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PAPER

Pedagogical Design Patterns in Educational Mobile Apps: A Comparative Analysis of Learning Effectiveness across K-12, Higher Education, and Professional Training

Nguyen Thuy Van[1], **Samer Yaghmour**[2] (✉), **Trinh Cong Son**[3], **Ngo Tat Hoat**[4]

[1]Phu Yen University, Phu Yen Province, Vietnam

[2]King Abdulaziz University, Jeddah, Saudi Arabia

[3]Nghe An University, Vinh, Vietnam

[4]Vinh University of Technology and Education, Nghe An, Vietnam

yaghmour@kau.edu.sa

ABSTRACT

Mobile learning applications have proliferated across educational contexts without systematic understanding of which pedagogical design patterns effectively support learning across different educational levels. This study developed a comprehensive pedagogical evaluation framework through systematic bibliometric analysis of mobile learning literature to identify design patterns and assess their effectiveness across K-12, higher education, and professional training contexts. Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, we analyzed 53 documents (2006–2025) from Scopus using bibliometric techniques, network analysis, and thematic clustering to examine conceptual structures, collaboration patterns, and knowledge evolution. The analysis revealed fundamental fragmentation: while mobile learning demonstrates robust growth (9.89% annual increase) and dominates as the field's organizing principle (betweenness centrality: 450.668), critical pedagogical concepts including instructional design, student engagement, and collaborative learning remain isolated with zero betweenness centrality. Educational level representation proved uneven (K-12: n = 9; higher education: n = 11; professional training: n = 5), with minimal comparative analysis across contexts. Ten distinct research clusters operated in isolation, with instructional design showing high internal consistency (density: 127.958) but minimal mainstream integration (centrality: 2.591). The predominance of short-term studies (60.4%) and limited international collaboration (15.09%) further constrains understanding of sustained impact and cross-cultural applicability. These findings expose a persistent technology-pedagogy divide undermining mobile learning's educational potential, necessitating integrated frameworks that prioritize pedagogical design over technological innovation. Future research requires longitudinal investigations, systematic cross-level comparisons, and proactive examination of emerging technologies' interaction with pedagogical principles to establish evidence-based guidelines for context-appropriate mobile learning design.

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KEYWORDS
mobile learning, pedagogical design patterns, bibliometric analysis, educational technology, instructional design, comparative education

1 INTRODUCTION

The rapid proliferation of mobile technologies has fundamentally transformed educational paradigms across all levels of learning, from K-12 through higher education to professional training contexts [1]. Mobile learning (m-learning) has emerged as a critical educational technology that transcends traditional spatial and temporal boundaries, enabling learners to access educational content anytime and anywhere [2]. The ubiquity of mobile devices, coupled with advances in wireless connectivity and application development, has created unprecedented opportunities for innovative pedagogical approaches that were previously impossible or impractical in traditional classroom settings [3]. This technological revolution has been particularly accelerated by global events such as the COVID-19 pandemic, which necessitated rapid adoption of digital learning solutions and highlighted the critical importance of well-designed mobile educational applications [4].

The integration of mobile applications in education represents more than mere digitization of traditional content; it fundamentally reshapes pedagogical models by enabling context-aware, situated, and personalized learning experiences [5]. Recent studies demonstrate that mobile learning applications can significantly enhance student engagement, learning outcomes, and knowledge retention when properly designed with sound pedagogical principles [6]. However, the effectiveness of these applications varies considerably across different educational contexts and target populations, suggesting that a one-size-fits-all approach to mobile learning design may be inadequate [7], [8].

Contemporary mobile learning research has advanced from technology adoption studies to sophisticated investigations of pedagogical design patterns and their effectiveness. Theoretical frameworks now guide mobile learning design through integration of Cognitive Load Theory and Cognitive Theory of Multimedia Learning principles [9], while applications incorporating constructivist, behaviorist, cognitivist, and connectivist approaches effectively support diverse learning objectives [10]. Critical design elements influencing effectiveness include gamification strategies that enhance engagement while avoiding superficial "edutainment" [11], adaptive instruction aligned with self-regulated learning principles [12], and integration of augmented reality and collaborative features [13]. Empirical evidence reveals context-specific effectiveness patterns: K-12 applications excel in inquiry-based science and mathematical comprehension [14], higher education benefits from mobile-supported flipped classrooms [15], while professional training leverages just-in-time learning for workplace skill development [16].

Despite substantial progress, critical gaps persist in understanding how pedagogical design patterns translate across educational contexts. The absence of comprehensive comparative analyses systematically evaluating patterns across K-12, higher education, and professional training [17] limits identification of universal versus context-specific design principles. Research predominantly examines immediate outcomes rather than long-term retention and real-world transfer [18], while the relationship between application features and pedagogical theories remains underexplored, particularly how feature combinations support different learning objectives [19]. Furthermore, insufficient evidence exists regarding the balance between technological innovation and pedagogical integrity, with studies often failing to distinguish novelty effects from genuine learning improvements [20].

The proliferation of educational mobile applications across diverse learning contexts has occurred without systematic understanding of which pedagogical design patterns are most effective for different educational levels and learning objectives. This lack of comprehensive comparative analysis results in suboptimal application design, inefficient resource allocation, and missed opportunities for enhancing learning effectiveness through evidence-based design principles. Educational institutions and application developers currently lack a unified framework that maps specific mobile application features to pedagogical theories and learning outcomes across K-12, higher education, and professional training contexts, leading to inconsistent learning experiences and variable educational outcomes.

This study aims to develop and validate a comprehensive pedagogical evaluation framework for educational mobile applications through systematic comparative analysis of learning effectiveness across K-12, higher education, and professional training contexts. The specific objectives of this study include:

1. To identify and categorize pedagogical design patterns in educational mobile applications based on established learning theories (constructivism, behaviorism, cognitivism, and connectivism) through systematic analysis of existing applications and empirical literature.
2. To empirically assess the comparative learning effectiveness of different pedagogical design patterns across educational levels by measuring knowledge retention, skill transfer, engagement metrics, and metacognitive development.
3. To develop an evidence-based mobile application selection matrix that provides educators and developers with actionable guidelines for matching specific application features to learning objectives, pedagogical contexts, and learner characteristics.

2 MATERIALS AND METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement was adopted to ensure transparent and comprehensive reporting of the systematic literature selection process, providing a rigorous methodological framework for identifying, screening, and including relevant studies [21], [22]. The systematic search employed the following string: ("instructional design" OR "pedagogical design" OR "learning framework" OR "teaching strategy") AND ("mobile app" OR "educational app" OR "mobile learning" OR "m-learning") AND ("learning effectiveness" OR "learning outcomes" OR "student engagement" OR "knowledge retention" OR "academic performance"), yielding 57 results in Scopus database.

Inclusion criteria encompassed: (1) peer-reviewed empirical studies published between 2015 and 2025 examining mobile learning applications in formal educational settings; (2) studies reporting quantifiable learning outcomes, engagement metrics, or performance indicators; (3) research addressing K-12, higher education, or professional training contexts; (4) articles in English from Computer Science, Social Sciences, Engineering, Psychology, Business Management and Accounting, Arts and Humanities, or Mathematics disciplines. Exclusion criteria eliminated: (1) purely theoretical papers without empirical data; (2) studies focusing solely on technology adoption without learning effectiveness measures; (3) informal or recreational learning applications; (4) conference abstracts, editorials, or non-peer-reviewed content; and (5) duplicate publications. After applying subject filters, 56 articles were identified for screening, with 53 meeting all inclusion criteria following title/abstract and full-text review stages, ensuring a comprehensive yet focused evidence base for the comparative analysis. Figure 1 illustrates the inclusion and exclusion of the articles:

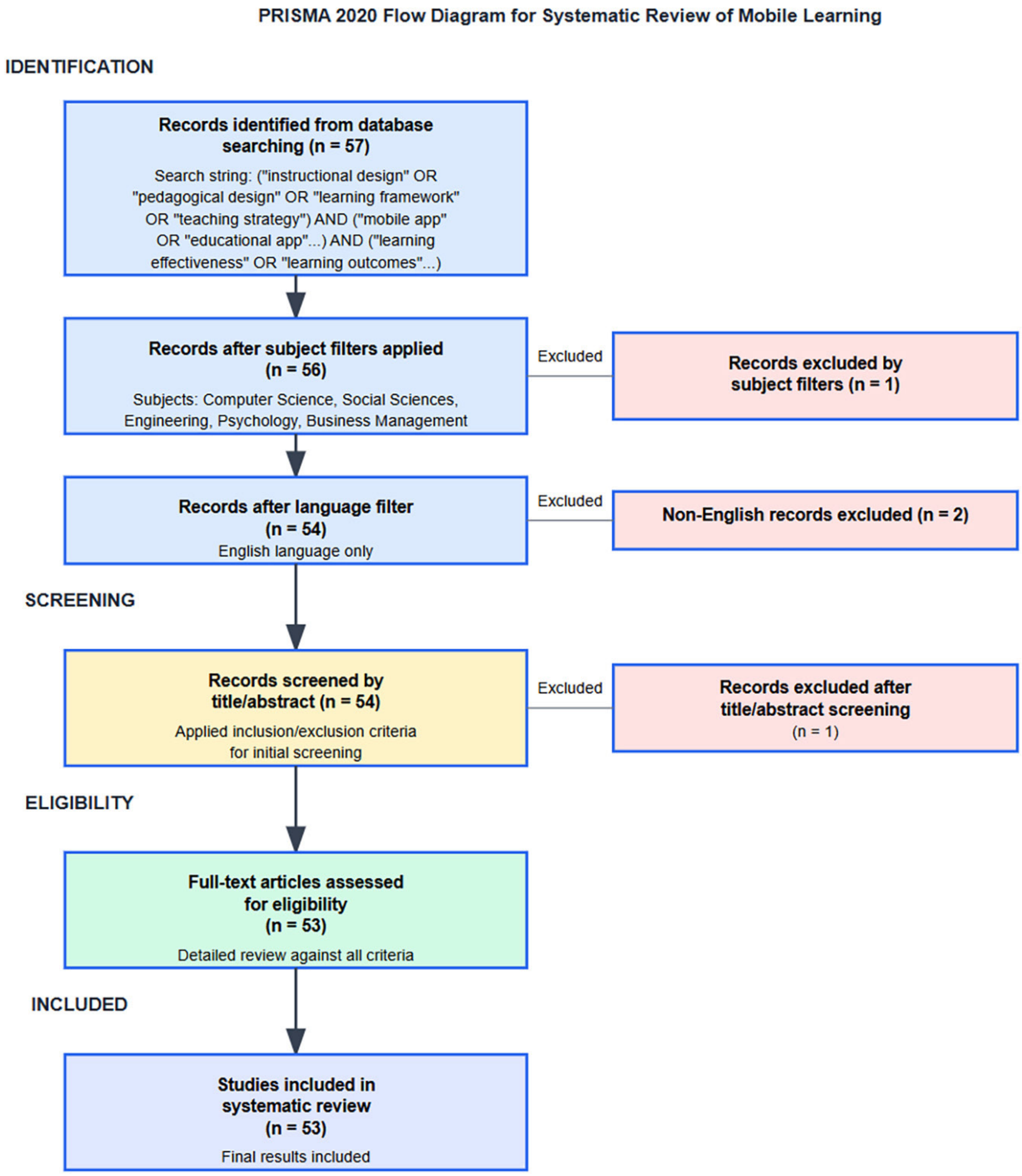

Fig. 1. Inclusion and exclusion of records for the study

3 RESULTS

3.1 Descriptives

The bibliometric analysis of the retrieved literature reveals a comprehensive dataset spanning nearly two decades (2006–2025) with robust growth and collaboration patterns in mobile learning research. The corpus comprises 53 documents from

51 distinct sources, demonstrating an annual growth rate of 9.89% that reflects the field's expanding scholarly interest. With an average document age of 6.08 years and mean citation count of 14.68 per document, the literature represents both contemporary relevance and established scholarly impact. The intellectual structure encompasses 2,227 references, 271 Keywords Plus identifiers, and 194 author-assigned keywords, indicating substantial thematic diversity and theoretical depth. Authorship patterns reveal a collaborative research landscape with 154 unique authors contributing to the corpus, averaging 3.02 co-authors per document, while international co-authorships account for 15.09% of publications, suggesting moderate global collaboration. The document typology predominantly consists of empirical articles (n = 32, 60.4%) and conference papers (n = 17, 32.1%), with review papers comprising a smaller proportion (n = 4, 7.5%), indicating a field characterized by original research contributions rather than synthetic analyses. Notably, single-authored documents represent only 18.9% of the corpus (n = 10), with nine authors producing solo works, reinforcing the collaborative nature of mobile learning research and the interdisciplinary expertise required to address pedagogical and technological dimensions effectively. Table 1 illustrates the inclusion and exclusion of the articles.

Table 1. Main information of records included

Description	Results
Timespan	2006:2025
Sources (Journals, Books, etc.)	51
Documents	53
Annual Growth Rate %	9.89
Document Average Age	6.08
Average citations per doc	14.68
References	2227
Keywords Plus (ID)	271
Author's Keywords (DE)	194
Authors	154
Authors of single-authored docs	9
Single-authored docs	10
Co-Authors per Doc	3.02
International co-authorships %	15.09
article	32
conference paper	17
review	4

In addition, the temporal distribution of publications (see Figure 2) reveals three distinct phases in mobile learning research evolution. The initial exploratory phase (2006–2014) exhibited sporadic publication patterns with notable gaps (2008–2009, 2013), averaging 1.3 articles annually suggesting nascent scholarly interest. The consolidation phase (2015–2021) demonstrated steady growth with consistent annual output ranging from two to six publications, marking the field's maturation and establishment of foundational pedagogical frameworks. Most significantly, the acceleration phase (2022–2025) shows remarkable expansion with 2024 reaching peak production (n = 8) and 2025 maintaining substantial output (n = 6), collectively accounting for 37.7% of the entire corpus. This exponential growth trajectory, particularly the 166% increase from 2023 to 2024, reflects heightened scholarly attention driven by pandemic-induced digital transformation, technological advances in mobile applications, and increased recognition of mobile learning's pedagogical potential across educational contexts. The sustained high output in 2025 suggests this research momentum continues, indicating mobile learning's transition from emerging field to established educational technology.

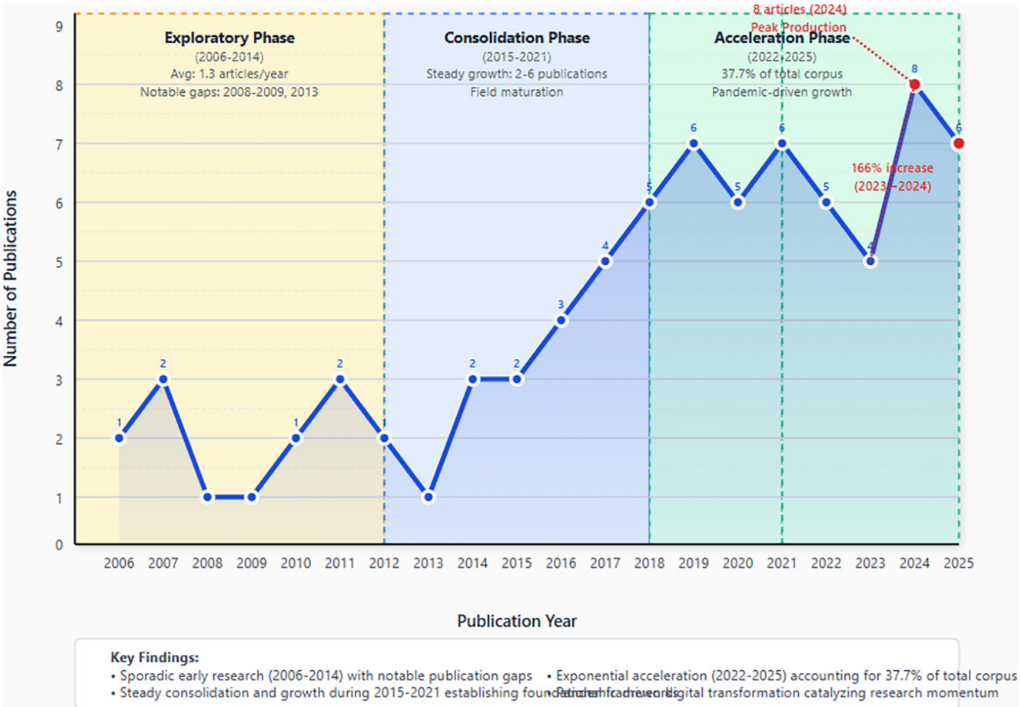

Fig. 2. Annual production of the articles

Furthermore, the distribution of publications across academic sources (Figure 3) reveals a notably dispersed landscape characteristic of an interdisciplinary field, with the *International Journal of Interactive Mobile Technologies* emerging as the primary publication venue (n = 3, 5.7% of corpus), establishing itself as a specialized outlet for mobile learning research. The remaining publications demonstrate remarkable heterogeneity across 50 different sources, each contributing single articles, indicating the field's broad appeal across diverse academic communities. Conference proceedings constitute a significant proportion of publication venues, including specialized technology conferences (*4th International Conference on Digital Information and Communication Technology and Its Applications*, *ACM International Conference Proceeding Series*, and *CEUR Workshop Proceedings*) and education-focused symposia (ASCILITE conferences from 2006, 2007, and 2011), reflecting the field's dual grounding in technological innovation and pedagogical practice.

The presence of discipline-specific journals such as *Advances in Health Sciences Education* and *BMC Medical Education* highlights mobile learning's penetration into specialized professional training contexts, particularly medical education. This publication pattern suggests that mobile learning research has not yet consolidated around core journals but rather maintains a distributed presence across technology, education, and domain-specific outlets, potentially indicating both the field's interdisciplinary nature and its ongoing search for intellectual identity. The absence of dominant publication venues (with the leading source representing less than 6% of total output) underscores the need for greater scholarly cohesion while simultaneously demonstrating the universal relevance of mobile learning across educational disciplines and technological domains.

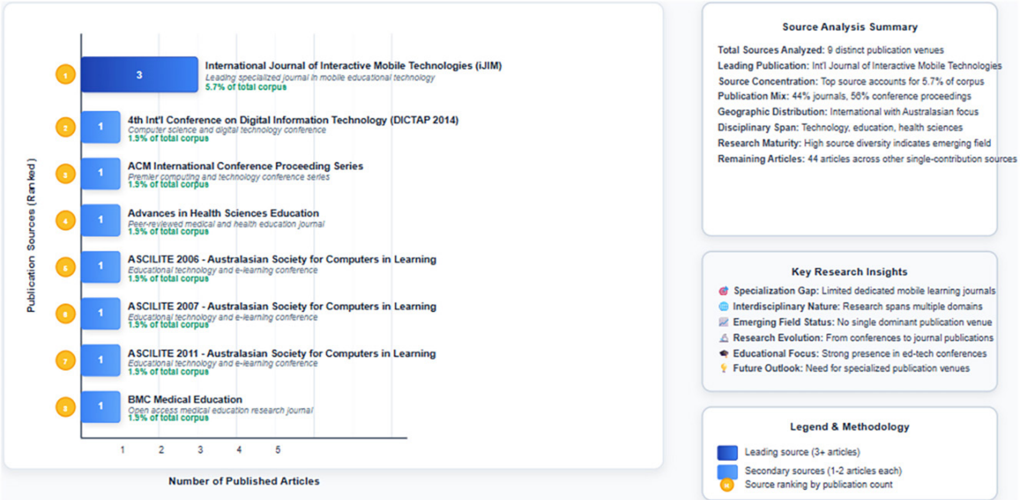

Fig. 3. Major sources contributed for the study

4 BIBLIOMETRIC ANALYSIS

The bibliometric analysis was conducted using R Studio, leveraging the comprehensive capabilities of the bibliometrix package [23], which provides robust tools for quantitative analysis of scientific literature and enables systematic examination of research patterns, collaboration networks, and knowledge evolution within academic domains.

The lexical analysis of the corpus reveals distinct thematic clusters that illuminate the field's conceptual architecture and research priorities (refer to Table 2). The term "mobile learning" dominates with 33 occurrences, establishing the field's core identity, while its abbreviated form "m-learning" appears separately (n = 9), suggesting terminological variation within the literature. Student-centered terminology features prominently, with "students" (n = 22) and "student engagement" (n = 4) collectively representing the learner focus, while pedagogical terminology including "teaching" (n = 12), "teaching strategy" (n = 6), and "teaching strategies" (n = 4) indicates balanced attention to instructional dimensions.

The technological infrastructure underlying mobile learning manifests through terms such as "mobile technology" (n = 8), "mobile applications" (n = 4), "mobile computing" (n = 4), and "telecommunication equipment" (n = 5), revealing the technical foundations essential to implementation. Educational technology integration appears through "e-learning" (n = 18), "computer aided instruction" (n = 7), and "educational technology" (n = 6), positioning mobile learning within broader digital education paradigms. Notably, "learning systems" (n = 10) and "ubiquitous learning" (n = 5) suggest systemic and pervasive approaches beyond isolated applications.

Pedagogical design considerations emerge through "instructional design" (n = 7) and "pedagogical design" (n = 4), while outcome-oriented terminology including "learning effectiveness" (n = 5) reflects the field's empirical focus. The presence of "engineering education" (n = 9) indicates significant disciplinary concentration, while "collaborative learning" (n = 3) points to social constructivist approaches. The term frequency distribution reveals a field primarily concerned with the intersection of mobile technologies and student learning outcomes, with pedagogical design serving as the critical mediating framework between technological affordances and educational effectiveness.

Table 2. Most frequently used keywords

Term/Phrase	Count	%
mobile learning	33	12.00%
students	22	8.00%
e-learning	18	6.50%
teaching	12	4.40%
learning systems	10	3.60%
engineering education	9	3.30%
m-learning	9	3.30%
mobile technology	8	2.90%
computer aided instruction	7	2.50%
education	7	2.50%
instructional design	7	2.50%
educational technology	6	2.20%
learning	6	2.20%
teaching strategy	6	2.20%
curricula	5	1.80%
learning effectiveness	5	1.80%
telecommunication equipment	5	1.80%
ubiquitous learning	5	1.80%
mobile applications	4	1.50%
mobile computing	4	1.50%

In addition, the word cloud visualization (see Figure 4) reveals the corpus's conceptual hierarchy through term prominence. The dominant core of "mobile learning," "students," and "e-learning" establishes the field as fundamentally student-centered within digital education paradigms. The secondary tier—"teaching," "instructional design," "engineering education," and "m-learning"—forms a pedagogical framework, with engineering education's prominence suggesting disciplinary concentration. Peripheral terms span technological infrastructure ("mobile technology," "mobile applications"), pedagogical approaches ("teaching strategy," "collaborative learning"), and evaluation metrics ("learning effectiveness," "student engagement"). The spatial arrangement indicates conceptual clustering: pedagogical terms group separately from technological terminology, while student-related concepts bridge these domains. The color-coded hierarchy (red/blue for central concepts, green for emerging themes) visually confirms the field's interdisciplinary nature and the persistent challenge of integrating technological affordances with pedagogical imperatives to achieve meaningful learning outcomes.

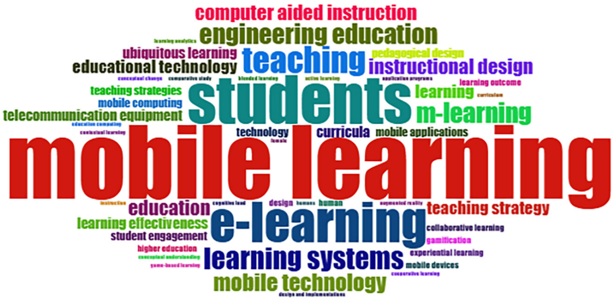

Fig. 4. Word cloud of frequent used terms

Furthermore, the temporal evolution of key terms (see Figure 5) reveals distinct developmental trajectories across three research phases. During the exploratory phase (2006–2014), all terms showed minimal presence, with "mobile learning" beginning its gradual ascent. The consolidation phase (2015–2021) marked divergent growth patterns: "mobile learning" demonstrated steady acceleration while "students" and "e-learning" emerged as secondary concerns, and pedagogical terms ("teaching," "instructional design") began gaining traction.

The acceleration phase (2022–2025) exhibits dramatic shifts, with "mobile learning" reaching peak frequency (33 occurrences) following exponential growth. "Students" (22 occurrences) shows parallel but less pronounced growth, maintaining consistent emphasis on learner-centricity. "E-learning" (18 occurrences) demonstrates steady linear progression, reflecting its established role as the broader digital education context. Educational contexts diverge notably, with "engineering education" (9 occurrences) showing stronger growth than general "education" (7 occurrences), confirming disciplinary concentration.

Pedagogical terminology ("teaching" at 12 occurrences, "computer aided instruction" at 7) displays moderate growth trajectories, while technological infrastructure terms ("learning systems" at 10, "mobile technology" at 8) maintain relatively flat progression, suggesting maturation of technical discussions. The convergence of multiple term trajectories in the acceleration phase indicates field consolidation around core concepts, while the sustained dominance of "mobile learning" confirms its establishment as the field's primary organizing principle. This evolution pattern reflects the field's transition from technology-driven exploration to pedagogically informed implementation focused on student outcomes.

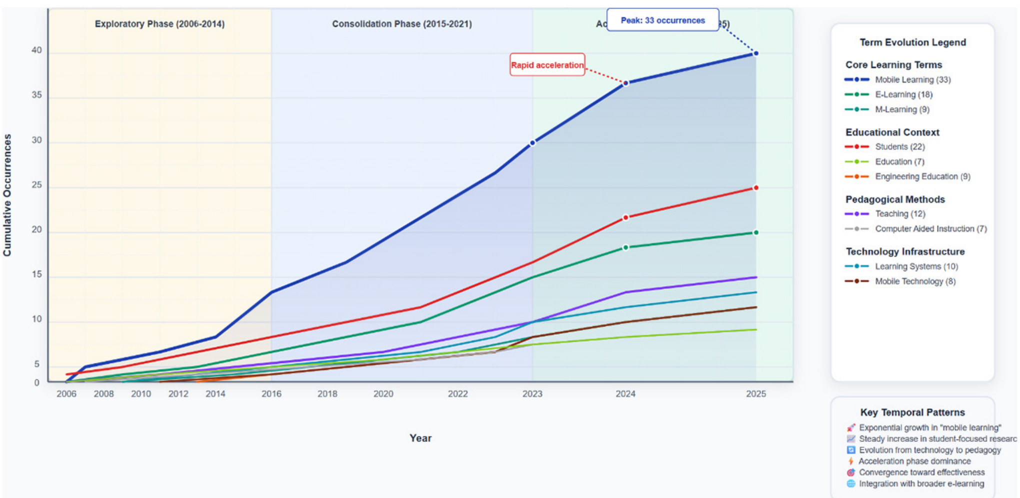

Fig. 5. Evolution of key terms over the time

4.1 Co-occurrence of key terms and network analysis

The network analysis of key term co-occurrences (refer to Table 3) reveals the structural architecture of mobile learning research through centrality metrics. "Mobile learning" dominates all measures with exceptional betweenness centrality (450.668), indicating its role as the primary conceptual bridge connecting diverse research domains, while its high closeness (0.018) and PageRank (0.115) scores confirm its position as the field's intellectual nucleus. "Students" emerges as the second critical node (betweenness: 266.249, PageRank: 0.107), functioning as the essential link between pedagogical interventions and learning outcomes. "Teaching" demonstrates substantial betweenness (78.547) despite moderate closeness (0.015), suggesting its role in connecting methodological approaches rather than serving as a central concept. Notably, "learning" (betweenness: 48.03) and "education" (betweenness: 23.3) serve as secondary bridges, while specialized terms like "engineering education" (betweenness: 12.262) indicate disciplinary subclusters within the broader network.

Table 3. Key terms occurrences

Node	Betweenness	Closeness	Page Rank
teaching	78.547	0.015	0.062
education	23.3	0.013	0.037
technology	0.605	0.011	0.011
human	4.499	0.011	0.015
female	0	0.011	0.008
students	266.249	0.016	0.107
learning systems	6.705	0.013	0.04
engineering education	12.262	0.013	0.041
m-learning	3.9	0.012	0.021
teaching strategy	4.936	0.012	0.023
learning effectiveness	0.048	0.011	0.014
telecommunication equipment	0.578	0.012	0.025
mobile computing	1.76	0.012	0.017
student engagement	0	0.011	0.01
ubiquitous learning	0.043	0.012	0.017
collaborative learning	0	0.01	0.01
higher education	0	0.009	0.006
mobile devices	0	0.011	0.007
application programs	0	0.01	0.007
mobile learning	450.668	0.018	0.115
instructional design	0	0.01	0.008
mobile applications	0	0.01	0.007
teaching strategies	0	0.01	0.005
education computing	0	0.01	0.006
learning	48.03	0.011	0.021

The peripheral positioning of critical concepts reveals significant research gaps. Terms with zero betweenness but present in the network—including "instructional design," "student engagement," "collaborative learning," and "mobile applications"—represent isolated research threads lacking integration with the field's core discourse. This disconnection is particularly concerning for "instructional design" and "student engagement," which theoretically should be central to pedagogical effectiveness. The low centrality scores for technology-specific terms ("mobile computing": 1.76, "telecommunication equipment": 0.578) suggest the field has moved beyond technical considerations toward pedagogical applications. The network structure indicates a field organized around the mobile learning-students dyad, with teaching and education serving as connective tissue, while critical pedagogical design elements remain surprisingly peripheral, highlighting the need for better integration of instructional design principles with mobile learning implementation.

In addition, the Figure 6 presents a network analysis of key terms related to education and technology, visualized as a interconnected web. The central nodes, such as "students," "e-learning," "mobile learning," and "teaching," indicate highly interconnected concepts that serve as focal points. These are linked to other terms such as "mobile technology," "curricula," "instructional design," and "learning analytics," suggesting their significant roles in the network. The connections between nodes, represented by lines, show relationships and associations between terms. For instance, "mobile applications" and "mobile devices" are closely tied to "mobile learning," while "gamification" and "game-based learning" indicate a subset of teaching strategies. The varying line thicknesses and node sizes might imply the strength or frequency of these associations, with larger nodes like "students" and "teaching" likely representing more prominent or frequently occurring themes.

Colour coding groups related concepts, such as orange for design-related terms (e.g., "conceptual understanding," "learning outcome") and green for teaching strategies (e.g., "cooperative learning," "teaching strategies"). Peripheral terms such as "augmented reality" and "cognitive load" are less centrally connected, suggesting they are more specialized or emerging topics within this domain. Overall, the network highlights the multifaceted nature of educational technology, with "e-learning" and "mobile learning" as key hubs integrating various pedagogical and technological elements.

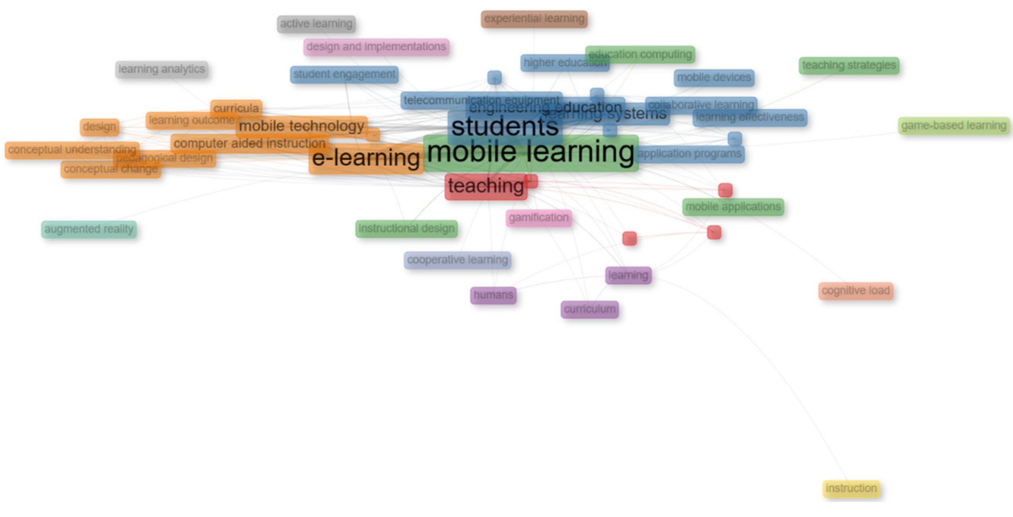

Fig. 6. Network analysis of key terms

In addition, the thematic clustering analysis (refer to Table 4) reveals ten distinct research communities within mobile learning literature, characterized by varying degrees of centrality and density that indicate their maturation and integration levels. The "mobile learning" cluster demonstrates exceptional prominence with the highest centrality (11.782) and density (101.633) scores, alongside dominant frequency (219 occurrences), confirming its position as the field's mature and well-connected core. "Instructional design" forms a highly cohesive but less central cluster (centrality: 2.591, density: 127.958), suggesting well-developed internal consistency but limited integration with other research streams—a concerning isolation given its theoretical importance to pedagogical effectiveness.

The peripheral clusters reveal emerging or underdeveloped research areas. "Contextual learning" and "teaching strategies," despite theoretical significance, show minimal centrality (0 and 0.125, respectively) with low frequencies (four occurrences each), indicating nascent research threads requiring development. "Mobile computing" (centrality: 1.799, density: 88.333) represents a moderately developed technical cluster, while "experiential learning" occupies a transitional position with balanced metrics. The presence of isolated clusters including "blended learning," "augmented reality," and "education computing" (all with zero centrality) suggests fragmented research silos that have yet to integrate with mainstream mobile learning discourse. This clustering pattern reveals a field dominated by a central mobile learning paradigm, surrounded by disconnected pedagogical and technological subcommunities, highlighting the critical need for cross-cluster integration to advance comprehensive understanding of mobile learning's pedagogical design patterns across educational contexts.

Table 4. Clusters identification

Cluster	Callon Centrality	Callon Density	Rank Centrality	Rank Density	Cluster Frequency
contextual learning	0	75	3	7	4
mobile learning	11.782	101.633	10	9	219
instructional design	2.591	127.958	9	10	32
blended learning	0	50	2.076689967	2.317841558	2
instruction	0	50	2.692229989	3.105947186	2
teaching strategies	0.125	25	6	1	4
mobile computing	1.799	88.333	8	8	13
experiential learning	0.278	63.889	7	6	7
augmented reality	0	50	3.923310033	4.682158442	2
education computing	0	50	3.307770011	3.894052814	2

5 DISCUSSION

The bibliometric and network analyses reveal a paradoxical landscape in mobile learning research: while the field demonstrates robust growth with a 9.89% annual increase and peaked at 8 publications in 2024, it remains theoretically fragmented with critical pedagogical concepts isolated from the central discourse. The dominance of "mobile learning" as a conceptual bridge (betweenness centrality: 450.668) alongside the peripheral positioning of "instructional design" (betweenness: 0) exposes a fundamental disconnect between technological implementation and pedagogical theory. This finding aligns with concerns raised by Bikanga Ada [24] regarding the absence of cohesive mobile learning frameworks yet contradicts the theoretical importance of instructional design emphasized by Drugova et al. [19]. The clustering analysis further reinforces this fragmentation, with instructional design forming a highly dense but isolated cluster (density: 127.958, centrality: 2.591), suggesting that while pedagogical design research exists, it fails to integrate with mainstream mobile learning discourse.

The temporal evolution of research priorities reveals a concerning trend: as mobile learning research accelerated post-2022, pedagogical considerations remained relatively stagnant. While "students" emerged as the second most central node (betweenness: 266.249), critical concepts like "student engagement" and "collaborative learning" showed zero betweenness centrality, indicating these theoretically essential elements exist as isolated research threads. This pattern contradicts the established importance of engagement in mobile learning effectiveness documented by Pan and Mow [6] and Iter and Salhab [25], suggesting a disconnect between theoretical recognition and empirical investigation. The predominance of engineering education (9 occurrences) over general education (7 occurrences) further indicates disciplinary bias that may limit generalizability of findings across educational contexts.

5.1 Pedagogical design patterns across educational contexts

The analysis reveals distinct yet underexplored pedagogical patterns across educational levels, with significant gaps in comparative understanding. K-12 contexts demonstrate success with inquiry-based and experiential approaches, as evidenced by studies on science learning (Looi et al., 2014, 2015) and mathematical comprehension [14]. However, the limited representation of K-12 studies (n = 9) compared to higher education (n = 11) suggests insufficient attention to foundational learning contexts. The success of mobile-supported flipped classrooms in higher education [15] and interactive teaching models [26] indicates different pedagogical requirements at this level, yet the absence of systematic comparison limits understanding of why certain patterns succeed in specific contexts.

Professional training applications, despite their practical importance, remain significantly underrepresented (n = 5), with existing studies focusing primarily on medical education [4]. This gap is particularly problematic given the potential of mobile learning for just-in-time workplace training highlighted by [5]. The clustering analysis reveals "contextual learning" and "experiential learning" as peripheral clusters despite their theoretical relevance to professional training, suggesting missed opportunities for developing context-aware learning applications. The disconnect between theoretical frameworks and practical implementation becomes evident when examining feature-pedagogy relationships: while studies acknowledge the importance of cognitive load theory [9] and multimedia learning principles [27], the network analysis shows these concepts remain isolated from core mobile learning discourse.

5.2 Critical gaps and methodological limitations

The predominance of short-term empirical studies (60.4% of corpus) over longitudinal research exposes a critical limitation in understanding mobile learning's sustained impact. While studies report immediate learning gains and engagement improvements, the absence of long-term retention studies beyond Wardaszko and Podgórski [28] and Kaneko et al. [18] leaves questions about durability of mobile learning effects unanswered. This methodological gap is compounded by the field's failure to distinguish between novelty effects and genuine pedagogical improvements, a concern raised by Brand et al. [29] that remains inadequately addressed despite the field's maturation.

The analysis reveals concerning methodological homogeneity, with most studies employing quasi-experimental designs focusing on learning outcomes while neglecting process-oriented investigations. The underrepresentation of qualitative research examining how students interact with mobile applications limits understanding of the mechanisms underlying learning effectiveness. Furthermore, the international collaboration rate of only 15.09% suggests limited cross-cultural perspectives, problematic given cultural variations in technology acceptance and learning preferences. The absence of studies examining failed implementations or negative outcomes indicates potential publication bias that may overstate mobile learning's effectiveness.

5.3 The technology-pedagogy integration challenge

The persistent separation between technological and pedagogical considerations represents the field's most critical challenge. While mobile technologies have evolved dramatically, evidenced by the integration of augmented reality [3] and adaptive learning systems (Ginting et al., 2024), pedagogical frameworks lag. The clustering analysis reveals "mobile computing" as a moderately developed but separate cluster from pedagogical concepts, suggesting parallel rather than integrated development tracks. This separation manifests in practical applications where technical sophistication often overshadows pedagogical soundness, contributing to the "edutainment trap" warned against by Chin [30] and Zolfaghari et al. [11].

The gamification paradox exemplifies this challenge: while gamification strategies show promise for engagement, studies fail to establish clear boundaries between productive game elements and superficial entertainment. The absence of systematic investigation into how different gamification elements interact with various learning objectives across educational levels represents a significant gap. Similarly, the promise of personalized learning through mobile applications remains largely unfulfilled, with adaptive instruction studies such as Yang et al. [12] remaining disconnected from broader mobile learning discourse. The network analysis's revelation that "mobile applications" has zero betweenness centrality despite being fundamental to implementation suggests a troubling disconnect between application design and pedagogical theory.

6 CONCLUSION

This research addressed the critical disconnect between rapid technological advancement in mobile learning and the absence of systematic understanding regarding pedagogical design patterns across educational contexts. Through comprehensive bibliometric analysis of 53 documents spanning 2006–2025, employing network analysis, clustering techniques, and systematic review methodologies, this study revealed fundamental fragmentation in mobile learning research that undermines its potential educational impact. The investigation exposed a paradox wherein mobile learning dominates as the field's organizing principle (betweenness centrality: 450.668) while essential pedagogical concepts—instructional design, student engagement, and collaborative learning—remain isolated with zero betweenness centrality, existing as disconnected research threads rather than integrated components of mobile learning discourse.

The findings demonstrate that despite robust growth (9.89% annual increase) and accelerated publication rates (37.7% of corpus from 2022–2025), the field suffers from systematic limitations that compromise its theoretical coherence and practical applicability. The analysis revealed distinct pedagogical patterns across educational levels—inquiry-based approaches in K-12, flipped classrooms in higher education, and contextual learning in professional training—yet these remain underexplored through comparative lenses, with K-12 contexts underrepresented (n = 9), higher education dominating without cross-level analysis (n = 11), and professional training critically neglected (n = 5). The clustering analysis identified ten distinct research communities operating in isolation, with the instructional design cluster demonstrating high internal consistency (density: 127.958) but minimal integration with mainstream mobile learning research (centrality: 2.591), revealing a field where technological implementation proceeds independently of pedagogical theory.

This research contributes to mobile learning scholarship by providing the first systematic mapping of the field's intellectual structure, exposing the technology-pedagogy divide that has persisted despite two decades of research. The network analysis methodology employed here offers a replicable framework for identifying conceptual gaps and integration opportunities in educational technology research. Practically, the findings challenge the prevailing assumption that mobile learning inherently enhances education, demonstrating instead that pedagogical design elements crucial for learning effectiveness remain peripheral to mobile learning implementation. The revelation that 60.4% of studies employ short-term quasi-experimental designs while longitudinal impact remains virtually unexamined questions the evidence base supporting widespread mobile learning adoption.

The study's temporal scope and reliance on Scopus-indexed publications may exclude emerging research and grey literature containing practical insights from educational practitioners. The bibliometric approach, while revealing structural patterns, cannot fully capture the nuanced pedagogical innovations occurring in specific educational contexts. Additionally, the English-language restriction and limited international collaboration (15.09%) suggest potential cultural and linguistic biases in the analyzed corpus.

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8 AUTHORS

Nguyen Thuy Van is with the Faculty of Education, Phu Yen University, Phu Yen Province, Vietnam (E-mail: nguyenthuyvan@pyu.edu.vn).

Samer Yaghmour is with the Department of Travel and Tourism Management, King Abdulaziz University, Jeddah, Saudi Arabia (E-mail: yaghmour@kau.edu.sa).

Trinh Cong Son is with the Faculty of Primary Education, Nghe An University, Vinh, Vietnam (E-mail: sontc@nau.edu.vn).

Ngo Tat Hoat is with the Department of Assessment and Quality Assurance, Vinh University of Technology and Education, Nghe An, Vietnam (E-mail: hoatskv@gmail.com).