SYSTEMATIC / NARRATIVE REVIEW ARTICLE

Unlocking the potential of augmented reality in education: Insights from a systematic review of AR-enhanced instructional approaches

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ABSTRACT

Introduction: This review explores instructional approaches for AR-enhanced learning to improve student motivation, engagement, and learning outcomes. With AR technology gaining momentum, educators aim to implement best practices that leverage its benefits in diverse subject areas.

Materials and Methods: Using a systematic review approach and following PRISMA guidelines, this study analyzed 26 peer-reviewed articles published from 2014 to 2024.

Results: Findings were grouped around three central themes: AR's impact on learning and motivation, instructional approaches that support AR integration, and barriers to AR adoption in educational contexts. The analysis suggests that inquiry-based and collaborative approaches with AR improve student engagement, understanding, and academic performance. These results underscore the need for thoughtfully designed AR activities that provide a balance between student autonomy and guided instruction to avoid cognitive overload. However, challenges like accessibility, inclusivity, and limited resources remain obstacles to broader implementation, especially in under-resourced areas.

Conclusion: Future research should concentrate on developing standardized frameworks for AR in education, improving inclusivity, and assessing AR's long-term impact on learning outcomes across various educational settings.

KEYWORDS:
Instructional strategies, augmented reality, educational approaches, education

INTRODUCTION

Augmented reality (AR) has the potential to enhance learning by adding interactive and immersive elements that extend beyond traditional classroom methods. By enabling learners to visualise abstract ideas, manipulate three-dimensional models, and engage in hands-on digital experiences, AR is particularly useful in disciplines such as science, medicine, and engineering where spatial understanding is critical.[1,2] As technology-enhanced learning grows, interest has increased in how AR can be used effectively to strengthen comprehension and engagement.

Research indicates that AR can improve learning outcomes by enhancing engagement, supporting spatial reasoning, and helping learners understand complex information through real-time interaction with digital objects. 3 Studies also report increased motivation, particularly in areas requiring visualisation of abstract or dynamic content. However, AR's impact depends heavily on how it is integrated into instructional design. Comparisons between self-directed and guided AR activities show inconsistent results, with no clear agreement on which approach yields stronger learning benefits.[4]

Uncertainties remain regarding the best practices for AR implementation across educational contexts. Key questions involve selecting suitable AR tools, balancing learner autonomy with guidance, and preventing cognitive overload when activities are poorly aligned with learning goals. 5 This review addresses these gaps by examining instructional strategies used in AR-enhanced learning and synthesising evidence to identify approaches that most effectively support learning performance, engagement, and understanding.

MATERIALS AND METHODS

Identification

This study followed systematic review procedures to identify relevant research on AR in education. After selecting key terms and their synonyms, search strings were developed for Scopus, Web of Science, and ERIC (see Table I). These databases were chosen for their strong coverage of interdisciplinary and education-related studies, ensuring a robust evidence base.[6] The search yielded 776 records across the three databases. Titles and abstracts were screened to determine relevance to the research question.

Screening

During the screening phase, studies were examined to ensure they addressed the research questions on instructional strategies for AR in education. After removing duplicates, 203 records remained for full-text assessment (Table II). Only peer-reviewed journal articles published in English between 2014 and 2024 were included to maintain methodological consistency. Conference papers, book chapters, and dissertations were excluded. All references were managed in Mendeley to organise citations and eliminate 59 duplicate records.

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Eligibility
In the eligibility phase, 144 articles were screened by title and abstract to determine their relevance to the research objectives. A total of 118 were excluded for being outside the scope, unrelated to the topic, or lacking full access. Ultimately, 26 articles met all criteria and were included in the final review.

Quality Appraisal
Three independent reviewers evaluated all 26 studies using the eight-item CASP checklist (Table III). The quality appraisal was conducted by experts with over 10 years of experience in educational technology, providing a consistent evaluation of studies from varied evidence sources.[7] The appraisal examined clarity of aims, methodological alignment, and the appropriateness of data collection and analysis. Any differences in scoring were resolved through discussion, with a fourth reviewer consulted when necessary. All studies met acceptable quality standards and were retained for synthesis, as summarised in Table III.

Data Abstraction and Analysis
An integrative approach was used to synthesise findings across varied study designs. Key information was extracted and reviewed collectively, then organised into preliminary themes. Coding differences were resolved through discussion. Three experts in educational technology and instructional design reviewed the refined themes to ensure clarity and alignment with the study objectives.

The questions are as follows below:
1. How does the use of augmented reality (AR) technology influence learning outcomes and motivation among health professional students compared to traditional learning methods?
2. What are the most effective instructional approaches for implementing augmented reality (AR) to enhance students' comprehension and engagement in anatomy education?
3. What are the primary challenges and limitations of using augmented reality (AR) in higher education, and how do these factors affect its effectiveness in enhancing learning outcomes?

RESULTS

Table IV outlines how the authors thoroughly analyzed 26 publications to extract assertions or information pertinent to the study's focus and Figure 1 shows a PRISMA flowchart detailing the search and selection processes.

This review synthesized evidence from 26 studies on the use of augmented reality (AR) in educational. The results were organized into three main themes: (i) the impact of AR on learning outcomes and motivation, (ii) instructional approaches for effective AR implementation, and (iii) challenges and limitations influencing AR adoption.

Impact of AR on Learning Outcomes and Motivation
Across the reviewed studies, augmented reality (AR) consistently improved academic performance, conceptual understanding, and learner engagement. Many investigations reported higher post-test scores and better retention among students using AR compared with traditional instruction.[8,9,13,18,19,23,26,30] These benefits were especially evident in science, medical, and engineering subjects that rely on spatial reasoning, where interactive 3D models helped learners understand abstract or dynamic concepts more effectively than static resources.

AR also enhanced motivation, with studies noting increased curiosity, emotional involvement, and overall satisfaction.[9,11,13,18,20,25] Its immersive qualities promoted intrinsic motivation by increasing enjoyment and reducing boredom. Overall, the evidence indicates that AR enhances both cognitive and affective learning when aligned with clear learning objectives.

Instructional Approaches for Effective AR Implementation
Most studies highlighted that the effectiveness of augmented reality (AR) depends on the instructional framework used to support it. Inquiry-based learning was the most common approach, with several studies reporting improvements in scientific inquiry, problem-solving, and higher-order thinking when AR was embedded within structured investigations.[9,16,17,21,24,32] These designs encouraged exploration, hypothesis testing, and linking virtual observations to real-world concepts.

Collaborative and game-based approaches were also widely used. AR activities involving teamwork or gamification enhanced communication, participation, and shared problem-solving, supporting social learning and deeper conceptual understanding.[14,19,27,29]

Several studies implemented systematic instructional design models such as ADDIE or design-based learning (DBL).[15,17,22,28,30] These frameworks ensured alignment with learning goals and reduced unnecessary cognitive load, leading to better comprehension and application of concepts.

Overall, AR produced stronger outcomes when integrated within inquiry-based, collaborative, or design-model pedagogies rather than used in isolation.

Challenges and Limitations of AR in Education
Despite its benefits, several challenges limit AR implementation. Technical constraints—including limited devices, unstable connectivity, and insufficient support—reduce accessibility, especially in under-resourced settings.[15,21,26,31] These issues reduced accessibility, particularly in under-resourced settings. Pedagogical issues also arise when AR content is overly complex or misaligned with learning goals, leading to cognitive overload and reduced instructional value.[15,18,23,27] Poor alignment with curriculum objectives further limited instructional value. Social and contextual barriers further restrict use, as many educators lack adequate training, and accessibility concerns affect students with disabilities or those in rural areas[21,24,30] Addressing technological gaps, instructional misalignment, and educator readiness is essential. AR can enhance learning when supported by strong design and sufficient resources.

Table I: The Search String

Scopus	TITLE-ABS-KEY (("learn* approach*" OR "learn* technique*" OR "instructional technique*" OR "teach* strategie*" OR "instructional strategie*") AND ("augmented reality") AND ("education")) AND (LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))
Wos	("learn* approach*" OR "learn* technique*" OR "instructional technique*" OR "teach* strategie*" OR "instructional strategie*") AND ("augmented reality") AND ("education") (Topic) and 2024 or 2023 or 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2014 (Final Publication Year) and Article (Document Types) and English (Languages)
ERIC	augmented reality AND ("learning approaches" OR "instructional techniques" OR "learning techniques" OR "teaching strategies" OR "instructional strategies") AND education

Table II: The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2014–2024	< 2014
Literature type	Journal (Article)	Conference, Book, Review

Table III: The Quality Appraisal

		Yes Expert 1 2 3	No Expert 1 2 3	Total agreement (%)	Comments
Section A: Are the results valid?	1. Was there a clear statement of the aims of the research?	/ / /		100	Excellent
	2. Is a qualitative, quantitative and mixed-method research approach appropriate?	/ / /		100	Excellent
	3. Was the research design appropriate to address the aims of the research?	/ / /		100	Excellent
	4. Was the recruitment strategy appropriate to the aims of the research?	/ / /		100	Excellent
	5. Was the data collected in a way that addressed the research issue?	/ / /		100	Excellent
Section B: What are the results	6. Was the data analysis sufficiently rigorous?	/ / /		100	Excellent
	7. Is there a clear statement of findings?	/ / /		100	Excellent
Section C: How valuable is the research?	8. How valuable is the research?	/ / /		100	Excellent

DISCUSSION

This review of 26 studies shows that augmented reality (AR), when embedded within instructional frameworks, generally improves learning outcomes, engagement, and motivation. The effects are strongest in science and health-related disciplines that require visual–spatial and procedural understanding. Common pedagogical approaches include inquiry-based, collaborative, and design-model strategies, though variations in study quality and learner groups warrant cautious interpretation.[35,36]

In medical and health-science education, AR has been effective for teaching anatomy, clinical skills, and radiology by helping learners visualise complex structures and procedures. Tools such as AEducaAR, which combine AR with 3D printing, have improved anatomical understanding, confidence, and motivation.[18] AR-based nursing and radiology modules similarly enhance procedural performance and reduce reliance on static 2D materials.[37] By overlaying dynamic 3D structures onto real-world views, AR supports both cognitive and psychomotor learning.[38]

When implemented through structured instructional models, AR promotes deeper and more sustained learning. Inquiry-based designs encourage exploration and concept construction, while collaborative and game-based approaches support active participation and teamwork. Systematic models such as ADDIE help ensure alignment with learning goals and reduce cognitive overload.[39,40] Through this structured use, AR can bridge theoretical knowledge with practical application, strengthening students' clinical preparedness.[41]

Despite these benefits, challenges persist. Hardware costs, connectivity issues, and limited technical support restrict use in low-resource settings.[39] Misaligned or overly complex AR content can overwhelm learners, while many educators lack sufficient training. Social and accessibility barriers, particularly for students with disabilities, further limit adoption.[42,43] Addressing these issues requires improved infrastructure, stronger instructional design, and continuous professional development, alongside research on AR's long-term learning impact.

Table IV: Summary of Selected Article

No	Authors	Title	Journal	Findings
1	Huang et al. [8]	Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment	Computers & Education (2016)	- Improved engagement, curiosity, and learning effectiveness.
2	Chiang et al. [9]	An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities	Educational Technology & Society (2014)	- Better achievement and motivation; reduced cognitive load.
3	Cai et al.[10]	Tablet-based AR technology: Impacts on students' conceptions and approaches to learning mathematics according to their self-efficacy	British Journal of Educational Technology (2019)	- Enhanced understanding and learning approach, especially among high self-efficacy learners.
4	Hsieh [11]	Development and Application of an Augmented Reality Oyster Learning System for Primary Marine Education	Electronics (2021)	- Improved learning achievement, interest, and interactivity.
5	Hsu [12]	Learning English with Augmented Reality: Do learning styles matter?	Computers & Education (2017)	- Self-directed and task-based AR yielded similarly high learning effectiveness.
6	Czok et al. [13]	Learning Effects of Augmented Reality and Game-Based Learning for Science Teaching in Higher Education in the Context of Education for Sustainable Development	Sustainability (2023)	- Increased motivation and engagement; comparable achievement to traditional learning.
7	Kamal and Junaini [14]	The Effects of Design-Based Learning in Teaching Augmented Reality for Pre-University Students in The ICT Competency Course	International Journal of Scientific & Technology Research (2019)	- DBL approach improved academic performance and both LOTS and HOTS.
8	Nasir and Fakhruddin [15]	Design and Analysis of Multimedia Mobile Learning Based on Augmented Reality to Improve Achievement in Physics Learning	International Journal of Information and Education Technology (2023)	- AR-based mobile learning improved physics achievement.
9	Chiang et al. [16]	Students' online interactive patterns in augmented reality-based inquiry activities	Computers & Education (2014)	- AR inquiry learning increased interaction, concentration, and higher-order thinking.
10	Wen et al. [17]	Integrating augmented reality into inquiry-based learning approach in primary science classrooms	Education Tech Research Dev (2023)	- AR-supported inquiry enhanced autonomy and creative thinking.
11	Cercenelli et al. [18]	AEducaAR, Anatomical Education in Augmented Reality: A Pilot Experience of an Innovative Educational Tool Combining AR Technology and 3D Printing	International Journal of Environmental Research and Public Health (2022)	- Improved motivation, confidence, and anatomical understanding.
12	Rodríguez-Abad et al.[19]	Online (versus face-to-face) augmented reality experience on nursing students' leg ulcer competency: Two quasi-experimental studies	Nurse Education in Practice (2023)	- AR improved performance, motivation, satisfaction, and learning outcomes.
13	Li et al. [20]	From motivational experience to creative writing: A motivational AR-based learning approach to promoting Chinese writing performance and positive writing behaviours	Computers & Education (2023)	- Motivational AR approach improved writing performance and immersion.
14	Lin et al. [21]	Mitigating the Urban-rural Digital Divide: A Dual Scaffolding-embedded Mobile Augmented Reality Learning Approach in the Post-COVID-19 Pandemic	Educational Technology & Society (2023)	- Dual-scaffolding AR improved achievement, cognition, and self-efficacy.
15	Lee and Hsu [22]	Sustainable Education Using Augmented Reality in Vocational Certification Courses	Sustainability (2021) Anatomical Sciences Education (2016)	- AR improved learning effectiveness and reduced cognitive load.
16	Küçük et al. [23]	Learning Anatomy via Mobile Augmented Reality: Effects on Achievement and Cognitive Load	Journal of Pedagogical Research (2024)	- Mobile AR enhanced anatomy achievement and lowered cognitive effort.
17	Rizki et al. [24]	Cooperative model, digital game, and augmented reality-based learning to enhance students' critical thinking skills and learning motivation	Int. J. Innovation and Learning (2018)	- AR + cooperative digital learning improved critical thinking and motivation.
18	Harncharnchai and Saeheaw [25]	Context-aware learning using augmented reality and WebQuest to improve students' learning outcomes in history	Education and Information Technologies (2024)	- Improved outcomes and engagement; high learner satisfaction.
19	Weng et al. [26]	Can an augmented reality-integrated gamification approach enhance vocational high school students' learning outcomes and motivation in an electronics course?		- AR gamification improved outcomes across cognitive, affective, and psychomotor domains.

Table IV: Summary of Selected Article

No	Authors	Title	Journal	Findings
20	Cascales-Martínez et al. [27]	Using an Augmented Reality Enhanced Tabletop System to Promote Learning of Mathematics: A Case Study with Students with Special Educational Needs	EURASIA Journal of Mathematics Science and Technology Education (2017)	- Improved knowledge, motivation, and collaboration among special-needs learners.
21	Hsu [28]	Effects of gender and different augmented reality learning systems on English vocabulary learning of elementary school students	Univ Access Inf Soc (2019)	- Two AR gaming systems produced high vocabulary learning effectiveness.
22	Cheng et al. [29]	An in-depth analysis of the interaction transitions in a collaborative Augmented Reality-based mathematic game	Interactive Learning Environments (2019)	- AR-based collaborative game showed dynamic, non-linear interaction patterns.
23	Ruiz-Ariza et al. [30]	Effect of augmented reality game Pokemon GO on cognitive performance and emotional intelligence in adolescent young	Computers & Education (2018)	- Improved attention, concentration, and sociability; no effect on memory or maths.
24	Bos et al. [31]	Educational Technology and Its Contributions in Students' Focus and Attention Regarding Augmented Reality Environments and the Use of Sensors	Journal of Educational Computing Research (2019)	- AR increased focus and attention compared to other digital platforms.
25	Giancaspro et al. [32]	An active learning approach to teach distributed forces using augmented reality with guided inquiry	Computer Applications in Engineering Education (2024)	- Guided-inquiry AR improved understanding and corrected misconceptions.
26	Chen et al. [33]	Supporting informal science learning with metacognitive scaffolding and augmented reality: effects on science knowledge, intrinsic motivation, and cognitive load	Research in Science & Technological Education (2023)	- Metacognitive scaffolding + AR improved science knowledge and intrinsic motivation.

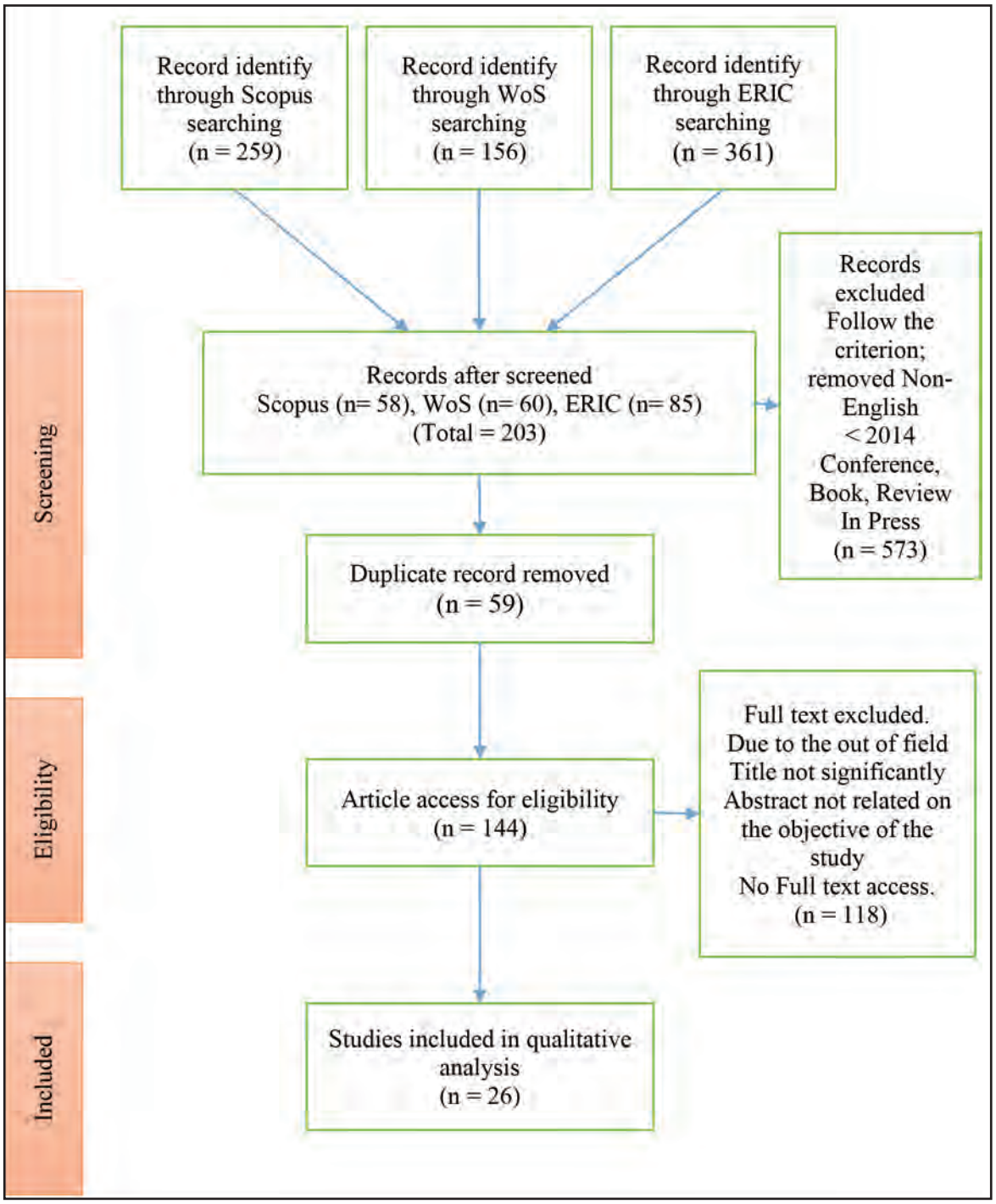

Fig. 1: Flow Diagram of the Proposed Searching Study [34]

Review Strengths and Weaknesses

A key strength of this review is its rigorous methodology and broad coverage of educational contexts. The systematic search identified 26 peer-reviewed studies across multiple databases, providing a credible evidence base on AR use in health sciences and STEM education. However, limiting the review to English-language, peer-reviewed publications excluded grey literature and may introduce reporting bias. Considerable variation in AR applications and instructional models also prevented meta-analysis due to data heterogeneity.

CONCLUSION

Augmented reality has strong potential to improve learning when paired with structured instructional approaches such as inquiry-based and collaborative designs. Its success, however, depends on effective design, educator support, and adequate

infrastructure. Addressing technical, pedagogical, and social barriers through coordinated institutional efforts is essential. Developing clear implementation frameworks, ensuring inclusive access, and evaluating long-term outcomes will further strengthen its use. With these supports, AR can become a sustainable tool that promotes engagement and deep learning.

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