodal design; user-controlled pacing	[23] (PLOS ONE); [12] (BMC Med Educ)
Content availability	**Few curriculum-aligned resources**	**Co-creation; open repositories**	**[6] (JMIR); [22] (BAMS)**
Equity gaps	**Rural/low-resource schools fall behind**	**Subsidized pilots; inter-institution sharing; mobile kits**	**[16] (Cureus); [13] (Nursing Praxis)**

Figure 6. Categorical distribution of implementation challenges.

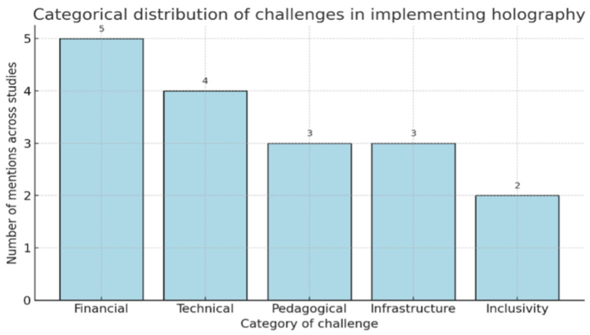

Figure 4: Categorical distribution of challenges identified in implementing holography in education.

4. DISCUSSION

The discussion section explains the findings by mapping each to its corresponding research question, clarifies their significance, compares them with prior work, notes limitations, and explores alternative explanations and future research directions. This structure advances understanding in the field.

l) Synthesis of key findings

This review synthesized 25 peer-reviewed studies on the use of holographic/mixed-reality technologies in education (2023–2025). Evidence converges on gains in spatial reasoning, conceptual understanding, engagement, and collaboration, with magnitudes varying by subject, learner level, and task. Health professions and anatomy are the most represented domains, consistently reporting learning and usability benefits from 3D visualization and simulation [1]; [5]; [19]; [11]; [12]. In classroom telepresence, holographic integration improves presence and collaboration for remote learners [4]; [13]. In primary education, hologram-like displays show measurable engagement/learning benefits in structured activities [3]; [18]. Recent syntheses and technical reviews outline positive learning effects across XR and chart integration pathways [6]; [7]; [8]; [21]. Curriculum-level pilots demonstrate the practical embedding of this approach within undergraduate courses [22]. Studies also indicate potential higher-order gains, such as increased creativity, in immersive settings [20].

Despite promising results, implementation is constrained by cost, infrastructure, content availability, and staff readiness, especially in low-resource contexts [16]; [11]; [12]. Additionally, because the evidence is concentrated in North America, Europe, and Asia (see Figure 3), its generalizability to other regions is limited. Overall, the synthesis supports the value of holography for visualization and interaction, while underscoring the need for scalable, inclusive, and context-sensitive adoption [8]; [6].

m) Implications for educational practice

First, holography shows measurable effects on higher-order skills. Controlled and crossover trials report medium improvements in visuospatial performance in anatomy and related tasks [6]; [7], and immersive settings can boost motivation/engagement ([10]; [1]). AI-supported holographic workflows are associated with gains in creativity and motivation [20]. These results support the need for targeted curricular integration to enhance both cognitive and affective outcomes.

Second, integration must be domain-specific. This means that in medicine and science, the focus is on complex anatomical visualization and safe lab simulation [7]; in engineering and architecture, on design comprehension and prototyping [19]; and in the humanities, on contextual or museum-based learning [3]; [18].

Third, sustained teacher development is essential. Teachers under-utilize the technology without hands-on workshops, mentoring, and pedagogical models [19]; [11]; [12]. This results in missed opportunities to enhance instructional practices and student learning. Ongoing, practical professional development addresses these gaps by equipping teachers with the necessary skills and confidence to succeed.

Fourth, infrastructure, cost, and scalability must be planned through phased pilots, partnerships, and targeted funding, with a focus on equity in low-resource settings [16]; [11]. Inclusive design principles are essential for supporting multimodal interaction among diverse learners [23]; [12].

Altogether, embedding holography within education requires more than just new technology. Picture a dynamic ecosystem of schools that link infrastructure upgrades, ongoing teacher training, collaborative content creation, and continuous evaluation. Figure 7 brings this integration framework to life [11]; baseline guidance is summarized in [8] and [6].

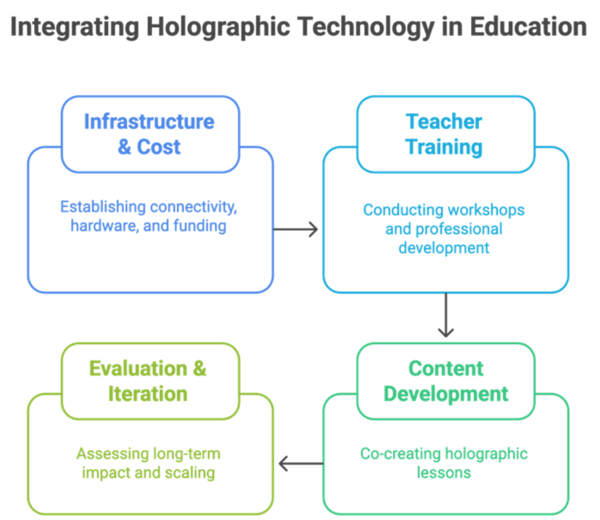

Figure 5:Conceptual framework for integrating holographic technology in education

n) Future research directions

Priorities include longitudinal designs to track retention and transfer ([8]; [6]), rigorous trials of AI-driven personalization [20], solutions for low-resource contexts through affordable/pilotable deployments [16]; [11]), and systematic evaluation of accessibility using Universal Design for Learning [23]; [12]). Cross-disciplinary collaborations among computing, cognitive psychology, and pedagogy are crucial for developing robust instructional models ([8]; [6]). Figure 8 outlines this roadmap.

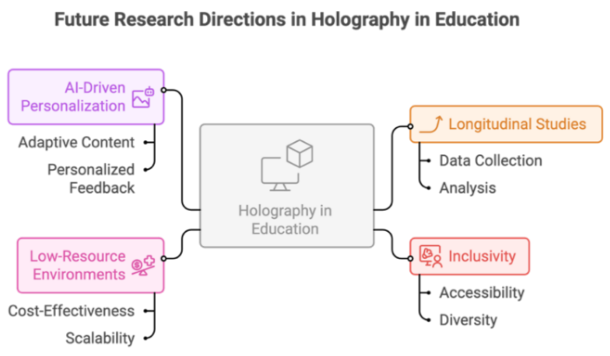

Figure 6:Roadmap for future research directions in holographic education

2) Building on this roadmap, implementation barriers and solution pathways are consolidated in Table 6 (Section 3.4), which can inform the design of future trials and

5. CONCLUSION

a) Summary of main findings

This narrative review synthesized 25 peer-reviewed studies (2023–2025) on holographic and mixed-reality applications in education. Reported gains in engagement, visuospatial skills, conceptual understanding, and collaboration span disciplines such as anatomy/health professions, engineering and design, primary education, and distance learning. Key trials and syntheses include [1], [5], [19], [6], [7], [8], [4], [3], and [20].

At the same time, recurring barriers were identified, including acquisition and maintenance costs, infrastructure constraints, the need for sustained teacher development, and technical issues (resolution, latency, and lighting) that can degrade learning experiences. These constraints are documented in feasibility and implementation studies and reviews [16]; [11]; [21]; [12]. Collectively, the literature suggests that phased adoption, targeted funding/partnerships, and structured professional development are key enablers of equitable scale-up [11]; [22].

In short, holography demonstrates clear pedagogical value. However, its successful integration depends on aligning technology with the context, including budget, infrastructure, and staff readiness, rather than treating it as a stand-alone solution [8]; [6].

b) Significance and broader impact

The broader significance of holographic technology lies in its capacity to make complex ideas tangible and interactive, to support safe simulation, and to widen participation through multimodal interfaces. Studies demonstrate benefits from realistic clinical and laboratory practice, as well as creative and motivational gains, and richer participation for remote learners [1]; [5]; [4]; [20]; [18]. Inclusive design work emphasizes the importance of feasibility and accessibility considerations in authentic teaching settings [23]; [12].

Looking ahead, embedding holography within curriculum design, teacher development, and institutional policy can help translate these benefits at scale, while technical benchmarks and infrastructure planning address reliability and equity [21]; [11]. As such, holography presents a credible model for the future of interactive learning, linking immersive visualization with evidence-based pedagogy across various subjects and settings [7]; [22])..

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