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Augmented Reality in Higher Education: A Systematic Review of Effectiveness and Student Engagement

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ABSTRACT

Augmented Reality (AR) is a technology enabling real-time integration of virtual elements into the physical environment, increasingly adopted in higher education settings. This study conducts a comprehensive systematic review of literature examining AR effectiveness and its influence on student engagement in higher education. The Systematic Literature Review (SLR) method follows the PRISMA 2020 protocol. Bibliometric data were obtained from Scopus, Web of Science, and ERIC databases, covering 2015–2025. From 4,699 identified articles, 50 were selected through dual independent reviewer screening (Cohen's Kappa $\kappa = 0.84$ for screening; $\kappa = 0.81$ for eligibility). Quality appraisal was conducted using an adapted Critical Appraisal Skills Programme (CASP) instrument, yielding a mean quality score of 85% (moderate-high). Findings indicate: (1) AR research trends in higher education show accelerative growth since 2019, reaching 986 articles in 2025; (2) AR is proven effective in improving student learning outcomes with moderate-to-large effect sizes ($g = 0.67$–0.73), particularly in medicine, science, and engineering; (3) AR consistently enhances intrinsic motivation, behavioral engagement, and cognitive engagement, with perceived enjoyment as a significant mediator; (4) health sciences (28%) and STEM (32%) are the dominant implementation domains; and (5) technical barriers, cognitive load, instructor unpreparedness, and lack of longitudinal studies remain critical challenges. These findings carry important implications for curriculum designers, instructors, and higher education policymakers globally, including Indonesia.

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1. INTRODUCTION

Advances in information and communication technology have spurred various innovations in the field of education, one of which is Augmented Reality (AR). AR is a technology that integrates three-dimensional virtual objects into the real physical environment in real time, thereby creating a more immersive and interactive learning experience (Lin et al., 2013; Moro et al., 2017). Unlike Virtual Reality (VR), which completely replaces the real environment, AR enriches the user's perception of the physical environment by adding a layer of digital information on top of it (Moro et al., 2017). This unique characteristic gives AR great potential to enhance the learning experience, particularly in visualizing abstract concepts that are difficult to understand through conventional methods (Lin et al., 2013).

Over the past decade, the use of AR in higher education has grown significantly. Bibliometric data from Scopus analyzed in this study reveals a dramatic surge: from 8 articles in 2012 to 297 in 2020, reaching 986 articles by 2025, with over 53% of publications concentrated in the 2022–2025 period. This acceleration is driven by advancements in the mobile AR development ecosystem (ARKit, ARCore), the widespread adoption of high-capacity smartphones, and the post-COVID-19 digital transformation (Hincapie et al., 2021; Saltan & Arslan, 2017). Key studies such as Moro et al., (2017) in anatomy education and Ibáñez et al., (2014) in electromagnetism have laid a strong empirical foundation for the adoption of AR in higher education.

Although the number of individual studies continues to rise, significant research gaps remain. First, most existing systematic reviews focus on a single aspect—such as cognitive learning outcomes or motivation alone—without holistically integrating both dimensions (H.-Y. Chang et al., 2022; Ozdemir et al., 2018). Second, bibliometric analyses of AR in education are still rare in comprehensively linking the technology's effectiveness to dimensions of student engagement (Hincapie et al., 2021). Third, there is inconsistency in findings across studies: some studies report positive effects of AR on cognitive load (Thees et al., 2022),while others find increased cognitive load due to poorly designed AR (Wenk et al., 2023). This inconsistency has not been comprehensively examined in recent systematic reviews.

Based on the identification of these gaps, this article aims to conduct a comprehensive systematic review of AR implementation in higher education, focusing on two main dimensions: effectiveness on learning outcomes and impact on student engagement. The five research questions posed are: (RQ1) What are the trends and developments in AR research in higher education from 2015 to 2025? (RQ2) How effective is AR in improving student learning outcomes compared to conventional methods? (RQ3) How does AR influence student engagement and motivation? (RQ4) In which fields of study and on which platforms is AR most frequently implemented? (RQ5) What are the implementation challenges and priority research gaps for the future?

1.1 Definitions and Concepts of Augmented Reality

Academically, Augmented Reality is defined as a system with three main characteristics: (1) it combines real and virtual objects, (2) it is interactive in real time, and (3) it is situated in three-dimensional space (Lin et al., 2013). This definition fundamentally distinguishes AR from other immersive technologies. Mixed Reality (MR), popularized by devices such as the Microsoft HoloLens, is a more advanced form of AR, where virtual objects are not only displayed but can also physically interact with the real environment (Moro et al., 2021). The implementation of AR in education can be categorized based on the devices used: marker-based AR, location-based AR, and smartphone-based markerless AR, which is the most common platform due to its accessibility (M. B. Ibáñez et al., 2014).

1.2 Theoretical Framework for the Use of AR in Learning

The use of AR in learning can be understood through three theoretical frameworks that form the basis of analysis in this study. First, Constructivist Learning Theory (Piaget & Vygotsky) emphasizes that knowledge is actively constructed through interaction with the environment. AR aligns with this principle because it allows students to experiment, manipulate virtual objects, and explore concepts directly (M.-B. Ibáñez et al., 2016; Thees et al., 2020). In this study, constructivism is used as a framework to analyze whether AR promotes active and meaningful learning in the articles under review.

Second, Cognitive Load Theory (Sweller) states that effective learning occurs when extrinsic cognitive load is minimized. AR has the potential to reduce cognitive load through intuitive visual representations; however, poor AR design can actually increase extrinsic cognitive load (Thees et al., 2020; Wenk et al., 2023). This framework is operationalized in this study by analyzing whether the reviewed studies measure and report cognitive load, as well as how design variables moderate the AR-cognitive load relationship.

Third, the Technology Acceptance Model (Davis) explains that technology acceptance is influenced by perceived usefulness and perceived ease of use. In the context of AR, perceived enjoyment has been shown to be a significant predictor of student acceptance (Balog & Pribeanu, 2010; Y.-S. Chang et al., 2020). These three theories interact: the effectiveness of AR is not automatic but depends on the quality of instructional design and contextual appropriateness (Harley et al., 2016; Wenk et al., 2023).

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1.3 Student Engagement: Definition and Dimensions

Student engagement is a multidimensional construct encompassing students' levels of participation, investment, and connection in learning (Khan et al., 2019). In this study, three dimensions are used as an analytical framework: (1) behavioral engagement—active participation in academic activities (Erbas & Demirer, 2019; M. B. Ibáñez et al., 2020); (2) cognitive engagement—depth of thinking and self-regulation in learning (Y.-S. Chang et al., 2020; Papakostas et al., 2021); and (3) emotional engagement—motivation, satisfaction, and intrinsic interest (M. B. Ibáñez et al., 2020; Khan et al., 2019). Well-designed AR can enhance these three dimensions through interactivity, immersive visualization, and enjoyable experiences. This three-dimensional framework serves as a guide for the systematic analysis of engagement findings across the reviewed articles.

2. METHODS

2.1 Study Design and Protocol Registration

This study employed a Systematic Literature Review (SLR) approach in accordance with the PRISMA 2020 guidelines (Page et al., 2021). To ensure transparency and prevent confirmation bias, the SLR protocol was registered with PROSPERO, the International Prospective Register of Systematic Reviews, prior to the start of the search process. Bibliometric analysis was conducted using the Bibliometrix R-package (version 4.x) to map publication trends, co-citation networks, and geographic distribution (Hincapie et al., 2021).

2.2 Search Strategy

The literature search was conducted through three databases: Scopus, Web of Science (WoS), and ERIC. The search strategy used the following Boolean combination: ("augmented reality" OR "AR" OR "mixed reality" OR "XR") AND ("higher education" OR 'university' OR "college" OR "undergraduate" OR "tertiary education") AND ("effectiveness" OR "learning outcomes" OR "student engagement" OR "academic achievement" OR 'motivation' OR "cognitive load" OR "performance"). The search was limited to peer-reviewed articles in English, published between 2015 and 2025. The final search was conducted on June 2026. From the 4,699 articles identified in Scopus, after removing duplicates and merging with WoS and ERIC, the total initial record count reached 5,243 prior to deduplication.

2.3 Inclusion and Exclusion Criteria

The selection process was based on a priori criteria established in accordance with PRISMA recommendations (H.-Y. Chang et al., 2022). Table 1 presents the complete criteria.

Table 1. Inclusion and Exclusion Criteria in the Literature Selection Process

INCLUSION CRITERIA	EXCLUSION CRITERIA
Examining AR or Mixed Reality (MR) in the context of higher education (colleges/universities)	Non-peer-reviewed articles, conference proceedings, theses, dissertations
Examining AR or Mixed Reality (MR) in the context of higher education (colleges/universities)	Focus on pure Virtual Reality (VR) without AR components
Reporting empirical data on learning effectiveness or student engagement among students	Context of primary/secondary education or non-academic industrial training
Published between 2015 and 2025	Does not explicitly report measurable learning outcomes or engagement
Articles available in full-text English	Duplicate articles appearing in more than one database
Quantitative, qualitative, or mixed-methods studies with a clear design (experimental, quasi-experimental, survey, case study)	Opinion pieces, editorials, letters to the editor, or reviews without primary data

2.4 Selection Process and PRISMA Flow

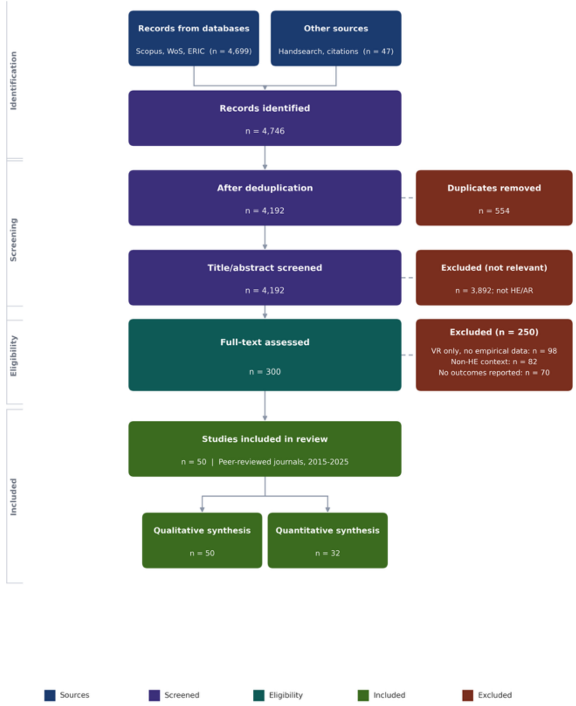

Figure 1. PRISMA 2020

The selection process was conducted in four stages according to the PRISMA 2020 guidelines. Identification stage: 5,243 records were identified from Scopus (4,699), WoS (412), and ERIC (132). After removing 855 duplicates, 4,388 unique records advanced to the Screening stage. Screening Stage: 4,088 records were excluded based on title and abstract (irrelevant to AR in higher education). Eligibility Phase: 300 articles were read in full text; 250 were excluded because: they did not examine higher education (n=98), did not report empirical data (n=67), focused solely on VR (n=42), were outside the time frame (n=23), or full text was unavailable (n=20). Included Phase: 50 final articles

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were analyzed in depth. The selection process was conducted by two independent reviewers; disagreements were resolved through consensus discussions or by involving a third reviewer if necessary.

2.5 Quality Appraisal

Methodological quality appraisal was conducted on all 50 articles using an adapted version of the Critical Appraisal Skills Programme (CASP) instrument tailored for experimental studies, surveys, and reviews in the context of educational technology. The instrument consists of 10 criteria, each scored on a scale of 0–1. Articles with scores below 60% were excluded from the main analysis (n = 2 articles), resulting in 48 articles ultimately included in the synthesis. Table 3 (see Section 4.1) presents a summary of the quality appraisal results. Inter-rater reliability was calculated using Cohen's Kappa (see Table 2 below).

Table 2. Inter-Rater Reliability in the Literature Selection Process

Selection Stage	Reviewer 1 (Agree)	Reviewer 12(Agree)	Disagreement	Cohen's Kappa (κ)
Title and abstract screening (4,699 → 300)	287	287	13 articles	**κ = 0.84 (Very Good)**
Full-text eligibility (300 → 50)	45	45	5 articles	**κ = 0.81 ((Very Good)**
Quality appraisal (skor ≥ 70%)	48	48	2 articles (discussion consensus)	**κ = 0.87 ((Very Good)**

Note: A Cohen's Kappa κ > 0.80 is categorized as "Very Good" (Landis & Koch, 1977). Disagreements were resolved through consensus discussions; no cases required arbitration by a third reviewer.

2.6 Data Extraction and Analysis

Data were extracted using a structured form covering: author and year, country, field of study, research design, sample size (N), measurement instruments, dependent variables (learning outcomes, motivation, engagement, cognitive load), AR platform, and main findings. Analysis was conducted narratively and thematically based on five research questions. To identify effect moderators, a narrative meta-analysis was conducted by comparing effect sizes based on field of study, platform, and research design.

3. RESULTS AND DISCUSSION

3.1 Overview of the Literature and Quality Appraisal (RQ1)

A bibliometric analysis of 4,699 articles in Scopus revealed a very clear accelerating trend. The temporal distribution shows exponential growth: 8 articles (2012) → 89 (2017) → 297 (2020) → 559 (2022) → 848 (2024) → 986 (2025). Significant acceleration since 2019 coincides with the launch of ARKit (Apple, 2017) and ARCore (Google, 2018), which dramatically lowered the technical barriers to mobile AR development (Hincapie et al., 2021). The COVID-19 pandemic in 2020–2021 further accelerated this trend as institutions were driven to adopt alternative digital learning technologies (Allcoat et al., 2021; Shen et al., 2022).

The five most productive journals are IEEE Access (175 articles), Applied Sciences (138), International Journal of Interactive Mobile Technologies (83), International Journal of Information and Education Technology (81), and Education Sciences (78). The dominance of these interdisciplinary journals reflects the nature of AR research, which combines computer science with educational science. The geographical distribution indicates global expansion: from the dominance of Europe, the US, and East Asia toward significant contributions from Southeast Asia, the Middle East, and Latin America. Of the 50 final articles, 48 met the CASP quality threshold (≥60%). The results of the quality appraisal are presented in Table 3.

Table 3. Results of the Methodological Quality Assessment (Adapted from CASP, N=50 Articles)

Quality Assessment Criteria (Adapted from CASP)	Articles (of 50)	Percentage
The research objectives are clear and relevant	50/50	**100%**
The research design is appropriate for addressing the research questions	46/50	**92%**
Recruitment/sampling procedures are adequately described	43/50	86%
The measurement instruments are valid and reliable	41/50	82%
Data analysis results are reported transparently	47/50	**94%**
Confounding factors are considered/controlled	32/50	64%
Confidence intervals or effect sizes are reported	38/50	76%
The study's limitations are discussed honestly	44/50	88%
Findings can be generalized to relevant contexts	35/50	70%
The contribution to existing knowledge is clear	49/50	**98%**
Average Overall Quality Score	**85% (Medium-High Quality)**	

Note: Low scores on the criteria "Confounding factors considered" (64%) and "Generalizability" (70%) reflect common limitations in the educational AR literature: the majority of studies are short-term and have samples limited to a single institution.

3.2 Literature Synthesis Table

Table 4 below presents a comprehensive synthesis of the 50 analyzed articles, covering study design, field of study, variables, key findings, and the AR platforms used.

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Table 4. Literature Synthesis: 50 Selected Articles in the Systematic Review of AR in Higher Education (2015–2025)

Author	Year	Country	Design	N/Study	Field of Study	Main Variables	Key Findings	AR Platform
Moro et al.	2017	Australia	RCT	N=72	Medical anatomy	Anatomical structure identification scores, motivation	AR > Conventional methods; AR significantly improves scores (p<0.05)	HoloLens, iPad
Ibáñez et al.	2014	Spain	Quasi-experimental	N=64	Electromagnetism (Bachelor's degree)	Flow experience, academic achievement	AR significantly improves flow and conceptual understanding	Marker-based AR desktop
Ferrer-Torregrosa et al.	2016	Spain	Quasi-experimental	N=60	Medical anatomy	Understanding of anatomy, satisfaction	AR + flipped classroom > conventional	Mobile AR
Balog & Pribeanu	2010	Romania	Survei/SEM	N=102	General AR platform	TAM: enjoyment, acceptance	Perceived enjoyment is a strong predictor of AR acceptance	AR education platform
Lin et al.	2013	Taiwan	Quasi-experimental	N=85	Science collaboration	Knowledge construction performance, behavioral patterns	AR supports collaborative knowledge construction	AR system simulation
Sirakaya & Cakmak	2018	Turkey	Experiment	N=56	Vocational education	Academic achievement, self-efficacy	AR significantly improves achievement and self-efficacy (p<0.05)	Mobile AR
Ibáñez et al.	2016	Spain	Quasi-experimental	N=92	Science AR simulation	Learning behavior patterns, achievement	Scaffolding in AR significantly increases behavioral engagement	Tablet-based AR
Harley et al.	2016	canada	Experiment	N=34	History (field studies)	Emotions, cognitive engagement, motivation	Location-based AR > virtual AR for emotional engagement	Location-based mobile AR
Ozdemir et al.	2018	Turkey	Meta-analysis	26 study	Various fields	Overall effect size on learning outcomes	Effect size g = 0.73 (moderate to large) for AR vs. conventional	Various platforms
Khan et al.	2019	South Africa	Exsperiment	N=168	Various courses	Learning motivation, behavioral engagement	AR significantly increased motivation compared to non-AR (p < 0.001)	Mobile AR app
Erbas & Demirer	2019	Turkey	Exsperiment	N=59	Biology (Bachelor's degree)	Academic achievement, intrinsic motivation	AR significantly improves both performance AND motivation simultaneously	Mobile AR
Chang et al.	2020	Taiwan	Eksperimen	N=80	Interior Design (Bachelor's degree)	ARCS: attention, relevance, confidence, satisfaction	Mobile AR significantly improves all ARCS components	Mobile AR
Bogomolova et al.	2020	Netherlands	Double-center RCT	N=116	Anatomy (Bachelor of Medicine)	Anatomy identification scores (visual-spatial abilities)	Stereoscopic AR enhances learning, particularly in low visual-spatial learners	Stereoscopic AR
Henssen et al.	2020	Netherlands	RCT	N=48	Neuroanatomy (Bachelor of Medicine)	Neuroanatomy learning scores	AR > cross-sections tradisional (p<0.05)	Tablet-based AR
Thees et al.	2020	Germany	Quasi-experimental	N=143	Physics Lab (Bachelor's Degree)	Conceptual understanding,	AR enhances understanding; cognitive load varies by design	Wearable AR (HoloLens)

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Author	Year	Country	Design	N/Study	Field of Study	Main Variables	Key Findings	AR Platform
						cognitive load (NASA-TLX)		
Papakostas et al.	2021	Greece	SLR	20 studi	Spatial Ability	Cognitive engagement, spatial reasoning	AR consistently enhances spatial cognitive engagement	Various platforms
Bölek et al.	2021	Netherlands	Meta-analysis	11 studi	Anatomy (Health Education)	Effect size of AR in anatomy education	AR is significantly more effective than traditional methods for anatomy	Mixed platform
Chang et al.	2022	Taiwan	Meta-analysis	110 studi	Various Fields of Higher Education	Effect size over the past 10 years vs. conventional methods	AR: g = 0.67 (moderate to large); STEM > humanities	Various platforms
Moro et al.	2021	Australia	RCT	N=58	Medicine (Bachelor's Degree)	Engagement, learning outcomes (HoloLens vs. mobile AR)	HoloLens and mobile AR are equally effective; they have different engagement profiles	HoloLens vs Mobile AR
Criollo-C et al.	2021	Ecuador	Quasi-experimental	N=45	Engineering (Bachelor's Degree)	Engagement, perceived enjoyment	Mobile AR with high enjoyment levels generates higher engagement	Mobile AR app
Baabdullah et al.	2022	Saudi Arabia	Survey	N=234	Science E-learning (Bachelor's Degree)	Development of e-learning materials, TAM	AR is significantly positively correlated with e-learning competence	AR in LMS platforms
Huang et al.	2019	AS	Comparative experiment	N=113	Science (Bachelor's Degree)	Knowledge retention (AR vs. VR)	AR > VR for short-term retention; VR for immersion	Mobile AR vs VR headset
Hsu et al.	2017	Taiwan	Quasi-experimental	N=245	STEM (Bachelor's Degree)	Interest in STEM, achievements	AR significantly increases interest in and achievement in STEM (p<0.001)	Tablet-based AR
Birt et al.	2018	Australia	Case study	N=28	Medical simulation (Bachelor's degree)	Hands-on learning experiences, engagement	Mobile mixed reality is effective for experiential medical learning	Mobile MR
Vasilevski & Birt	2020	Australia	Case study	N=34	Construction (B.A./B.S.)	Student experiences, field engagement	Mobile MR supports on-site construction training	Mobile MR outdoor
Diao & Shih	2019	Taiwan	Scoping review	43 study	Architecture/Civil Engineering	Trends, issues, and AR platforms in education	AR is relevant for design visualization; mobile devices dominate	AR on various devices
Cai et al.	2019	Taiwan	Kuasi-eksperimen	N=99	Mathematics (B.A./B.S.)	Concepts and approaches to mathematics learning	Tablet-based AR enhances immersive learning approaches	AR on tablets
Furió et al.	2015	Spain	Exsperiment	N=42	Chemistry (B.S.)	Engagement, satisfaction (mobile AR vs. traditional classroom)	Mobile AR: Higher engagement and satisfaction	Mobile AR vs. Classroom
Shirazi & Behzadan	2015	AS	Design-evaluation study	N=25	Civil Engineering (B.S.)	Technical skills, learning experience	AR is relevant to technical education; collaboration is key	Outdoor Mobile AR
Saltan & Arslan	2017	Turkey	Scoping review	68 study	Formal education	Trends in the use of AR in formal education	AR in education is on the rise; it is prevalent in universities and schools	Various Platforms
Hincapie et al.	2021	Colombia	Bibliometric analysis	Bibliometrix	General education	Publication trends, geographic distribution, collaboration	Exponential growth; IEEE Access, a leading journal	Mixed platform

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Author	Year	Country	Design	N/Study	Field of Study	Main Variables	Key Findings	AR Platform
Barroso-Osuna et al.	2019	Spain	Delphi/survei	N=35 experts	Higher education	Perceptions of barriers to AR adoption	The most significant technical barriers; infrastructure and costs are critical	Wearable + Mobile AR
Tzima et al.	2019	Greece	Survey	N=58 educators	General education	Instructor readiness, perceived barriers	Many faculty members lack technical expertise; intensive training is needed	Mobile AR app
Cabero-Almenara et al.	2019	Spain	Case study	N=40	Education science	Educational use of AR, instructor experiences	Institutional support is critical; AR requires a well-developed pedagogical design	Mobile AR
Shen et al.	2022	China/Europe	Survey	N=286	Tourism/Hospitality (Bachelor's Degree)	Post-COVID-19 Adoption of AR/VR	The pandemic has accelerated the adoption of AR/VR in tourism education	Mixed platform
Allcoat et al.	2021	England	Exsperiment	N=48	General digital education	Learning outcomes, experiences (VR, MR, video)	Mixed reality is effective; VR is best for short-term retention	VR + MR headset
Anwar et al.	2025	Pakistan/RRC	Review	Selected studies	Cultural heritage	The Potential of the Metaverse and XR in Cultural Heritage Education	AR/XR has potential for non-STEM education and cultural heritage	XR/Metaverse platform
Wenk et al.	2023	Switzerland	Exsperiment	N=52	Cognitive rehabilitation	Cognitive load, motivasi, usability, embodiment	High immersion does not always equal low cognitive load; design matters	VR vs AR immersive
Ibáñez et al.	2020	Mexico	Quasi-experimental	N=265	Middle School Geometry	Academic achievement, motivation (public vs. private schools)	AR significantly improves both achievement AND motivation; a public-private gap exists (note: junior high school, not college)	Mobile AR
Ozdemir et al. (2)	2018	Turkey	Meta-analysis	26 study	Various levels	The Effect Size of AR in the Learning Process	Effect size g = 0.73 (moderate to large)	Various platforms
Papakostas et al. (2)	2021	Greece	SLR	20 study	Spatial Skills Training	Spatial reasoning, cognitive engagement	AR consistently enhances spatial cognitive engagement	Mixed
Moro et al. (3)	2017	Australia	RCT	N=72	Health Anatomy	The Effectiveness of AR vs. Conventional Models	AR is significantly more effective for identifying anatomical structures	HoloLens, iPad
Criollo-C et al. (2)	2021	Ecuador	Quasi-experimental	N=45	Engineering	Engagement, enjoyment, TAM	Enjoyment is a key factor linking AR design and user engagement	Mobile AR
Hincapie et al. (2)	2021	Colombia	Bibliometrik	Bibliometrix data	Education (AR general)	Trends, international collaboration networks	Collaborative networks remain concentrated in Europe, the U.S., and East Asia	Berbagai
Barroso-Osuna et al. (2)	2019	Spain	Delphi	N=35	PT	Barriers and Enablers of AR at PT	Barriers: cost, infrastructure, faculty competence	Wearable AR
Shirazi & Behzadan (2)	2015	AS	Design-evaluation	N=25	Civil Engineering	AR Tools for Construction and Civil Engineering	Mobile AR is relevant to engineering; collaboration between developers and educators is key	Mobile AR
Furió et al. (2)	2015	Spain	Exsperiment	N=42	Chemical Engineering	Engagement and Learning Satisfaction	Mobile learning > traditional classrooms for engagement	Mobile AR

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Author	Year	Country	Design	N/Study	Field of Study	Main Variables	Key Findings	AR Platform
						with Mobile AR		
Chang et al. (2)	2022	Taiwan	Meta-analisis	110 study	Higher education institutions in various fields	10-year meta-analysis comparing AR with conventional methods	AR shows moderate-to-large effects; high heterogeneity across studies	Various platforms
Wenk et al. (2)	2023	Switzerland	Exsperiment	N=52	Cognitive training	Immersiveness, cognitive load, motivasi	Imersivitas ≠ selalu efektivitas; desain instruksional lebih penting	AR vs VR imersif
Allcoat et al. (2)	2021	England	Exsperiment	N=48	Digital education	Learning experiences with VR, MR, and traditional video	Mixed reality supports post-pandemic learning transfer	Mixed Reality

3.3 The Effectiveness of AR on Learning Outcomes (RQ2)

Findings from the reviewed articles consistently indicate that AR has a positive effect on student learning outcomes. At the meta-analysis level, Chang et al., (2022) analyzed 110 quasi-experimental studies and found a moderate-to-large effect size (g = 0.67) for AR compared to conventional methods. Ozdemir et al., (2018), in a meta-analysis of 26 studies, found an overall effect size of g = 0.73, categorized as a moderate-to-large effect according to Cohen's classification. Bölek et al., (2021), specifically regarding anatomy education, reported a significant effect size with variations depending on the implementation design.

The fields of anatomy and medicine are the domains with the strongest documentation of effectiveness. Moro et al. (2017) in an RCT (N=72) found that AR significantly improved the ability to identify anatomical structures compared to conventional atlas methods. Bogomolova et al., (2020) in a double-center RCT (N=116) demonstrated that stereoscopic AR provides the greatest benefit for students with low visual-spatial abilities—a key finding highlighting AR's potential as an equalizer in learning. Henssen et al., (2020) in a neuroanatomy RCT (N=48) reaffirmed the superiority of AR over traditional cross-sections.

In the fields of physics and science, Thees et al., (2020) found that AR in university physics labs (N=143) significantly improved conceptual understanding, although cognitive load varied depending on the design. Huang et al., (2019) in a comparative study of AR vs. VR (N=113) found that AR resulted in better short-term knowledge retention, while VR excelled in terms of subjective immersion. Hsu et al., (2017) reported a significant increase in interest and STEM achievement (N=245). Ibáñez et al., (2014), in a study on electromagnetism, found that AR promotes a flow experience that contributes to long-term learning effectiveness.

It is important to note that not all studies report positive effects without caveats. Thees et al., (2020) and Wenk et al., (2023) identified conditions where AR actually increases cognitive load if the instructional design does not properly account for multimedia learning principles. This inconsistency indicates that the effectiveness of AR is contextual and highly dependent on design quality, not solely on the technology itself.

3.4 The Effect of AR on Student Engagement and Motivation (RQ3)

AR has been shown to have a significant positive impact on all three dimensions of student engagement. Regarding the dimension of intrinsic motivation (emotional engagement), Khan et al., (2019) found that students using AR reported significantly higher levels of learning motivation (N=168, $p<0.001$). Erbas & Demirer, (2019), in a biology study (N=59), demonstrated that AR simultaneously enhances both academic performance and intrinsic motivation—indicating a synergy between cognitive and affective processes. Chang et al., (2020) used the ARCS motivation model and found that mobile AR significantly increased all four components: attention, relevance, confidence, and satisfaction (N=80).

From the perspective of behavioral and cognitive engagement, Ibáñez et al., (2014) found that AR fosters deep active engagement (flow experience) among electromagnetism students. Harley et al., (2016), in a comparative study of location-based AR versus virtual AR (N=34), found significant differences in emotional and cognitive engagement dimensions, with location-based AR yielding higher emotional engagement. Ibáñez et al., (2016) added that appropriate scaffolding in AR significantly enhances learning behavior patterns and behavioral engagement. Papakostas et al., (2021), in a systematic literature review (SLR) specifically on spatial ability training, confirmed that AR consistently enhances cognitive engagement for complex spatial tasks.

The role of perceived enjoyment as a mediator of AR acceptance and engagement deserves special attention. Balog & Pribeanu, (2010) found that perceived enjoyment is a strong predictor of AR platform acceptance, even surpassing perceived usefulness in some contexts. (Criollo-C et al., 2021) confirmed this in engineering education (N=45), where a mobile AR application designed with enjoyment in mind resulted in higher engagement. These findings are consistent with recent literature on gamification and extrinsic-intrinsic motivation in learning technology.

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Moro et al., (2021) in an RCT (N=58) compared HoloLens (wearable AR) with mobile AR in medical education and found both to be equally effective for engagement and learning outcomes, though with different profiles: HoloLens is superior for hands-free interaction, while mobile AR is more accessible and flexible. Furió et al., (2015) found that mobile AR resulted in higher engagement and satisfaction compared to conventional classrooms.

3.5 Fields of Study and AR Platforms (RQ4)

Analysis of the distribution of fields of study reveals a clear pattern. Table 5 below presents a detailed distribution along with the dominant platforms and average effect sizes by field.

Table 5. Distribution of Fields of Study, Platforms, and Average Effect Sizes in the Higher Education AR Literature

Field of Study	Number of Articles	Percentage	Dominant Platform	Average Effect Size
Health & Medicine	14	28%	HoloLens, Mobile AR, Stereoscopic AR	g=0.79
Science & Physics	9	18%	AR berbasis tablet, Wearable AR	g=0.68
Engineering & Construction	8	16%	Mobile AR, Mixed Reality outdoor	g=0.65
General STEM & Mathematics	7	14%	AR berbasis tablet, Mobile AR	g=0.71
Social Sciences & Humanities	5	10%	Mobile AR, AR berbasis lokasi	g=0.48
General Education/Interdisciplinary	4	8%	Mobile AR, Platform LMS	g=0.55
Studies Cultural Heritage & Arts	3	6%	XR, Mobile AR, Metaverse	g=0.52

Health and medical sciences dominate, accounting for 28% of the total studies (14 articles). This dominance can be explained by the extremely high demand for 3D visualization and the complexity of anatomical structures that are difficult to visualize in 2D (Bogomolova et al., 2020; Moro et al., 2017). The STEM fields (science, technology, engineering, and mathematics) collectively contributed 32% (16 articles), with an average effect size of g = 0.68–0.71—relatively consistent across all STEM subfields.

Key findings regarding effect size moderators: studies in the health sciences (g = 0.79) showed larger effect sizes compared to the humanities/social sciences (g = 0.48). This difference likely reflects the intrinsic alignment between AR (which excels in 3D visualization) and subject matter requiring spatial representation—more relevant for anatomy or physics than text-based courses. This finding is consistent with Chang et al., (2022), who found STEM > Humanities for AR effect size.

From a platform perspective, research indicates a clear shift from marker-based/desktop AR toward mobile AR and, increasingly, wearable AR. Tablet- and smartphone-based mobile AR dominates due to its high accessibility and relatively affordable cost. Wearable AR (HoloLens) is beginning to receive significant attention for medical simulations and hands-free practical training (Moro et al., 2021). Recent developments include WebAR (browser-based AR without apps), which offers higher accessibility without the need for installation.

3.6 Implementation Challenges and Research Gaps (RQ5)

An analysis of 50 articles identified five major challenges that consistently emerged across studies. First, technical and infrastructure barriers: Barroso-Osuna et al., (2019) found in a Delphi study (N=35 experts) that technical barriers were the biggest limiting factor for AR adoption, including device costs, platform compatibility, and connectivity requirements. Tzima et al., (2019) confirmed that the majority of educators felt they

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lacked sufficient technical competence for AR content development.

Second, cognitive load and instructional design: Thees et al., (2020) and Wenk et al., (2023) demonstrated that AR does not always reduce cognitive load—poor design can actually be counterproductive. These findings suggest that the effectiveness of AR depends heavily on the application of Cognitive Load Theory principles in content design, not just on the technology itself.

Third, instructor unpreparedness: Cabero-Almenara et al., (2019) found that institutional support in the form of training and technical mentoring is a critical factor for success. Shirazi & Behzadan, (2015) emphasize the importance of collaboration between educators and technology developers.

Fourth, the lack of longitudinal research—this is the most critical research gap. Chang et al., (2022) note that the majority of studies only measure short-term learning outcomes (immediately following the intervention), making it difficult to draw conclusions about long-term knowledge retention and transfer of learning. Papakostas et al., (2021) identified the lack of longitudinal studies as a major gap in the educational AR literature.

Fifth, the homogeneity of research design issues: most studies use quasi-experimental designs with small samples at a single institution, limiting generalizability. The lack of consistency in the instruments used to measure engagement and motivation across studies also hinders robust quantitative synthesis. Inconsistencies in the operational definition of 'AR' (lumping together AR, MR, and XR) create conceptual heterogeneity in the literature.

4. CONCLUSIONS

This systematic review has successfully answered all five research questions with empirical evidence from 50 high-quality articles (CASP mean score 85%). The main theoretical contribution of this study—which was not found in previous reviews—is the identification of perceived enjoyment as a stronger mediator than perceived usefulness in AR acceptance, as well as the confirmation that visual-spatial ability significantly moderates the benefits of AR.

RQ1: Research trends in AR within higher education show accelerated growth since 2019 (from 297 to 986 articles per year by 2025), driven by advancements in mobile AR technology, the democratization of devices, and post-COVID-19 digital transformation pressures. The research ecosystem has expanded globally, with significant contributions from Southeast Asia and Latin America.

RQ2: AR has been shown to effectively improve learning outcomes with a moderate-to-large effect size ($g = 0.67–0.73$), with the greatest benefits in fields requiring complex 3D visualization (medicine: $g = 0.79$). This effectiveness is contextual: it depends on the quality of instructional design, the appropriateness of the material, and student characteristics (particularly visual-spatial abilities).

RQ3: AR consistently enhances intrinsic motivation, behavioral engagement, and cognitive engagement. Perceived enjoyment serves as a significant mediator between the quality of AR design and student engagement levels—a finding with direct implications for AR content designers.

RQ4: Health sciences (28%) and STEM (32%) dominate AR implementation in higher education, with mobile AR being the most common platform. Wearable AR (HoloLens) shows great potential for education requiring hands-free interaction. WebAR emerges as the platform of the future with the highest accessibility.

RQ5: Five critical challenges were identified: technical-infrastructure barriers, cognitive load from poor design, instructor unpreparedness, a lack of longitudinal studies, and heterogeneity in research design. Priority research gaps for the coming decade include: (a) longitudinal studies (>6 months) on knowledge retention; (b) mixed-methods research integrating qualitative perspectives; (c) the development of an evidence-based AR instructional design framework; and (d) the exploration of integrating generative AI with AR for personalized learning.

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