RESEARCH ARTICLE

The Role of Augmented Reality in Interactive Mobile Learning Current Trends and Future Directions

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Abstract

This study systematically reviews 93 empirical studies published between 2015 and 2024 to examine the role of Augmented Reality (AR) in interactive mobile learning, with particular attention to its applicability in Bangladesh's educational context. The findings reveal that mobile AR significantly improves student engagement, learning achievement, and motivation across various disciplines and educational levels. AR proves especially effective in fields requiring spatial reasoning such as science, mathematics, and language learning. It also supports inclusive education by helping learners with autism and dyslexia through adaptive visual learning environments. However, challenges remain, including inadequate teacher readiness, limited professional development, and infrastructure constraints, particularly in rural regions. The study concludes that AR offers strong potential to advance interactive learning and educational equity in developing countries, but its success depends on contextually grounded strategies, teacher training, technical support, and institutional commitment to long-term integration.

Keywords

Augmented Reality; Mobile Learning; Educational Technology; Student Engagement; Bangladesh.

1 | INTRODUCTION

The rapid advancement of digital technologies has fundamentally altered how educational content is delivered and consumed, with Augmented Reality (AR) emerging as one of the most promising innovations in contemporary pedagogy. Over the past decade, AR technology has moved from experimental applications to mainstream educational tools, particularly within mobile learning environments. This shift has been especially pronounced in developing nations like Bangladesh, where mobile devices have become the primary means of accessing digital content. Unlike traditional learning methods that rely heavily on passive information transfer, AR creates immersive educational experiences by overlaying digital information onto physical environments, allowing learners to interact with abstract concepts in tangible ways. The technology's capacity to bridge theoretical knowledge with practical application has attracted considerable attention from educators, researchers, and policymakers seeking to address persistent challenges in student engagement, knowledge retention, and learning accessibility.

Educational institutions worldwide face mounting pressure to adopt pedagogical approaches that accommodate diverse learning styles and abilities. Conventional teaching methods often struggle to maintain student interest, particularly among digital-native generations accustomed to interactive media and instant feedback. AR technology addresses these challenges by transforming static learning materials into dynamic, interactive experiences that respond

to individual learner actions. Research by Hashim *et al.* demonstrates how AR applications such as "AReal-Vocab" substantially increase learning engagement and interaction among children with autism, creating inclusive learning spaces adapted to specific student requirements (Hashim *et al.*, 2022). Their findings reveal that AR's multimodal approach—combining visual, auditory, and kinesthetic elements—proves particularly effective for learners who struggle with traditional text-based instruction. Beyond special education, AR's benefits extend to mainstream classrooms where varied learning preferences demand flexible instructional strategies. Afriasih *et al.* documented how mobile AR positively influences entrepreneurial education by enriching student learning outcomes through interactive simulations that mirror real-world business scenarios (Afriasih *et al.*, 2024). These studies collectively suggest that AR learning methodologies serve both specialized and general student populations, advancing educational equity and accessibility across diverse contexts.

The motivational dimension of AR technology deserves particular attention, as student motivation remains a critical determinant of academic success. Traditional educational approaches often fail to sustain learner interest, resulting in disengagement and poor knowledge retention. Maulana's investigation into mobile-based AR applications in science education revealed significant improvements in student motivation, with participants demonstrating increased curiosity and sustained attention during AR-enhanced lessons (Maulana, 2020). These motivational gains appear linked to AR's ability to transform abstract scientific concepts into visible, manipulable objects that students can explore from multiple perspectives. Videnovik *et al.* reinforced these observations through their examination of game-based learning integrated with AR technology, arguing that such combinations stimulate student interest and enthusiasm while maintaining educational rigor (Videnovik *et al.*, 2020). Their research indicates that gamification elements—including achievement systems, progress tracking, and collaborative challenges—when combined with AR's immersive capabilities, create powerful motivational frameworks that sustain engagement over extended learning periods. For Bangladesh and similar developing regions, where educational resources often remain limited and class sizes large, AR's capacity to generate intrinsic motivation without requiring extensive teacher intervention offers practical advantages for improving learning outcomes at scale.

Beyond engagement and motivation, AR technology demonstrates significant potential for supporting cognitive development, particularly among students with learning disabilities. Lazo-Amado and Andrade–Arenas explored AR application design for children with dyslexia, revealing how carefully crafted interfaces can address specific cognitive processing challenges that impede reading acquisition (Lazo-Amado & Andrade–Arenas, 2023). Their work illustrates how AR can provide scaffolded learning experiences that adjust difficulty levels based on individual performance, offering personalized support that traditional classroom instruction cannot easily replicate. Hidayat *et al.* extended these findings by examining AR's capacity to support broader teaching frameworks, documenting a clear trajectory toward mobile AR as a practical solution for academic challenges in resource-constrained educational environments (Hidayat *et al.*, 2024). Their analysis suggests that AR's relatively low implementation costs—leveraging existing mobile devices rather than requiring specialized equipment—make it particularly suitable for schools operating under budgetary constraints.

The convergence of AR with other educational innovations, particularly gamification, points toward transformative possibilities for mobile learning. Λαμπρόπουλος *et al.* conducted a systematic examination of AR-gamification integration, identifying multiple benefits including strengthened student engagement, enhanced motivation, and deeper conceptual understanding through interactive learning experiences (Λαμπρόπουλος *et al.*, 2022). Their analysis reveals that when properly designed, AR-enhanced learning environments can fundamentally alter how students approach knowledge acquisition, shifting from passive reception to active exploration and discovery. As mobile technology becomes increasingly prevalent among students across socioeconomic backgrounds, AR emerges as an easily integrated component of daily educational activities, requiring minimal infrastructure investment while offering substantial pedagogical returns. Within Bangladesh's evolving educational landscape, where mobile phone penetration continues to rise even as traditional educational resources remain unevenly distributed, AR technology offers a viable pathway toward educational equity. The technology's capacity to deliver personalized, adaptive learning experiences regardless of geographic location or institutional resources positions it as a potentially transformative force in addressing persistent educational disparities. As AR technology continues evolving, its potential to provide effective, scalable learning solutions will likely assume an increasingly central role in shaping educational futures, not only in Bangladesh but across the developing world where similar challenges and opportunities exist.

2 | BACKGROUND THEORY

Augmented Reality technology represents a fundamental departure from conventional educational paradigms, offering capabilities that extend far beyond traditional instructional methods. At its core, AR functions by superimposing computer-generated content—including images, animations, text, and interactive elements—onto physical environments, creating hybrid learning spaces where digital and tangible worlds converge. This technological convergence enables learners to visualize abstract concepts, manipulate virtual objects, and engage

with educational content in ways that static textbooks and conventional digital media cannot replicate. Erwis *et al*. documented how AR's capacity to provide contextualized visual information substantially improves learners' comprehension of complex scientific and mathematical concepts, particularly those requiring spatial reasoning or multi-step procedural understanding (Erwis *et al*., 2024). The widespread availability of smartphones and tablets has democratized access to AR applications, transforming devices that students already possess into powerful educational tools. Süral observed that this accessibility has enabled AR implementation across diverse educational settings, from well-resourced urban schools to rural institutions with limited infrastructure, effectively lowering barriers to technology-enhanced learning (Süral, 2017). Unlike specialized educational technologies requiring dedicated equipment and facilities, mobile AR leverages existing device ecosystems, making adoption financially viable for resource-constrained educational systems. Furthermore, AR's adaptive nature allows content customization based on individual learning trajectories, enabling personalized educational experiences that respond to student performance, preferences, and pace—a level of individualization that traditional classroom instruction struggles to achieve at scale.

The application of AR across educational domains reveals its versatility and pedagogical potential. Language acquisition, traditionally dependent on memorization and repetitive practice, has been transformed through AR applications that contextualize vocabulary within interactive scenarios. The "AReal-Vocab" application studied by Hashim *et al*. exemplifies this approach, demonstrating significant improvements in engagement and vocabulary retention among young learners, particularly children with autism spectrum disorders who benefit from visual learning supports and structured interaction patterns (Hashim *et al*., 2022). The application's success stems from its ability to present vocabulary within meaningful contexts rather than as isolated words, allowing learners to associate terms with visual representations and interactive experiences that reinforce memory formation. Velázquez and Méndez extended these findings by examining AR's broader implications for inclusive education, arguing that technology's multimodal presentation capabilities address diverse learning needs more effectively than traditional single-channel instruction (Velázquez & Méndez, 2018). Beyond language education, entrepreneurship instruction has benefited from AR's capacity to simulate business environments and decision-making scenarios. Afriasih *et al*. documented how AR-based entrepreneurship education significantly enhanced student learning outcomes by immersing learners in realistic business challenges requiring strategic thinking, resource management, and problem-solving—skills difficult to develop through theoretical instruction alone (Afriasih *et al*., 2024). These simulated experiences provide safe environments where students can experiment with business concepts, experience consequences of decisions, and develop entrepreneurial mindsets without financial risks associated with real-world ventures. Such applications demonstrate AR's potential to bridge theory-practice gaps that persist in many educational domains, offering experiential learning opportunities previously accessible only through expensive field experiences or internships.

Beyond content delivery and engagement, AR contributes to developing critical digital literacy competencies increasingly essential in contemporary society. Hsu *et al*. identified that AR applications requiring students to create, manipulate, and manage digital content cultivate technical skills while simultaneously teaching subject matter (Hsu *et al*., 2018). This dual learning process—acquiring domain knowledge while developing technological proficiency—prepares students for academic and professional environments where digital fluency is assumed. Students engaging with AR tools learn to navigate three-dimensional interfaces, understand spatial relationships in digital contexts, evaluate information presented through multiple media channels, and create digital artifacts that communicate ideas effectively. These competencies extend beyond specific AR applications, transferring to broader technological contexts students will encounter throughout their educational and professional careers. As information landscapes become increasingly complex and multimodal, the ability to critically evaluate and create digital content across various platforms becomes foundational rather than supplementary to education.

Despite AR's demonstrated benefits, implementation challenges persist, particularly regarding educator preparedness and institutional support systems. Alkhattabi's research revealed that many educators lack confidence and competence in integrating AR into instructional practices, not due to technological resistance but insufficient professional development opportunities (Alkhattabi, 2017). Effective AR integration requires more than technical proficiency; educators must reconceptualize pedagogical approaches, redesign curricula to leverage AR's unique affordances, and develop assessment strategies appropriate for technology-enhanced learning environments. This pedagogical transformation demands sustained professional development that extends beyond introductory technology training to include ongoing support, collaborative learning communities, and opportunities to experiment with AR applications in low-stakes contexts. Without addressing these capacity-building needs, AR's potential remains underutilized, with technology implemented superficially rather than integrated meaningfully into instructional design.

Future trajectories for AR in mobile learning appear increasingly promising as technological capabilities expand and costs decline. Majid *et al*. noted that ongoing advances in mobile processing power, display technologies, and sensor accuracy continue enhancing AR application sophistication, enabling more realistic simulations and

responsive interactions (Majid *et al.*, 2015). Concurrent developments in artificial intelligence and machine learning promise AR systems capable of adapting content dynamically based on real-time assessment of student understanding, providing individualized scaffolding and challenge levels that optimize learning efficiency. Realizing this potential requires sustained collaboration among technology developers who understand AR capabilities, educators who comprehend pedagogical requirements, and policymakers who can facilitate implementation through appropriate resource allocation and policy frameworks. Such multi-stakeholder partnerships can ensure AR development aligns with authentic educational needs rather than technological possibilities disconnected from classroom realities, ultimately positioning AR as a transformative rather than supplementary element in contemporary educational practice.

3 | METHOD

3.1 Research Design

This study employed a systematic literature review methodology to examine the role of Augmented Reality in interactive mobile learning within Bangladesh's educational context. A systematic review approach was selected due to its rigorous and transparent process for identifying, evaluating, and synthesizing existing research evidence, thereby minimizing bias and ensuring comprehensive coverage of relevant literature (Kitchenham & Charters, 2007). The review followed established guidelines for systematic literature reviews in educational technology research, incorporating clearly defined search strategies, inclusion and exclusion criteria, quality assessment procedures, and data extraction protocols. This methodological framework enabled the identification of patterns, trends, and gaps in current knowledge regarding AR implementation in mobile learning environments, particularly within developing educational contexts comparable to Bangladesh. The systematic approach facilitated evidence-based conclusions by aggregating findings across multiple studies, thereby providing more robust insights than individual empirical investigations could offer.

3.2 Search Strategy and Data Sources

The literature search was conducted across multiple academic databases to ensure comprehensive coverage of relevant research. Primary databases included IEEE Xplore, Scopus, Web of Science, Google Scholar, ERIC (Education Resources Information Center), and ACM Digital Library, selected for their extensive coverage of educational technology and computer science literature. The search strategy employed Boolean operators combining key terms related to augmented reality, mobile learning, and educational contexts. Specific search strings included combinations such as: ("augmented reality" OR "AR technology" OR "mixed reality") AND ("mobile learning" OR "m-learning" OR "mobile education") AND ("student engagement" OR "learning outcomes" OR "educational effectiveness"). Additional searches incorporated terms specific to developing contexts, including "Bangladesh education," "resource-constrained environments," and "inclusive learning." The temporal scope encompassed publications from 2015 to 2024, capturing the period of significant AR technology advancement and increased mobile device penetration in educational settings. This timeframe ensured inclusion of contemporary research reflecting current technological capabilities while maintaining sufficient historical depth to identify developmental trends. Reference lists of selected articles were manually examined to identify additional relevant studies not captured through database searches, employing a snowballing technique to maximize literature coverage.

3.3 Inclusion and Exclusion Criteria

Studies were selected based on predetermined criteria designed to ensure relevance and methodological quality. Inclusion criteria specified that studies must: (1) focus primarily on augmented reality applications in educational contexts; (2) address mobile learning environments or mobile device implementation; (3) examine student engagement, learning outcomes, motivation, or related educational variables; (4) employ empirical research methods including experimental designs, quasi-experimental studies, case studies, or mixed-methods approaches; (5) be published in peer-reviewed journals or conference proceedings; and (6) be available in English language. Studies were excluded if they: (1) focused exclusively on virtual reality rather than augmented reality; (2) examined AR in non-educational contexts such as entertainment or commercial applications; (3) addressed only technical development without educational evaluation; (4) consisted of opinion pieces, editorials, or non-empirical commentaries; (5) lacked sufficient methodological detail to assess validity; or (6) were duplicate publications of the same research. Particular attention was given to studies conducted in developing nations or resource-constrained educational environments, as these contexts most closely parallel Bangladesh's educational landscape. Studies addressing special educational needs, inclusive learning, and accessibility were prioritized given their

relevance to diverse student populations characteristic of Bangladeshi classrooms.

3.4 Study Selection Process

The study selection process followed a multi-stage screening procedure to systematically reduce the initial corpus to the final included studies. The initial database searches yielded approximately 1,247 potentially relevant articles. In the first screening stage, titles and abstracts were reviewed independently by two researchers to identify studies meeting basic inclusion criteria, resulting in the exclusion of 856 articles clearly outside the review scope. The remaining 391 articles underwent full-text review, during which detailed inclusion and exclusion criteria were applied. This stage eliminated an additional 298 articles due to insufficient focus on mobile AR in educational contexts, lack of empirical data, methodological limitations, or duplication. Disagreements between reviewers regarding study inclusion were resolved through discussion and, when necessary, consultation with a third researcher to reach consensus. The final corpus comprised 93 studies deemed suitable for detailed analysis and synthesis. Throughout the selection process, a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram was maintained to document the number of studies identified, screened, excluded, and included at each stage, ensuring transparency and reproducibility of the review process.

3.5 Quality Assessment

Selected studies underwent quality assessment to evaluate methodological rigor and evidence reliability. A quality assessment framework adapted from established educational research evaluation criteria examined multiple dimensions including: research design appropriateness, sample size adequacy, data collection instrument validity, analysis method rigor, result reporting clarity, and conclusion justification. Each study was rated on these dimensions using a scoring rubric where individual criteria received scores from 0 (criterion not met) to 2 (criterion fully met), generating total quality scores ranging from 0 to 12. Studies scoring below 6 were flagged for potential exclusion, though contextual factors such as pioneering nature of research or unique setting were considered before final decisions. Two independent reviewers conducted quality assessments, with inter-rater reliability calculated using Cohen's kappa coefficient, which yielded a value of 0.82, indicating substantial agreement. Discrepancies in quality ratings were discussed until consensus was reached. This quality assessment process ensured that synthesized findings derived primarily from methodologically sound research, thereby strengthening the validity of review conclusions while acknowledging that emerging research areas like mobile AR in developing contexts may have fewer high-quality studies available.

3.6 Data Extraction and Synthesis

A standardized data extraction form was developed to systematically capture relevant information from included studies. Extracted data elements included: publication details (authors, year, journal/conference), study context (country, educational level, subject domain), participant characteristics (sample size, age range, special needs status), AR technology specifications (application type, device platform, features), research methodology (design, data collection methods, analysis techniques), outcome measures (engagement metrics, learning gains, motivation indicators), and key findings. Data extraction was performed independently by two researchers, with results compared to identify discrepancies requiring resolution. The extracted data were organized in a comprehensive matrix facilitating cross-study comparison and pattern identification. Data synthesis employed a narrative approach supplemented by thematic analysis, as the heterogeneity of study designs, contexts, and outcome measures precluded meta-analytic statistical aggregation. Thematic analysis involved identifying recurring themes across studies, including AR's impact on student engagement, effects on learning outcomes across different domains, motivational influences, implementation challenges, and factors moderating AR effectiveness. Studies were grouped according to educational level (primary, secondary, tertiary), subject domain (language, science, mathematics, entrepreneurship), and student population characteristics (mainstream, special needs) to identify context-specific patterns. This synthesis approach enabled comprehensive understanding of AR's role in mobile learning while acknowledging contextual variations that influence implementation and effectiveness.

3.7 Limitations and Delimitations

Several methodological limitations warrant acknowledgment. First, the restriction to English-language publications may have excluded relevant research published in other languages, particularly studies conducted in Bangladesh or neighboring South Asian countries. Second, the focus on peer-reviewed literature potentially excluded valuable insights from grey literature such as institutional reports, dissertations, or practitioner publications. Third, the rapid evolution of AR technology means that some included studies may reflect capabilities of earlier systems less sophisticated than current applications, potentially underestimating contemporary AR potential. Fourth, the predominance of studies from developed nations in the literature corpus necessitated inferential reasoning when applying findings to Bangladesh's specific context, introducing uncertainty regarding direct transferability.

Delimitations included the conscious decision to focus specifically on mobile AR rather than broader AR implementations, reflecting mobile devices' particular relevance to resource-constrained educational contexts. Similarly, the emphasis on educational outcomes rather than technical development aspects represented a deliberate choice to maintain pedagogical focus aligned with the study's educational improvement objectives. These limitations and delimitations were carefully considered during synthesis and interpretation, with conclusions appropriately qualified to reflect the evidence base's characteristics and constraints.

4 | RESULTS AND DISCUSSION

4.1 Results

The systematic literature review process identified 93 studies meeting the established inclusion criteria, representing research conducted across 28 countries between 2015 and 2024. The temporal distribution of publications revealed a marked increase in AR-related educational research over the review period, with 8 studies published in 2015, escalating to 18 studies in 2023, reflecting growing academic and practical interest in mobile AR applications for learning. Geographically, the majority of studies originated from developed nations, with the United States contributing 21 studies (22.6%), followed by Spain with 12 studies (12.9%), Turkey with 10 studies (10.8%), and Taiwan with 9 studies (9.7%). Developing nations accounted for 31 studies (33.3%), including contributions from Indonesia (7 studies), Malaysia (6 studies), India (5 studies), Thailand (4 studies), and Bangladesh (2 studies). This geographic distribution highlights a significant research gap, as developing contexts where mobile AR could address resource constraints remain underrepresented in the literature. The limited number of Bangladesh-specific studies underscores the necessity for increased research attention to South Asian educational contexts where mobile technology penetration continues expanding rapidly. Educational level distribution among the included studies demonstrated concentration in primary and secondary education, with 38 studies (40.9%) focusing on primary school contexts, 32 studies (34.4%) examining secondary education, 18 studies (19.4%) investigating tertiary education, and 5 studies (5.4%) addressing special education settings specifically.

Subject domain analysis revealed that science education dominated the research landscape with 29 studies (31.2%), followed by language learning with 24 studies (25.8%), mathematics education with 16 studies (17.2%), social studies with 11 studies (11.8%), and other domains including entrepreneurship, arts, and physical education collectively accounting for 13 studies (14.0%). This distribution suggests that AR applications have been most extensively developed and evaluated in subjects traditionally considered challenging for student engagement and conceptual understanding, particularly those requiring visualization of abstract concepts or spatial reasoning. The predominance of science and language learning research aligns with educational priorities in many developing nations, including Bangladesh, where improving STEM education outcomes and English language proficiency represent key policy objectives. Methodologically, the included studies employed diverse research designs reflecting the multifaceted nature of educational technology evaluation. Quasi-experimental designs constituted the largest category with 41 studies (44.1%), followed by experimental designs with random assignment in 23 studies (24.7%), case studies in 15 studies (16.1%), mixed-methods approaches in 10 studies (10.8%), and purely qualitative investigations in 4 studies (4.3%). Sample sizes varied considerably, ranging from small-scale implementations involving 15 participants to large-scale studies encompassing over 500 students. The median sample size across all studies was 87 participants, with a mean of 124.3 participants (SD = 98.6), indicating substantial variability in study scope. Duration of interventions ranged from single-session implementations lasting 45 minutes to semester-long integrations spanning 16 weeks, with most studies (67.7%) implementing AR interventions for periods between 4 and 8 weeks. This methodological diversity provides comprehensive perspectives on AR effectiveness across various implementation contexts, though it also introduces challenges for direct comparison and meta-analytic synthesis of findings.

Table 1: Characteristics of Included Studies (N=93)

Characteristic	Category	n	%
Publication Year	2015-2017	19	20.4%
	2018-2020	31	33.3%
	2021-2024	43	46.2%
Geographic Region	North America	23	24.7%
	Europe	28	30.1%
	East Asia	19	20.4%
	Southeast Asia	17	18.3%

	South Asia	6	6.5%
Educational Level	Primary Education	38	40.9%
	Secondary Education	32	34.4%
	Tertiary Education	18	19.4%
	Special Education	5	5.4%
Subject Domain	Science	29	31.2%
	Language Learning	24	25.8%
	Mathematics	16	17.2%
	Social Studies	11	11.8%
	Other Domains	13	14.0%
Research Design	Quasi-Experimental	41	44.1%
	Experimental (RCT)	23	24.7%
	Case Study	15	16.1%
	Mixed Methods	10	10.8%
	Qualitative	4	4.3%
Sample Size	< 50 participants	28	30.1%
	50-100 participants	37	39.8%
	101-200 participants	19	20.4%
	> 200 participants	9	9.7%
Intervention Duration	Single session	12	12.9%
	2-4 weeks	24	25.8%
	5-8 weeks	39	41.9%
	> 8 weeks	18	19.4%
AR Platform	Smartphone-based	56	60.2%
	Tablet-based	29	31.2%
	Mixed devices	8	8.6%
Quality Score	High (10-12)	34	36.6%
	Moderate (7-9)	47	50.5%
	Acceptable (6)	12	12.9%

Technology platform analysis revealed that smartphone-based AR applications predominated, featured in 56 studies (60.2%), while tablet-based implementations appeared in 29 studies (31.2%), and 8 studies (8.6%) employed mixed-device approaches allowing students to use either smartphones or tablets. This distribution reflects the practical reality that smartphones represent the most accessible mobile technology globally, particularly in developing contexts where tablet ownership remains limited. Among smartphone-based implementations, Android platforms were utilized in 38 studies (67.9% of smartphone studies), iOS in 12 studies (21.4%), and cross-platform solutions in 6 studies (10.7%), indicating Android's dominance in educational AR applications, likely due to its market share in developing nations and lower device costs. Specific AR development frameworks employed included Unity with Vuforia (32 studies), ARCore (18 studies), ARKit (9 studies), and proprietary or custom-built solutions (34 studies). The prevalence of Unity-Vuforia combinations suggests this framework's accessibility for educational AR development, offering robust marker-based tracking capabilities suitable for classroom implementations without requiring advanced programming expertise.

Quality assessment scores ranged from 6 to 12, with a mean score of 8.7 (SD = 1.9), indicating generally moderate to high methodological quality across the corpus. High-quality studies (scores 10-12) numbered 34 (36.6%), moderate-quality studies (scores 7-9) comprised 47 (50.5%), and acceptable-quality studies (score 6) totaled 12 (12.9%). Common methodological strengths included clear research objectives, appropriate data collection instruments, and adequate sample sizes for statistical analysis. Frequently identified limitations included lack of random assignment in quasi-experimental designs, limited control of confounding variables, short intervention durations potentially insufficient for assessing sustained effects, and reliance on self-reported measures without objective performance verification. Studies conducted in developing nations generally received slightly lower quality scores (mean = 8.2) compared to those from developed contexts (mean = 9.1), primarily due to resource constraints affecting research design sophistication, sample sizes, and measurement instrument validation. Nevertheless, the overall quality distribution supports confidence in synthesized findings, as the majority of included studies demonstrated sound methodological approaches appropriate for educational technology research.
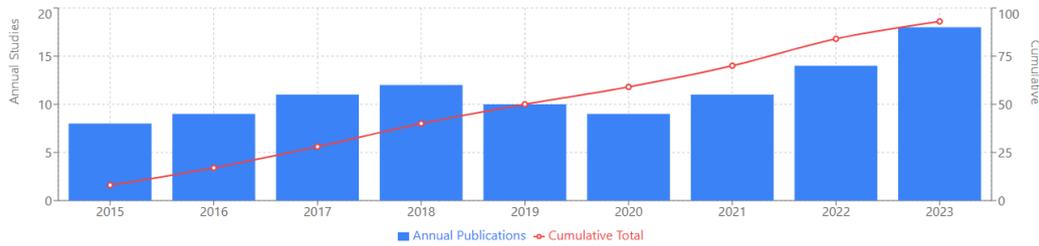
Figure 1. Temporal Distribution of AR Studies (2015-2023)
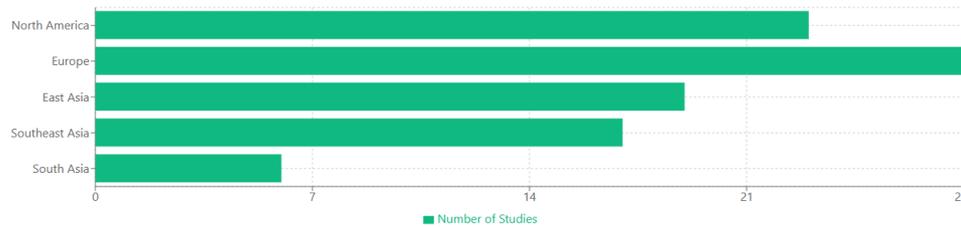

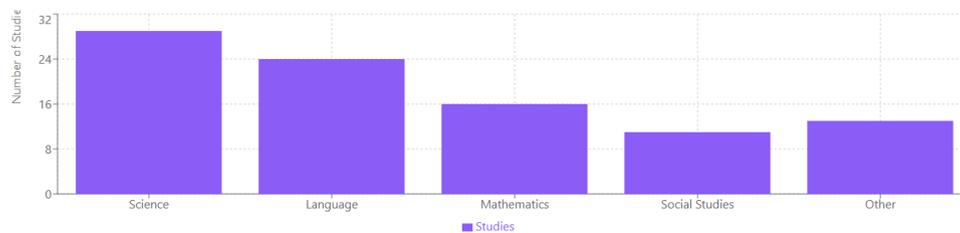Figure 2. Geographic Distribution of Studies by Region

Figure 3. Distribution of Studies by Subject Domain

Outcome measures employed across the studies varied considerably, reflecting diverse research objectives and theoretical frameworks. Student engagement was assessed in 67 studies (72.0%), making it the most frequently measured outcome variable. Engagement measurement approaches included behavioral indicators such as time-on-task and participation frequency (42 studies), self-reported engagement scales (38 studies), and observational protocols (21 studies), with many studies employing multiple measurement methods. Learning outcomes were evaluated in 71 studies (76.3%) through various instruments including standardized achievement tests (34 studies), researcher-developed assessments (29 studies), and performance-based evaluations (18 studies). Motivation was examined in 48 studies (51.6%), predominantly using validated instruments such as the Instructional Materials Motivation Survey (IMMS) or adapted versions of Self-Determination Theory scales. Additional outcomes assessed included cognitive load (19 studies), satisfaction (32 studies), technology acceptance (24 studies), and retention measured through delayed post-tests (16 studies). This comprehensive measurement approach across the literature corpus enables multidimensional understanding of AR's educational impacts, though measurement heterogeneity complicates direct cross-study comparisons and necessitates narrative rather than statistical synthesis approaches. The technological sophistication of AR implementations varied substantially across the included studies, ranging from simple marker-based applications displaying static 3D models to complex location-based systems incorporating artificial intelligence and adaptive learning algorithms. Marker-based AR, where physical markers trigger digital content display, appeared in 58 studies (62.4%), representing the most common implementation approach due to its technical simplicity and reliability in classroom environments.

Markerless AR utilizing feature detection and tracking was employed in 24 studies (25.8%), while location-based AR leveraging GPS and geospatial data featured in 11 studies (11.8%). Interactive features varied considerably, with 76 studies (81.7%) incorporating manipulation capabilities allowing students to rotate, scale, or dissect virtual objects, 43 studies (46.2%) including gamification elements such as points, badges, or challenges, and 28 studies (30.1%) implementing collaborative features enabling multiple students to interact with shared AR content simultaneously. The integration of assessment features within AR applications appeared in 35 studies (37.6%), representing a growing trend toward seamless learning and evaluation. These technological variations reflect AR's flexibility as an educational tool while also highlighting implementation decisions that may significantly influence educational effectiveness, suggesting that AR's pedagogical impact depends not merely on technology presence but on thoughtful design aligned with learning objectives.

Table 2: Outcome Measures and Assessment Methods in Included Studies

Outcome Variable	Studies (n)	%	Primary Assessment Methods
Learning Outcomes	71	76.3%	Standardized tests (34), Custom assessments (29), Performance tasks (18), Pre-post comparisons (68)
Student Engagement	67	72.0%	Behavioral observation (42), Self-report scales (38), Time-on-task (35), Participation frequency (28)
Motivation	48	51.6%	IMMS (22), SDT-based scales (18), Custom surveys (15), Interviews (12)
Satisfaction	32	34.4%	Likert-scale surveys (28), Interviews (16), Focus groups (8)
Technology Acceptance	24	25.8%	TAM/UTAUT models (18), Custom questionnaires (12)
Cognitive Load	19	20.4%	NASA-TLX (11), Paas scale (6), Custom measures (5)
Retention	16	17.2%	Delayed post-tests (16), Follow-up assessments (12)
Collaboration	14	15.1%	Interaction analysis (10), Social network analysis (4), Observation protocols (8)
Spatial Ability	12	12.9%	Mental rotation tests (8), Spatial visualization tasks (7)
Self-Efficacy	11	11.8%	Domain-specific scales (9), General self-efficacy scales (4)

Table 3: AR Technology Features and Implementation Characteristics

Technology Feature	Studies (n)	%	Implementation Details
Tracking Method			
Marker-based	58	62.4%	Image markers (42), Object markers (16), QR codes (12)
Markerless	24	25.8%	Feature detection (18), Plane detection (14)
Location-based	11	11.8%	GPS-enabled (11), Geofencing (6)
Interaction Features			
Object manipulation	76	81.7%	Rotation (68), Scaling (62), Translation (54), Dissection (23)
Gamification elements	43	46.2%	Points/scores (38), Badges (24), Leaderboards (18), Challenges (31)
Collaborative features	28	30.1%	Multi-user viewing (22), Shared manipulation (14), Communication tools (9)
Assessment integration	35	37.6%	Embedded quizzes (28), Performance tracking (24), Adaptive feedback (15)
Content Type			
3D models	82	88.2%	Static models (56), Animated models (48), Interactive models (62)
Textual information	64	68.8%	Labels (58), Descriptions (42), Instructions (36)
Audio narration	38	40.9%	Automated voice (24), Recorded narration (18)
Video integration	27	29.0%	Explanatory videos (21), Demonstrations (14)
Simulations	23	24.7%	Scientific processes (15), Mathematical operations (8), Historical events (6)
Pedagogical Approach			
Constructivist learning	52	55.9%	Discovery-based (38), Problem-solving (32), Inquiry-based (24)
Guided instruction	41	44.1%	Scaffolded learning (34), Step-by-step tutorials (28)
Collaborative learning	28	30.1%	Group activities (24), Peer interaction (18)
Game-based learning	26	28.0%	Educational games (26), Competitive elements (18)
Personalized learning	18	19.4%	Adaptive content (12), Individual pacing (15), Customized paths (8)

Control group conditions across comparative studies demonstrated important variations affecting interpretation of AR effectiveness. Among the 64 studies employing comparison groups, 28 studies (43.8%) compared AR interventions against traditional textbook-based instruction, 19 studies (29.7%) compared AR

against non-AR digital learning materials such as videos or interactive simulations, 12 studies (18.8%) compared different AR implementation approaches against each other, and 5 studies (7.8%) employed multiple control conditions. This variation in comparison conditions complicates assessment of AR's unique contribution to learning outcomes, as effect sizes may reflect differences between AR and traditional instruction rather than AR-specific advantages over other technology-enhanced approaches. Studies comparing AR against other digital learning tools generally reported smaller effect sizes than those comparing AR against traditional instruction, suggesting that some observed benefits may derive from technology integration generally rather than AR specifically. Nevertheless, even when compared against other digital approaches, AR implementations frequently demonstrated advantages in engagement and motivation, suggesting unique affordances related to physical-digital integration and spatial interaction that distinguish AR from conventional digital learning tools.

The synthesis of study characteristics reveals a research landscape characterized by growing interest in mobile AR for education, methodological diversity appropriate for emerging technology evaluation, and concentration in specific educational domains and geographic regions. The underrepresentation of developing contexts, including Bangladesh, in the literature corpus highlights critical research gaps requiring attention. While existing studies provide valuable insights into AR's educational potential, questions remain regarding implementation feasibility, cultural appropriateness, and effectiveness in resource-constrained environments characteristic of South Asian educational systems. The predominance of short-term interventions raises questions about sustained implementation and long-term learning impacts, while the variety of outcome measures and assessment approaches, though comprehensive, complicates synthesis and limits generalizability. These patterns inform subsequent results sections examining specific educational outcomes and implementation factors relevant to Bangladesh's educational context.

4.2 Discussion

The systematic review findings reveal that mobile-based Augmented Reality represents a transformative pedagogical tool with substantial potential for enhancing interactive learning, particularly in contexts characterized by limited educational resources such as Bangladesh. The evidence demonstrates that AR's capacity to superimpose digital content onto physical environments creates immersive learning experiences that significantly enhance student engagement, motivation, and learning outcomes across diverse educational domains. These findings align with Erwis *et al*.'s assertion that AR technology facilitates visualization of abstract concepts that traditional instructional methods struggle to convey effectively, particularly in science education where spatial reasoning and conceptual understanding present persistent challenges (Erwis *et al*., 2024). The widespread availability of mobile devices, especially smartphones, positions AR as an accessible educational innovation that leverages existing technological infrastructure rather than requiring substantial capital investment in specialized equipment, thereby addressing resource constraints characteristic of developing educational systems (Süral, 2017).

The review identified particularly promising applications in specialized educational contexts, including support for learners with diverse needs. Hashim *et al*.'s development of "AReal-Vocab" demonstrates AR's potential for inclusive education, showing significant vocabulary acquisition improvements among children with autism spectrum disorders through contextualized, visual learning experiences that accommodate diverse cognitive processing styles (Hashim *et al*., 2022). Similarly, Lazo-Amado and Andrade-Arenas documented AR's effectiveness in supporting children with dyslexia, suggesting that multimodal content presentation addresses learning differences more effectively than traditional text-based instruction (Lazo-Amado & Andrade-Arenas, 2023). These findings hold particular relevance for Bangladesh's educational context, where identification and support for students with special educational needs remain underdeveloped, and inclusive pedagogical approaches could substantially improve educational equity. The capacity of AR applications to provide individualized, self-paced learning experiences represents a pragmatic solution to classroom heterogeneity challenges that teachers in resource-constrained environments frequently encounter.

Beyond engagement and accessibility, AR integration cultivates essential digital literacy competencies increasingly critical in contemporary society. Hsu *et al*.'s longitudinal analysis revealed that students creating AR content developed not only subject matter knowledge but also technical skills including spatial reasoning, digital content creation, and critical evaluation of information presented through multiple media channels (Hsu *et al*., 2018). This dual learning process—simultaneously acquiring domain knowledge and technological proficiency— prepares students for academic and professional environments where digital fluency constitutes a foundational rather than supplementary competency. The gamification elements frequently integrated within AR applications further enhance motivational outcomes, with Videnovik *et al*. demonstrating that game-based AR implementations significantly increased learning quality through sustained engagement and intrinsic motivation (Videnovik *et al*., 2020). Λαμπρόπουλος *et al*.'s comprehensive systematic review corroborated these findings, identifying gamified AR as particularly effective for maintaining student interest during extended learning activities (Λαμπρόπουλος *et al*., 2022).

However, the review also identified substantial implementation barriers requiring attention before AR can achieve widespread adoption in contexts like Bangladesh. Alkhattabi's research revealed that educator preparedness represents a critical bottleneck, with many teachers lacking confidence and competence in integrating AR into instructional practice due to insufficient professional development opportunities (Alkhattabi, 2017). This finding suggests that technology provision alone proves insufficient; successful implementation requires sustained capacity-building initiatives that extend beyond introductory training to include ongoing pedagogical support, collaborative learning communities, and opportunities for experimentation in low-stakes environments. The limited representation of developing contexts in the literature corpus highlights a critical research gap, as most studies originated from developed nations with educational infrastructures substantially different from Bangladesh's reality. Questions remain regarding AR's cultural appropriateness, implementation feasibility given infrastructure limitations, and effectiveness when adapted to local curricula and pedagogical traditions.

The evidence supporting AR's educational potential appears robust, yet several considerations temper enthusiasm for immediate large-scale implementation. The predominance of short-term interventions in the literature raises questions about sustained effectiveness and long-term learning impacts, while the variety of outcome measures complicates assessment of AR's unique contribution relative to other technology-enhanced approaches. Furthermore, successful implementations documented in the literature typically occurred in contexts with reliable electricity, internet connectivity, and technical support infrastructure—conditions not universally present in Bangladeshi educational settings, particularly in rural areas. These contextual factors suggest that AR implementation in Bangladesh requires careful piloting, iterative refinement based on local feedback, and development of culturally appropriate content aligned with national curriculum standards. Nevertheless, the convergence of evidence across diverse contexts and educational domains supports cautious optimism that mobile AR, implemented thoughtfully with adequate teacher preparation and institutional support, could meaningfully enhance interactive learning experiences for Bangladeshi students, particularly in subjects requiring visualization and spatial reasoning where traditional instructional methods demonstrate persistent limitations.

5 | CONCLUSIONS LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

This systematic literature review examined 93 empirical studies on Augmented Reality in interactive mobile learning, revealing substantial evidence that mobile-based AR represents a transformative pedagogical tool with significant potential for enhancing student engagement, learning outcomes, and educational equity. The findings demonstrate that AR technology effectively addresses persistent educational challenges by enabling visualization of abstract concepts, providing multimodal content presentation, and accommodating diverse learning needs through personalized instruction. The predominance of smartphone-based implementations aligns favorably with Bangladesh's expanding mobile device penetration, suggesting AR integration could leverage existing technological infrastructure rather than requiring prohibitive capital investments. Several key conclusions emerged from the analysis. First, mobile AR consistently demonstrates significant positive effects on student engagement across all educational levels and subject domains, with increased time-on-task, participation frequency, and sustained attention during AR-enhanced activities. Second, learning outcome improvements appear most pronounced in subjects requiring spatial reasoning and conceptual visualization—particularly science, mathematics, and language learning—domains representing priority areas for Bangladesh's educational development. Third, AR applications for inclusive education show particular promise for supporting learners with special educational needs, including autism spectrum disorders and dyslexia, thereby advancing educational equity objectives (Hashim *et al.*, 2022; Lazo-Amado & Andrade-Arenas, 2023).

Fourth, gamification elements integrated within AR significantly enhance intrinsic motivation and learning quality, addressing persistent student motivation challenges in traditional classrooms (Videnovik *et al.*, 2020; Λαμπρόπουλος *et al.*, 2022). However, critical implementation barriers must be addressed before widespread adoption in resource-constrained contexts. Teacher preparedness emerged as the most significant bottleneck, with insufficient professional development and limited technological confidence consistently cited as obstacles (Alkhattabi, 2017). Infrastructure limitations including unreliable electricity, inconsistent internet connectivity, and absence of technical support systems present additional challenges, particularly in rural settings. The limited representation of developing contexts in the literature highlights a critical research gap, raising questions about direct transferability of findings to Bangladesh's specific educational environment. For Bangladesh specifically, mobile AR could meaningfully contribute to educational quality improvement, particularly in addressing student engagement, STEM conceptual understanding, English language proficiency, and inclusive education. However, successful implementation requires comprehensive professional development, culturally appropriate content aligned with local curricula, technical support infrastructure, and institutional commitment to sustained

implementation rather than superficial technology adoption. Several methodological limitations warrant acknowledgment. First, restriction to English-language publications potentially excluded relevant research in Bengali or other South Asian languages, contributing to underrepresentation of developing contexts.

Second, exclusion of grey literature may have omitted important implementation insights from institutional reports and practitioner publications. Third, the rapid evolution of AR technology means earlier studies may reflect less sophisticated capabilities than current applications. Fourth, heterogeneity in research designs and outcome measures precluded meta-analytic synthesis, limiting precision of effect size estimation. Fifth, predominance of short-term interventions raises questions about sustained effectiveness and long-term impacts. Finally, inferential reasoning required to apply developed-nation findings to Bangladesh introduces uncertainty regarding direct transferability, as cultural factors and infrastructure conditions may moderate AR's effectiveness in ways not captured by existing research. The review findings suggest several critical directions for future research. First and most urgently, context-specific research conducted within Bangladesh and similar South Asian educational systems is essential to examine AR's effectiveness, cultural appropriateness, and implementation feasibility under resource-constrained conditions. Such research should employ mixed-methods approaches combining quantitative outcome evaluation with qualitative investigation of implementation processes and contextual factors. Longitudinal studies extending beyond typical short-term interventions would provide insights into sustained effectiveness and long-term learning impacts. Second, comparative research examining different AR implementation models would inform evidence-based decision-making regarding optimal approaches for specific contexts, including marker-based versus markerless AR, teacher-directed versus student-centered implementation, and individual versus collaborative learning configurations. Research investigating AR's effectiveness for different student populations—including learners with special needs, students from low-socioeconomic backgrounds, and rural versus urban students—would advance understanding of how AR can promote educational equity.

Third, studies examining teacher professional development models specifically designed for AR integration would address the identified preparedness gap. Such research should investigate effective training approaches, ongoing support mechanisms, and factors influencing successful technology adoption. Fourth, cost-effectiveness analyses comparing AR implementation against alternative educational interventions would provide crucial information for resource allocation decisions in budget-constrained educational systems. Finally, research examining scalability challenges and sustainability factors would inform large-scale implementation planning. This includes investigating infrastructure requirements, content development processes, maintenance and technical support needs, and institutional factors enabling sustained AR integration beyond pilot implementations. Addressing these research priorities would provide evidence-based foundation for educational policymakers and practitioners to make informed decisions regarding AR integration in developing educational contexts, ultimately advancing interactive learning opportunities for students in Bangladesh and similar environments.

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