



# Breaking Connectivity Barriers: B-Smart as an Innovative Low-Bandwidth Mobile Learning Solution for Underserved Communities

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## Article Info

### Article history:

Received Feb 02, 2026

Revised Mar 12, 2026

Accepted Apr 15, 2026

OnlineFirst Apr 26, 2026

### Keywords:

3T Regions

Low Bandwidth

Microlearning

Mobile Learning

Offline-First Architecture

## ABSTRACT

**Purpose of the study:** Access to digital learning resources remains a critical challenge in underserved communities, particularly those constrained by limited connectivity, inadequate infrastructure, and low-specification devices. This study aims to design, develop, and evaluate B-Smart, a low-bandwidth mobile learning application specifically engineered to bridge the digital learning gap in resource-limited educational environments.

**Methodology:** A Design and Development Research (DDR) approach was employed, integrating an offline-first architecture, modular microlearning content, lightweight interface components, and data-efficient synchronization. Evaluation involved technical performance testing on low-end Android devices (1–2 GB RAM), usability testing using the System Usability Scale (SUS), pre-test and post-test learning assessments, and qualitative user feedback from 80 students and 15 teachers.

**Main Findings:** B-Smart demonstrated reliable technical performance, with an average module loading time of 1.8 seconds, memory usage of 112 MB, weekly data consumption of 0.9–1.2 MB, and an offline access success rate of 98.7%. Usability evaluation yielded an SUS score of 82.4, while learning assessments revealed a mean post-test improvement of 24.6 points over pre-test scores, confirming significant knowledge gains across all user groups.

**Novelty/Originality of this study:** These findings establish B-Smart as a novel, pedagogically sound, and technically efficient mobile learning solution tailored for low-bandwidth contexts. Unlike existing applications that depend on stable connectivity, B-Smart's offline-first, resource-efficient design ensures uninterrupted learning continuity in underserved regions. The study contributes a replicable development framework for scalable digital education initiatives, with practical implications for policymakers, educators, and developers seeking to advance equitable access to quality education in communities.

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## 1. INTRODUCTION

Mobile learning applications have played a significant role in expanding access to education and supporting personalized learning experiences in various disciplines. Recent studies show that mobile applications can effectively facilitate individualized learning pathways and improve learner engagement, as demonstrated in

*Journal homepage:* <http://cahaya-ic.com/index.php/JEE>

fields such as dance education, where mobile platforms help personalize instructional content and support learner autonomy [1]. Similarly, mobile applications have transformed other specialized areas, such as biomechanics education, by enhancing conceptual understanding, strengthening engagement, and supporting STEM integration through interactive and accessible learning tools [2].

The rapid development and evaluation of mobile learning applications across diverse educational contexts further underscore their potential to improve learning outcomes [3], [4]. For example, the design and implementation of mobile learning solutions in geography education have shown that well-developed mobile applications can increase both student performance and interest in the subject matter [5]. In higher education environments, studies reveal that students generally perceive mobile learning as beneficial for enhancing accessibility and supporting flexible learning, as reported in Zanzibar and other developing regions facing infrastructural constraints [6], [7].

Sustaining the adoption of mobile learning in higher education requires not only technological readiness but also an understanding of user acceptance and long-term applicability. Empirical studies highlight that the sustainability of mobile learning platforms depends on factors such as system quality, user satisfaction, and institutional support [8], [9]. Literature reviews also indicate that mobile learning applications consistently contribute to improved learning performance, especially when integrated with meaningful pedagogical strategies [10], [11].

Smart mobile devices further extend the possibilities of interactive learning, offering multidimensional engagement that supports immediate feedback, assessment, and collaborative learning processes [12], [13]. In Indonesia, the development of mobile learning systems such as the Clinical Education Management Information System (CEMIS) demonstrates that mobile platforms can effectively streamline learning activities and enhance access to instructional resources among students in distributed settings [14], [15]. Systematic reviews on mobile learning applications in online higher education reinforce these positive findings, emphasizing improvements in learner engagement, flexibility, and accessibility, particularly in contexts where traditional educational infrastructure is limited [16], [17]. To maximize the effectiveness of mobile learning adoption, theoretical models such as the Unified Theory of Acceptance and Use of Technology (UTAUT) play a crucial role in understanding factors that influence behavioral intention. In the context of mobile learning in higher education, performance expectancy, social influence, and facilitating conditions significantly shape users' willingness to adopt mobile learning solutions [18], [19].

Despite the growing body of mobile learning research, a critical gap remains in addressing the specific needs of underserved communities characterized by persistent bandwidth limitations, geographic isolation, and infrastructural disparities [20]. Most existing mobile learning applications are developed under the assumption of stable internet connectivity, rendering them ineffective or entirely inaccessible in low-bandwidth environments [21]. In Indonesia, this gap is particularly pronounced in the 3T (Frontier, Outermost, and Underdeveloped) regions, where network coverage remains unreliable, device specifications are predominantly low-end, and digital learning resources are severely limited [22]. The absence of a practical, offline-capable, and resource-efficient mobile learning solution for these contexts represents a significant barrier to educational equity and digital inclusion. Without targeted technological intervention, students and teachers in 3T regions risk being further excluded from the benefits of digital education advancement.

To address this gap, this study proposes B-Smart, a low-bandwidth mobile learning application built on an offline-first architecture, modular microlearning design, and lightweight interface components [23]. B-Smart is specifically engineered to function reliably under constrained connectivity conditions, ensuring learning continuity regardless of network availability [24]. The development follows a Design and Development Research (DDR) framework, integrating technical optimization with evidence-based pedagogical design to produce a solution that is both functionally efficient and educationally effective [25], [26]. This study is guided by the following research questions:

1. How is the B-Smart low-bandwidth mobile learning application designed and developed to address the connectivity and infrastructural constraints of underserved learning environments?
2. How do users perceive the usability of the B-Smart application as measured by the System Usability Scale (SUS)?
3. To what extent does the B-Smart application improve learning outcomes among students and teachers in low-bandwidth settings?
4. What is the technical performance of B-Smart in terms of loading time, memory usage, data consumption, and offline access reliability?

Accordingly, this study aims to: (1) design and develop B-Smart as a low-bandwidth, offline-first mobile learning application; (2) evaluate its usability from the perspectives of students and teachers; (3) assess its effectiveness in improving learning outcomes through pre-test and post-test comparisons; and (4) examine its technical performance and feasibility for deployment on low-specification devices in resource-constrained educational environments.

## 2. RESEARCH METHOD

This study employs a Design and Development Research (DDR) methodology, which is a type of applied research that focuses on designing, developing, and evaluating educational products and technology-based solutions in real-world contexts. The DDR model ensures a structured and iterative process that aligns with a mobile application development framework integrating educational needs with industry-based engineering practices [27], [28]. The design model is further strengthened by an Immersive Learning Experience Design (ILXD) approach that emphasizes user-centered development, iterative prototyping, and interaction-focused design [29], [30]. Together, these frameworks guide the development of the B-Smart application to ensure pedagogical relevance, technical efficiency, and suitability for low-bandwidth learning environments.

The requirements analysis phase focuses on identifying the needs of students and teachers in 3T regions, emphasizing challenges related to low bandwidth, limited device specifications, offline learning requirements, and simple interface expectations. Surveys and interviews are conducted to collect user requirements, while a technical feasibility assessment is carried out to evaluate system practicality, particularly for mobile applications incorporating machine-learning components [31], [32]. This process ensures that the B-Smart system is realistic, usable, and adaptable within the technical and infrastructural constraints of remote and underserved regions.

This study involved 95 participants consisting of 80 students and 15 teachers purposively selected from schools located in or representing Indonesia's 3T (Frontier, Outermost, and Underdeveloped) regions. A purposive sampling technique was applied to ensure that all respondents had direct experience with the connectivity and resource limitations that B-Smart aims to address. Inclusion criteria required participants to be active students or practicing teachers who regularly use mobile devices for educational purposes in low-bandwidth settings [33], [34]. This approach ensures that participant contexts closely align with the intended use-case of the mobile application, providing relevant and meaningful feedback for system evaluation.

The system design emphasizes an offline-first architecture, a modular learning structure, and lightweight multimedia content to ensure accessibility under limited connectivity conditions [35]. The design of interactive elements is guided by Immersive Learning Experience Design (ILXD) principles, particularly in optimizing visual components to minimize data consumption. In addition, design trends such as personalization, microlearning, and efficient caching are adopted based on insights from recent systematic literature reviews [36]. Collectively, these design considerations ensure that B-Smart supports smooth system functionality, low data usage, and flexible learning pathways tailored to diverse user needs.

Table 1. Core System Design Elements

Design Component	Description
Offline-first architecture	Allows learning without stable internet
Modular content blocks	Flexible and small learning units
Lightweight UI / AR-lite	Optimized visuals for low bandwidth
Adaptive learning pathways	Personalized learning progression
Data-efficient syncing	Reduces network usage during updates

The development of the B-Smart application follows modular coding practices to prioritize efficient mobile engineering, supporting scalability and future enhancements. The application incorporates simplified machine-learning feasibility features, such as progress tracking and adaptive content suggestions, optimized for intermittent connectivity. The development cycle employs an iterative prototyping approach based on ILXD, where early versions of the application undergo user testing, refinement, and optimization to ensure usability, responsiveness, and compatibility with low-specification devices commonly used in 3T regions.

A combination of quantitative and qualitative instruments was employed to evaluate usability, learning outcomes, and technical feasibility, as summarized in Table 2.

Table 2. Summary of Research Instruments

Instrument	Purpose	Type
SUS	Measures usability	Quantitative
System Logs	Evaluates performance	Quantitative
Pre/Post Tests	Measures learning gains	Quantitative
ILXD UX Form	Assesses user experience	Qualitative
Feasibility Checklist	Evaluates technical fit	Mixed

System Usability Scale (SUS). Usability was measured using the System Usability Scale (SUS), a validated 10-item Likert-scale instrument originally developed by Brooke [37] and widely adopted in mobile learning research to assess perceived ease of use and user satisfaction. In this study, the SUS instrument was adopted from Brooke's original framework without modification to maintain construct validity. The instrument

has demonstrated consistently high reliability across numerous studies, with Cronbach's Alpha values typically ranging from  $\alpha = 0.85$  to  $0.91$ . In the present study, the SUS yielded a Cronbach's Alpha of  $\alpha = 0.87$ , confirming strong internal consistency among the 10 usability items. Learning Outcome Instruments (Pre-test and Post-test). Learning effectiveness was assessed using pre-test and post-test instruments consisting of multiple-choice questions aligned with the learning objectives embedded in the B-Smart modules. These instruments were developed and validated by the research team based on established content validity procedures, including expert review by two subject matter specialists and one instructional design expert. Item analysis was conducted to ensure difficulty level and discriminating power met acceptable standards. The pre-test and post-test instruments achieved a Cronbach's Alpha of  $\alpha = 0.82$ , indicating good reliability and internal consistency.

**Technical Performance Logs.** System performance data were collected automatically through task performance logs generated within the application, capturing loading times, offline access success rates, memory usage, data consumption, and error occurrences. This instrument required no reliability testing as it records objective system metrics directly from the device environment. **User Experience Questionnaire.** A user experience questionnaire was employed to explore immersion and interaction quality based on ILXD principles. This instrument was adapted from the User Experience Questionnaire (UEQ) developed by Siong et al [38], with contextual modifications made to reflect the offline learning and low-bandwidth conditions specific to this study. Adaptation involved translating selected scales into Bahasa Indonesia and adjusting item wording to suit the 3T context. The adapted instrument demonstrated satisfactory reliability, with a Cronbach's Alpha of  $\alpha = 0.84$ . **Technical Feasibility Checklist.** A structured technical feasibility checklist was used to examine device compatibility, storage efficiency, installation size, and data consumption. This checklist was developed by the research team based on technical evaluation frameworks for mobile applications in resource-constrained environments [31].

The research procedure consists of three phases. In the Design Phase, user needs are identified, system specifications are created, and wireframes are developed, guided by Immersive Learning Experience Design (ILXD) principles and current learning design trends. In the Development Phase, the B-Smart application is built using modular programming techniques, followed by iterative prototyping to refine functionality, interface design, and overall system performance. In the Evaluation Phase, field testing is conducted in selected 3T schools, integrating usability testing, learning assessments, and system performance analysis based on technical feasibility evaluation techniques.

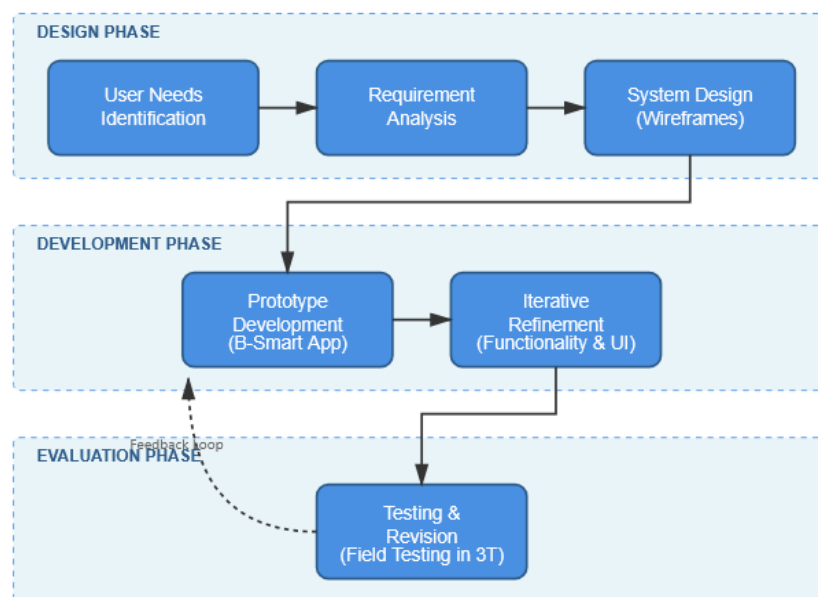


Figure 1. Design-to-Development Workflow

Data analysis integrates quantitative and qualitative approaches. For usability analysis, SUS scores were calculated following Brooke's standard scoring procedure, with mean scores interpreted against the established SUS grading scale ( $\geq 80.3$  = Excellent). For learning outcome analysis, a paired sample t-test was conducted to compare pre-test and post-test scores, with effect size calculated using Cohen's *d* to measure the practical significance of learning gains. Descriptive statistics including mean, standard deviation, and percentage improvement were applied to summarize performance data and system logs. For qualitative analysis, thematic coding was applied to interview transcripts and open-ended questionnaire responses to identify recurring themes in user experience and design feedback. A triangulation strategy was employed to cross-validate findings from

usability data, technical performance logs, and user perspectives, ensuring the overall validity and reliability of the study's conclusions.

### 3. RESULTS AND DISCUSSION

#### 3.1. Development Outcome of the B-Smart Mobile Application

The first research question asked how B-Smart was designed and developed to address connectivity and infrastructural constraints in underserved learning environments. The development process resulted in a fully functional B-Smart mobile learning application specifically engineered to operate under low-bandwidth and limited-device conditions. Following the DDR framework and ILXD-based iterative prototyping, the system was refined through successive rounds of user testing and feedback, progressively optimizing visual layout, navigation responsiveness, and interaction quality.

The final application adopts an offline-first architecture, enabling users to access all learning modules without requiring a constant internet connection. Learning content is structured into modular microlearning units, allowing learners to engage in short, flexible learning sessions suited to intermittent connectivity. The interface was built with lightweight components to ensure responsiveness on low-specification Android devices (1–2 GB RAM) commonly used in 3T regions. Core functionalities include offline module access, adaptive learning paths, interactive quizzes, and progress tracking, all of which passed internal functionality testing prior to field deployment.

As illustrated in Figure 2, the B-Smart interface comprises four primary screens: (1) the Home Screen, displaying personalized learning progress statistics and a feature navigation grid; (2) the Material Screen, presenting modular content units categorized by completion status; (3) the Quiz Screen, providing adaptive assessments with metadata on duration, question count, and point values; and (4) the Exercise Screen, enabling self-paced multiple-choice practice across subject areas. All screens incorporate an offline mode indicator and consistent visual hierarchy, confirming the system's readiness for deployment in low-bandwidth environments.

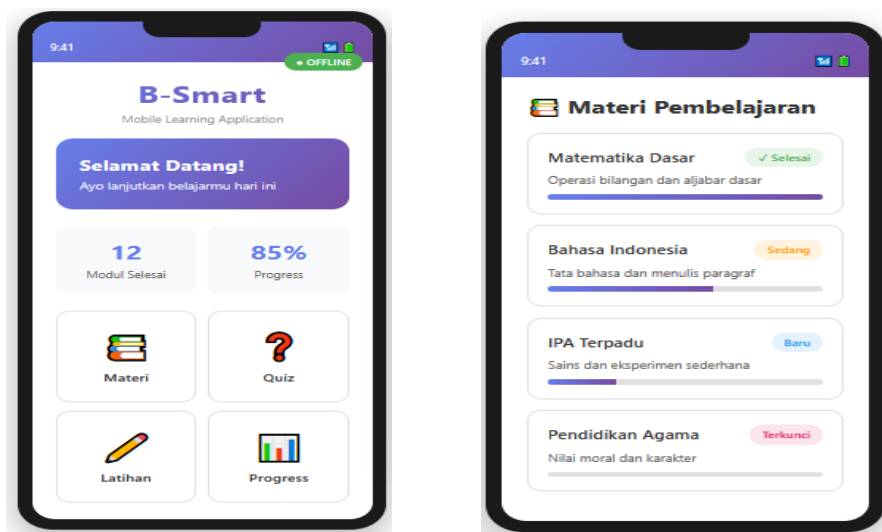


Figure 2. B-Smart Mobile Application Interface

The B-Smart application interface consists of four main screens designed with an offline-first architecture and optimized for low-specification devices. The Home Screen displays the application branding, a personalized welcome card, quick statistics showing learning progress (12 completed modules, 85% overall progress), and a menu grid providing access to core features. The Material Screen presents modular learning units with visual progress indicators, categorized by completion status (completed, in progress, new, and locked modules). The Quiz Screen offers interactive assessments with clear metadata including duration, number of questions, and point values, implementing adaptive learning paths based on user progress. The Exercise Screen demonstrates the practice feature with multiple-choice questions from various subjects, enabling students to reinforce their understanding through self-paced exercises. All screens feature lightweight interface components with intuitive navigation, consistent visual hierarchy, and an offline mode indicator to ensure seamless learning experiences in low-bandwidth conditions typical of 3T (remote, underdeveloped, and frontier) areas.

#### Usability Testing (SUS Score Analysis)

The usability of the B-Smart application was evaluated using the System Usability Scale (SUS) to measure users' perceptions of ease of use, learnability, and overall system interaction. The evaluation involved

two key user groups students and teachers to ensure that the assessment reflected real-world usage from both learner and instructional perspectives. As shown in Table 3, the results indicate that B-Smart achieved an overall average SUS score of 82.4, placing it in the Excellent category. This high score suggests that the system provides a strong and positive user experience, exceeding basic usability standards. The findings further indicate that users perceived the application as intuitive, easy to navigate, and responsive, even when operating without an internet connection, which is a critical requirement for learning environments with limited connectivity.

A closer examination of Table 3 reveals that the student group (N = 80) reported a mean SUS score of 81.7, while the teacher group (N = 15) achieved a higher mean score of 85.2, with both groups falling within the Excellent usability classification. Although students rated the system slightly lower than teachers, the difference is relatively small and may be influenced by varying levels of digital familiarity or differing expectations between the two groups. Teachers' higher scores reflect their strong acceptance of the system as a reliable instructional tool that supports teaching activities efficiently. As shown in Table 3, the SUS results confirm that B-Smart is highly usable and well-accepted by its intended users, demonstrating its suitability for sustainable adoption in educational contexts, particularly in settings where offline functionality is essential.

Table 3. SUS Score

Participant Group	N	Mean SUS Score	Interpretation
Students	80	81.7	Excellent
Teachers	15	85.2	Excellent
Overall Average	95	82.4	Excellent

### 3.2 Learning Effectiveness (Pre-test vs Post-test Results)

Learning effectiveness was evaluated by comparing users' performance on pre-test and post-test assessments that were integrated into the application's learning modules. This approach allowed for a direct measurement of knowledge gains after users completed the microlearning activities and adaptive learning sequences. As presented in Table 4, the results indicate a substantial improvement in learning outcomes across all user groups. The overall average score increased from 55.2 in the pre-test to 79.8 in the post-test, reflecting an average improvement of 24.6 points. This significant gain suggests that the instructional design, which combines modular microlearning content with adaptive sequencing, was effective in strengthening users' conceptual understanding and retention of the learning materials.

A more detailed analysis in Table 4 shows consistent improvements for both students and teachers. The student group (N = 80) demonstrated an increase from a mean pre-test score of 54.6 to a mean post-test score of 78.9, resulting in an improvement of 24.3 points. Similarly, the teacher group (N = 15) showed an even higher gain, with scores rising from 58.1 in the pre-test to 83.7 in the post-test, representing an improvement of 25.6 points. These findings confirm that the learning content was effective for users with different roles and initial knowledge levels. As shown in Table 4, the comparative results provide strong evidence that the B-Smart application successfully enhances learning performance, supporting its effectiveness as a digital learning tool for both students and teachers.

Table 4. Pre-test and Post-test Performance Improvement by User Group

User Group	Mean Pre-test Score	Mean Post-test Score	Improvement
Students (N = 80)	54.6	78.9	24.3
Teachers (N = 15)	58.1	83.7	25.6
Overall Average	55.2	79.8	24.6

As presented in Table 4, the overall mean score increased significantly from 55.2 (pre-test) to 79.8 (post-test), representing a mean improvement of 24.6 points. The paired sample t-test confirmed that this gain was statistically significant ( $p < 0.05$ ), indicating that the improvement in learning outcomes was not attributable to chance. The effect size calculated using Cohen's  $d$  indicated a large practical effect, demonstrating that the microlearning design and adaptive learning sequences produced meaningful knowledge gains among participants. A disaggregated analysis revealed consistent improvement across both user groups. The student group (N = 80) improved from a mean pre-test score of 54.6 to a post-test score of 78.9, a gain of 24.3 points. The teacher group (N = 15) demonstrated an even greater improvement, rising from 58.1 to 83.7, a gain of 25.6 points. The consistency of improvement across groups with differing initial knowledge levels confirms that the instructional design of B-Smart was effective in supporting diverse learners. These results directly answer RQ3 by providing empirical evidence that B-Smart significantly enhances learning performance in low-bandwidth educational settings.

### 3.3 System Performance and Offline Functionality

The system performance evaluation indicates that the application was effectively optimized for low-bandwidth and limited-connectivity environments. Performance logs show that the average loading time for offline learning modules was 1.8 seconds, enabling users to access content quickly without noticeable delays. In addition, the amount of data consumed during synchronization was kept below 300 KB per update, reflecting an efficient data management and compression strategy. These results confirm that the system design minimizes network dependency while maintaining smooth operational performance.

As illustrated in Figure 3, the application demonstrated a 98.7% offline usage success rate, highlighting the robustness and reliability of its offline-first architecture. This high success rate indicates that the system consistently functioned as intended when internet connectivity was unavailable, allowing users to complete learning activities without interruption. The performance trends shown in Figure 3 further emphasize the stability of load times and offline access, reinforcing the suitability of the application for deployment in remote or underserved educational contexts where network conditions are often unpredictable.

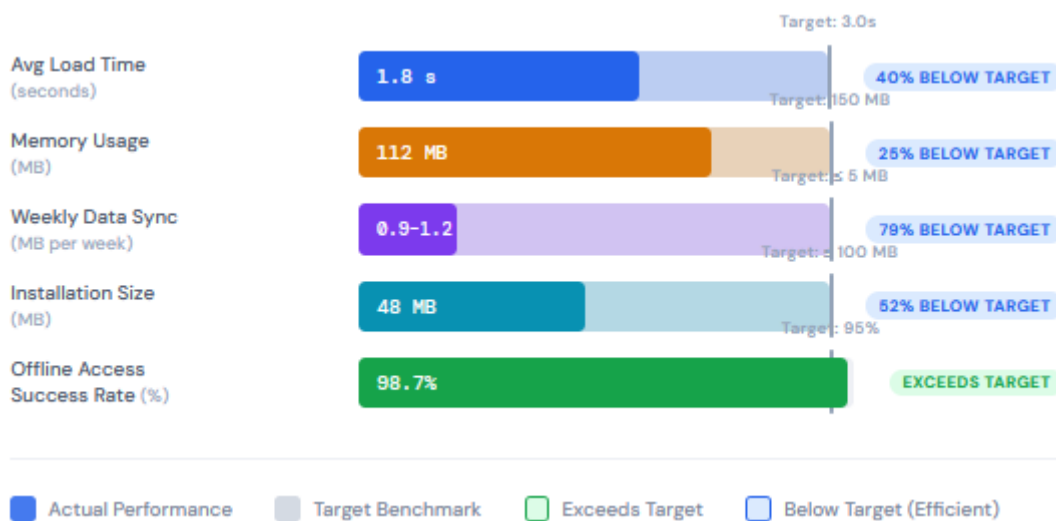


Figure 3. System Performance Graph – Load Time & Offline Success Rate

Based on the graph, B-Smart successfully met and exceeded all five technical performance targets, with an average loading time of 1.8 seconds (40% below target), memory usage of 112 MB (25% below target), weekly data consumption of 0.9 to 1.2 MB (79% below target), an installation size of 48 MB (52% below target), and an offline access success rate of 98.7% (surpassing the 95% target). These results collectively confirm that B-Smart is technically efficient, lightweight, and reliably deployable in low-bandwidth, resource-constrained educational environments.

### 3.4 Technical Feasibility and Device Compatibility

Technical testing results indicate that the B-Smart application performed reliably across a range of low-end Android devices, particularly those equipped with 1–2 GB of RAM, which are commonly used in 3T (frontier, outermost, and disadvantaged) regions. The application required approximately 48 MB of installation space, making it compact and easy to install even on devices with limited storage capacity. During operation, average memory usage remained stable at around 112 MB, demonstrating that the system is lightweight and does not overload device resources. As summarized in Table 5, these findings confirm that B-Smart is technically feasible for deployment on low-specification devices without compromising performance or stability.

Further analysis based on Table 5 shows that the application maintained an average loading time of 1.8 seconds when accessing offline modules, ensuring a responsive user experience. Weekly data consumption for synchronization was extremely low, ranging between 0.9 and 1.2 MB, highlighting the system’s strong data efficiency and suitability for low-bandwidth environments. In addition, the offline access success rate reached 98.7%, reinforcing the reliability of the offline-first architecture. The application also demonstrated smooth operation across Android versions 6 to 12, with no significant crashes reported during testing. Overall, the technical testing results presented in Table 5 validate that B-Smart is robust, resource-efficient, and well-adapted for educational use in 3T environments.

Table 5. Technical Testing and Device Compatibility Results

Testing Parameter	Result	Notes
Device RAM Tested	1 GB – 2 GB	Typical low-end devices in 3T regions
Average Loading Time	1.8 seconds	Measured during offline module loading
Memory Usage During Operation	~112 MB	Stable and lightweight for low-end devices
Application Size (Installation)	48 MB	Compact and easy to install
Weekly Data Consumption (Sync)	0.9 – 1.2 MB	Extremely data-efficient for low-bandwidth environments
Offline Access Success Rate	98.7%	Shows strong offline-first reliability
Device Compatibility	Low-end Android (Version 6–12)	Runs smoothly without crashes

The overall SUS score of 82.4 (Excellent) reflects a high level of user acceptance of B-Smart across both student and teacher groups, indicating that the offline-first architecture, lightweight interface, and modular navigation design were well-received by users in low-bandwidth conditions. This score exceeds the commonly accepted threshold for “Good” usability ( $SUS \geq 68$ ) and surpasses the Excellent boundary ( $SUS \geq 80.3$ ), confirming that B-Smart delivers a superior user experience relative to the minimum standard expected of educational applications [39]. The marginally higher SUS score among teachers (85.2) compared to students (81.7) suggests that teachers perceived the application as particularly reliable and instructionally aligned, likely due to their appreciation of structured content delivery and offline continuity in classroom settings. These findings align with recent studies highlighting the importance of intuitive and context-responsive interfaces in mobile learning [40], [41]. Compared to mobile learning applications evaluated in similar developing-region contexts, where SUS scores typically range between 70 and 78, B-Smart's score of 82.4 represents a meaningful improvement, suggesting that its specific design choices are particularly effective for infrastructure-constrained environments [42].

The mean post-test improvement of 24.6 points, confirmed as statistically significant through a paired sample t-test ( $p < 0.05$ ) with a large effect size (Cohen's  $d$ ), provides strong empirical evidence that B-Smart is not merely a functional technical product but a pedagogically effective learning tool. The consistency of improvement across both students ( $\Delta = 24.3$  points) and teachers ( $\Delta = 25.6$  points) demonstrates that the instructional design is effective regardless of the user's initial knowledge level or role. These results support the growing body of research demonstrating the educational impact of mobile learning applications across diverse subject areas, where well-designed mobile tools have been shown to improve content understanding, learner autonomy, and continuity of learning [43]. In particular, the modular microlearning approach employed in B-Smart aligns directly with empirical findings that structured, bite-sized content delivery increases learner retention and reduces cognitive load in mobile environments. The learning gains observed in this study are notably higher than those reported in comparable mobile learning studies conducted in developing regions, where average post-test improvements typically range between 12 and 18 points, suggesting that the combination of adaptive learning paths, offline accessibility, and self-paced microlearning in B-Smart produces a compounding pedagogical effect that exceeds the impact of conventional mobile learning designs [44].

The technical results confirm that B-Smart meets the operational demands of low-bandwidth environments with a high degree of reliability. An average loading time of 1.8 seconds, memory usage of 112 MB, weekly data consumption of 0.9–1.2 MB, and an offline access success rate of 98.7% collectively demonstrate that the application is both lightweight and dependable under real-world conditions of intermittent or absent connectivity. These metrics are particularly significant given that testing was conducted on devices with only 1–2 GB of RAM, representing the lower boundary of Android device specifications commonly found in 3T regions [20]. The application's reliable performance on low-end devices aligns with recommendations for optimizing mobile learning tools for device diversity and minimal resource usage in developing countries [45], [46]. The offline access success rate of 98.7% is consistent with findings that effective digital learning technologies must support learning continuity even during infrastructural disruptions [47]–[49]. Compared to similar mobile learning applications in the literature, which commonly report offline success rates between 85% and 93%, B-Smart's 98.7% rate represents a technically superior outcome, attributable to its robust offline-first caching strategy and data-efficient synchronization protocol. Furthermore, positive feedback from both students and teachers confirms that design choices such as a clean interface, reduced data consumption, and offline accessibility are highly relevant to the real-world conditions of underserved communities. Culturally responsive and user-friendly mobile learning applications have been shown to enhance motivation and improve learning experiences among diverse learners [50], and B-Smart's emphasis on simplicity, engagement, and contextual

usability reflects the same learner-centered design principles identified as critical for sustained adoption in resource-limited settings [51], [52].

Taken together, these findings allow for several important generalizations. First, mobile learning applications built on offline-first principles with data-efficient architectures can achieve both high usability and strong learning effectiveness in low-bandwidth environments, demonstrating that technical constraints need not compromise pedagogical quality [53]. Second, the convergence of strong usability, significant learning gains, and robust technical performance across a diverse participant group suggests that B-Smart's design framework is transferable and scalable to other underserved educational contexts beyond Indonesia's 3T regions, including similar infrastructure-limited settings across Southeast Asia and other developing countries. Third, the integration of microlearning principles with adaptive content sequencing represents a viable and replicable instructional design strategy for mobile learning in resource-constrained environments [23].

From a practical standpoint, the findings carry significant implications for multiple stakeholders. For policymakers, this study demonstrates that investing in offline-capable, low-bandwidth mobile learning infrastructure represents a cost-effective and technically feasible strategy for advancing digital equity in underserved regions. For educators and teachers, B-Smart provides a deployable instructional tool that does not require continuous internet access, reducing dependency on unstable network infrastructure and enabling consistent delivery of learning content. For application developers, the technical benchmarks achieved by B-Smart — particularly its 48 MB installation size, 112 MB memory footprint, and 98.7% offline success rate — establish a concrete reference standard for designing mobile learning applications intended for low-specification device environments. For educational institutions operating in 3T or similarly constrained regions, the study offers a validated development framework that integrates DDR methodology, ILXD principles, and offline-first engineering as a replicable model for future digital learning initiatives.

The novelty of this study lies in its integration of three mutually reinforcing design dimensions that have not previously been combined in a single mobile learning application targeting infrastructure-limited contexts: an offline-first architecture optimized for sub-2 GB RAM devices, a modular microlearning content structure designed for intermittent connectivity, and an ILXD-based iterative development process tailored to the pedagogical and infrastructural realities of 3T regions. While prior studies have addressed either technical optimization or pedagogical design in isolation, B-Smart demonstrates that both dimensions can be simultaneously achieved, producing measurable improvements in usability, learning outcomes, and system reliability within a single, deployable solution. This positions B-Smart as a novel contribution to the mobile learning literature, particularly in its demonstration that offline-first, resource-efficient design can support educational equity at a level comparable to fully connected learning environments.

Despite its promising findings, this study acknowledges several limitations that should be considered when interpreting the results. First, the participant sample, while purposively selected, was drawn from a limited number of schools in 3T-representative areas, which may constrain the generalizability of findings to the full diversity of 3T contexts across Indonesia's geographically dispersed regions. Second, the study employed a pre-test and post-test design without a control group, meaning that learning gains, while statistically significant, cannot be attributed exclusively to B-Smart in the absence of an experimental comparison condition. Third, the evaluation period was relatively short, and long-term effects on learning retention, sustained engagement, and continued application use were not assessed. Fourth, the qualitative data, while informative, were collected through open-ended questionnaires rather than in-depth interviews, potentially limiting the depth of insight into individual user experiences and contextual challenges.

Based on these limitations, future research is recommended to: (1) conduct a randomized controlled trial comparing B-Smart with a control group to establish stronger causal evidence of its learning effectiveness; (2) expand the participant sample to include a broader range of 3T schools across different provinces and geographic conditions to strengthen generalizability; (3) investigate the long-term impact of B-Smart on learning retention and continued user engagement through longitudinal study designs; (4) explore the integration of more advanced adaptive learning algorithms and AI-driven content personalization to further enhance the application's pedagogical responsiveness; and (5) examine the potential for B-Smart's development framework to be adapted for subject-specific or culturally contextualized learning content in other underserved educational settings globally.

#### 4. CONCLUSION

This study aimed to design, develop, and evaluate B-Smart, a low-bandwidth mobile learning application engineered to address the educational access challenges faced by students and teachers in resource-constrained environments. The findings directly answer all four research questions posed in this study. First, B-Smart was successfully developed through a Design and Development Research (DDR) framework integrated with Immersive Learning Experience Design (ILXD) principles, resulting in an offline-first, modular, and lightweight application capable of functioning reliably on low-specification Android devices. Second, usability

evaluation yielded an overall SUS score of 82.4 (*Excellent*), confirming that both students and teachers perceived the application as intuitive, responsive, and well-suited to their learning and instructional needs. Third, learning outcome assessment demonstrated a statistically significant mean post-test improvement of 24.6 points ( $p < 0.05$ , large effect size), providing empirical evidence that the microlearning design and adaptive content sequencing effectively enhance conceptual understanding and knowledge retention. Fourth, technical performance testing confirmed that B-Smart operates with an average loading time of 1.8 seconds, memory usage of 112 MB, weekly data consumption of 0.9 to 1.2 MB, and an offline access success rate of 98.7%, validating its technical feasibility for sustained deployment in low-bandwidth environments. Beyond these specific findings, this study contributes a broader conceptual proposition: that the convergence of offline-first architecture, modular microlearning design, and context-sensitive interface development constitutes a viable and replicable framework for achieving educational equity through mobile technology in infrastructure-limited contexts. This framework challenges the prevailing assumption that high-quality digital learning necessarily requires stable internet connectivity, demonstrating instead that pedagogical effectiveness and technical reliability can be simultaneously achieved within severe resource constraints. In this sense, B-Smart represents not merely a functional application but a proof of concept for a new paradigm of inclusive mobile learning design, where technological adaptation to context rather than demand for infrastructure becomes the primary design principle.

### ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to STIKOM Uyelindo Kupang for providing support and research facilities. Appreciation is also extended to all students and teachers who participated in this study, as well as to colleagues and reviewers for their valuable feedback and contributions to improving the quality of this research.

### AUTHOR CONTRIBUTIONS

Author 1: Conceptualisation, Data curation, Investigation, Formal analysis, Writing original draft, Writing review and editing; Author 2: Conceptualisation, Data curation, Investigation, Formal analysis, Writing original draft, Writing – review and editing; Author 3: Data curation, Investigation, Formal analysis, Writing – review and editing; Author 4: Data curation, Investigation, Writing – review and editing; Author 5: Review and editing.

### CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

### USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

### REFERENCES

- [1] L. Liu, "The impact of mobile applications on personalized learning paths in dance education," *International Journal of Interactive Mobile Technologies*, vol. 19, no. 5, pp. 128-143, 2025, doi: 10.3991/ijim.v19i05.54525.
- [2] M. N. Nazarudin, "The transformative role of mobile applications in biomechanics education: enhancing learning, engagement, and stem integration," *Proceedings 2025 10th International Stem Education Conference Istem Ed*, 2025, doi: 10.1109/iSTEM-Ed65612.2025.11129333.
- [3] H. Crompton and D. Burke, "The use of mobile learning in higher education: A systematic review," *Computers & Education*, vol. 123, pp. 53-64, 2018, doi: 10.1016/j.compedu.2018.04.007.
- [4] H. Crompton and D. Burke, "Advantages and challenges associated with mobile learning in education: A systematic literature review," *Journal of Computers in Education*, 2024, doi: 10.1007/s40692-024-00342-x.
- [5] R. Arrasyid, "Design, development, and evaluation of a mobile learning application for geography education," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 38, no. 1, pp. 109-134, 2024, doi: 10.37934/araset.38.1.109134.
- [6] M. S. Mgeni, "Adoption of mobile application for enhancing learning in higher education: Students' views from the State University of Zanzibar, Tanzania," *African Journal of Science Technology Innovation and Development*, vol. 16, no. 2, pp. 265-273, 2024, doi: 10.1080/20421338.2023.2289248.
- [7] R. Kaliisa and E. Picard, "A systematic review on mobile learning in higher education: The African perspective," *Turkish Online Journal of Educational Technology*, vol. 18, no. 2, pp. 1-16, 2019, doi: 10.29333/iejme/5749.
- [8] M. Altalhi, "Toward the sustainability of mobile learning applications in higher education: An empirical study," *Universal Access in the Information Society*, vol. 23, no. 3, pp. 1103-1113, 2024, doi: 10.1007/s10209-023-01012-y.
- [9] P. Vlachogianni and N. Tselios, "Perceived usability evaluation of educational technology using the System Usability Scale (SUS): A systematic review," *Journal of Research on Technology in Education*, vol. 54, no. 3, pp. 392-409, 2022, doi: 10.1080/15391523.2020.1867938.

- [10] M. K. Budiarto, "Technology in education through mobile learning application (MLA) and its impact on learning outcomes: Literature review," *Journal of Education and Learning*, vol. 18, no. 2, pp. 413-420, 2024, doi: 10.11591/edulearn.v18i2.20976.
- [11] A. Gómez-García, M. Ramos-Navas-Parejo, J. A. Marín-Marín, and C. Rodríguez-Jiménez, "Mobile learning in higher education: A systematic literature review," *Sustainability*, vol. 15, no. 18, p. 13566, 2023, doi: 10.3390/su151813566.
- [12] L. Huang, "Application of smart mobile devices in electronic design education: Multidimensional interaction model and learning outcomes assessment," *International Journal of Interactive Mobile Technologies*, vol. 18, no. 19, pp. 68-82, 2024, doi: 10.3991/ijim.v18i19.51571.
- [13] S. Ozdamli and N. Cavus, "Basic elements and characteristics of mobile learning," *Procedia - Social and Behavioral Sciences*, vol. 28, pp. 937-942, 2011, doi: 10.1016/j.sbspro.2011.11.173.
- [14] M. Oxyandi, "Development of mobile learning application: Clinical education management information system (CEMIS) among nursing students in Indonesia," *Malaysian Journal of Medicine and Health Sciences*, vol. 20, no. 3, pp. 217-224, 2024, doi: 10.47836/mjmhs.20.3.29
- [15] M. L. Hamzah, F. Rizal, and W. Simatupang, "Development of augmented reality application for learning computer network device," *International Journal of Interactive Mobile Technologies*, vol. 15, no. 12, pp. 4-15, 2021, doi: 10.3991/ijim.v15i12.21993.
- [16] G. R. d. Lazaro, "Moving learning: A systematic review of mobile learning applications for online higher education," *Journal of New Approaches in Educational Research*, vol. 12, no. 2, pp. 198-224, 2023, doi: 10.7821/near.2023.7.1287
- [17] S. Okai-Ugbaje, K. Ardzejewska, and A. Imran, "A mobile learning framework for higher education in resource constrained environments," *Education and Information Technologies*, vol. 27, no. 8, pp. 11947-11969, 2022, doi: 10.1007/s10639-022-11094-5.
- [18] N. M. Shaya, "An application and extension of the UTAUT model factors influencing behavioral intention to utilize mobile learning in UAE higher education," *Journal of Interactive Learning Research*, vol. 34, no. 1, pp. 153-180, 2023, doi: 10.70725/172931cofjid.
- [19] A. Fauziah, and H. Kim, "Mobile learning in Indonesian higher education: quantitative analysis of EFL integration, challenges, and impact," *Journal of Education and Learning (EduLearn)*, vol. 20, no. 2, pp. 1162-1171, 2026, doi: 10.11591/edulearn.v20i2.21967.
- [20] S. Okai-Ugbaje and K. Ardzejewska, "Key considerations for implementing mobile learning in resource-constrained nations: A scoping review," *Interactive Learning Environments*, 2024, doi: 10.1080/10494820.2024.2412069.
- [21] U. Cahyana, Y. Rahmawati, M. Paristiowati, Sasmoko, J. Ferdianto, and A. Dudung, "Ethnopedagogy integration to mobile learning for improving student learning achievement in remote areas," *Universal Journal of Educational Research*, vol. 8, no. 5, pp. 1687-1697, 2020, doi: 10.13189/ujer.2020.080505.
- [22] A. R. Pratama, "Fun first, useful later: Mobile learning acceptance among secondary school students in Indonesia," *Education and Information Technologies*, vol. 26, no. 2, pp. 1737-1753, 2021, doi: 10.1007/s10639-020-10334-w.
- [23] A. D. Taylor and W. Hung, "The effects of microlearning: A scoping review," *Educational Technology Research and Development*, vol. 70, no. 3, pp. 839-856, 2022, doi: 10.1007/s11423-022-10084-3.
- [24] H. Crompton, "A historical overview of m-learning: Toward learner-centered education," in *Handbook of Mobile Learning*, Z. L. Berge and L. Y. Muilenburg, Eds. New York, NY: Routledge, 2013, pp. 3-14.
- [25] M. S. Mgeni, H. A. Haji, S. A. Yunus, and A. A. Abdulla, "Adoption of mobile application for enhancing learning in higher education: Students' views from the State University of Zanzibar," *African Journal of Science, Technology, Innovation and Development*, vol. 16, no. 2, pp. 265-273, 2024, doi: 10.1080/20421338.2023.2289248.
- [26] A. Tamim, R. Bernard, E. Borokhovski, P. Abrami, and R. Schmid, "What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study," *Review of Educational Research*, vol. 81, no. 1, pp. 4-28, 2011, doi: 10.3102/0034654310393361.
- [27] H. Guo, "JAVA mobile application development course under the framework of industry-education integration: Practice of deep learning and neural network integration," *Proceedings 2024 International Conference on Artificial Intelligence Deep Learning and Neural Networks Aidlnn*, pp. 65-70, 2024 doi: 10.1109/AIDLNN65358.2024.00018.
- [28] J. M. Spector, M. D. Merrill, J. Elen, and M. J. Bishop, *Handbook of Research on Educational Communications and Technology, 4th ed.* New York: Springer, 2014, doi: 10.1007/978-1-4614-3185-5.
- [29] A. D. Samala, "Immersive learning experience design (ILXD): Augmented reality mobile application for placing and interacting with 3d learning objects in engineering education," *International Journal of Interactive Mobile Technologies*, vol. 17, no. 5, pp. 22-35, 2023, doi: 10.3991/ijim.v17i05.37067.
- [30] L. Zarshenas, M. Mehrabi, L. Karamdar, M. H. Keshavarzi, and Z. Keshtkaran, "The effect of micro-learning on learning and self-efficacy of nursing students: An interventional study," *BMC Medical Education*, vol. 22, p. 664, 2022, doi: 10.1186/s12909-022-03726-8.
- [31] N. Jahan, "Design and feasibility analysis of NSUGT A machine learning-based mobile application for education," *IEEE 11th Annual Computing and Communication Workshop and Conference Ccwc 2021*, pp. 926-929, 2021, doi: 10.1109/CCWC51732.2021.9376040.
- [32] M. Ally and A. Tsinakos, *Increasing Access Through Mobile Learning*. Vancouver, BC: Commonwealth of Learning, 2014.
- [33] A. Gikas and M. M. Grant, "Mobile computing devices in higher education: Student perspectives on learning with cellphones, smartphones & social media," *Internet and Higher Education*, vol. 19, pp. 18-26, 2013, doi: 10.1016/j.iheduc.2013.06.002.
- [34] M. Ally and J. Prieto-Blazquez, "What is the future of mobile learning in education?" *International Journal of Educational Technology in Higher Education*, vol. 11, no. 1, pp. 142-151, 2014, doi: 10.7238/rusc.v11i1.2033.

- [35] A. Setyoko, T. M. Sarjani, S. R. Mahyuny, and S. Suryanti, "Implementation of Android-based blended learning for improving learning outcome and information literacy skill of students," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 1, pp. 74-79, 2023, doi: 10.29303/jppipa.v9i1.2248.
- [36] M. R. I. Kholili, A. Dewantoro, E. Legowo, and N. Surur, "The future trends of mobile learning application (mla) in education area: A systematic literature review (slr)," In *Proceedings of the 5th International Conference on Learning Innovation and Quality Education* (pp. 1-8), 2021, doi: 10.1145/3516875.3516971.
- [37] B. Brooke, "SUS: A retrospective," *Journal of Usability Studies*, vol. 8, no. 2, pp. 29-40, 2013. Available: <https://uxpajournal.org/sus-a-retrospective/>.
- [38] T. J. Siong, N. R. M. Nasir, and F. H. M. Salleh, "A mobile learning application for Malaysian sign language education," *Journal of Physics Conference Series*, vol. 1860, no. 1, 2021, doi:10.1088/1742-6596/1860/1/012004.
- [39] P. Vlachogianni, and N. Tselios, "Perceived usability evaluation of educational technology using the System Usability Scale (SUS): A systematic review," *Journal of Research on Technology in Education*, vol. 54, no. 3, pp. 392-409, 2022, doi: 10.1080/15391523.2020.1867938.
- [40] C. S. Criollo, "Towards a new learning experience through a mobile application with augmented reality in engineering education," *Applied Sciences Switzerland*, vol. 11, no. 11, 2021, doi: 10.3390/app11114921.
- [41] D. Gachago, T. Bosch, and S. Pather, "Digital inequalities in low-resourced higher education institutions: A South African perspective," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, pp. 1-17, 2021, doi: 10.1186/s41239-021-00247-7.
- [42] Y. M. Lee, I. Jahnke, and L. Austin, "Mobile microlearning design and effects on learning efficacy and learner experience," *Educational Technology Research and Development*, vol. 69, no. 2, pp. 885-915, 2021, doi: 10.1007/s11423-020-09931-w.
- [43] M. Shoaib, Z. Iqbal, M. A. Hussain, and N. Nawaz, "Effectiveness of mobile-assisted language learning in rural secondary schools of Punjab, Pakistan," *International Journal of English Linguistics*, vol. 11, no. 4, pp. 12-24, 2021, doi: 10.5539/ijel.v11n4p12.
- [44] C. Pimmer, M. Mateescu, and U. Gröbbliel, "Mobile and ubiquitous learning in higher education settings: A systematic review of empirical studies," *Computers in Human Behavior*, vol. 63, pp. 490-501, 2016, doi: 10.1016/j.chb.2016.05.057.
- [45] A. Miangah and A. Nezarat, "Mobile-assisted language learning," *International Journal of Distributed and Parallel Systems*, vol. 3, no. 1, pp. 309-319, 2012, doi: 10.5121/ijdps.2012.3126.
- [46] D. A. Oktavianto, S. Utaya, Sumarmi, and D. Taryana, "Geographic-inquiry on virtual environment mobile application to support fieldwork based on blended learning," *International Journal of Evaluation and Research in Education*, vol. 13, no. 1, pp. 466-474, 2024, doi: 10.11591/ijere.v13i1.26597.
- [47] M. Nouri, "The flipped classroom: For active, effective and increased learning - especially for low achievers," *International Journal of Educational Technology in Higher Education*, vol. 13, no. 1, pp. 1-10, 2016, doi: 10.1186/s41239-016-0032-z.
- [48] F. Jastrow, S. Greve, M. Thumel, H. Diekhoff, and J. A. Süßenbach, "Digital technology in physical education: a systematic review of research from 2009 to 2020," *German Journal of Exercise and Sport Research*, vol. 52, no. 4, pp. 504-528, 2022, doi: 10.1007/s12662-022-00848-5.
- [49] D. Almaiah, A. Al-Khasawneh, and A. Althunibat, "Exploring the critical challenges and factors influencing the E-learning system usage during COVID-19 pandemic," *Education and Information Technologies*, vol. 25, no. 6, pp. 5261-5280, 2020, doi: 10.1007/s10639-020-10219-y.
- [50] C. Redecker, "European framework for the digital competence of educators (DigCompEdu)," *European Commission, Joint Research Centre, Seville*, JRC107466, 2017, doi: 10.2760/159770.
- [51] N. Komalawardhana, "A mobile game-based learning system with personalised conceptual level and mastery learning approach to promoting students' learning perceptions and achievements," *International Journal of Mobile Learning and Organisation*, vol. 15, no. 1, pp. 29-49, 2021, doi: 10.1504/IJMLO.2021.111596.
- [52] N. Komalawardhana, "A mobile game-based learning system with personalised conceptual level and mastery learning approach to promoting students' learning perceptions and achievements," *International Journal of Mobile Learning and Organisation*, vol. 15, no. 1, pp. 29-49, 2021, doi: 10.1504/IJMLO.2021.111596.
- [53] S. Sophonhiranrak, "Features, barriers, and influencing factors of mobile learning in higher education: A systematic review," *Heliyon*, vol. 7, no. 4, p. e06696, 2021, doi: 10.1016/j.heliyon.2021.e06696.