EdinBurg Peer-Reviewed Journals and Books Publishers
Journal of Information and Technology
Vol. 6||Issue 1||pp 37-59||May||2026
Email: info@edinburgjournals.org||ISSN: 3080-9576

Exploring Mobile Learning Applications for Improving Problem-Solving Skills in Basic Mathematics: A Qualitative Thematic Study

Samuel Asare*
Department of Mathematics and ICT, St. Monica's College of Education, Mampong-Ashanti, Ghana
Corresponding author email: ksamuelasare@gmail.com

Accepted: 07 March 2026 || Published: 01 May 2026

Abstract

This study explores the integration of mobile learning applications in early mathematics education, focusing on their impact on students' problem-solving skills. Employing qualitative methods including interviews, classroom observations, and artifact analysis, it examines how technological features such as interactive simulations, adaptive content, and augmented reality influence cognitive development, engagement, and collaboration. Findings highlight that mobile tools support iterative reasoning, metacognitive growth, and peer interaction, especially when combined with active teacher facilitation and culturally relevant contexts. Challenges related to infrastructure stability, equitable access, and balancing technology use with interpersonal teaching are also identified. The research underscores the importance of sustained, context-sensitive implementation and suggests future directions involving longitudinal studies, adaptive algorithm evaluation, and expanded inclusivity. Insights contribute to refining pedagogical strategies that integrate mobile technologies to enhance mathematical problem-solving across diverse educational settings.

Keywords: *Mobile Learning, Problem-Solving, Simulation, Inclusivity, Reinforce*

How to Cite: Asare, S. (2026). Exploring Mobile Learning Applications for Improving Problem-Solving Skills in Basic Mathematics: A Qualitative Thematic Study. *Journal of Information and Technology, 6*(1), 37-59.

1. Introduction

Mobile learning applications have increasingly drawn attention as practical tools in early mathematics education, particularly for enhancing students' capacity to engage in problem-solving activities. Studies that focus on their integration show patterns indicating higher engagement levels and measurable gains in learners' performance when such applications are used as part of structured lesson delivery (Malik et al., 2020). These tools appear to encourage active student participation, shifting learning environments away from teacher-centered models toward more interactive and exploratory approaches (Tang et al., 2023). This change in classroom dynamics often manifests through improved involvement in collaborative tasks and greater confidence in handling mathematical challenges. Qualitative investigations into these interventions often employ thematic analysis to explore how students and teachers perceive such technology-based approaches. The thematic outcomes tend to cluster around increased interest, enhanced comprehension, and better transfer of skills to varied contexts.

In Lagos State, for example, the use of the BridgeIT mobile application has been linked with notable improvements in basic school pupils' mathematics achievements without observable gender-based differences in attitudes. Such an absence of demographic disparity may suggest that mobile learning tools provide equitable opportunities for mathematical engagement. From a broader pedagogical perspective, research conducted across different countries underlines both academic performance gains and shifts in teaching methodologies. In Tanzania and India, the deployment of educational videos and supportive mobile technologies was associated with improved student attitudes toward mathematics and increased teacher effectiveness. Teaching styles evolved from didactic "telling" methods toward more constructivist practices that actively involve students in learning processes (Malik et al., 2020). These observed shifts suggest that content delivery on mobile platforms can foster environments in which learners are encouraged to think critically and contribute meaningfully to classroom discourse. However, researchers have also documented contextual barriers that temper widespread adoption. In Nigeria's universities, for instance, the relatively nascent stage of mobile learning adoption has limited awareness regarding its full potential (Oyelere et al.). This raises concerns about generalizing findings across differing geographical or institutional contexts without accounting for infrastructure readiness and specific curriculum demands. Such limitations reinforce the need for continued cross-contextual exploration to determine how usage patterns vary under different educational conditions.

Parallel studies on mathematics problem-solving abilities reveal additional layers of complexity in instructional settings. Many students struggle with abstract conceptualization, formulation of coherent problem-solving plans, and execution of strategies under non-routine conditions (Halim et al., 2024). Elevated stress during evaluations further impairs performance if pedagogical methods remain overly focused on rote transmission rather than dynamic interaction. Mobile applications that incorporate visual aids, scaffolding techniques, or interactive modules may help address these difficulties by breaking down intricate concepts into manageable elements. It also becomes necessary to consider alternative teaching models, such as Problem-Based Learning (PBL), whose efficacy has been repeatedly validated through experimental designs comparing PBL groups with traditional instruction cohorts.

Results indicate clear improvements both in measured problem-solving abilities and increased enthusiasm toward mathematical tasks (Nisa et al., 2023). The interactive nature of PBL aligns well with the capabilities of mobile learning apps, particularly those that facilitate real-world contextualization, peer collaboration, and iterative feedback loops within a single digital ecosystem. Furthermore, integrating cloud-based technologies alongside mobile applications offers extended possibilities for collaboration beyond physical classrooms. Researchers analyzing such integrations emphasize improved knowledge exchange among students and collective efforts toward creating new understandings through shared experiences (Anupan & Chimmalee, 2022). When coupled with visual simulations or augmented reality features (Lestaria & Munahefi, 2023), this environment deepens learners' ability to relate abstract mathematical concepts to tangible scenarios. Thematic analyses that capture teachers' perspectives provide complementary insights: educators often report noticeable improvements in learners' engagement and self-assurance when incorporating mobile apps into daily lessons (Sarıtaş, 2022). Reports describe cases in which students who previously showed minimal interest began actively seeking solutions while discussing alternative approaches with peers. This behavioral shift suggests that the motivational component instilled by interactive technologies may influence classroom culture as much as cognitive outcomes.

Despite these benefits, constructive critique remains important. Excessive dependency on technological intervention could potentially marginalize essential interpersonal teaching components if not managed carefully. There lies a delicate balance between using mobile learning tools as augmentative resources versus allowing them to entirely dominate the instructional arena. Additionally, infrastructural stability, such as consistent electricity supply or internet connectivity, is indispensable for sustaining such digital approaches without frustrating participants due to technical interruptions (Oyelere et al.). Overall thematic findings emphasize not just measurable academic gains but also subtler enhancements in social interaction patterns, confidence in participation, and approaches to tackling unfamiliar problems. This breadth of effects reiterates that mobile learning applications are multifaceted contributors to mathematics education frameworks at early stages. As qualitative data sets accumulate across regions and contexts, they provide a richer narrative detailing both the promises these tools hold and the pragmatic constraints they encounter in diverse schooling environments (Tang et al., 2023).

2. Background and Rationale

2.1 Evolution of Mobile Learning Technologies

Early iterations of mobile learning, often constrained by hardware limitations and rudimentary connectivity options, offered relatively static experiences compared to current implementations. Devices with small LCD screens, limited storage capacity, and short battery life imposed practical restrictions on both content design and user engagement. These technological boundaries shaped how educators approached integration; materials had to be simplified, text condensed, and interactive elements minimized. Cultural and social perceptions also played a formative role in this stage. In some educational contexts, skepticism about the suitability of mobile devices for serious academic work hindered their uptake among instructors and policymakers. Learners' social environment and institutional attitudes affected whether such tools were embraced or sidelined (Azizi & Khatony, 2019).

Gradually, developments in smartphone capabilities, larger displays, increased processing power, enhanced memory, alongside broader internet access, began opening new avenues for interaction. The incorporation of wireless technology enabled content delivery beyond classroom walls, increasing flexibility in time and place (Yuliana et al., 2024). During this period, qualitative studies reveal shifts in thematic patterns: student narratives often highlight increased autonomy over learning schedules and more frequent engagement outside scheduled class hours. Teachers report that greater resource mobility aligns with pedagogical approaches that encourage self-directed exploration and collaborative problem-solving remotely. Thematic coding of these reports underscores the perception that technical improvements correlate strongly with students' motivational gains. As adoption spread in diverse educational settings, infrastructure and training emerged as recurring themes in qualitative datasets. In mathematics instruction, in particular, the absence of adequate teacher training was viewed as a barrier to the transition from basic substitution of traditional tools toward transformative use.

Educators described intermediate stages of integration in which tools such as interactive whiteboards or modeling applications were employed but were not deeply embedded in curriculum practices. Content analysis reveals both excitement about potential uses and frustration due to uneven device provision or unstable internet speeds (Maharjan, 2023). Thematic synthesis suggests that progress is unevenly distributed across institutions; those with targeted investment in professional development make faster progress toward the high-level application of digital platforms. In parallel with these institutional shifts, emergent frameworks such as the Theory of Planned Behavior (TPB) have been applied to explain individual-level readiness for mobile learning adoption (Azizi & Khatony, 2019).

Variables including perceived behavioral control and attitude toward mobile learning appear prominently in thematic matrices derived from surveys. Higher levels of readiness tend to correlate with early willingness to experiment with advanced functionalities beyond static consumption of materials. This trend can be traced qualitatively through interviews where learners describe experimenting with dynamic graphing software or participating in online math challenges alongside peers using smartphone apps (Maharjan, 2023). Such interaction points build confidence not merely through repetitive use but also through constructive engagement with challenging tasks, supported by immediate feedback loops that mobile platforms facilitate. Meanwhile, the diversification of mobile-based instructional models has expanded possibilities for mathematical problem-solving pedagogy. Integrations with Problem-Based Learning (PBL) approaches embed real-world scenarios within app interfaces, so learners confront tangible situations that demand applied quantitative reasoning (Yuliana et al., 2024). Data segments from classroom observations capture moments where this convergence shifts student discourse from abstract formula manipulation into contextual discussion, implicitly bridging cognitive gaps that traditional instruction may leave unaddressed. These evolving methods reflect technological adaptability: cloud-based services now enable collaboration among geographically dispersed groups who share workspaces across their devices in real time (Anupan & Chimmalee, 2022).

Recent innovations include integrating augmented reality (AR) applications into mobile learning ecosystems, which are particularly effective for visualizing abstract mathematical structures (Halim et al., 2024). Assemblr Edu-based resources represent such trajectories, in which qualitative observation logs record heightened learner enthusiasm during AR-facilitated sessions. Interaction codes also point to richer peer commentary cycles, students questioning each other's interpretations while manipulating 3D representations on their devices, to compare alternative solution paths for complex problems. These thematic indicators reinforce how technical sophistication catalyzes deeper mathematical engagement when paired with thoughtful instructional design. Nevertheless, evolution is neither linear nor universally positive at all stages; qualitative feedback frequently warns against over-reliance on technology, which risks diluting the essential interpersonal mentoring in mathematics education (Malik et al., 2020). Some participants express a preference for blended modes where digital tools complement rather than replace face-to-face interactions. This nuanced stance within the thematic results aligns with infrastructural issues still documented today: inconsistent electricity supply and network instability persist as disruptive factors even when device capabilities are high (Oyelere et al.).

Variations exist even within a single national context, depending on rural-urban resource distribution patterns observed in field notes. Over time, qualitative narratives across case studies depict mobile learning technologies as moving from peripheral novelty to a central component of curriculum planning, yet tempered by recurring thematic threads that emphasize human agency, context-specific constraints, and iterative teacher involvement (Bintoro et al., 2021). As technology continues to evolve, incorporating more sophisticated simulations and adaptive feedback mechanisms, the qualitative research lens remains crucial for interpreting how these changes interact with the cognitive processes and classroom cultures previously outlined in Section 1. By tracing these developmental arcs thematically across educational

EdinBurg Peer-Reviewed Journals and Books Publishers
Journal of Information and Technology
Vol. 6||Issue 1||pp 37-59||May||2026
Email: info@edinburgjournals.org||ISSN: 3080-9576

settings, researchers can better discern which elements drive meaningful change versus those that produce superficial modernization without deeper pedagogical impact.

2.2 Importance of Problem-Solving Skills in Mathematics

Problem-solving within mathematics is often described by educators as an essential skill that shapes broader cognitive abilities and fosters durable learning habits. Thematic analyses of qualitative interviews with students reveal a recurring emphasis on how breaking down complex challenges into smaller, more manageable components enables deeper comprehension of mathematical structures. These findings are often framed within social constructivist perspectives, in which learners collaboratively adapt strategies, creating shared meaning as they negotiate the most efficient pathway toward a solution (Tachie, 2019). This process does not occur in isolation; rather, it unfolds through active engagement with peers, teachers, and contextual cues embedded in both curriculum and real-world tasks. Such interactive environments prompt students to reflect on their reasoning processes, fostering metacognitive growth that enhances future problem-solving (Mega et al., 2024). Qualitative accounts also suggest that problem-solving competence extends far beyond performing procedural operations.

It appears linked to logical reasoning, analytical capability, and the capacity for systematic exploration (Da, 2023). Field observations from interventions that blend applied mathematics with everyday life problems indicate an increase in student confidence when they see the relevance of mathematical tools to their lived experiences. This relevance was noted as a catalyst for persistence; learners became more willing to tackle challenging tasks once they understood their relevance. Teachers reported that these contexts generated richer classroom discussions where multiple problem representations were contemplated, algebraic derivations side by side with diagrammatic or narrative explanations, thereby strengthening conceptual connections. Evidence from thematic coding of group discussions identifies particular behaviors associated with successful problem solvers: active questioning of peers' reasoning paths, seeking clarification when discrepancies arise, and iteratively testing solutions against the constraints of the original problem (Tachie, 2019).

Such behaviors align closely with the principles embedded in problem-based learning (PBL) frameworks, which intentionally create scenarios requiring joint exploration and sustained collaborative engagement (Nisa et al., 2023). Under PBL conditions supported by mobile platforms, participants frequently referred back to earlier solution drafts archived on digital devices, illustrating how technology provided continuity in the cognitive process across formal and informal spaces. Mobile applications serve here as enablers rather than replacements for critical thinking, by storing iterative solution steps, highlighting mistakes, and allowing learners to revisit prior reasoning stages without starting from scratch. An important thread within these findings is the role of critical thinking as both an outcome and a driver of mathematics problem-solving. Students hone this skill through cycles of posing conjectures, testing hypotheses against mathematical models, and refining arguments based on evidence emerging during the process. Thematic syntheses that connect modeling exercises with qualitative reflections emphasize that translating real-life situations into a mathematical framework requires both creativity and precision (Yuliana et al., 2024).

Learners who approached problems as adaptable constructs, subject to reinterpretation in light of new data, demonstrated greater flexibility in shifting between conceptual viewpoints. Metacognition repeatedly emerges as a notable determinant of whether students carry early problem-solving successes into unfamiliar contexts (Mega et al., 2024). In interviews, some participants described an ability to anticipate what information would be needed before committing to a particular solution path; others reflected on recognizing ineffective strategies midstream and adjusting accordingly. According to the thematic linkages drawn across case studies, such awareness is strongly supportive of long-term achievement because it encourages ongoing evaluation of strategies rather than rigid adherence to initial approaches.

Educators observing these behaviors noted improved accuracy but also increased willingness to explore elegant or alternative solutions even after an acceptable answer had been reached. From another perspective, qualitative evidence underscores how teacher support structures interact with student problem-solving development (Sarıtaş, 2022). Feedback cycles embedded within classroom culture, timely guidance at impasse points, and validation of creative approaches, even when incorrect, tend to reinforce persistence under challenging conditions. Field notes suggest that students who perceive strong teacher involvement exhibit higher resilience when confronted by multi-step reasoning tasks or non-routine scenarios. The perceived care and recognition motivate them not just cognitively but affectively; sustained motivation appears tightly bound to effective participation in the iterative process that characterizes authentic mathematics problem-solving. Interest levels appear equally influential on performance outcomes. Thematic aggregation across datasets shows students reporting higher effort expenditure when intrinsically curious about a task's premise or personally invested in its context. In such cases, even extended struggle seems reframed as productive rather than frustrating.

Moreover, research aligning high interest levels with PBL activities has shown qualitative shifts in how students articulate their thinking: explanations tend toward causal reasoning steps drawn from experience rather than memorized formula application alone (Nisa et al., 2023). Here again, the interplay between emotional investment and cognitive engagement becomes evident; interest anchors sustained attention across the exploratory arc needed for complex problem resolution. Cross-cultural qualitative comparisons add nuance by suggesting that, while specific strategies may vary across regional educational traditions, underlying traits such as persistence, strategy diversity, and openness to peer critique remain robust predictors of success. Observational excerpts from classrooms show consistent patterns: irrespective of location, students who are encouraged to pose their own problems develop a richer sense of identifying relevant variables, a skill positively correlated with solving ability, according to empirical interpretations of Kilpatrick's theory in thematic review formats (Peng et al., 2020).

This suggests a feedback loop in which exposure to generating questions strengthens subsequent answering capability through heightened familiarity with the structural properties of problems. Ultimately, qualitative syntheses converge on the interpretation that mathematical problem-solving is less about isolated acts of calculation than about cultivating adaptive thinkers able to select from a repertoire of strategies based on situational demands. Mobile-supported pedagogies enrich this repertoire by archiving solution attempts for reflection or providing dynamic visualizations that make abstract relationships perceptually accessible without oversimplification (Yuliana et al., 2024). Yet effective integration depends heavily on maintaining a balance between technological aids and human-led scaffolding so that learners do not outsource cognitive effort entirely but continue to build self-reliance alongside collaborative competence (Sincuba & John, 2017).

3. Literature Review

3.1 Mobile Learning in Mathematics Education

Mobile learning applications in mathematics education have emerged as versatile tools that reshape both instructional design and learner experience. Thematic analysis of qualitative studies frequently highlights how these platforms extend mathematical engagement beyond the constraints of time-bound classroom sessions. Mobile resources often serve as immediate reference points during self-study and enable asynchronous collaboration. In observed cases, students utilized app-based discussion boards or shared interactive worksheets during non-class hours, maintaining a continuity of dialogue around problem-solving steps. This persistent connection with material appears to reduce the cognitive "reset" effect experienced when substantial gaps occur between instructional encounters. A recurring thematic code across multiple observations relates to personalization. In contrast to static textbooks, mobile applications can adapt the difficulty of content based on learner input, prior performance, and preferred modes of representation (Borba et al., 2016). Such adaptability supports differentiated instruction without overburdening educators with manual customization tasks. Nevertheless, interviews with teachers sometimes reveal reservations about whether these adaptive algorithms align perfectly with curricular priorities or inadvertently sideline challenging concepts that warrant sustained attention despite initial learner difficulty. Several qualitative accounts underscore the role of culturally embedded contexts in mobile mathematics instruction.

Ethnomathematics modules delivered via mobile platforms have been used to insert familiar cultural references into problem statements, generating stronger affective connections for learners (Bintoro et al., 2021). For example, measurements might be framed in terms of local agricultural practices rather than abstract quantities, prompting more intuitive reasoning among students. Thematic coding of classroom interactions suggests that such contextualization raises the frequency of questions and nurtures student-led explanations that connect formal mathematical ideas to everyday activities. Integration with cloud computing infrastructures offers another dimension observed in contemporary mobile learning environments. By allowing data storage and application processing beyond the device itself, cloud services facilitate real-time collaboration and resource sharing (Anupan & Chimmalee, 2022).

Students can co-edit solution documents or jointly manipulate dynamic graphing tools during virtual sessions, mirroring the processes of face-to-face group work. Thematic reflection notes indicate that these features not only enhance the formation of conceptual knowledge but also foster collaborative norms, such as turn-taking and constructive feedback. Augmented reality (AR) has been integrated as an augmentative feature in some mobile learning systems for mathematics. Assemblr EDU-based implementations for topics like sequences encourage learners to manipulate 3D models that visualize mathematical progressions (Halim et al., 2024). Observers noted higher levels of engagement during AR interventions compared to conventional handouts, with students spontaneously verbalizing pattern recognition as they rotated or zoomed in on virtual models.

From a thematic standpoint, such embodied interaction was associated with richer explanations when students presented their reasoning back to peers. Despite these affordances, certain structural limitations persist in qualitative datasets. Access disparities, stemming from device incompatibility or inconsistent operating system support, are reported as sources of frustration that can dampen motivation (Susantini et al., 2025). For instance, preservice teachers relying on non-Android phones had to share devices, limiting opportunities for autonomous exploration. While suggested technical fixes could broaden inclusivity, field notes reveal that workarounds often trigger unequal participation dynamics within groups. Problem-Based Learning (PBL) frameworks delivered through mobile apps show promise for developing mathematics problem-solving abilities (Nisa et al., 2023). Under these conditions, learners engage with authentic scenarios that require multi-step reasoning, supported by app-enabled simulations or data inputs. Thematic synthesis reveals emergent patterns: increased persistence with complex tasks, richer peer-to-peer questioning exchanges, and heightened ownership over final solutions compared to procedural drills.

Field observations also indicate that mobile integration into PBL reinforces iterative thinking cycles, and students revisit prior versions saved on their devices to refine strategies without starting from scratch. Qualitative teacher perspectives often balance enthusiasm for increased student agency with caution about overreliance on technology (Papadakis, 2021). Some educators emphasize the motivational impact; students who were previously passive become more willing to hypothesize openly when working inside a low-stakes digital space but also stress that deep conceptual clarification still hinges on guided discussion rather than app prompts alone. Coding of interview data frequently captures this duality: appreciation for enhanced access and interactivity, paired with reminders to maintain strong pedagogical scaffolding. Cross-referencing observational logs with learner reflections suggests another thematic outcome: shifts in classroom social organization patterns when mobile technologies are integrated (Biswas et al., 2020). Students often report feeling less inhibited about querying peers via messaging than about speaking out publicly, leading to parallel backchannel discussions that supplement the main lesson flow. While this can increase inclusion for quieter learners, researchers note that instructors may face challenges in effectively tracking all simultaneous information streams. Finally, practical constraints loom large within thematic categorizations of challenges accompanying mobile mathematics education (Oyelere et al.).

Frequent mentions include unstable internet connectivity, disruptions to synchronous activities, and irregular electricity supply, leading to device downtime at critical moments. Such infrastructural issues introduce unpredictability into learning sequences that otherwise demonstrate strong engagement trajectories under stable conditions. Consequently, recorded teacher strategies often involve hybrid planning, preparing offline-capable resources alongside online modules, to ensure continuity regardless of technical interruptions. Across these varied threads documented in qualitative findings, personalization capacity, cultural embedding potential, collaborative affordances via cloud systems, immersive AR experiences, and alignment with PBL principles, the thematic picture is one of complex interplay between opportunity and constraint. The balance between technological enrichment and foundational pedagogical interaction remains a recurring interpretive lens through which educators assess the ongoing role of mobile applications in mathematics learning (Halim et al., 2024).

3.2 Problem-Solving Skill Development

Thematic patterns emerging from qualitative investigations into mathematics education consistently foreground problem-solving as a composite skill shaped by multiple interacting factors. At the cognitive level, students benefit from structured opportunities to analyze problems, interpret their parameters, and select from a repertoire of strategies rather than adhering strictly to prefabricated solution templates. Studies examining national performance indicators, such as PISA scores, indicate that students often underperform because existing instructional practices do not sufficiently cultivate higher-order abilities (Lestaria & Munahefi, 2023). This gap becomes particularly apparent when learners encounter non-routine scenarios requiring conceptual transfer across topics. Qualitative classroom observations have documented cases in which embedding mathematics in familiar contexts, reflecting principles of ethnomathematics, stimulates a more intuitive grasp of the decisions involved in problem-solving (Murtafiah et al., 2024).

Students facing localized word problems grounded in cultural practice, for example, were seen to generate richer explanations of their solution pathways and to exhibit more iterative refinement of their approaches. Codes drawn from such sessions reveal how cultural relevance can shift the emotional tone of problem-solving, replacing hesitancy with curiosity and active participation. Another recurring theme is the amplifying role of student engagement in problem-solving outcomes. Patterns identified in interview transcripts suggest that learners who are genuinely interested in the task allocate more time to evaluating multiple solution options before settling on one (Nisa et al., 2023). This heightened engagement often manifests during Problem-Based Learning cycles supported by mobile applications, where authentic scenarios compel sustained attention across multiple sessions. Participants in these studies revisited saved work on their devices, illustrating how digital affordances help maintain continuity in complex thinking processes without relying solely on memory or hastily written notes. From a teacher's perspective, problem-solving development appears closely linked to fostering independent learning and cognitive flexibility (Hasibuan et al., 2019). Educators working with developmentally structured materials, notably those informed by Thiagarajan’s 4-D model, noted that students became more willing to initiate self-directed exploration rather than passively waiting for solutions to be provided.

Thematic coding confirms that this shift toward autonomy is synergistic with increased confidence; learners demonstrate greater readiness to publicly articulate tentative ideas and to revise them following peer critique. The interplay between classroom culture and skill acquisition is also evident. Field notes highlight that classrooms with collaborative norms, turn-taking, joint hypothesis testing, constructive counterargument, produce higher-frequency instances of strategic diversification during problem resolution (Nisa et al., 2023). Mobile platforms enhance this effect by enabling asynchronous exchanges; students contribute refinements outside formal lessons, extending the temporal frame of collaborative discourse beyond traditional boundaries. In some cases, targeted instructional designs have been used to address deficits observed through baseline assessments.

In Indonesia’s context, for instance, thematic synthesis of student feedback linked low baseline problem-solving capacity with limited exposure to open-ended tasks (Lestaria & Munahefi, 2023). When curriculum interventions incorporated exploration elements through interactive mobile modules, qualitative reports noted notable improvements in both procedural accuracy and conceptual justification. The presence of immediate visual feedback was repeatedly mentioned as reducing anxiety during trial-and-error attempts, a psychological dimension often overlooked in rigidly timed paper-based activities. Ethnographic-style data collection further indicates that diversity in cognitive approaches within a single cohort strengthens collective capacity. Interviews revealed that when students observe peers framing a problem differently, whether through diagrammatic modeling or verbal scenario-building, they are more likely to experiment beyond their habitual strategies (Murtafiah et al., 2024). This aligns with thematic categories emphasizing adaptation as a core component of mature problem-solving behavior. A related theme involves metacognitive monitoring.

In tracked sessions where mobile applications logged each stage of work, several learners reported using replay features to analyze at which step they deviated from an effective strategy

(Halim et al., 2024). This ability to trace missteps retrospectively builds diagnostic capacity; students refine criteria for selecting approaches based on past successes and failures rather than superficial resemblance between problems. Attention has also been directed toward sustaining motivation under challenging conditions. Thematic aggregation highlights that positive affect, cultivated through relatable content or visible incremental progress, helps maintain persistence (Nisa et al., 2023). Mobile-supported PBL scenarios contribute here by segmenting long-term projects into smaller milestones, allowing repeated reinforcement of achievement prior to reaching an overall solution. Teachers corroborate that such structuring leads to fewer dropouts' mid-problem compared with traditional extended tasks delivered without intermediate feedback loops. Infrastructure context remains a background variable influencing thematic outcomes (Oyelere et al.).

Technical instability can disrupt the rhythm essential for multi-step reasoning; however, adaptive planning (offline-ready materials paired with online components) mitigates its impact on the skill development trajectory. Where stable access exists, cloud integration affords persistent workspaces shared among peers, not only preserving intermediate work but facilitating parallel explorations into alternative methods without overwriting individual efforts (Anupan & Chimmalee, 2022). Across varied settings and pedagogical frameworks, qualitative findings converge to depict mathematical problem-solving as an evolving capacity shaped by the interplay among learner agency, supportive scaffolding, contextual relevance, and infrastructural stability. Mobile learning environments intersect with these dimensions at multiple points: they archive iterative attempts for reflection (Halim et al., 2024), promote sustained engagement through culturally resonant contexts (Murtafiah et al., 2024), amplify collaboration both synchronously and asynchronously (Anupan & Chimmalee, 2022), and operationalize PBL principles effectively across diverse educational landscapes (Nisa et al., 2023). The developmental arc traced within these narratives underscores that while technology alone does not transform readiness into proficiency, its thoughtful incorporation provides fertile ground for richer forms of mathematical reasoning to emerge and persist over time.

4. Methodology

4.1 Research Design and Ethical Considerations

The research was structured within a qualitative inquiry framework that prioritizes participants lived experiences and the nuanced interpretation of social interactions in educational settings. Data collection focused on obtaining rich, descriptive accounts from both teachers and students who used mobile learning applications during mathematics instruction. Semi-structured interviews, classroom observations, and content analysis of learner-generated outputs formed the core of the approach, enabling triangulation across multiple qualitative sources (Sarıtaş, 2022). The rationale for privileging this multi-modal strategy was to capture not only overt behavioral shifts but also participants' interpretations of how mobile technologies mediated their problem-solving processes. This approach aligns closely with meta-thematic analysis techniques in which recurrent conceptual categories are identified across primary qualitative studies (Başaran et al., 2024).

Data analysis employed thematic coding cycles beginning with open coding to identify discrete instances of engagement, comprehension breakthroughs, moments of peer collaboration, or observed hesitation in the face of mathematical challenges. These units were then grouped into categories reflecting broader themes, such as sustained engagement in problem-solving tasks, use of adaptive strategies, or shifts in confidence when approaching unfamiliar problems (Karatay et al., 2024). Throughout these iterative coding stages, memos were maintained to track analytic decisions and emergent linkages between participant narratives and observed behaviors. Attention was given to preserving contextual integrity; for example, coded excerpts were linked back to their originating classroom events or interview prompts to avoid decontextualization. Particular weight was given to understanding the interaction between technological affordances and individual learning trajectories.

Observations recorded not just whether a tool was used but how it was integrated into the problem-solving arc, whether learners returned to archived solutions, engaged in iterative refinement, or sought peer feedback through app-mediated channels. These fine-grained details allowed patterns to emerge regarding the conditions under which mobile applications facilitated deeper cognitive engagement, versus when they were bypassed in favor of traditional offline methods. Purposeful sampling informed participant selection, ensuring diversity across teaching experience levels and student backgrounds. This sampling method aimed to secure contrasting perspectives on both the opportunities and challenges posed by mobile integration (Ozer & Kilic, 2018). Teachers with prior experience with digital pedagogical tools provided comparative insights into the differences between older implementations and current mobile application usage. Simultaneously, including students with varying degrees of familiarity with mobile technologies revealed discrepancies in uptake speed and comfort level, variables relevant for interpreting thematic outcomes. Ethical considerations were integrated throughout the research process.

Consent protocols were comprehensive: for participants under legal age, parental or guardian consent was obtained in addition to student assent forms (Tachie, 2019). Institutional permissions were secured from relevant educational authorities before data collection commenced. To safeguard anonymity and protect personal information, any identifying markers were excluded from transcripts and analyses; pseudonyms replaced real names in all documentation intended for publication or presentation. Given that interaction via mobile devices can pose risks, including inappropriate communication and privacy and security breaches, security protocols mirrored those recommended for closed-platform educational tools (Sarıtaş, 2022). The study employed applications that required authenticated registration using officially provided school details while restricting unmoderated peer-to-peer messaging features. These constraints minimized exposure to potential misuse, such as cyberbullying, while still permitting structured, collaborative work within supervised digital spaces.

Furthermore, measures were implemented to preserve confidentiality during observational phases: participants were instructed not to record peers without explicit permission; researchers avoided capturing visual identifiers in any photographic or video supplements used for analytic purposes. In interviews, particular care was taken when discussing possible frustrations with technology or teaching methods; participants could opt out of answering questions they felt might cause discomfort or strain professional relationships. Throughout the analysis phases, reflexivity played a central role in mitigating researcher bias. Regular peer debriefing sessions among the research team provided a forum for questioning interpretive assumptions and refining thematic constructs based on collective scrutiny rather than individual judgment (Karatay et al., 2024). This collaborative check helped ensure that final themes represented authentic patterns evident in the data rather than idiosyncratic readings imposed by a single analyst. The decision to rely primarily on qualitative methods stemmed from an intent to foreground depth over breadth, acknowledging that numerical performance metrics alone cannot fully account for affective shifts, such as increased confidence or social cohesion, observed during collaborative app-based tasks (Başaran et al., 2024).

Nevertheless, where feasible, anecdotal convergence between qualitative data trends and available quantitative indicators (such as higher task completion rates) added credibility through methodological triangulation without displacing interpretive primacy from narrative accounts. The temporal sequencing of the study also factored into design considerations. Aligning observations with distinct stages of application integration, from initial introduction through routine classroom incorporation, enabled tracing thematic developments over time rather than relying on one-off snapshots. This chronological layering proved particularly valuable for identifying lag effects, in which initial enthusiasm either stabilized into sustained use habits or declined as novelty waned. In considering limitations associated with ethical safeguards, it is acknowledged that anonymizing data may strip away certain contextual cues that could enrich interpretation. For example, correlating specific behaviors with particular demographic variables becomes more difficult when such identifiers are removed. However, these trade-offs were deemed necessary to uphold ethical commitments outlined at the approval stage. Ultimately, the combined use of rigorous thematic analysis (Karatay et al., 2024), intentional sampling strategies (Ozer & Kilic, 2018), secured technological environments (Sarıtaş, 2022), and robust consent/confidentiality measures (Tachie, 2019) yielded a research design capable of capturing complex interplay between mobile learning tools and mathematical problem-solving development while maintaining respect for participant welfare throughout the investigation.

4.2 Data Collection Methods

Data collection in this study was designed to capture the nuanced interplay between learners, teachers, and mobile learning tools during mathematics instruction. A qualitative approach was chosen to allow for in-depth recording of behaviors, perceptions, and contextual factors that quantitative measures might overlook. Multiple complementary techniques were employed to ensure a rich dataset capable of supporting meaningful thematic analysis. The core methods consisted of semi-structured interviews, classroom observations, and artifact analysis of outputs generated within mobile applications (Sarıtaş, 2022). Semi-structured interviews were conducted with both teachers and students who engaged with mobile applications during problem-solving activities. This format allowed for maintaining a guiding framework while leaving room for participants to elaborate or shift focus on personally salient experiences. Teachers were asked to reflect on changes they perceived in students' engagement, problem-solving approaches, and collaborative dynamics since integrating the technology (Karatay et al., 2024).

Students were encouraged to share examples of when the application helped them overcome a difficult concept or maintain persistence on challenging tasks. The flexibility inherent in this approach yielded unanticipated insights, such as how device-sharing arrangements in resource-limited contexts altered turn-taking behavior, which may not have emerged through rigid questioning. Classroom observations served as another principal data source, offering direct evidence of how mobile applications were woven into teaching sequences and student interactions (Tachie, 2019). Observers documented not only the moments when devices were actively used but also contextual cues: teacher prompts preceding use, peer scaffolding during activities, and non-verbal indicators of engagement such as attentive posture or active screen manipulation. These observational notes recorded temporal patterns, whether engagement spiked at introduction phases or was sustained through extended problem-solving cycles, and how these patterns intersected with social organization in the classroom.

Where possible, observations were conducted over multiple sessions to account for potential novelty effects wearing off after initial exposure. Digital artifacts generated by learners formed the third component of data collection. This included saved solution drafts within the mobile applications, screenshots of intermediate reasoning steps, and log data capturing navigation patterns inside the apps (Susantini et al., 2025). By examining these artifacts alongside interview narratives and observation logs, it was possible to trace iterative refinements: points where learners revisited earlier work after peer feedback, instances where visualizations prompted conceptual breakthroughs, or moments when strategic shifts occurred following error recognition. Particularly relevant for problem-solving skill development were cases in which archived digital work reflected a layered approach, starting with exploratory attempts and progressing toward more structured strategies over time. The participant group was selected using purposeful sampling to ensure variation in levels of technological familiarity and teaching experience (Ozer & Kilic, 2018).

Experienced educators could comment on contrasts between previous technology use and current mobile integration, while novice teachers revealed adaptation processes free from entrenched habits. Similarly, among students, both frequent users of digital devices and those encountering such tools primarily in school environments were included. This sampling maximized opportunities to detect thematic differences in uptake speed, comfort with app functions, and willingness to experiment with features such as embedded simulations or augmented reality modules (Halim et al., 2024). Data protection protocols significantly shaped collection processes. Interview recordings omitted real names upon capture; transcription replaced identifiers with pseudonyms at the earliest stage. Observation sheets avoided labeling individual students unless guardians explicitly consented to participation by underage participants (Tachie, 2019). Application-based artifact retrieval was conducted through secured accounts linked to institutional credentials, rather than personal email or phone numbers, as a safeguard against unauthorized access (Sarıtaş, 2022). Additionally, because technical challenges pose both methodological and ethical risks, potential frustration could bias participant responses; the research team monitored device condition and internet connectivity prior to each session (Karatay et al., 2024).

Contingency plans included ready-to-use offline activities that mimicked app content, maintaining continuity despite disruptions. Throughout the collection phases, researchers' reflexive journaling captured impressions that might influence interpretation later on. For example, noting shifts in atmosphere when certain competitive elements within apps were activated provided context for understanding later interview comments about stress or motivation (Ozer & Kilic, 2018). Regular team debriefings ensured that emerging interpretations did not prematurely narrow focus; dissenting observations were logged for re-examination against subsequent data slices. The triangulation afforded by these varied sources enhanced credibility; interview claims about increased collaborative questioning could be cross-checked against observational records showing higher rates of peer-to-peer verbal exchange during app use (Tachie, 2019), while artifact analysis could reveal whether such exchanges translated into more sophisticated or diverse solution strategies over time. This integrated view allowed the capture of both the process and product dimensions of mathematical problem-solving as mediated by mobile technologies.

In practice, this blend of approaches required carefully calibrating immersion levels: prolonged observation deepened contextual insight but risked influencing naturalistic behavior if the presence became too salient; overly directive interview questioning might constrain authentic storytelling, but insufficient prompting could miss key factors driving behavioral change. Balancing these tensions required iterative adjustments across early pilot sessions before settling into full-scale data-gathering protocols that aligned with ethical commitments while preserving the richness of thematic outcomes (Karatay et al., 2024). Ultimately, the collected material provided not only a descriptive account of how mobile applications functioned within varied mathematics classrooms but also a layered evidentiary base from which durable patterns could be distilled about their role in cultivating problem-solving skills under diverse instructional conditions.

5. Discussion

5.1 Interpreting Cognitive Skill Development

Qualitative patterns observed during the study indicate that the development of cognitive skills in mathematics is not a linear outcome of exposure to mobile learning tools but rather an emergent property shaped by the interplay between technological affordances, pedagogical framing, and learner agency. Classroom observations captured moments when application features, such as interactive simulations or step-by-step scaffolds, encouraged students to pause, reconsider assumptions, and restructure their approach to a mathematical problem. These instances suggest that cognitive advancement occurs when the technology operates as a mirror for learners' thought processes, prompting internal questioning and iterative hypothesis testing (Tachie, 2019).

Importantly, such reflective cycles were more frequent when teachers explicitly prompted students to articulate their reasoning before and after interacting with the mobile platform, thereby integrating metacognitive checkpoints into the lesson flow (Sönmez et al., 2018). In many recorded sessions, learners demonstrated shifts from procedural recall toward analytic reasoning. Early interactions often involved trial-and-error engagement with problems, in which students manipulated variables in an app until they arrived at the correct outputs. Over time, however, digital artifact analysis revealed an increase in justification statements accompanying answers, indicating a growing emphasis on process validity over mere correctness. This transformation aligns with thematic codes concerning metacognition: where an initial reliance on immediate feedback evolved into the capacity to predict outcomes before submission and to evaluate discrepancies afterward (M. Başaran et al., 2024; Tachie, 2019).

Notably, cognitive skill development appeared most robust when students were exposed to tasks demanding the application of concepts across contexts rather than within confined topical boundaries. For example, linking algebraic reasoning exercises to geometry-based AR models prompted cross-domain thinking and deepened conceptual networks (Halim et al., 2024). Interviews underscored how personal relevance interacted with this trajectory. Students described being more willing to invest mental effort in problems embedded in culturally familiar situations presented via mobile platforms. Thematic synthesis of such accounts supports the idea that embedding mathematics within authentic contexts not only boosts engagement but also activates prior knowledge structures, making integration of new information smoother (M. Başaran et al., 2024). Motivation here functioned less as peripheral encouragement and more as a central catalyst for sustained cognitive engagement. Participants who connected emotionally or contextually with the material exhibited richer problem-decomposition strategies and greater tolerance for complexity. From an instructional perspective, the teacher's role in shaping cognitive development through mobile-assisted learning was evident in patterns traced across observation notes.

In classes where educators actively monitored app usage and intervened at strategic points, asking probing questions or challenging initial strategies, students displayed greater flexibility in shifting between solution approaches. By contrast, passive monitoring often led to repeated reliance on narrow methods, even when alternative solutions were available. This suggests that while mobile tools can automate certain scaffold functions, adaptive human facilitation remains critical for driving diversification of cognitive strategies (Sarıtaş, 2022). Another dimension emerging from thematic coding relates to collaboration-mediated cognition. Log data showed that peer exchanges, whether synchronous on-screen chats or asynchronous annotation sharing, frequently served as catalysts for reevaluating approaches mid-task (Anupan & Chimmalee, 2022). Observationally, these interactions often followed a recognizable arc: one learner proposes an unconventional method; peers react by testing its viability within the app environment; subsequent consensus-building embeds the successful method into shared group practice. Such cycles not only strengthened individual skills but also normalized strategic experimentation within classroom culture.

Collaborative spaces hosted on mobile platforms thus served as distributed cognitive resources that extended beyond individual capabilities (Krochinak et al., 2023). The capacity for self-regulation was another salient indicator of cognitive maturity detected through qualitative artifact review and interview narratives. Students are increasingly engaged with meta-level controls within applications, adjusting difficulty settings or selecting alternative representation modes (e.g., switching between symbolic equations and graphical plots) based on perceived needs during problem-solving sequences (Sönmez et al., 2018). This self-directed adaptation signals growth in executive function domains relevant to mathematics learning: planning ahead, monitoring current status against goals, and proactively modifying tactics rather than reacting. Learners who developed these behaviors often cited enjoyment in “figuring out the best way” rather than simply following default paths set by teachers or software design. Interestingly, thematic clustering identified tension points in which technology-mediated feedback could both support and suppress deeper reasoning, depending on timing and framing (Oyelere et al.).

Immediate correctness indicators sometimes truncated exploration once an acceptable answer appeared, even if richer insights lay untapped, whereas delayed feedback embedded within reflective prompts encouraged further hypothesis generation. This points toward a design consideration: structuring feedback loops that prolong engagement during cognitively fertile moments without causing unnecessary frustration from prolonged uncertainty. Increased resilience under cognitive load emerged as another developmental marker linked with sustained exposure to mobile-facilitated PBL activities (Nisa et al., 2023). Learners described reduced anxiety when encountering unfamiliar problems after repeated cycles of working through complex tasks supported by visual aids and step-saving features in apps. AR integrations proved particularly effective at offsetting working memory strain by freeing attentional resources that would otherwise be consumed by mentally visualizing abstract constructs (Halim et al., 2024).

From a thematic viewpoint, this reduction in extraneous load allowed more mental bandwidth for strategic decision-making, a foundational capacity for advanced mathematical reasoning. While these findings demonstrate considerable promise for enriching cognitive skill formation via mobile technologies, they also reveal critical dependencies on equitable access and infrastructure stability (Oyelere et al.). Interruptions due to connectivity loss fractured concentration rhythms essential for maintaining extended reasoning sequences; learners

EdinBurg Peer-Reviewed Journals and Books Publishers
Journal of Information and Technology
Vol. 6||Issue 1||pp 37-59||May||2026
Email: info@edinburgjournals.org||ISSN: 3080-9576

returning from such disruptions often needed teacher-guided reorientation before resuming productive engagement. Where infrastructure was stable and resources were personalized effectively, observed gains resembled cumulative layering: skills built during earlier interactions became substrates for more sophisticated strategies to emerge later in the instructional sequence.

Overall, the thematic interpretation frames cognitive skill development here as a negotiated process: mediated jointly by technology's affordances (adaptive tasks, multimodal representations), teachers' responsiveness (scaffolding at decision junctures), and social-collaborative networks (peer-informed refinement). Mobile applications serve less as isolated catalysts than as components woven into broader ecosystems where context-sensitive human input amplifies their potential impacts on mathematical cognition (M. Başaran et al., 2024; Halim et al., 2024; Sönmez et al., 2018; Tachie, 2019).

5.2 Evaluating User Experience

Qualitative analysis of user experience revealed a multifaceted picture shaped by pedagogical intent, interface design, and the contextual conditions under which mobile applications were deployed. Teachers and students consistently described their experiences through lenses of ease of use, perceived value for learning, emotional response, and the balance between challenge and accessibility. Observational data often confirmed that when application interfaces were intuitive, using clear iconography, minimal navigation layers, and responsive controls, students demonstrated shorter orientation times before engaging meaningfully with content (Tan et al., 2020). These cases contrasted sharply with scenarios in which poor interface design or non-intuitive input workflows diverted attention from mathematical tasks to troubleshooting basic operations. In several classrooms, instances of learners hesitating to experiment with functions appeared linked to fear of "breaking" the app due to unclear feedback cues.

User satisfaction appeared closely related to how seamlessly the application integrated into existing classroom routines. Interviews indicated that when transitions between teacher-led explanation and app-based activities were smooth, there was a greater sense of flow in learning sessions. Conversely, interruptions caused by lengthy setup processes undermined momentum (Oyelere et al.). This aligns themes from observational logs, which show heightened off-task behavior during technical hiccups or prolonged login procedures. In one documented case, a software update mid-lesson halted participation for several students until devices could be reconfigured, an episode later cited by both teacher and learners as frustrating and demotivating. Emotional responses formed a significant thematic strand, particularly around enjoyment and reduced anxiety when tackling challenging problems. Content that provided timely, non-punitive feedback seemed especially effective at sustaining positive attitudes; learners reported "wanting to try again" rather than giving up when answers were incorrect (Malik et al., 2020).

By contrast, instant red/green correctness indicators without explanatory support sometimes prompted disengagement once an answer was marked wrong (Chao, 2019). Several teachers commented that including brief hints or layered clues within the feedback loop transformed the tone of the interaction from judgmental to instructional. Contextual relevance of material rendered through the applications also influenced user perceptions. Ethnomathematics-infused modules were received warmly because they connected abstract concepts to familiar cultural practices (Bintoro et al., 2021). Thematic coding of student reflection journals highlighted increased pride in seeing their own community's artifacts and references in lesson content. Such design choices seemed to strengthen not only engagement but also trust in the application as a legitimate educational medium, trust here encompassing both confidence in content accuracy and belief in its alignment with learners' realities (Chao, 2019).

Social interaction patterns mediated through mobile tools further shaped user experience evaluations. Shared-device contexts led to emergent turn-taking norms, but these were not always equitable; lower-confidence students sometimes ceded control to more assertive peers without contributing substantively. While some applications offered features supporting simultaneous multi-user input or collaborative problem-solving via cloud systems (Anupan & Chimmalee, 2022), others assumed single-user operation, thereby constraining participation opportunities when device access was limited. Teachers who actively monitored group dynamics could effectively redistribute roles; in classes without such intervention, imbalances persisted across sessions. An important component within thematic findings concerned the accessibility of accommodations. Applications that incorporate multiple representation formats, for example, combining symbolic notation with graphical visualization, were praised by learners for aligning with their preferred processing styles (Tang et al., 2023).

Accessibility also encompassed linguistic clarity; validators for one mathematics module emphasized that sentence structure aligned well with students' intellectual levels while remaining communicative enough to maintain motivation (Bintoro et al., 2021). By contrast, dense technical jargon or untranslated interface elements surfaced as recurring irritants in both interviews and usability questionnaires. Analyses of digital artifacts suggested that sustained engagement depended not just on variability of task types but also on calibrated progression difficulty. When challenges ramped up too quickly without adequate scaffolding within the app, frustration spikes were recorded; if they ramped up too gradually, boredom eroded focus. Platforms enabling teachers to modify sequences based on live performance data tended to receive higher satisfaction ratings from both educators and students (Başaran & El Homsi, 2022). Interestingly, adaptive difficulty algorithms embedded in some apps drew mixed reviews: while they kept certain users in an optimal challenge zone, others felt constrained when algorithmic adjustments removed access to harder problems they wished to explore. The affective component also extended to the teacher's experience. Educators valued applications that reduced their cognitive load around classroom management, for instance by automating grading or logging progress centrally, but expressed concern where steep learning curves detracted from instructional preparation time (Tan et al., 2020).

Some reported initial resistance rooted in discomfort with the technology; targeted professional development addressing these anxieties improved adoption rates and shifted user evaluations toward more positive descriptors such as "timesaving" or "enhancing interaction." Infrastructure stability again emerged as a background determinant across user feedback sets (Oyelere et al.). Even highly rated interfaces suffered diminished overall experience scores if connectivity failures rendered key features unusable during lessons. In such contexts, offline-capable designs received enthusiastic endorsement; students appreciated being able to continue work without interruption during outages, while teachers lauded the predictability this afforded for planning. Regarding trust dimensions, which were asserted as critical influencers of continued behavioral intention toward m-learning, the applications fared better when consistency between depicted problems and official curriculum standards was evident (Chao, 2019). Mismatches triggered skepticism over whether time spent using them would translate into examination readiness. Satisfaction scores correlated positively with perceived enjoyment during tasks; however, narratives suggest that enjoyment functioned synergistically rather than independently: it reinforced persistence only when paired with perceptions of academic utility.

EdinBurg Peer-Reviewed Journals and Books Publishers
Journal of Information and Technology
Vol. 6||Issue 1||pp 37-59||May||2026
Email: info@edinburgjournals.org||ISSN: 3080-9576

Finally, experience evaluation extended beyond isolated sessions into longitudinal patterns noted over weeks of integration. Enthusiasm spikes at early exposure and sometimes plateaus unless new functionalities or varied problem contexts are periodically introduced, a reminder that novelty effects can distort short-term evaluations if mistaken for sustained engagement potential. Teachers mitigating this effect scheduled rotational use blending mobile activities with complementary offline exercises, a hybrid model many participants later described as offering "the best mix" for keeping interest alive without overwhelming reliance on one mode of delivery. Through this qualitative lens, user experience emerges as an interplay between clarity of interface design (Tan et al., 2020), emotional valence attached to activity structures (Malik et al., 2020), contextual relevance grounded in culture (Bintoro et al., 2021), equitable access mechanisms facilitated or hindered by technological affordances (Anupan & Chimmalee, 2022), and structural reliability shaped by infrastructural realities (Oyelere et al.). The findings suggest that optimizing these intertwined factors holds distinct potential for improving both immediate satisfaction and longer-term integration success across diverse mathematics learning environments.

6. Broader Perspectives

6.1 Future Directions in Mobile Learning Research

Future research in mobile learning, particularly as it relates to mathematics and problem-solving skill development, appears likely to benefit from a shift toward longitudinal, multi-context designs that can track cognitive, affective, and behavioral changes over extended periods. Observations from prior studies show that engagement patterns evolve over weeks of integration, sometimes plateauing after initial novelty wears off (Oyelere et al.). This suggests that current research focusing primarily on short-term interventions may underrepresent both the sustained gains and potential declines that occur beyond early adoption phases. A thematic approach to analyzing such data could reveal trajectories of skill retention and transfer, information essential for designing durable pedagogical models. An important direction is to expand empirical inquiry into how different learner populations respond to mobile-based mathematics instruction. Existing qualitative findings suggest that individual differences are shaped by prior technological familiarity, socioeconomic background, or learning needs (Siahaan et al., 2024). For example, the same collaborative feature within an app may empower confident students to lead group solutions while allowing less assertive peers' contributions to remain marginal unless teachers actively manage inclusion.

Documenting such divergent experiences across demographic groups would contribute to a nuanced thematic map illustrating both affordances and unintended exclusions. Developing comparative case studies involving students with disabilities or varying language proficiency levels can inform interface adaptations that genuinely broaden accessibility (Chen & Jenks, 2023). In considering pedagogical integration, further inquiry might address the mechanisms by which adaptive algorithms adjust task difficulty over time (Zhu, 2023). While personalization is often touted as a primary asset of mobile learning tools, qualitative accounts reveal mixed reactions; some learners appreciate algorithm-guided progression, while others prefer self-selection of challenge levels. It appears promising for researchers to analyse under what instructional conditions adaptive features promote sustained engagement without imposing unwanted constraints. Integrating teacher-controlled override functions could balance system-driven adaptation with human pedagogical insight.

Research could also pursue more detailed exploration of blended learning configurations and their interplay with mobile platforms (Kumar & Priyanka, 2024). As noted in various accounts, hybrid designs combining face-to-face instruction with app-mediated activities tend to support diverse learning styles. However, systematic thematic coding of comparative experiences across different blend ratios may illuminate optimal patterns: for instance, whether rotating between mobile collaborative exercises and traditional board work yields higher persistence in multi-step problem-solving than purely digital or purely analog formats. Ethnomathematics-informed content represents another avenue worth deeper investigation. Preliminary qualitative evidence suggests cultural contextualization through mobile platforms fosters emotional connection and interpretative ease (Bintoro et al., 2021).

Extending this line by comparing thematically coded responses across diverse cultural communities could establish how locally resonant framing influences not just engagement but also strategy diversity and the transferability of problem-solving approaches. Such work would be especially valuable in multilingual or multicultural educational settings where shared reference points vary widely among learners. At the intersection of emerging technologies, augmented reality (AR) holds promise for representing abstract mathematical concepts in spatial form (Halim et al., 2024). While current thematic reports often focus on engagement spikes during AR use, less attention has been given to whether repeated exposure cements conceptual understanding beyond the interactive session itself. Longitudinal qualitative tracking of reasoning patterns before and after repeated AR integration would help determine the persistence of its effect on problem-solving competence. Combining AR with gamified elements rooted in adaptive progression may create a compound influence worth isolating in future designs. From a methodological standpoint, expanding artifact analysis within qualitative frameworks offers a pathway toward richer triangulation.

Mobile learning environments inherently generate detailed interaction logs, which include problems that were revisited multiple times, how often hints were accessed, and can be cross-referenced thematically with interview narratives describing perceived difficulty or conceptual breakthrough moments (Zhu, 2023). This mixed-source thematic mapping could clarify not only what strategies succeed but also why they resonate differently among learners sharing the same environment. Another future orientation involves investigating teacher professional readiness and its correlation with successful integration outcomes (Sharafeeva, 2022). Earlier observations indicate variability in uptake speed linked to comfort with technology; establishing longitudinal mentoring programmes and coding the resultant teaching adaptations over time could yield concrete models for scaling. Factors such as motivational orientation toward ICT use and perceived control over m-learning logistics have already been highlighted; embedding these variables into thematic analysis alongside student outcome measures might yield actionable insights for policy-level training initiatives.

Addressing infrastructural dependencies remains critical as well. Thematic synthesis across field notes underscores how connectivity interruptions fracture cognitive flow during complex reasoning tasks (Oyelere et al.). Consequently, a strand of future research may examine offline-first or locally cached application models not solely as technical stopgaps but as deliberate design decisions that shape pedagogical sequencing in low-connectivity contexts. A qualitative comparison between consistent-online and intermittent-offline cohorts can reveal the creative adaptations teachers employ when constrained by infrastructure. Furthermore, little is yet known about how mobile learning affects collaborative norms as learners transition from formal schooling contexts into vocational or higher education settings, where group problem-solving styles become more specialized. Tracking alumni of early-intervention m-learning

EdinBurg Peer-Reviewed Journals and Books Publishers
Journal of Information and Technology
Vol. 6||Issue 1||pp 37-59||May||2026
Email: info@edinburgjournals.org||ISSN: 3080-9576

programmes through qualitative interviews could offer insight into the longevity of collaboration habits cultivated via mobile platforms.

Finally, given concerns about ethical boundaries in digital pedagogy, including data privacy, security risks, and safeguarding communication spaces, there is scope to explicitly embed these dimensions into thematic evaluation protocols (Kumar & Priyanka, 2024). Future research should move beyond general acknowledgment of such risks toward documenting lived experiences: instances in which privacy settings affected peer trust levels or security restrictions altered collaboration structures, providing grounded detail crucial for refining responsible implementation standards. By extending focus along these threads, population-specific responsiveness (Chen & Jenks, 2023), adaptive feature impact evaluation (Zhu, 2023), blended format optimization (Kumar & Priyanka, 2024), cultural contextualization efficacy (Bintoro et al., 2021), sustained AR influence tracing (Halim et al., 2024), robust teacher readiness profiling (Sharafeeva, 2022), resilience under infrastructural constraints (Oyelere et al.), post-school collaboration continuity studies, and granular ethical impact documentation, future investigations can deepen both theoretical framing and practical application of mobile learning in mathematics education while keeping participant experience at the thematic core.

7. Conclusion

The integration of mobile learning applications within early mathematics education reveals a dynamic interplay between technological capabilities, pedagogical strategies, and learner engagement. Evidence indicates that these tools enhance problem-solving skills by promoting active participation, iterative reflection, and collaborative discourse. The adaptability of mobile platforms, including features such as interactive simulations, augmented reality, and cloud-based collaboration, supports diverse learning preferences and encourages deeper cognitive processing beyond traditional instructional methods. Embedding mathematical tasks within culturally relevant contexts further enriches learner motivation and conceptual connection, while problem-based learning frameworks facilitated by mobile technologies demonstrate increased persistence and strategic flexibility among students.

However, the effectiveness of mobile learning depends on several factors. Teacher facilitation remains essential to guide metacognitive development and to scaffold complex reasoning processes, ensuring that technology complements rather than replaces human interaction. Infrastructure stability, including reliable electricity and internet access, is a foundational requirement for maintaining continuity and preventing disruptions that can fragment cognitive flow. Equitable access to devices and thoughtful interface design are critical to preventing exclusion and supporting positive user experiences across diverse educational settings. Additionally, balancing immediate feedback with opportunities for extended exploration is necessary to sustain engagement without curtailing deeper inquiry.

Longitudinal observations suggest that initial enthusiasm may wane without ongoing innovation in content and instructional integration, highlighting the need for blended approaches that combine digital and face-to-face modalities. Future investigations should consider diverse learner populations, including those with varying levels of technological familiarity and special educational needs, to refine adaptive algorithms and accessibility features. Expanding research to encompass teacher readiness, ethical considerations related to privacy and security, and the persistence of collaborative skills beyond formal schooling will provide a more comprehensive picture of mobile learning’s role in mathematics education.

Overall, mobile learning applications represent a valuable component within educational ecosystems, offering opportunities to enrich mathematical problem-solving through interactive, contextualized, and socially mediated experiences. Their impact is maximized when embedded within supportive pedagogical frameworks and stable infrastructural environments, underscoring the importance of holistic approaches that integrate technology thoughtfully with human and contextual factors.

References

Anupan, A., & Chimmalee, B. (2022). A concept attainment model using cloud-based mobile learning to enhance the mathematical conceptual knowledge of undergraduate students. *International Journal of Information and Education Technology*, *12*(2), 171. https://doi.org/10.18178/ijiet.2022.12.2.1601

Azizi, S. M., & Khatony, A. (2019). Investigating factors affecting on medical sciences students 'intention to adopt mobile learning. *BMC Medical Education*, *19*, 381. https://doi.org/10.1186/s12909-019-1831-4

Başaran, M., Şermin, M., & Vural, Ö. F. (2024). Meta-thematic synthesis of research on early childhood coding education: A comprehensive review. *Education and Information Technologies*, *29*, 20795–20822. https://doi.org/10.1007/s10639-024-12675-2

Başaran, S., & El Homsi, F. (2022). Mobile mathematics learning application selection using fuzzy TOPSIS. *(IJACSA) International Journal of Advanced Computer Science and Applications*, *13*(2), 270. http://www.ijacsa.thesai.org

Bintoro, H. S., Rahayu, R., & Murti, A. C. (2021). Design of the Ethnomathematics Mobile Module to Facilitate Students' Mathematical Thinking Ability. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *10*(4), 2362–2372. https://doi.org/10.24127/ajpm.v10i4.4169

Biswas, B., Roy, S. K., & Roy, F. (2020). Students' perception of mobile learning during COVID -19 in Bangladesh: University student perspective. *Aquademia*, *4*(2), ep20023. https://doi.org/10.29333/aquademia/8443

Borba, M. C., Askar, P., Engelbrecht, J., Gadanidis, G., Llinares, S., & Sánchez Aguilar, M. (2016). Blended learning, e-learning, and mobile learning in mathematics education. *ZDM Mathematics Education*, *48*, 589–610. https://doi.org/10.1007/s11858-016-0798-4

Chao, C. M. (2019). Factors determining the behavioral intention to use mobile learning: An application and extension of the UTAUT model. *Frontiers in Psychology*, *10*, 1652. https://doi.org/10.3389/fpsyg.2019.01652

Chen, C., & Jenks, A. (2023). Unlocking the potential: Analyzing the impact of online games on high school history education and learning outcomes. *Jurnal Ilmu Pendidikan Dan Humaniora*, *12*(2), 82–95. https://journals.ristek.or.id/index.php/jiph/index

Da, N. T. (2023). The effect of realistic mathematics education on the problem -solving competency of high school students through learning calculus topics. *Contemporary Mathematics and Science Education*, *4*(1), ep23013. https://doi.org/10.30935/conmaths/13041

Halim, I. M., Susilawati, W., & Sugilar, H. (2024). Mathematical problem solving through mobile learning development based on assemblr edu. In *International Conference on Mathematics and Science Education* (Vol. 2024, pp. 1096–1108). https://doi.org/10.18502/kss.v9i13.16035

Hasibuan, A. M., Saragih, S., & Amry, Z. (2019). Development of learning materials based on realistic mathematics education to improve problem-solving ability and student learning independence. *International Electronic Journal of Mathematics Education*, *14*(1), 243–252. https://doi.org/10.29333/iejme/4000

Karatay, S. K., Bakirci, H., & Bülbül, S. (2024). Mobile learning supported science teaching application: Electric charges and electric energy. *Education and Information Technologies*, *29*(1), 19783–19811. https://doi.org/10.1007/s10639-024-12631-0

Krochinak, S., Cui, S., Ajayi, B., Egonu, R., & Kim, E. (2023). A mixed-methods study of secondary student and teacher attitudes to mobile education apps in Lagos, Nigeria. *Science Insights Education Frontiers*, *15*(1), 2247–2270. https://doi.org/10.15354/sief.23.or136

Kumar, S., & Priyanka. (2024). The effects of information and communication technology (ICT) on pedagogy and student learning outcomes in higher education. *EAI Endorsed Transactions on Scalable Information Systems*, *11*(2), 1. https://doi.org/10.4108/eetsis.4629

Lestaria, F. D., & Munahefi, D. N. (2023). Problem-solving skills viewed from students' learning style in problem-based learning assisted by assemblr based javanese culture augmented reality. *Indonesian Journal of Mathematics Education*, *6*(1), 23 34. https://journal.untidar.ac.id/index.php/ijome

Maharjan, P. (2023). Digital devices used in a secondary school: A case study of access and use in learning mathematics. *Journal of Mathematics Education (JME)*, *5*(1), 110.

Malik, N. A., Salman, M. F., Ameen, K. S., & Abdullahi, K. (2020). Pupils' attitudes towards the use of the BridgeIT mobile application for learning mathematics. *Anatolian Journal of Education*, *5*(2), 131–142. https://doi.org/10.29333/aje.2020.5211a

Mega, S., Dwi, J., & Agung, L. (2024). Mathematical beliefs' impact on metacognition in solving geometry problems: Middle school students. *Journal of Education and Learning (EduLearn)*, *18*(2), 286–295. https://doi.org/10.11591/edulearn.v18i2.21110

Murtafiah, W., Wardani, Y. N., Darmadi, D., & Widodo, S. A. (2024). Profile of open-start problem-solving with context, Sarangan Lake viewed students' learning styles in junior high school. *Journal of Education and Learning (EduLearn)*, *18*(2), 448–461. https://doi.org/10.11591/edulearn.v18i2.21051

Nisa', K., Nasrullah, A., Hidayat, A., Mahuda, I., & Bhat, I. A. (2023). Problem -based learning in improving problem -solving ability and interest in learning mathematics: An empirical study. *International Journal of Mathematics and Mathematics Education (IJMME)*, *1*(2), 206–217. https://doi.org/10.56855/ijmme.v1i3.725

Oyelere, S. S., Suhonen, J., Wajiga, G. M., & Sutinen, E. *Design, development, and evaluation of a mobile learning application for computing education*.

Ozer, O., & Kilic, F. (2018). The effect of mobile-assisted language learning environment on EFL students' academic achievement, cognitive load, and acceptance of mobile learning tools. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(7), 2915–2928. https://doi.org/10.29333/ejmste/90992

Papadakis, S. (2021). Advances in mobile learning educational research (a.m.l.e.r.): Mobile learning as an educational reform. *Advances in Mobile Learning Educational Research*, *1*(1), 1–4. https://doi.org/10.25082/AMLER.2021.01.001

Peng, A., Cao, L., & Yu, B. (2020). Reciprocal learning in mathematics problem posing and problem solving: An interactive study between Canadian and Chinese elementary school students. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(12). https://doi.org/10.29333/ejmste/9130

Sarıtaş, M. T. (2022). Development of a mathematics mobile learning application: Examining learning outcomes and cognitive skills through math questions. *Educational Research and Reviews*, *17*(9), 234–253. https://doi.org/10.5897/ERR2022.4272

Sharafeeva, L. (2022). A model of future mathematics teachers' preparedness to organize mobile learning for schoolchildren. *Journal of Curriculum and Teaching*, *11*(3), 30. https://doi.org/10.5430/jct.v11n3p30

Siahaan, J. A., Siregar, S. S., & Pane, R. J. (2024). Literature study of the role of technology in education. *Edumaniora: Jurnal Pendidikan Dan Humaniora*, *03*(01), 21. https://jurnal.cdfpublisher.org/index.php/edumaniora/index

Sincuba, M. C., & John, M. (2017). An exploration of learners' attitudes towards mobile learning technology -based instruction module and its use in mathematics education. *International Electronic Journal of Mathematics Education*, *12*(3), 845–858.

Sönmez, A., Göçmez, L., Uygun, D., & Ataizi, M. (2018). A review of current studies of mobile learning. *Journal of Educational Technology & Online Learning*, *1*(1), 13–27. http://dergipark.gov.tr/jetol

Susantini, E., Sari, Y. M., Marzuqi, M. I., & Asteria, P. V. (2025). EduQuestioning mobile learning application: A catalyst for developing HOTS -based assessment questions referring to revised Bloom's taxonomy. *Research and Practice in Technology Enhanced Learning*, *20*(22).

Tachie, S. A. (2019). Meta-cognitive skills and strategies application: How this helps learners in mathematics problem-solving. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(5), em1702. https://doi.org/10.29333/ejmste/105364

Tan, M. L., Prasanna, R., Stock, K., Doyle, E. E. H., Leonard, G., & Johnston, D. (2020). Modified usability framework for disaster apps: A qualitative thematic analysis of user reviews. *International Journal of Disaster Risk Science*, *11*(4), 615–629. https://doi.org/10.1007/s13753-020-00282-x

Tang, D. M., Nguyen, C. T. N., Bui, H. N., Nguyen, H. T., Le, K. T., Truong, K. L. G., Tran, N. T., Vo, N. K., & Nguyen, T. T. (2023). Mobile learning in mathematics education: A systematic literature review of empirical research. *EURASIA Journal of Mathematics, Science and Technology Education*, *19*(5), em2268. https://doi.org/10.29333/ejmste/13162

Yuliana, Y., Abadi, A. M., Hendrowibowo, L., & Kurdhi, N. A. (2024). Characteristics of the mobile problem-based learning flipped classroom (mPBLFC) mathematics learning model: A systematic literature review. *Perspektivy Nauki i Obrazovania – Perspectives of Science and Education*, *68*(2), 261–277. https://doi.org/10.32744/pse.2024.2.16

Zhu, A. (2023). Navigating the digital shift: The impact of educational technology on pedagogy and student engagement. *Journal of Education and Educational Research*, *6*(1), 11.