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Architectural and Pedagogical Affordances of Mobile Systems for Problem-Based Learning: A Systematic Literature Review

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Abstract:

The integration of mobile systems in higher education has transitioned from static content delivery to dynamic, ubiquitous learning ecosystems. While Problem-Based Learning (PBL) demands high cognitive engagement and collaboration, there is a systemic gap between the architectural capabilities of mobile applications and their actual pedagogical effectiveness in facilitating PBL syntax. This Systematic Literature Review (SLR) aims to map and evaluate the interaction between the architectural configurations and pedagogical affordances of mobile systems in supporting PBL within higher education. Following the PRISMA guidelines, a systematic search was conducted on the Scopus database, supplemented by snowballing techniques, covering the last decade (2016–2026). A total of 32 empirical studies met the rigorous inclusion criteria and were analyzed using thematic synthesis. The findings reveal three dominant architectural spectrums: bespoke native/hybrid apps, mobile-optimized LMS integrations, and cloud-based collaborative architectures. Pedagogically, mobile systems distribute cognitive load through system-embedded and socio-collaborative scaffolding. Consequently, this socio-technical interaction significantly enhances Meaningful Learning and fosters Mindful and Joyful learning experiences. Mobile systems act as vital cognitive partners in PBL. Future research must pivot to domain-specific, customized M-PBL architectures integrating a Human-in-the-Loop (HITL) approach.

Keywords: Mobile Systems, Problem-Based Learning, Pedagogical Affordances, Software Architecture, Higher Education

Introduction

The global higher education landscape is currently undergoing a fundamental transformation as mobile technology transitions from a passive information distribution tool into an interactive and ubiquitous learning ecosystem. Mobile systems have radically altered student interactions with academic materials through adaptive features and personalized learning paths in the digital education era (Akhter et al., 2026). Current research highlights how ubiquitous learning environments, particularly those integrating learning management systems (LMS) and mobile applications, provide structural support for personalized learning anywhere and anytime (Suartama et al., 2020). In the context of higher education, this shift in technological infrastructure becomes highly crucial when confronted with pedagogical demands that require high-level cognitive engagement, particularly Problem-Based Learning (PBL). The PBL model necessitates a dynamic and flexible learning environment where students can collaboratively investigate various authentic real-world problems. This complex inquiry process can now be orchestrated more effectively through the utilization of connected mobile devices and virtual environments (Rattanakha et al., 2025).

The successful integration of PBL within a digital ecosystem relies heavily on the architectural and pedagogical affordances offered by the technology. Architecturally, the degree of flexibility and accessibility of mobile systems enables students to solve complex problems beyond the confines of traditional classrooms, a crucial element for contextual learning and independent inquiry (Fang, 2025), (Agustiana et al., 2025). Recent evaluations demonstrate that combining educational models with decision support systems in mobile applications significantly increases the effectiveness of e-learning environments (Ariawan et al., 2022; D G H Divayana et al., 2023). System architectures that integrate dynamic multimedia do not merely present information; they directly facilitate pedagogical affordances through digital collaboration. Shared workspace features embedded within mobile platforms have been empirically proven capable of improving students' action competence, problem-solving skills, and critical reasoning abilities (Cong & Ironsi, 2025). Furthermore, injecting cutting-edge pedagogical strategies into mobile applications, such as gamification and game-based learning, has been confirmed to increase learner motivation and active engagement throughout the PBL syntax (Dartini et al., 2026; Vallejo-Imbaquingo et al., 2025).

Despite this promising socio-technical synergy, current literature reveals a significant gap between architectural technological capabilities and pedagogical effectiveness in the field. Many educational mobile systems fail to achieve optimal cognitive outcomes because their development processes are not rooted in holistic instructional design models—such as ADDIE or Hannafin & Peck—or adequate learning theories (Khasyyatillah & Osman, 2022; Suartama et al., 2020; I. K. Sudarma et al., 2022). The misalignment of pedagogical design patterns with software architecture often hinders learners' comprehension at the higher education level (Nguyen Thuy Van et al., 2025). Additionally, the adoption of mobile technology in PBL is highly vulnerable to operational constraints, such as limited network infrastructure and poor User Experience (UX) design, which ultimately degrade the level of student acceptance and engagement (Benali & Ally, 2020; Eom, 2023). Evaluating user interfaces and system usability meticulously is a mandatory prerequisite for robust application development (Dewa Gede Hendra Divayana et al., 2021; Sandhiyasa et al., 2022). This reality emphasizes that merely

providing mobile devices without architectural and instructional cohesion can undermine the essence of the PBL inquiry method itself (Ariawan et al., 2024).

To bridge these theoretical and practical gaps, this Systematic Literature Review (SLR) aims to map and evaluate the interaction between technological architectural features and pedagogical strategies within mobile learning environments. Specifically, this study is formulated to answer the primary question: "How do the architectural configurations and pedagogical affordances of mobile systems interact to support the implementation of problem-based learning in the higher education context?". By identifying obstacles and opportunities from previous literature, this article seeks to formulate a new conceptual framework that can guide the development of resilient and pedagogically precise PBL-integrated mobile systems.

Method

Research Design

This research was designed as a Systematic Literature Review (SLR) to identify, evaluate, and synthesize empirical literature related to the architectural and pedagogical affordances of mobile systems in Problem-Based Learning (PBL). The execution and reporting of this SLR adhere to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standard guidelines to ensure transparency, methodological rigor, and reproducibility of the findings (Page et al., 2021).

Literature Search Strategy

The data collection process was conducted comprehensively through searches on major academic databases relevant to educational technology and computer science, specifically Scopus. To broaden the scope, forward and backward snowballing techniques were applied to key reference articles (*seed papers*). The search string was designed using Boolean operators: ("mobile system*" OR "mobile learning" OR "m-learning" OR "mobile application*" OR "mobile technolog*") AND ("problem-based learning" OR "problem based learning" OR "PBL") AND ("architecture" OR "affordance*" OR "pedagog*" OR "instructional design"). The search was limited to literature published within the last decade (2016–2026) to capture the most recent technological advancements.

Inclusion and Exclusion Criteria

To ensure the relevance and homogeneity of the analyzed literature, strict eligibility criteria were established. The inclusion and exclusion criteria applied during the screening process are detailed in [Table 1](#).

Study Selection and Quality Assessment

The literature selection process was systematically documented using the PRISMA 2020 flow diagram. Initially, records were screened based on their titles and abstracts. Subsequently, full-text articles were independently reviewed against the eligibility criteria. To ensure the methodological rigor of the included studies and minimize the risk of bias, a quality assessment was conducted using the Mixed Methods Appraisal Tool (MMAT). The MMAT was chosen because it allows for the simultaneous appraisal of various study designs—including quantitative (quasi-experimental), qualitative, and mixed-methods approaches—which are heavily represented in this review. Only studies that met the acceptable methodological quality threshold were retained for the final synthesis.

Table 1. Inclusion and Exclusion Criteria

Criterion	Inclusion Criteria	Exclusion Criteria
Thematic Focus	Studies explicitly discussing the architecture/features of mobile devices and their integration within the PBL syntax.	Studies solely discussing conventional PBL without mobile intervention, or solely discussing app architecture without PBL.
Technology Type	Interventions utilizing mobile systems with specific technological affordances.	Interventions using static, traditional desktop-based e-learning or general digital readiness without specific mobile apps.
Context & Population	Studies conducted in Higher Education settings, involving university students or lecturers.	Studies conducted at the K-12 level (primary/secondary schools) or corporate industry training.
Document Type	Primary empirical journal articles that have undergone a rigorous peer-review process.	Review articles (SLR/Meta-analysis), book chapters, conference proceedings, thesis/dissertations, and project reports.
Language & Time	Published in English between 2016 and 2026.	Published before 2016 or in languages other than English.

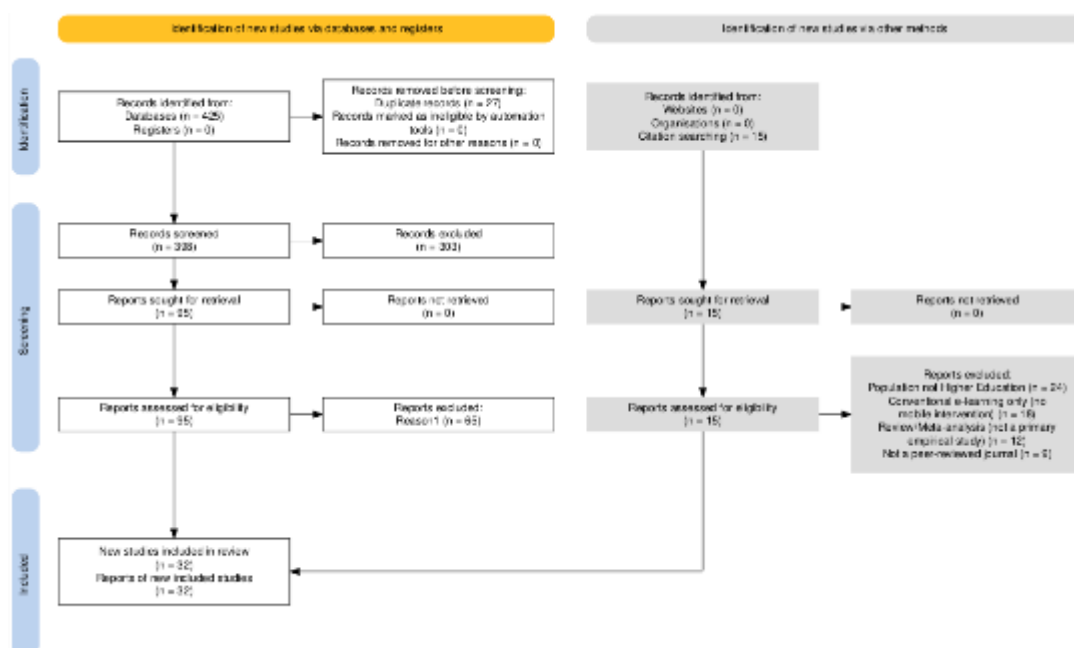


Figure 1. PRISMA 2020 Flow Diagram

Data Extraction and Analysis

Data from the final 32 primary studies were systematically extracted into a standardized matrix. The data extraction process captured 14 key components categorized into six main dimensions:

1. Metadata: Author(s), publication year, and research location.
2. Methodological Context: Study design, population, and sample size.
3. Architectural Affordances: Name of the system/platform, tech stack configurations, and essential technical features.
4. Pedagogical Affordances: PBL syntax integration and distributed scaffolding strategies.
5. Learning Outcomes: Cognitive outcomes (e.g., problem-solving skills) and affective/UX outcomes (e.g., user satisfaction, motivation).
6. Critical Synthesis: Key findings, study limitations, and future design recommendations.

Following the extraction, the data were analyzed using a thematic synthesis method. This approach allowed researchers to identify patterns, group extracted data into conceptual themes, and generate a cohesive narrative explaining the socio-technical interactions between mobile architectures and PBL pedagogy.

Results and Discussion

Demographic and Methodological Landscape

To understand how the architectural and pedagogical affordances of mobile systems are integrated into PBL in higher education, a descriptive analysis was conducted on the 32 articles meeting the inclusion criteria. Geographically, the integration of Mobile-PBL (M-PBL) shows a global adoption pattern, with strong representation from the Asian region and developing countries. Indonesia ranks highest (7 studies), followed by China (4 studies), and the United States (3 studies). The high concentration of research in developing economies indicates that mobile technology is viewed as a strategic and affordable solution to bridge the digital infrastructure gap in higher education (A. K. Amin & Sukestiyarno, 2021), (T. F. Sudarma, 2026).

Methodologically, the landscape is dominated by pragmatic evaluation designs. A majority of the studies adopted Quasi-Experimental designs to test the effectiveness of mobile application pedagogical affordances on naturally formed classes (Afikah et al., 2022). Several studies focused on Design-Based Research (DBR) and Research and Development (R&D) approaches, placing heavy emphasis on "Architectural Affordances" and detailing the software engineering process before system trials (Abdul et al., 2020), (Sindu & Permana, 2021). Mixed-methods approaches were also utilized to measure both cognitive outcomes and affective outcomes simultaneously (Doherty et al., 2018). The target population aligns tightly with STEM and Health Sciences, particularly Computer Science (Jevremovic et al., 2017), Software Engineering (Al-Qora'n et al., 2023), (Baccin et al., 2020), and Medicine (Zhu et al., 2025).

Table 2. Summary of the Included Primary Studies

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
G. Hwang et al., (2021) Taiwan	Quasi-experiment(n = 36 second-year university nursing students)	Mobile-Assisted Peer Assessment (MAPA): Integration of a mobile app (PubMed4Hh) for academic database search with an online peer assessment platform (Tronclass) accessible via mobile devices.	Students define clinical problems using the PICO (Problem, Intervention, Comparison, Outcome) model, search for literature evidence, and critique peers' PICO articles online.	Significant increase in critical thinking skills scores and learning achievement (empirical evidence search performance).
Torres-taborda et al., (2024) Colombia	Descriptive qualitative study(n = 29 9th-semester students)	PARCE: Developed using the Kotlin programming language (fully compatible with Android version 1.3.1).	Employers (representing the real world) upload "requirements" or authentic problems into the system for students to investigate and solve.	Improvement in problem-solving skills, decision-making, and information processing/research (ADR) in the workplace.
Prahani et al., (2020) Indonesia	Conceptual Model Development / Literature Study(n = No specific empirical participants; proposes a theoretical model)	MoLearn: A hybrid mobile and web system integrated with Internet of Things (IoT) and Big Data utilities to support the simultaneous management of virtual and offline classrooms.	Integrates the PBL (Theoretically) model into 5 BWML syntaxes: (1) IoT/Big Data-based orientation, (2) Investigation, (3) Analyzing, (4) Presenting, and (5) Evaluating.	Designed to boost Higher-Order Thinking Skills (HOTS), specifically analyzing (C4), evaluating (C5), and creating (C6), as well as data literacy.

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
Hsu et al., (2021) Taiwan	Quasi- Experime ntal / Quantitati ve Empirical Study(n = 60 Informati cs Engineeri ng students)	iOS App Programming Course Environment: Utilizes an MVC (Model-View- Controller) based framework, Camera API, Auto Layout, Core Data (local database), and Machine Learning integration.	The Design Thinking module integrates PBL stages into app development: (1) Defining real problems, (2) Brainstorming (Ideate), (3) Creating wireframes.	Students successfully designed, programmed, and completed functional application prototypes to solve real-world technical problems.
Zakaria et al., (2023) Malaysia	Modified Nominal Group Techniqu e(n = 11 experts)	Mobile learning and video conference app: A service-oriented architecture facilitating synchronous (video conference) and asynchronous communication (media sharing, exploration).	The integration of M-Learning and PBL (M-PBL) yields 30 structured instructional activities across 5 phases (Problem orientation, Execution, etc.).	(Theoretically) Promotes higher problem-solving skills and critical thinking as students explore mathematical concepts collaboratively.
Abdul et al., (2020) Brunei Darussalam	Design and Developm ent Research (ADDIE model)(n = 1st- semester Polytechn ic students)	Islamic Education PBL Mobile App: An ADDIE-based development framework integrated with behaviorism and constructivism learning theories.	PBL is integrated through a design phase encompassing authentic problem identification, learning objective determination, and collaborative strategies.	(Theoretically) Enhances the understanding of complex religious knowledge and content mastery through deeper material engagement.
Ozdamli & Turan, (2017)	Quantitati ve Method(n = 130	Edmodo Social Learning Network & App Inventor: Utilizes a cloud-	The platform supports Project- Based Learning syntax through	The experimental group using the TS- PBL method demonstrated

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
Cyprus and Turkey	Computer Engineering students)	based educational network (Edmodo) for learning management and visual block-based App Inventor for system design.	team collaboration: investigating applied problems and developing software solutions.	significantly higher academic achievement and design success scores.
(T. F. Sudarma, (2026) Indonesia	Quasi- experimen- tal(n = 60 students)	Mobile Learning: Does not detail specific software architecture but uses mobile technology integration as a flexible supplement for digital learning resource access.	PBL is integrated with M-Learning to facilitate 6 Arends stages: confronting the problem, analyzing, gathering information, presenting solutions, etc.	Significant improvement in Critical Thinking Skills (Explain & Interpret, Analyze Information, Evaluate Arguments, Decision Making) with a high N-Gain.
Athilingam et al., (2016) USA	Theory- Based Development (n = 10 heart failure outpatient s)	Heart MAPP Education: Developed using a hybrid web-mobile architecture (HTML, JavaScript) with media integration and 3D Avatar rendering.	The "Scenarios" module presents real-world problems (problem orientation) where patients must respond to daily health management questions.	70% of patients reported acquiring new information regarding disease management.
(Wu et al., 2024) China	Conceptu- al Review / Viewpoint (n = Medical students and doctors as the target populatio- n)	ChatGPT: An advanced Natural Language Processing (NLP) model based on a Large Language Model (LLM) architecture.	ChatGPT can be configured to act as a virtual patient or facilitator in PBL and Case-Based Learning (CBL), presenting realistic clinical scenarios.	(Theoretically) Improves clinical reasoning skills, case analysis, and medical decision- making capabilities.

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
Guiza, (2026) Colombia	Quasi-experimental Mixed-Methods (n = 62 first-year Engineering students)	Mobile-supported Web Platform: A responsive custom platform, optimized for small screens, supporting online code submission, compilation, and data validation.	Implements a 5-stage PBL cycle: (1) Problem framing, (2) Team analysis, (3) Individual coding & peer review, (4) Iterative testing, (5) Reflection.	Significant improvement in computational thinking and algorithm design skills across the Knowing, Doing, and Being dimensions.
Martínez-Gómez & Nicolalde, (2025) Ecuador	Mixed-Methods (n = First-year university mathematics students)	EQUALINEALES: Developed using MIT App Inventor (visual programming blocks, Java backend).	The app acts as the primary mediation tool for 8 PBL steps, including contextual problem exploration, independent study, and group information sharing.	100% of students passed the course post-intervention.
Hudder et al., (2019) USA	Non-experimental / Observational (n = 1135 first and second-year medical students)	Osmosis: Utilizes Natural Language Processing (NLP) algorithms to process curriculum documents and Machine Learning for student usage pattern analysis.	The platform is integrated with the PBL curriculum track, breaking down clinical case scenarios into learning resources/quizzes for investigation.	Anecdotal: Reports of increased average scores in basic science exams for intensive users (superusers).
Kang et al., (2024) USA	Latent Variable Modeling (n = 2)	Cognitive Tutor Algebra I: A data log-based ITS utilizing machine learning algorithms for time-series analysis to track learning behaviors.	The system directs students through adaptively tailored problem sets (individualized learning),	Enables the mapping of student learning behavior patterns (Flow vs. Off-task) that correlate with learning

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
			allowing them to work independently based on mastery.	achievement outcomes.
Qu & Li, (2024) China	Mixed-Methods (n = Hybrid learning students)	Responsive web-mobile platform: Employs a Knowledge Space Vector Model (TF-IDF), Collaborative Filtering recommendation system, and Expert Discovery algorithms.	Content metadata mapping is aligned with project stages (PBL tasks) so students can dynamically access relevant materials based on progress.	Significant increase in knowledge mastery (87% fully aligned) and problem-solving capabilities.
S. Amin et al., (2022) Indonesia	Quasi-experimental (n = 58 Social Science Education students)	PBHL Model: A hybrid learning environment combining face-to-face meetings with online learning resources/management.	Integrates PBL phases (problem identification, investigation, reflection) with hybrid components (online discussions and digital materials).	Significant increase in students' environmental sensitivity.
Hasan et al., (2017) Saudi Arabia	Course Development Framework (n = Second-year CS students)	Web and Mobile App M-Learning Platform: Peer-2-Peer Connect Ring Framework, Cloud IDE-based architecture, and Local Database integration (offline sync).	Students are placed in groups (6 members), perform independent exercises, and collaborate to find solutions to real-world problems.	(Theoretically) Enhances problem-solving skills and the understanding of Java programming logic.
Cong & Ironsi, (2025) China	Mixed-Methods (n = 120 undergraduate students)	Mobile Application: A mobile-learning platform supporting app-based collaboration.	PBL activities are facilitated via the mobile app to support collaboration and critical inquiry	Significant improvement in problem-solving and critical thinking skills based on pre- and post-

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
			toward actualizing SDG mandates.	intervention assessments.
(Jevremovic et al., 2017) Serbia & Bosnia and Herzegovina	Case study and quantitative experiment (n = Computer Network course students)	IPA-PBL: Web-based ITS; architecture consists of a Content Composer, IPv4 Problem Generator, Pedagogy Module, and Ontology.	PBL is applied by dividing problems into 7 complexity levels (Level 0-6) across 3 phases (Basic, Intermediate, Advanced).	Significant improvement in IPv4 exam results and a more evenly distributed knowledge acquisition (reduced standard deviation of scores).
Arain et al., (2019) Saudi Arabia	Mixed-methods (n = 110 3rd-year medical students)	e-PBL Intranet Platform: A local web/server-based intranet system for electronic case distribution.	AV aids (abnormal heart auscultation sounds) are integrated as triggers in PBL scenarios to stimulate clinical reasoning.	No significant difference found in OSCE (objective structured clinical examination) scores between intervention and control groups.
Jou et al., (2016) Taiwan	Quasi-experimental (n = Engineering students)	Theme-based Mobile APP: Built using cloud technology, integrating chemical symbols, experimental themes, texts, and interactive rendering elements.	The mobile learning app acts as the core medium to facilitate problem-based learning activities for material synthesis.	Significant positive effect on learning performance and practical material synthesis skills.
Sudo et al., (2025) Japan	Mixed-methods (n = First-year health science students)	PBBL Mobile App: Asynchronous learning app integrated with real-time learning logs and data-driven tracking.	Facilitates Project-Based Blended Learning (PBBL); students practice and reflect collectively while working on	Increased self-study time and positive correlation between consistent study habits and academic test scores.

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
			authentic projects as a team.	
Rosalia et al., (2020) Brazil	Quasi-experimental (n = 115 nurses and 35 nursing students)	mSmartAVC: A mobile clinical evaluation application specifically designed for bedside diagnostic use.	Stroke clinical cases are modeled through a PBL workflow, where users must identify signs and provide correct care pathways.	Significant increase in stroke detection knowledge and imaging test interpretation.
Lin et al., (2024) Australia	Learning Analytics / Data Mining (n = Human-to-human tutoring dialog logs)	Intelligent Tutoring System (ITS): Linguistic analysis utilizing Natural Language Processing (NLP) for politeness marker identification.	N/A (Focuses strictly on evaluating tutor dialogue strategies rather than explicit PBL syntax).	Appropriate politeness strategies positively correlate with student performance and learning persistence.
Esmat et al., (2024) Egypt	Quasi-experimental and AHP framework (n = 60 CS students)	AI-Enhanced Mobile App: 3-layer architecture (Presentation, Business, Data) using Java and ASP.NET.	Integrates the PBL cycle: (1) Problem definition, (2) Resource exploration, (3) Concept mapping, (4) Design/coding, (5) Testing.	Significant improvement in programming competence compared to the traditional control group.
Rizal et al., (2024) Indonesia	Quasi-experimental (n = 50 first-year students)	PBLMS: Integrates a mobile-based LMS accessible via smartphones, featuring task management, discussions, and quizzes.	Embeds 5 PBL Syntaxes: (1) Problem finding, (2) Group discussion, (3) Independent study, (4) Problem-solving, (5) Presentation.	Significant improvement in Creative Thinking Skills (CTS) with an N-Gain of 0.61.
Suhrman & Prayogi, (2023) Indonesia	Quasi-experimental (n = 88 high	Assistive Virtual Simulation: Integration of PhET virtual simulations	Integrated into 5 PBL phases: Problem orientation,	Significant improvement in Critical Thinking Skills (CTS);

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
	school students)	within a mobile learning application.	organization, investigation/exp erimentation, presentation, and reflection.	Experimental group N-Gain = 0.65.
Al-Jundi et al., (2017) Canada	Survey / Acceptability trial(n = 9 vascular surgery trainees)	Polltogo: A smartphone response system application designed for the delivery of daily multiple-choice questions.	N/A (The study does not utilize explicit PBL syntax, focusing on spaced question deployment).	Not specifically measured for cognition (primarily focuses on UX and high technological acceptance).
Ismail et al., (2018) Malaysia	Quasi-experimental(n = Form 2 students)	DicScience PBL: A custom mobile application designed specifically for problem-based scientific terminology learning.	The PBL environment is directly integrated into the software design flow and application development process.	Significant improvement in students' Critical Thinking Skills across experimental cohorts.
A. K. Amin & Sukestiyarno, (2021) Indonesia	Quasi-experimental(n = 188 vocational students)	MBPBL via Schoology: LMS accessed via mobile devices, integrating multimedia such as YouTube links, e-books, and journals.	Executes 5 PBL stages (Problem Posing, Organization, Investigation, Developing, Evaluating) via a face-to-face and mobile LMS combination.	Significant improvement in mathematical problem-solving skills (Experimental N-Gain: 44%).
Al-Qora'n et al., (2023) Jordan	Design and Development Research(n = 62 Software Eng. students)	Mobile-PBL: Integration architecture of mobile learning (front-end, digital media) with a collaboration platform (Microsoft Teams).	Implements 4 integration stages: (1) Discovery, (2) Analysis, (3) Application/Solution, (4) Evaluation/Improvement.	Deepened understanding of software architectural patterns and enhancement of practical design skills.

Study (Year) & Location	Research Design & Sample Size	Mobile System Architecture & Tech Stack	Pedagogical Affordance (PBL Integration)	Key Cognitive Outcomes
Rattanakha et al., (2025) Thailand	Pilot Study(n = University students)	C-PBL Mobile & Virtual Learning System: AI-powered smart classrooms integrating artificial intelligence and virtual reality technologies.	Students use analytical thinking to distinguish problems systematically and engage in small-group activities in virtual environments.	Promotes students' analytical thinking, curiosity, and the creation of their own bodies of knowledge.

Architectural Affordances of Mobile Systems

The effectiveness of PBL implementation in digital environments depends heavily on how the software infrastructure is designed. The analysis reveals a broad spectrum of technological configurations:

1. **Bespoke Native and Hybrid Apps:** Numerous studies designed applications from scratch. Applications were developed using high-level programming languages such as Kotlin for Android (Torres-Taborda et al., 2024) or the Model-View-Controller (MVC) framework using Swift/Xcode for iOS (Hsu et al., 2021). This native approach allows the utilization of built-in Application Programming Interfaces (APIs) and local database integration to overcome network latency. Furthermore, the integration of API endpoints like REST API in mobile environments proves highly effective for real-time monitoring and dynamic task handling (Indrawan et al., 2022).
2. **Mobile-Optimized Learning Management System (LMS) Integration:** A dominant approach is the utilization of LMS platforms accessed via mobile devices (Rizal et al., 2024). This architecture stands out due to its plug-and-play capabilities with third-party applications, such as integration with PubMed4Hh for literature searches (Hwang et al., 2021) or linking with virtual simulations (Prayogi & Al., 2023).
3. **Cloud-Based Distributed Architectures and Collaborative Apps:** These systems offload computational burdens from devices to servers, allowing real-time drafting and synchronization of project tasks (Wijaya et al., 2020).

The constructed architectures provide technical affordances for PBL syntax, including Ontology-Based Problem Generators that dynamically present problems (Jevremovic et al., 2017), and Role-Based Access Control (RBAC) that serves as a digitized project validation tool (Torres-Taborda et al., 2024). Advanced architectural configurations in educational contexts often utilize structural algorithms and feature-oriented software development to ensure mobile health and educational applications operate efficiently (Wijaya et al., 2020).

Pedagogical Affordances and PBL Syntax Mapping

Mobile systems orchestrate PBL stages through structured interface mechanisms while distributing students' cognitive loads. Mobile applications facilitate the "Problem

Orientation" phase by bringing students closer to empirical realities. For instance, in nursing, systems integrate the PICO model to define problems using the PubMed4Hh database (Hwang et al., 2021). In business disciplines, internship platforms allow employers to upload authentic problems directly into students' applications (Torres-Taborda et al., 2024). The use of multimedia and authentic contexts has long been proven to trigger active problem-solving skills compared to traditional static models (Satyawati et al., 2023).

To overcome cognitive overload during distributed investigation and solution design, mobile applications implement multi-dimensional scaffolding strategies. System-Embedded Scaffolding provides adaptive hints and breaks down complex problem-solving into micro-steps (Kang et al., 2024). Socio-Collaborative Scaffolding highlights the implementation of Peer Assessment where students learn from peers using critical metrics, while expert guidance is facilitated through asynchronous validation mechanisms (Hwang et al., 2021). Implementing a specific framework like study, explore, implement, and evaluate (SEIE) inside a digital learning environment has been shown to improve conceptual understanding dramatically (Setemen et al., 2023).

Impact of Socio-Technical Interactions on Learning Outcomes

The interaction between M-PBL architecture and pedagogy transforms the learning experience to be more Meaningful, Mindful, and Joyful. The M-PBL environment delivers a measurable impact on the escalation of Higher-Order Thinking Skills (HOTS) (Afikah et al., 2022; Prahani & Al., 2020). Integrating digital innovations, such as smart adaptive mobile learning and gamification, significantly impacts student engagement and innovation (Jayanta et al., 2025). Mobile system interventions trigger a significant surge in Standardized Mean Difference (SMD) (Wei et al., 2025). These abilities are evident in artifact-based outcomes, such as the successful design of functional prototypes for industrial problems (Esmat et al., 2024), and the escalation of clinical reasoning accuracy (Hwang et al., 2021).

Regarding self-regulation and satisfaction, there is a significant surge in users' Intrinsic Motivation dimensions (Jou et al., 2016). Spatial and temporal flexibility stimulates self-regulation; students are more mindful of their learning trajectories and enjoy dynamic collaboration. The incorporation of contextual elements like local wisdom into digital environments further drives engagement and HOTS among students (Suastra et al., 2024). However, some studies capture concerns regarding the potential reduction of empathy and deep human interaction if pedagogical interactions in the classroom become overly dominated by screen mediation (Wu et al., 2024).

Critical Gaps and Sustainable Design Recommendations

This review critically exposes scalability barriers that future M-PBL designs must resolve. Architectural vulnerabilities, reliance on third-party vendors, and unintuitive UI design can erode motivation. Research mapping trends suggest that interface precision and system interoperability are major roadblocks to successful mobile learning (Turmuzi et al., 2023), (Aryanto & al., 2021). In systems utilizing artificial intelligence models, there is a fatal risk of misinformation or "AI hallucinations," which is highly dangerous for precision disciplines (Esmat et al., 2024; Turmuzi et al., 2023). The absence of physical lecturers due to system automation often triggers feelings of socio-emotional isolation in students.

Furthermore, a critical thematic gap emerges from the synthesized literature. The current trajectory of M-PBL research is disproportionately skewed towards STEM and

health sciences, leaving a profound void in integrated educational contexts that bridge empirical inquiry with humanities, cultural preservation, and religious values. For instance, the application of sophisticated M-PBL architectures remains virtually unexplored in domains requiring deep philological analysis or the preservation of ancient indigenous languages. Aligning with the ethos of integrated science education, it is imperative that future technological interventions break this disciplinary hegemony. Developing culturally responsive M-PBL systems that contextualize problem-solving within local wisdom and religious-cultural frameworks will not only enrich the learning ecosystem but also provide a more holistic and meaningful educational experience for students in diverse academic environments.

Future development must pivot from off-the-shelf applications to domain-specific customized architectures. Sustainable M-PBL must adopt a Human-in-the-Loop (HITL) approach, positioning technology as a "cognitive partner" rather than a lecturer replacement. There must be features that balance algorithmic exploration and human-based collaborative validation, supplemented by longitudinal studies to measure the efficacy of M-PBL systems on students' skill retention in the real workforce (Warpala et al., 2025).

Conclusion

This Systematic Literature Review has comprehensively explored and mapped the interaction between the architectural configurations and pedagogical affordances of mobile systems in supporting Problem-Based Learning (PBL) in higher education. This study concludes that current mobile systems have transcended their function as mere static content distribution mediums; they have transformed into socio-technical ecosystems that dynamically orchestrate the entire PBL syntax. The integration of software architectures—ranging from bespoke native apps and optimized LMS to cloud-based systems—with essential features such as problem generators, role-based access control, and offline synchronization, has proven capable of effectively accommodating problem orientation and distributed investigation phases.

The synergy between architectural robustness and pedagogical precision empirically culminates in the enhancement of learning outcomes quality. Students not only experience an escalation in Higher-Order Thinking Skills (HOTS) and decision-making but also gain a more Meaningful, Mindful, and Joyful learning experience. Nevertheless, excessive scaffolding automation risks triggering socio-emotional isolation and reducing human empathy in the classroom. Future research and development (R&D) must focus on designing customized M-PBL system architectures that are specialized based on scientific domains, longitudinally validated, and fundamentally adopt a Human-in-the-Loop (HITL) approach. This approach is crucial to ensure that mobile technology remains a cognitive partner that bridges human interaction, rather than an instrument of digital alienation.

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