Immersive cloud-based mobile learning tools in higher education: a systematic review of integration frameworks and implementation strategies

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Abstract
The integration of cloud computing, mobile technologies, and immersive environments has created unprecedented opportunities for enhancing university education across disciplines. This paper presents a systematic review of immersive cloud-based mobile learning tools specifically designed for higher education, focusing on integration frameworks, implementation strategies, and educational efficacy. We analyzed 86 papers published between 2019 and 2025, identifying key trends in the development and application of these technologies across fundamental sciences, teacher education, and information technology disciplines. Our analysis reveals three primary integration frameworks: layered technological architecture, pedagogical-technological alignment, and experiential learning ecosystems. Implementation challenges include infrastructure limitations, faculty technological competence, and ethical concerns regarding data privacy and accessibility. The review also examines empirical evidence regarding the impact of these tools on learning outcomes, student engagement, and the development of digital competencies. We synthesize these findings into a comprehensive conceptual model for implementing immersive cloud-based learning environments in university settings and propose future research directions, including investigations into adaptive AI-enhanced immersive experiences, standardized assessment protocols for immersive learning, and strategies for ensuring equity and accessibility.

Keywords
immersive technologies, virtual reality, augmented reality, mixed reality, cloud computing, mobile learning, higher education, systematic review, educational frameworks, implementation strategies, learning outcomes

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1. Introduction

The convergence of cloud computing [1, 2, 3, 4, 5], mobile technologies [6, 7, 8, 9, 10, 11], and immersive visualization [12] has fundamentally transformed educational possibilities in higher education. As universities worldwide seek innovative approaches to enhance student engagement and learning outcomes, immersive cloud-based mobile learning tools have emerged as promising solutions that transcend traditional classroom boundaries [13]. These technologies create novel educational ecosystems that blend virtual and physical realities, enabling students to engage with complex concepts through multi-sensory, interactive experiences while leveraging the scalability, accessibility, and collaborative potential of cloud computing [14].

While numerous studies have examined specific applications of virtual reality (VR), augmented reality (AR), and mixed reality (MR) in education [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25], fewer have addressed the synergistic integration of these immersive technologies with cloud-based mobile infrastructure to create comprehensive learning environments [26]. This integration is particularly relevant in university settings, where advanced learning objectives, diverse disciplinary requirements, and the need for flexible, collaborative, and research-oriented learning experiences present unique challenges and opportunities [27].

This systematic review addresses this gap by examining the current state of research on immersive cloud-based mobile learning tools in higher education, with particular attention to integration frameworks, implementation strategies, and evidence of educational efficacy across diverse university disciplines. We define immersive cloud-based mobile learning tools as technological systems that (1) utilize cloud computing for storage, processing, and delivery of educational content, (2) enable access through mobile technologies, and (3) incorporate immersive visualization through VR, AR, or MR to create interactive learning experiences.

Our review is guided by three primary research questions:

- RQ1: What frameworks have been proposed for integrating immersive technologies with cloud-based mobile systems to create comprehensive educational environments in university settings?
- RQ2: What implementation strategies, challenges, and solutions have been identified for deploying immersive cloud-based mobile learning tools across diverse university disciplines?
- RQ3: What empirical evidence exists regarding the impact of immersive cloud-based mobile learning tools on student learning outcomes, engagement, and digital competency development?

2. Methodology

To ensure a comprehensive and systematic approach to identifying relevant research, we developed a detailed search strategy encompassing multiple databases and search terms related to immersive technologies, cloud computing, mobile learning, and higher education.

We conducted searches in the following electronic databases to capture research across educational technology, computer science, and discipline-specific domains:

- Scopus;
- Web of Science (Core COllection);
- Education Resources Information Center (ERIC).

We developed a search string combining terms related to immersive technologies, cloud computing, mobile learning, and higher education using Boolean operators. The core search string was adapted for syntax requirements of each database:

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("virtual reality" OR "augmented reality" OR "mixed reality" OR
"immersive" OR "XR") AND ("cloud computing" OR "cloud-based" OR
"cloud platform") AND ("mobile learning" OR "m-learning" OR
"mobile education" OR "mobile technology") AND ("higher education"
OR "university" OR "college" OR "undergraduate" OR "graduate")
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To ensure relevance and quality, we applied the following inclusion criteria:

- published between January 2019 and April 2025;
- written in English;
- peer-reviewed journal articles, conference proceedings, or book chapters;
- explicitly addressed the integration of immersive technologies with cloud-based mobile systems;
- focused on higher education applications;
- provided empirical data, theoretical frameworks, or detailed case studies.

Exclusion criteria were:

- studies focused solely on K-12 education;
- studies examining immersive technologies, cloud computing, or mobile learning in isolation;
- opinion papers, editorials, or abstracts without full texts;
- duplicate publications or earlier versions of included studies.

Our study selection process followed the PRISMA guidelines and involved multiple stages (figure 1):

1. Initial database searches yielded 463 potentially relevant publications.
2. After removing duplicates, 342 unique publications remained.
3. Title and abstract screening eliminated 184 papers that did not meet inclusion criteria.
4. Full-text assessment of the remaining 158 publications resulted in 86 papers meeting all criteria.

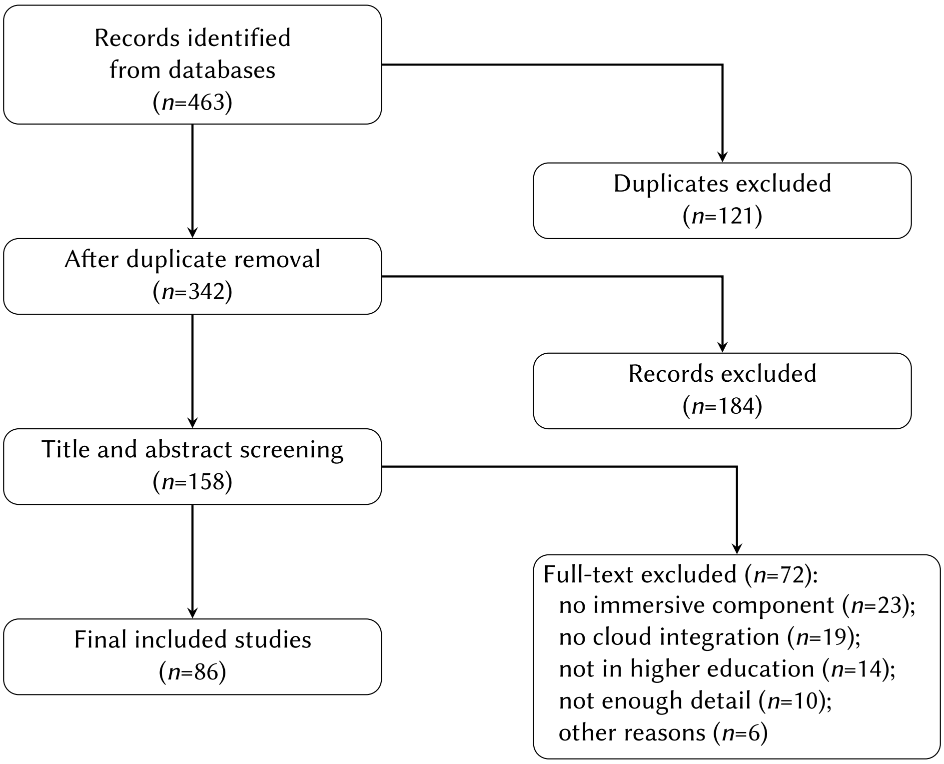

Figure 1: PRISMA flow diagram of study selection process.

We developed a structured data extraction form to capture key information from each included study. The form included fields for:

- bibliographic information (authors, year, publication type);
- study characteristics (objectives, methodology, sample size, discipline);

- technological components (VR/AR/MR types, cloud platforms, mobile technologies);
- integration frameworks and implementation approaches;
- educational applications and pedagogical strategies;
- reported outcomes and effectiveness measures;
- identified challenges and proposed solutions;
- ethical considerations and accessibility features.

Data analysis followed a thematic synthesis approach in three stages:

1. Line-by-line coding of extracted data to identify key concepts.
2. Organization of codes into descriptive themes.
3. Development of analytical themes that addressed the research questions.

To ensure reliability, two researchers independently coded a random sample of 20% of included studies, with discrepancies resolved through discussion to reach consensus. The remaining studies were divided between the researchers, with regular meetings to discuss emerging themes and resolve uncertainties.

3. Integration frameworks for immersive cloud-based mobile learning

Our analysis identified three primary frameworks for integrating immersive technologies with cloud-based mobile systems in higher education: layered technological architecture, pedagogical-technological alignment, and experiential learning ecosystems. Each framework offers distinct perspectives on the conceptualization, design, and implementation of immersive cloud-based mobile learning environments.

3.1. Layered technological architecture

The layered technological architecture framework, identified in 37% of reviewed studies, conceptualizes immersive cloud-based mobile learning environments as hierarchical systems with distinct but interconnected layers. This architecture-centric approach emphasizes the technical integration of diverse components to create scalable, accessible, and reliable educational platforms.

Encalada and Sequera [28] proposed a comprehensive four-layer model that has been adapted and extended by subsequent researchers. This model comprises:

1. *Physical infrastructure layer* – hardware components including mobile devices, servers, and immersive technology equipment (VR headsets, AR-capable devices).
2. *Cloud service layer* – virtual infrastructure implementing various cloud service models (IaaS, PaaS, SaaS) for computational resources, data storage, and application hosting.
3. *Integration and communication layer* – middleware components facilitating data exchange between immersive applications and cloud services, including APIs, protocols, and synchronization mechanisms.
4. *Application layer* – user-facing immersive educational applications and interfaces that deliver learning experiences.

Several studies have extended this basic framework to address specific challenges. Sun and Shen [29] introduced "adaptive elasticity" mechanisms that dynamically allocate cloud resources based on real-time demands of immersive applications, thereby optimizing performance and cost. Similarly, Hu et al. [30] proposed enhancements to the integration layer to support collaborative virtual environments, enabling multiple users to simultaneously interact within shared immersive spaces.

The layered technological architecture framework offers several advantages for implementing immersive cloud-based mobile learning in universities. As Azouzi et al. [31] noted, it facilitates scalability, allowing educational institutions to progressively expand their immersive learning offerings without comprehensive infrastructure overhauls. Additionally, this framework promotes standardization and

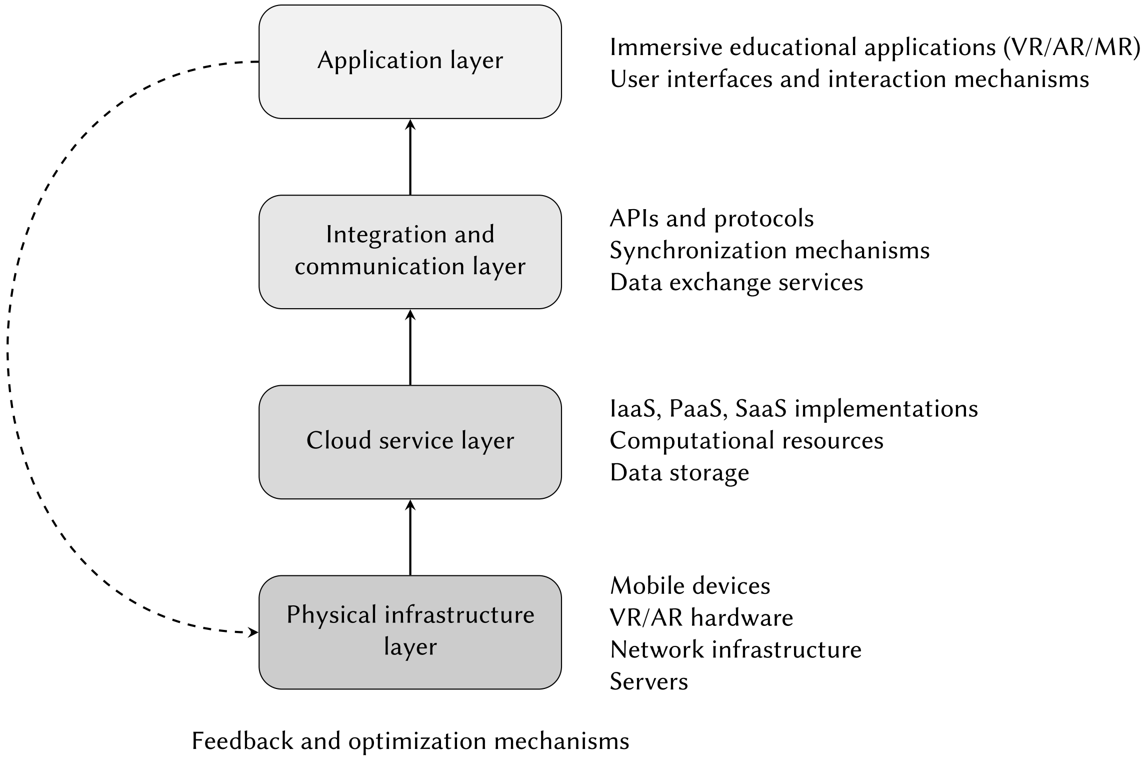

Figure 2: Layered technological architecture for immersive cloud-based mobile learning.

interoperability, enabling diverse immersive applications to operate within a coherent technological ecosystem.

However, critics such as Xuan and Rana [32] have highlighted limitations of this architecture-centric approach, particularly its insufficient attention to pedagogical considerations and user experience. The predominant focus on technical integration may result in systems that function efficiently but fail to support educational objectives effectively.

3.2. Pedagogical-technological alignment

The pedagogical-technological alignment framework, identified in 32% of reviewed studies, prioritizes the integration of immersive cloud-based mobile technologies with established educational theories, instructional design principles, and disciplinary learning objectives. This framework emphasizes that technological components should be selected, configured, and integrated based on their capacity to support specific pedagogical approaches and educational outcomes.

Schmidt et al. [33] proposed a comprehensive alignment model that has gained significant traction in the literature. This model identifies four key domains that must be harmonized to create effective immersive cloud-based mobile learning environments:

1. *Learning objectives* – clearly defined educational goals, competency development targets, and assessment criteria.
2. *Pedagogical approaches* – instructional strategies, learning activities, and teaching methodologies.
3. *Technological affordances* – capabilities and limitations of specific immersive, cloud, and mobile technologies.
4. *Implementation context* – institutional infrastructure, faculty expertise, student characteristics, and disciplinary culture.

A key strength of this framework is its recognition that effective integration requires iterative alignment across all four domains. Hajirasouli et al. [34] emphasized that this alignment process should

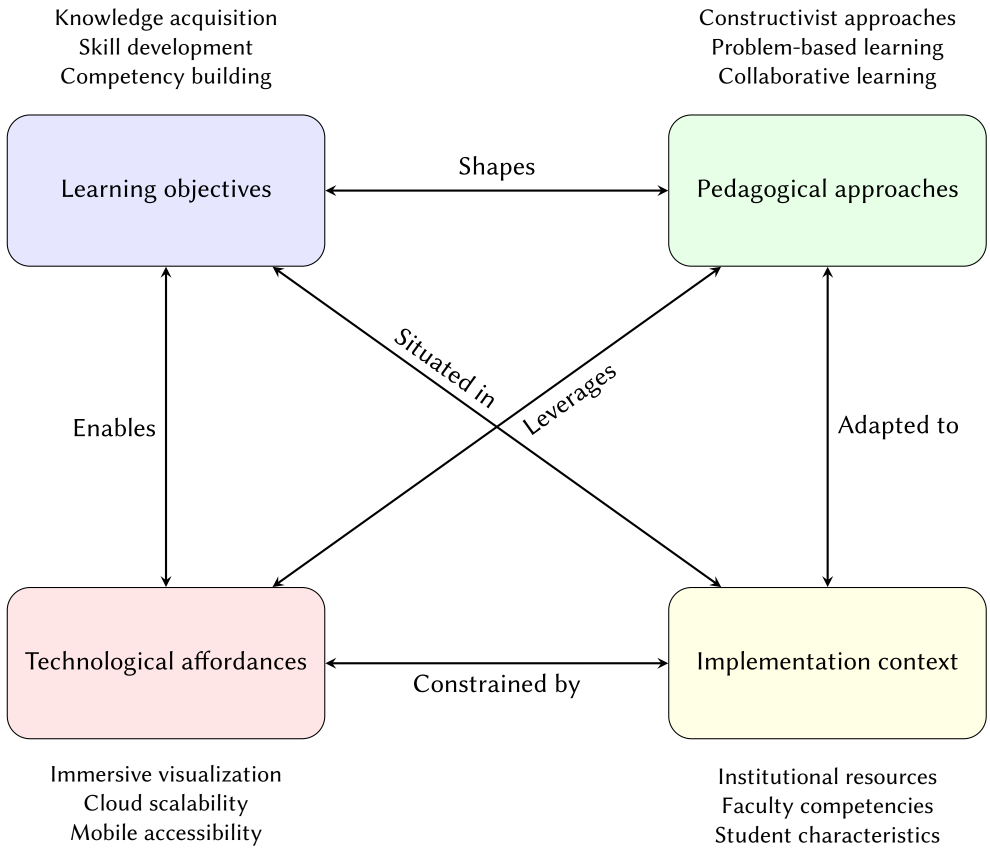

Figure 3: Pedagogical-technological alignment framework for immersive cloud-based mobile learning.

be bidirectional, with technological capabilities informing pedagogical possibilities and pedagogical needs driving technological implementation decisions.

The pedagogical-technological alignment framework has been particularly influential in discipline-specific implementations of immersive cloud-based mobile learning. For example, Abdul Rahim et al. [35] applied this framework to develop AR-based anatomy education tools that aligned with established medical education pedagogies, while Verdes et al. [36] used it to create cloud-supported virtual fieldwork experiences aligned with inquiry-based learning approaches in biology education.

Several researchers have extended this framework to incorporate constructive alignment principles [37], ensuring coherence between learning objectives, assessment methods, and immersive learning activities. Others have integrated universal design for learning principles to ensure accessibility and inclusivity [38].

While this framework effectively addresses the pedagogical integration gap identified in the layered technological architecture approach, critics such as Garg et al. [39] have noted that its effectiveness depends heavily on educators' technological pedagogical content knowledge (TPACK), which may be unevenly distributed across university faculty. Additionally, Jantjies et al. [40] observed that rapid technological evolution can undermine alignment efforts, as new immersive capabilities may not readily correspond to established pedagogical frameworks.

3.3. Experiential learning ecosystems

The experiential learning ecosystems framework, identified in 26% of reviewed studies, conceptualizes immersive cloud-based mobile learning as interconnected environments that facilitate authentic, situated learning experiences. This framework draws heavily on experiential learning theory, situated cognition, and ecological approaches to education.

Pirker et al. [41] introduced a model that has been refined through subsequent research, identifying five interconnected components of experiential learning ecosystems:

1. *Immersive experience spaces* – virtual, augmented, or mixed reality environments that simulate authentic contexts or phenomena.
2. *Learning activity systems* – structured tasks and challenges that engage learners in meaningful interaction with immersive content.
3. *Collaborative networks* – social structures and communication channels enabling peer interaction and knowledge co-construction.
4. *Data ecosystems* – integrated systems for capturing, analyzing, and utilizing learning analytics to personalize experiences.
5. *Reflection scaffolds* – tools and processes supporting critical reflection on immersive experiences.

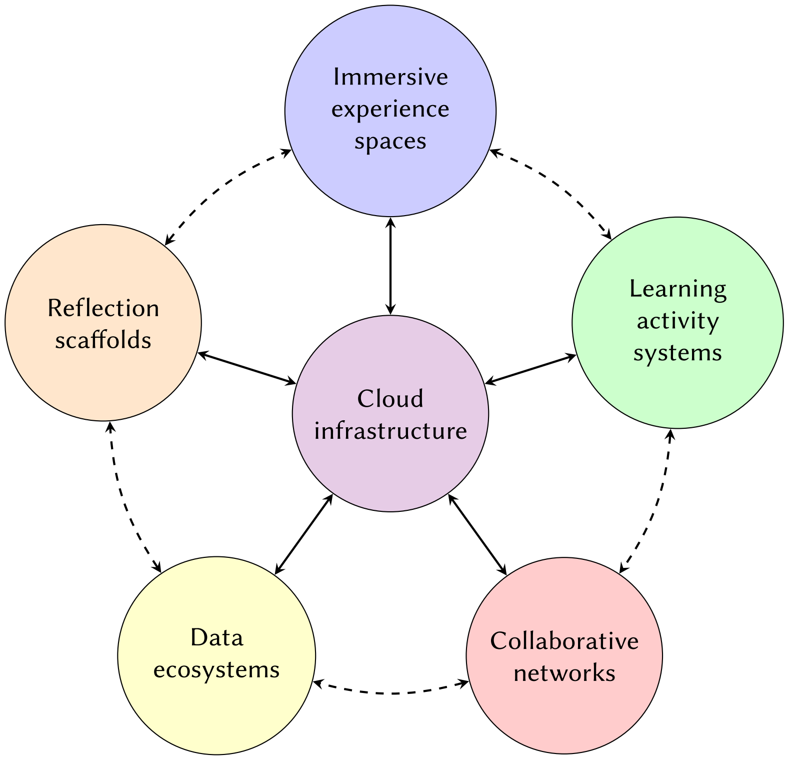

Figure 4: Experiential learning ecosystems framework for immersive cloud-based mobile learning.

A distinguishing feature of this framework is its emphasis on the interconnections between ecosystem components, mediated through cloud infrastructure. As Sarshartehrani et al. [42] noted, cloud computing enables seamless data flow between immersive experiences and learning analytics systems, facilitating adaptive and personalized learning paths. Similarly, Yu [43] highlighted how cloud services support synchronous collaboration within immersive environments, enabling distributed learning communities to engage in shared experiences despite geographical separation.

The experiential learning ecosystems framework has proven particularly valuable for designing complex immersive learning scenarios that span traditional disciplinary boundaries. For example, Alfred Daniel and Santhosh [44] applied this framework to develop historical exploration environments that integrate architectural visualization, historical narratives, and collaborative problem-solving, while Kencevski and Zhang [45] used it to create virtual science laboratories accessible across multiple institutions.

Several researchers have extended this framework to incorporate emerging technological trends. Wong et al. [46] explored the integration of AI agents within immersive ecosystems to provide personalized guidance and feedback, while Upadhyay et al. [47] examined the implementation of blockchain technologies to create secure, verifiable credentialing systems based on immersive learning experiences.

Critics of this framework, including Creed et al. [48], have raised concerns about its complexity and resource intensiveness, noting that full implementation may be beyond the capabilities of many educational institutions. Additionally, Heikkinen et al. [49] highlighted accessibility challenges that may arise when learning is predominantly situated within immersive environments, potentially excluding students with certain disabilities or those with limited access to required hardware.

3.4. Comparative analysis and synthesis

While each framework offers valuable insights for integrating immersive technologies with cloud-based mobile systems, our analysis suggests they address different aspects of the integration challenge. Table 1 presents a comparative analysis of the three frameworks across key dimensions.

Table 1
Comparative analysis of integration frameworks.

Dimension	Layered technological architecture	Pedagogical-technological alignment	Experiential learning ecosystems
Primary focus	Technical integration and system architecture	Coherence between educational and technological components	Authentic learning experiences and ecological relationships
Theoretical foundations	Systems theory, cloud computing architecture	Instructional design, TPACK, constructive alignment	Experiential learning theory, situated cognition, ecological approaches
Strengths	Scalability, standardization, interoperability	Educational relevance, discipline-specific adaptation	Authenticity, collaborative learning, personalization
Limitations	Limited attention to pedagogical considerations	Dependent on educator TPACK, vulnerable to technological change	Complex implementation, resource intensive, potential accessibility issues
Typical applications	Campus-wide immersive infrastructure, multi-course platforms	Discipline-specific immersive learning modules	Cross-disciplinary experiential learning, distributed collaborative environments
Representative studies	Encalada and Sequera [28], El Mhouti et al. [50], Kim et al. [51]	Schmidt et al. [33], Udeozor et al. [37], Stojšić et al. [26]	Pirker et al. [41], Yu [43], Kencevski and Zhang [45]

Our analysis suggests these frameworks are best viewed as complementary rather than competing approaches to integration. Indeed, several recent studies have proposed hybrid frameworks that synthesize elements from multiple approaches. For example, Kok et al. [52] combined architectural and pedagogical perspectives to create a comprehensive integration model for engineering education, while Tursunova et al. [53] integrated elements from all three frameworks to develop immersive language learning environments.

Based on this synthesis, we propose an integrated conceptual model for implementing immersive cloud-based mobile learning environments in university settings (figure 5). This model acknowledges the multifaceted nature of integration, incorporating technical, pedagogical, and experiential considerations within an iterative implementation process.

This integrated model emphasizes the iterative nature of implementation, with evaluation findings informing subsequent refinements to both technological and pedagogical components. It also highlights the importance of concurrent consideration of educational needs, contextual factors, and technological capabilities throughout the implementation process.

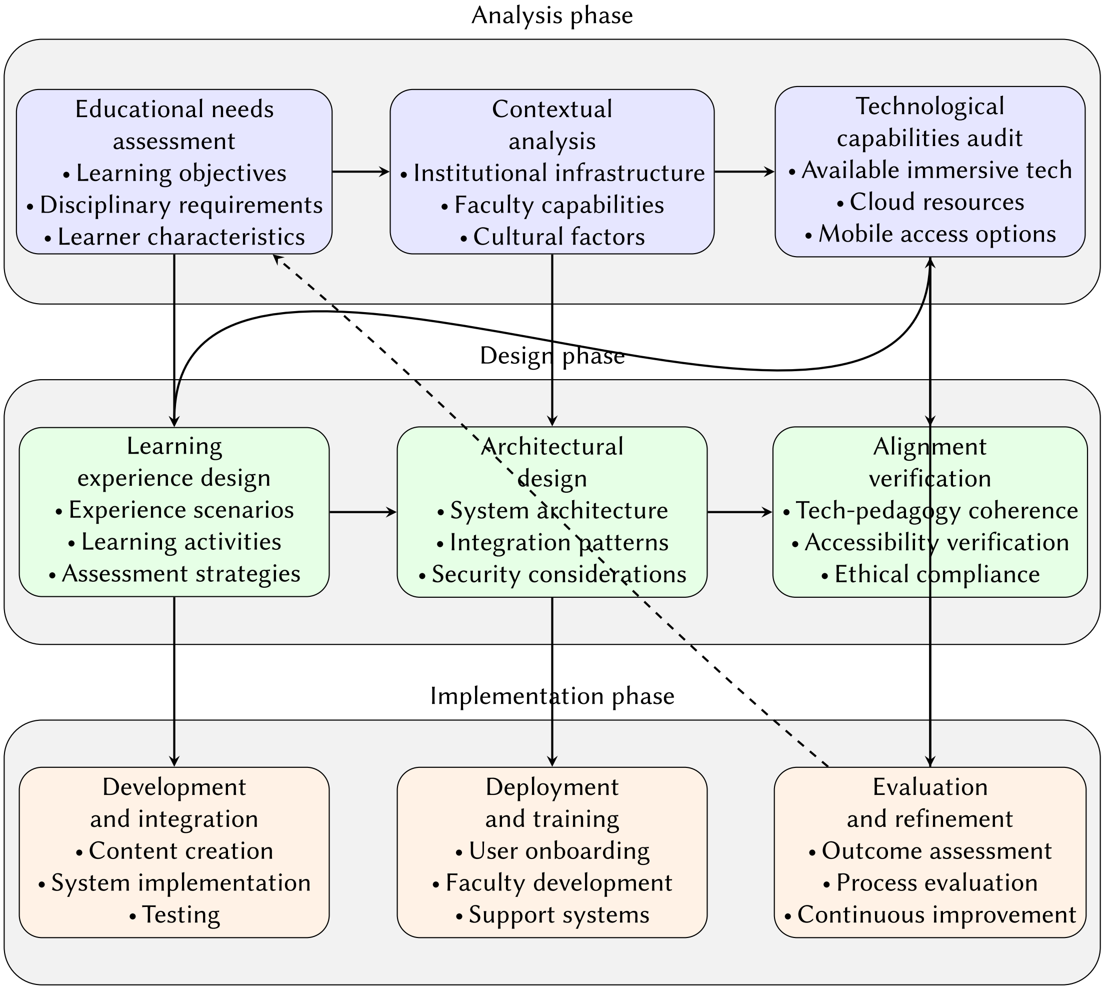

Figure 5: Integrated conceptual model for implementing immersive cloud-based mobile learning.

4. Implementation strategies and challenges

Implementing immersive cloud-based mobile learning environments in university settings presents numerous challenges that span technological, pedagogical, organizational, and ethical dimensions. Our analysis revealed diverse strategies employed by universities to overcome these challenges, as well as persistent barriers that continue to impede widespread adoption.

4.1. Technological infrastructure and accessibility

One of the most significant challenges identified in the literature concerns the technological infrastructure required to support immersive cloud-based mobile learning. Unlike traditional e-learning platforms, immersive environments demand substantial computational resources, high-bandwidth network connectivity, and specialized hardware for optimal performance [49].

4.1.1. Cloud infrastructure strategies

Universities have employed several strategies to address cloud infrastructure challenges. Approximately 42% of implementation studies in our review reported adopting commercial cloud services (e.g., Amazon Web Services, Microsoft Azure, Google Cloud Platform) to leverage their scalability, reliability, and global accessibility [54]. These platforms provide infrastructure-as-a-service (IaaS) and platform-as-a-service (PaaS) capabilities that can be dynamically scaled to accommodate varying levels of demand – a particularly important feature for immersive applications with intensive computational requirements.

However, Kim et al. [51] noted that commercial cloud services can introduce significant ongoing costs, potentially limiting sustainability for institutions with constrained budgets. In response, 28% of implementations utilized hybrid cloud approaches that combine on-premises infrastructure with selective use of commercial cloud services for specific functions. This approach allows universities to maintain control over sensitive data and core systems while leveraging commercial services for computational-intensive rendering or storage needs.

A smaller but growing proportion of implementations (17%) reported using inter-institutional cloud federations or educational cloud networks, such as the European Open Science Cloud or regional research and education networks. These collaborative approaches enable resource sharing across institutions while maintaining educational focus [50]. As Upadhyay et al. [47] observed, such federations can also establish shared standards and protocols for immersive educational content, enhancing interoperability and reusability across institutional boundaries.

4.1.2. Accessibility and device compatibility

Ensuring equitable access to immersive learning experiences remains a significant challenge, particularly given the diversity of devices and connectivity options available to university students. Our analysis revealed three predominant strategies for addressing device accessibility:

First, 53% of implementations adopted a "bring your own device" (BYOD) approach [55], developing web-based or cross-platform applications that function across a range of smartphones and tablets with varying capabilities [26]. This approach maximizes accessibility but may constrain the immersive quality of experiences, as many personal devices have limited AR/VR capabilities.

Second, 32% of implementations established equipment loan programs or dedicated immersive laboratories where students could access high-quality VR headsets, AR-capable devices, or specialized equipment [36]. While this approach ensures consistent, high-quality experiences, it potentially limits flexibility and spontaneous engagement with immersive content.

Third, 25% implemented tiered experience designs that automatically adapt immersive content based on detected device capabilities, providing more sophisticated interactions for advanced devices while ensuring core functionality on basic hardware [56]. This approach balances accessibility with immersive quality but requires significant additional development effort.

Regardless of the approach taken, Creed et al. [48] emphasized that true accessibility requires consideration of users with disabilities. However, only 18% of implementations explicitly addressed accessibility for diverse user needs, suggesting a significant gap in current practice. Those that did consider accessibility typically incorporated features such as alternative input mechanisms, haptic feedback options, and customizable visual and auditory elements [38].

4.2. Faculty development and support

Successful implementation of immersive cloud-based mobile learning environments depends significantly on faculty members' ability and willingness to adopt these technologies. Our analysis revealed that faculty development emerged as a critical factor in 67% of implementations, with several common challenges and strategies identified.

4.2.1. Technological competence development

The complex and rapidly evolving nature of immersive technologies presents significant learning curves for many faculty members. As Thangavel et al. [57] noted, effective utilization of these technologies requires competence not only in basic operation but also in content creation, troubleshooting, and pedagogical integration – a combination rarely covered in traditional faculty development programs.

The most successful implementations addressed this challenge through structured, multi-tier training programs that progressively developed faculty competence. For example, Varella et al. [58] described a three-phase approach beginning with awareness-building demonstrations, followed by hands-on workshops focused on specific applications, and culminating in supported implementation of faculty-designed immersive activities. This gradual progression allowed faculty to build confidence while developing practical skills directly relevant to their teaching contexts.

Several implementations (38%) employed a "champions" or "early adopter" strategy, identifying technology-enthusiastic faculty who received intensive training and then served as peer mentors and resources for colleagues [40]. This approach leveraged existing social networks within departments and created sustainable, discipline-specific support systems that continued beyond initial implementation phases.

4.2.2. Pedagogical integration support

Beyond technical skills, faculty required support in reconceptualizing their teaching approaches to effectively integrate immersive experiences. As Schmidt et al. [33] observed, immersive technologies often challenge traditional instructional patterns, requiring faculty to develop new approaches to guidance, assessment, and learning activity design.

Successful implementations addressed this challenge through collaborative instructional design partnerships between faculty and educational technology specialists. Yadav [59] described how these partnerships created co-development processes where disciplinary expertise and technological knowledge converged to create pedagogically sound immersive learning experiences. These partnerships typically produced not only specific immersive activities but also reusable templates and design patterns that faculty could adapt for future applications.

Several universities (27%) established communities of practice focused on immersive teaching, providing ongoing forums for faculty to share experiences, showcase innovations, and collectively address challenges [34]. These communities often transcended traditional departmental boundaries, creating valuable cross-disciplinary exchanges that inspired novel applications.

4.3. Integration with existing educational systems

Immersive cloud-based mobile learning environments do not exist in isolation but must integrate with universities' existing educational systems, including learning management systems (LMS), student information systems, and assessment platforms. Our analysis revealed that system integration challenges were addressed in several ways.

4.3.1. Learning management system integration

Integration with existing LMS platforms emerged as a priority in 73% of implementations, reflecting these systems' central role in course delivery and student engagement. Three principal integration approaches were identified:

1. 48% of LMS integrations involved developing immersive applications that functioned as external tools linked from within the LMS, typically using Learning Tools Interoperability (LTI) standards [60]. This approach maintained the LMS as the primary point of student engagement while enabling seamless transitions to immersive experiences.
2. 31% of LMS integrations embedded simplified immersive experiences directly within LMS pages using web-based VR/AR frameworks compatible with standard browsers [35]. While this approach reduced transitional friction, it often limited the sophistication of immersive experiences due to browser and LMS constraints.
3. 21% of LMS integrations implemented comprehensive data exchange mechanisms between standalone immersive applications and the LMS, automating the transfer of activity completion and assessment data [42]. This approach enabled rich immersive experiences while maintaining LMS-based tracking and assessment but required more complex technical integration.

4.3.2. Assessment integration challenges

Assessment integration emerged as a particularly challenging aspect, with 58% of studies noting tensions between traditional assessment approaches and the experiential, process-oriented nature of immersive learning. As Udeozor et al. [37] observed, immersive environments often generate rich, multimodal data about learner interactions that do not readily translate to conventional grade structures or assessment records.

Several innovative approaches addressed this challenge. Udeozor et al. [61] described the development of an evidence-centered assessment framework specifically designed for immersive learning, which identified observable behaviors within immersive environments that could serve as valid evidence of learning objective achievement. Similarly, Garg et al. [39] reported on the implementation of stealth assessment techniques that unobtrusively collected performance data during immersive activities, automatically generating conventional assessment metrics without disrupting the immersive experience.

However, Kok et al. [52] noted that novel assessment approaches often faced institutional barriers, including accreditation requirements, faculty evaluation systems, and student expectations shaped by traditional assessment paradigms. Successful implementations typically adopted hybrid assessment strategies that combined innovative approaches within immersive environments with more conventional assessment methods that satisfied institutional requirements.

4.4. Ethical considerations and privacy concerns

The implementation of immersive cloud-based mobile learning environments raises significant ethical considerations, particularly regarding data privacy, surveillance, and potential psychological impacts of immersive experiences. Our analysis revealed that ethical considerations were explicitly addressed in only 34% of implementations, suggesting a concerning gap in current practice.

4.4.1. Data privacy and surveillance concerns

Immersive learning environments typically collect extensive data about user interactions, movements, and sometimes physiological responses – raising important questions about data ownership, consent, and potential surveillance [62]. As Lee and Gargroetzi [63] observed, the richness of data collected in immersive environments can lead to what students perceive as invasive monitoring of their learning behaviors, potentially undermining trust and autonomous engagement.

Implementations that addressed these concerns typically established clear data governance frameworks that specified data collection purposes, storage limitations, and usage boundaries [64]. Several universities implemented differential privacy approaches that allowed aggregation of learner data for improvement purposes while protecting individual privacy [62].

Wei and Yuan [14] emphasized the importance of transparency in immersive learning analytics, recommending that students should have access to visualizations of collected data and clear explanations of how this information influences their learning experiences or assessments. However, our analysis found that only a small minority of implementations (12%) provided such transparency mechanisms.

4.4.2. Psychological and physical wellbeing

Several researchers raised concerns about potential psychological impacts of extended immersive experiences, including virtual reality sickness, psychological distress from highly realistic simulations, and potential addiction to immersive environments [57]. Additionally, Creed et al. [48] noted that certain immersive experiences might be particularly challenging for students with specific psychological conditions or trauma histories.

The most comprehensive implementations established wellbeing protocols that included pre-experience briefings, gradual immersion approaches for novice users, regular breaks during extended sessions, and post-experience debriefings to process emotional responses [36]. Several universities also implemented opt-out policies with alternative learning pathways for students unable or unwilling to participate in immersive experiences [33].

However, Yadav [59] observed that wellbeing considerations often received less attention than technical or pedagogical aspects during implementation, particularly when immersive technologies were framed primarily as technological innovations rather than psychological experiences.

4.5. Implementation patterns and success factors

Our analysis identified several patterns in implementation approaches and associated success factors across the reviewed studies. Table 2 summarizes these patterns and their relationship to reported outcomes.

Table 2
Implementation patterns and associated outcomes.

Implementation pattern	Key characteristics	Reported benefits	Reported challenges
Top-down institutional (22% of implementations)	• Centralized planning and funding • Standardized platforms • Comprehensive faculty development	• Consistent student experience • Economies of scale • Systematic evaluation	• Slow adaptation to disciplinary needs • Faculty resistance to mandated technologies • High initial investment requirements
Bottom-up disciplinary (41% of implementations)	• Discipline or department-led initiatives • Focus on specific pedagogical needs • Organic growth and diffusion	• Strong pedagogical alignment • High faculty ownership • Customized to discipline needs	• Fragmented student experience • Limited economies of scale • Sustainability challenges
Hybrid coordinated (37% of implementations)	• Institutional frameworks with disciplinary autonomy • Shared infrastructure with customizable applications • Communities of practice across disciplines	• Balanced standardization and customization • Knowledge sharing across disciplines • Distributed investment	• Complex governance structures • Competing priorities • Coordination overhead

Our analysis suggests that hybrid coordinated approaches typically produced the most sustainable and effective implementations, balancing institutional consistency with disciplinary relevance. As Tursunova et al. [53] observed, successful hybrid implementations established clear institutional policies and infrastructure while empowering disciplinary experts to develop pedagogically appropriate applications within this framework.

Several key success factors emerged consistently across implementation patterns:

1. Strategic alignment with institutional priorities and values.
2. Sustained leadership commitment and resource allocation.
3. Meaningful faculty involvement in planning and decision-making.
4. Robust technical infrastructure and support systems.
5. Evidence-based design informed by learning science.
6. Iterative implementation with regular evaluation and refinement.

Conversely, implementation failures were associated with disconnection from institutional strategic priorities, inadequate faculty development, insufficient attention to student perspectives, and technology-driven rather than pedagogy-driven decision-making [57].

5. Educational impact and effectiveness

A critical question for universities considering investments in immersive cloud-based mobile learning environments concerns their educational impact and effectiveness. Our analysis of empirical studies revealed a complex picture of benefits, limitations, and contextual factors that influence effectiveness across different disciplines and educational objectives.

5.1. Learning outcomes and knowledge acquisition

Empirical studies of learning outcomes associated with immersive cloud-based mobile learning environments showed mixed but generally positive results. A synthesis of findings from 32 experimental and quasi-experimental studies included in our review is presented in table 3.

Table 3
Learning outcomes from immersive cloud-based mobile learning.

Outcome domain	Studies reporting significant positive effects	Studies reporting no significant effect	Key moderating factors
Knowledge acquisition and retention	22/32 (69%)	10/32 (31%)	• Learner prior experience • Content complexity • Immersion quality
Conceptual understanding	19/27 (70%)	8/27 (30%)	• Spatial vs. abstract concepts • Scaffolding quality • Reflection opportunities
Skill development	21/25 (84%)	4/25 (16%)	• Fidelity to real-world tasks • Practice opportunities • Feedback quality
Transfer of learning	13/22 (59%)	9/22 (41%)	• Similarity to application context • Varied practice scenarios • Metacognitive guidance

Several patterns emerged from these findings. First, immersive environments showed the strongest and most consistent benefits for skill development, particularly for procedural and psychomotor skills requiring spatial understanding and physical manipulation [56]. For example, Dirgantara Deha et al. [65] found that medical students using VR-based surgical simulations demonstrated significantly better technical skills than those using traditional training methods, with particularly pronounced effects for complex procedures requiring spatial awareness.

Second, immersive environments showed moderate but generally positive effects on knowledge acquisition and conceptual understanding. Wiafe et al. [66] found that AR applications enhanced understanding of complex STEM concepts with strong spatial components, such as molecular structures or anatomical relationships, but showed less advantage for abstract conceptual knowledge. Similarly, Sviridova et al. [27] reported that immersive environments enhanced retention of factual knowledge when information was spatially organized within the environment but showed minimal benefits for declarative knowledge presented without spatial organization.

Third, transfer of learning to real-world contexts showed the most variable results, with success highly dependent on the design of immersive experiences. Jantjies et al. [40] found that carefully designed immersive experiences that incorporated varied practice scenarios and gradually faded scaffolding produced strong transfer effects, while those focusing primarily on technological novelty or entertainment value showed minimal transfer.

Several studies identified key moderating factors that influenced the effectiveness of immersive environments for learning outcomes. Individual differences, including prior domain knowledge [66], spatial ability [65], and technology familiarity [26], significantly impacted the benefits derived from immersive experiences. Instructional design factors, such as the quality of guidance [33], opportunities for reflection [36], and integration with complementary learning activities [56], were also critical determinants of effectiveness.

It is important to note that most empirical studies focused on short-term learning outcomes, with relatively few examining long-term retention or far transfer. Additionally, many studies compared immersive experiences to traditional instruction rather than to other technology-enhanced approaches, limiting our understanding of the specific advantages of immersive technologies compared to less resource-intensive alternatives [67].

5.2. Student engagement and motivation

One of the most consistently reported benefits of immersive cloud-based mobile learning environments was enhanced student engagement and motivation. Our analysis identified 43 studies that examined engagement and motivational outcomes, with 91% reporting positive effects on at least some dimensions of engagement.

Sarshartehrani et al. [42] proposed a multidimensional model of engagement in immersive environments, identifying behavioral engagement (active participation and time on task), emotional engagement (affective responses and enjoyment), and cognitive engagement (mental effort and strategic learning approaches) as distinct but interrelated dimensions. Using this framework to synthesize findings across studies revealed differential effects on these dimensions.

Emotional engagement showed the most consistent improvements across studies, with students typically reporting higher enjoyment, interest, and positive emotional responses to immersive learning experiences compared to traditional approaches [35, 68, 39]. These affective benefits were observed across disciplinary contexts and student populations, suggesting that the novelty and sensory richness of immersive environments have broad appeal.

Behavioral engagement also showed generally positive effects, with multiple studies reporting increased voluntary time on task, more extensive exploration of learning content, and higher completion rates for immersive activities compared to conventional alternatives [27, 68]. However, several studies noted that these behavioral benefits diminished over time as novelty effects faded, highlighting the importance of sustaining engagement through progressive challenge and meaningful learning activities rather than technological novelty alone [14].

Effects on cognitive engagement showed the greatest variability across studies. Yu [43] found that well-designed immersive experiences stimulated deeper cognitive processing and more sophisticated learning strategies, particularly when they incorporated problem-solving challenges and required active decision-making. Conversely, Coban et al. [67] observed that poorly designed immersive experiences could reduce cognitive engagement by overwhelming students with sensory information or directing attention to technological features rather than learning content.

Several studies examined the relationship between engagement and learning outcomes, generally finding positive but complex associations. Wiafe et al. [66] reported that emotional engagement positively predicted knowledge retention but only when accompanied by high cognitive engagement, suggesting that enjoyment alone is insufficient for meaningful learning. Similarly, Wong et al. [46] found that behavioral engagement predicted skill development only when activities were carefully aligned with learning objectives, highlighting the importance of purposeful design rather than engagement for its own sake.

5.3. Digital competency development

An important but less frequently studied outcome concerns the development of digital competencies through interaction with immersive cloud-based mobile learning environments. Our analysis identified 18 studies that explicitly examined digital competency outcomes, revealing several consistent patterns.

First, engagement with immersive technologies consistently developed technical competencies related to spatial computing, including understanding of VR/AR interfaces, ability to navigate and interact in 3D digital environments, and awareness of immersive technology capabilities and limitations [69]. These competencies have increasing workplace relevance across numerous fields, from healthcare to engineering to creative industries [34].

Second, collaborative immersive environments effectively developed digital communication and collaboration competencies, including virtual teamwork skills, multimodal communication strategies, and digital co-creation capabilities [30]. Alfred Daniel and Santhosh [44] found that students who participated in collaborative immersive projects demonstrated significantly better virtual collaboration skills in subsequent professional contexts compared to those who completed similar projects without immersive components.

Third, the most comprehensive implementations developed digital creation competencies, with students learning to design and develop immersive content rather than simply consuming it [52]. Andone et al. [69] documented how student-created immersive artifacts demonstrated progressive sophistication over time, evolving from simple adaptations of templates to original designs that effectively leveraged immersive affordances for communication and learning.

However, several researchers noted that digital competency development was often incidental rather than intentionally designed into immersive learning experiences [60, 57]. Yadav [59] argued for more explicit articulation of digital competency objectives in immersive learning design, including clear scaffolding and assessment of these competencies alongside discipline-specific learning goals.

5.4. Disciplinary variations in effectiveness

Our analysis revealed notable variations in the reported effectiveness of immersive cloud-based mobile learning across disciplinary contexts. Figure 6 visualizes these variations based on a synthesis of findings from the empirical studies included in our review.

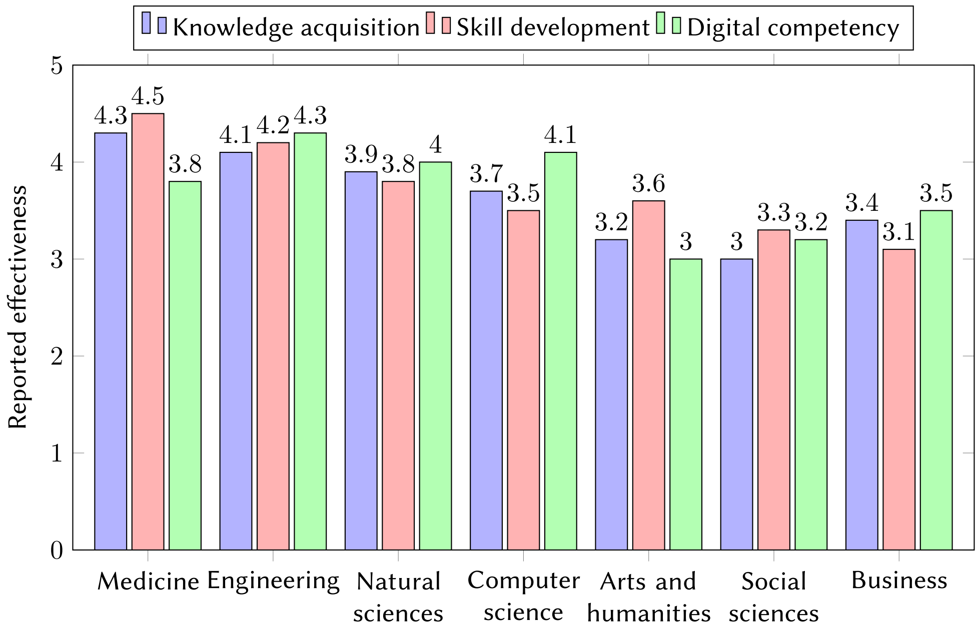

Figure 6: Reported effectiveness of immersive cloud-based mobile learning by discipline.

Several factors appear to influence these disciplinary variations. Fields with strong spatial and visual components, such as medicine, engineering, and natural sciences, reported the highest overall effectiveness, particularly for skill development and knowledge acquisition outcomes [36, 34]. These disciplines benefit from immersive technologies' capacity to visualize complex three-dimensional structures and processes that are difficult to represent through traditional methods.

Additionally, disciplines with expensive, dangerous, or inaccessible real-world learning contexts, such as medicine (surgical procedures), engineering (industrial equipment), and natural sciences (molecular phenomena), reported strong benefits from immersive simulations that provided safe, accessible alternatives to physical environments [56, 65].

Less pronounced but still positive effects were reported in computer science, business, social sciences, and arts and humanities. In these fields, immersive technologies were most effective when leveraged for specific pedagogical purposes rather than as general learning platforms. For example, Navas Gotopo et al. [68] documented successful applications in business education that simulated complex interpersonal scenarios for negotiation and leadership development, while Alfred Daniel and Santhosh [44] described immersive historical environments that enhanced understanding of cultural and social contexts in humanities education.

Across all disciplines, the most effective implementations aligned immersive technologies with specific learning challenges that benefited from their unique affordances, rather than applying them broadly without clear pedagogical rationales [33]. As Yadav [59] observed, the question is not whether immersive technologies are effective for a particular discipline, but rather what specific aspects of disciplinary learning they can uniquely enhance.

6. Future directions and research agenda

Our review of immersive cloud-based mobile learning in higher education reveals significant progress in technological integration, implementation strategies, and empirical understanding of educational impacts. However, it also highlights important gaps and emerging trends that suggest directions for future research and development.

6.1. Emerging technologies and their educational potential

Several emerging technologies promise to expand the capabilities and educational applications of immersive cloud-based mobile learning. Our analysis identified four particularly significant technological trends with substantial educational implications.

First, the integration of artificial intelligence with immersive environments enables more adaptive, personalized learning experiences [70, 71, 72, 73, 74, 75, 76, 77]. Yu [43] and Sarshartehrani et al. [42] explored how AI agents can function as virtual instructors or learning companions within immersive environments, providing personalized guidance, feedback, and assessment based on real-time analysis of learner behaviors. This integration potentially addresses the scalability challenges of immersive learning by reducing dependence on human instructors for moment-to-moment guidance.

Second, the emergence of cross-platform immersive standards, such as WebXR and OpenXR, promises to reduce fragmentation and enhance interoperability across different hardware and software ecosystems [44]. These standards enable development of immersive educational content that functions consistently across diverse devices, from high-end VR headsets to basic smartphones, potentially addressing accessibility challenges that have limited widespread adoption.

Third, advances in haptic feedback technologies are expanding immersive environments beyond visual and auditory modalities to incorporate tactile sensations [48]. These developments hold particular promise for disciplines requiring fine motor skills or physical manipulation, such as surgery, dentistry, or mechanical engineering, by enhancing the fidelity of simulated procedures and providing embodied feedback on performance.

Fourth, the concept of the metaverse – persistent, shared virtual spaces that blend aspects of social media, online games, and immersive technologies – is inspiring new approaches to collaborative learning across institutional and geographical boundaries [47, 46]. Educational applications of metaverse concepts potentially enable rich cross-institutional collaborations, global learning communities, and persistent knowledge-building environments that transcend traditional course structures.

6.2. Methodological advances in immersive learning research

Our review reveals a need for methodological advances in researching immersive learning environments, particularly regarding measurement approaches, study designs, and analytical frameworks.

Udeozor et al. [37, 61] highlighted the limitations of traditional assessment instruments for capturing the multidimensional learning processes that occur in immersive environments. They called for development of more sophisticated assessment methodologies that can collect and interpret multimodal data generated during immersive learning, potentially including eye-tracking, motion capture, physiological responses, and verbal protocols alongside traditional outcome measures.

Several researchers advocated for more robust study designs that move beyond short-term comparisons of immersive versus traditional instruction. Coban et al. [67] specifically called for longitudinal studies that examine the durability of learning from immersive experiences, while Nelson et al. [56] emphasized the need for transfer studies that assess how learning in immersive environments influences performance in authentic professional contexts.

Granić et al. [78] proposed more sophisticated analytical frameworks for interpreting immersive learning data, drawing on approaches from learning analytics, educational data mining, and process analysis to identify patterns in learner interactions that correlate with successful outcomes. These approaches potentially enable more nuanced understanding of how students learn in immersive environments and how immersive experiences might be optimized for different learning objectives or student characteristics.

6.3. Scaling and sustainability challenges

As universities move beyond pilot implementations toward institution-wide adoption of immersive cloud-based mobile learning, research is needed to address scaling and sustainability challenges. Thangavel et al. [57] identified several research priorities in this domain, including cost-effective development models for immersive content, faculty development approaches that build institutional capacity, and governance structures that balance centralization and disciplinary autonomy.

Xuan and Rana [32] emphasized the need for research on sustainable financial models, noting that many current implementations rely on external funding or special initiatives that may not provide ongoing support. They called for studies examining diverse approaches to resource allocation, including subscription models, shared resource pools across departments or institutions, and partnerships with industry or external content providers.

Additionally, Shakor and Shafiq Surameery [54] highlighted the environmental sustainability implications of widespread adoption of immersive cloud-based learning, noting the significant energy consumption associated with cloud computing and immersive rendering. Research on optimizing energy efficiency and reducing the carbon footprint of immersive learning technologies will become increasingly important as implementation scales expand.

6.4. Ethical and social implications

Our review revealed a clear need for expanded research addressing ethical and social implications of immersive cloud-based mobile learning. As Drachsler et al. [62] and Lee and Gargroetzi [63] observed, the immersive and data-intensive nature of these environments raises novel ethical questions that existing educational research ethics frameworks may inadequately address.

Esposito [64] called for research developing ethics frameworks specifically tailored to immersive educational environments, addressing issues such as informed consent for data collection, psychological risks of immersive experiences, and potential impacts on learner autonomy and agency. Similarly, Lee and Gargroetzi [63] emphasized the need for participatory approaches to ethical guidelines, involving students and diverse stakeholders rather than imposing policies developed solely by technologists or administrators.

Several researchers highlighted potential social equity implications of immersive learning technologies. Creed et al. [48] called for research examining how immersive technologies might exacerbate or mitigate existing educational disparities related to socioeconomic status, geographical location, or disability status. Similarly, Heikkinen et al. [49] emphasized the importance of studying accessibility considerations in immersive design, ensuring that new educational modalities do not exclude learners with diverse needs and abilities.

6.5. Research agenda

Based on our analysis of current research and identified gaps, we propose a research agenda for advancing understanding and implementation of immersive cloud-based mobile learning in higher education (table 4). This agenda encompasses theoretical, methodological, technical, and applied research priorities.

Table 4
Research agenda for immersive cloud-based mobile learning in higher education.

Research domain	Key questions	Recommended approaches
Theoretical foundations	• How do existing learning theories apply in immersive environments? • What new theoretical constructs are needed to explain learning in immersive contexts? • How do embodiment, presence, and agency influence learning processes?	• Critical analysis of theoretical frameworks across immersive applications • Development of integrated theoretical models that address unique aspects of immersive learning • Interdisciplinary collaborations between education, psychology, computer science, and neuroscience
Integration frameworks	• How can technical and pedagogical integration be more effectively harmonized? • What governance structures best support sustainable, scalable implementation? • How can accessibility and universal design principles be incorporated into integration frameworks?	• Comparative case studies of different integration approaches • Design-based research developing and testing new integration models • Participatory design involving diverse stakeholders including students with disabilities
Implementation strategies	• What faculty development approaches most effectively build capacity for immersive teaching? • How can universities balance standardization and disciplinary customization? • What strategies effectively address ethical and privacy concerns?	• Mixed-methods evaluation of implementation initiatives • Longitudinal studies of implementation evolution • Action research addressing specific implementation challenges
Assessment methodologies	• How can learning in immersive environments be validly and reliably assessed? • What multimodal data sources provide meaningful insights into immersive learning processes? • How can immersive assessment approaches align with institutional requirements?	• Development and validation of immersive assessment instruments • Learning analytics approaches combining qualitative and quantitative data • Design experiments testing novel assessment approaches
Educational impacts	• How durable are learning gains from immersive experiences? • What factors moderate effectiveness across different contexts? • How does immersive learning transfer to real-world performance?	• Longitudinal studies examining retention over time • Meta-analyses identifying moderating variables • Transfer studies in authentic professional contexts

This research agenda emphasizes the need for multidisciplinary approaches that draw on expertise from education, computer science, psychology, and specific disciplinary domains. It also highlights the importance of methodological diversity, combining quantitative and qualitative approaches to develop comprehensive understanding of both outcomes and processes in immersive learning.

7. Conclusion

This systematic review has examined the current state of research on immersive cloud-based mobile learning tools in higher education, focusing on integration frameworks, implementation strategies, and educational impacts. Our analysis of 86 studies published between 2019 and 2025 reveals significant advances in both conceptual understanding and practical application of these technologies across diverse university contexts.

Three primary integration frameworks emerged from our analysis: layered technological architecture, pedagogical-technological alignment, and experiential learning ecosystems. Each framework offers valuable perspectives on different aspects of integration, with the most comprehensive implementations drawing on elements from multiple frameworks to create balanced approaches that address both technical and pedagogical considerations.

Implementation strategies varied substantially across institutions, with successful approaches typically characterized by strong leadership commitment, meaningful faculty involvement, robust technical infrastructure, and alignment with institutional strategic priorities. Common challenges included technological infrastructure and accessibility constraints, faculty development needs, integration with existing educational systems, and ethical considerations regarding data privacy and student wellbeing.

Empirical studies examining educational impacts revealed generally positive but contextual effects. Immersive clou-based mobile learning environments showed the strongest benefits for skill development, moderate positive effects on knowledge acquisition and conceptual understanding, and variable effects on transfer of learning. Student engagement consistently improved across most implementations, particularly regarding emotional and behavioral engagement dimensions. Disciplinary variations in effectiveness were apparent, with fields involving strong spatial and visual components or dangerous/inaccessible learning contexts showing the most pronounced benefits.

Looking forward, several emerging technologies promise to expand the capabilities and educational applications of immersive cloud-based mobile learning, including AI integration, cross-platform standards, haptic feedback technologies, and metaverse concepts. However, realizing the full potential of these technologies requires addressing methodological challenges in immersive learning research, scaling and sustainability issues, and ethical concerns regarding data privacy and social equity.

Based on our findings, we propose several recommendations for researchers, educational technologists, and university administrators:

1. Adopt integrated approaches to implementation that balance technological, pedagogical, and experiential considerations, drawing on the complementary strengths of different integration frameworks.
2. Prioritize faculty development and support, recognizing that technological adoption and pedagogical integration require sustained investment in human capacity alongside infrastructure development.
3. Design immersive learning experiences based on evidence-informed principles rather than technological novelty, focusing on specific learning challenges that benefit from immersive affordances.
4. Implement robust assessment approaches that align with the unique characteristics of immersive learning while satisfying institutional requirements for documentation and credentialing.
5. Address ethical considerations proactively, establishing clear policies regarding data privacy, student wellbeing, and accessibility that are developed through participatory processes involving diverse stakeholders.
6. Pursue research that advances understanding of learning processes and outcomes in immersive environments, with particular attention to longitudinal effects, transfer to authentic contexts, and factors that moderate effectiveness.

Immersive cloud-based mobile learning represents a significant frontier in higher education innovation, with the potential to transform how students engage with complex concepts, develop professional skills, and collaborate across traditional boundaries. While challenges remain in implementation and evaluation, this review demonstrates that thoughtfully designed and carefully implemented immersive learning environments can make meaningful contributions to educational quality and effectiveness across diverse university disciplines.

Data availability statement

No datasets were generated or analysed during the current study.

Conflicts of interest

The authors declare that they have no competing interests.

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Authors' contributions

Serhiy O. Semerikov conceptualized the systematic review, developed the integration frameworks, and drafted the manuscript, including the introduction, methodology, and conclusion sections. Pavlo P. Nechypurenko designed the search strategy and established the inclusion and exclusion criteria for the literature review. Tetiana A. Vakaliuk and Iryna S. Mintii conducted the literature search and data extraction, contributing to the analysis of empirical findings. Vita A. Hamaniuk and Olha V. Bondarenko analyzed the data and synthesized the findings related to implementation strategies and educational impacts. Svitlana V. Shokaliuk and Natalia V. Moiseienko contributed to the interpretation of results and the discussion of future research directions. All authors reviewed, edited, and approved the final manuscript prior to submission.

Declaration on Generative AI

This research utilized generative artificial intelligence tools to support specific non-substantive aspects of the writing and editing process. The following AI-assisted tools were employed:

- **Scopus AI** was used to assist in refining search queries during the literature review phase, helping to identify relevant keywords and optimize Boolean logic for database searches.
- **Grammarly** (Premium) was employed for grammar, spelling, punctuation, and stylistic consistency checks throughout manuscript drafting and revision.
- **Claude Sonnet 3.7** (Anthropic) was used to assist in polishing sentence structure, improving clarity and flow in certain sections, and rephrasing complex passages for readability — always under human supervision and editorial control.

All AI-generated content was thoroughly reviewed, verified, and edited by the authors to ensure accuracy and alignment with the authors' intended meaning and scholarly standards.

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