

## Development of m-learning in flipped classroom learning model to increase interest and understanding of mathematics concepts

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### ABSTRAK

Pembelajaran matematika di Indonesia menghadapi tantangan rendahnya minat belajar dan keterbatasan pemahaman konsep siswa, yang tercermin dari skor PISA 2022 Indonesia sebesar 366 poin. Penelitian ini bertujuan mengembangkan M-learning berbasis model flipped classroom untuk meningkatkan minat dan pemahaman konsep matematika siswa. Metode penelitian menggunakan model ADDIE, dengan pendekatan SDLC diterapkan khusus pada tahap pengembangan. Subjek penelitian ini 69 siswa kelas XI SMA Negeri 1 Cawas. Instrumen pengumpulan data meliputi kuesioner validasi ahli, kuesioner respons pengguna, kuesioner minat belajar, dan tes pemahaman konsep matematika. Hasil penelitian menunjukkan M-learning sangat layak menurut validasi ahli media (rata-rata 3,84) dan ahli materi (rata-rata 3,9); dan dinilai sangat praktis oleh guru (rata-rata 3,96) serta praktis oleh siswa (rata-rata 3,36). Implementasi M-learning meningkatkan minat belajar sebesar 20,2% dan pemahaman konsep matematika sebesar 72,70%. M-learning flipped classroom terbukti efektif meningkatkan minat dan pemahaman konsep matematika.

### ABSTRACT

Mathematics education in Indonesia faces challenges of low learning interest and limited conceptual understanding among students, reflected in Indonesia's 2022 PISA score of 366 points. This research aims to develop M-learning based on the flipped classroom model to enhance students' interest and understanding of mathematical concepts. The research method employed the ADDIE model, with the SDLC approach, specifically applied in the development phase. The research subjects were 69 eleventh-grade students of State High School 1 Cawas. The data collection instruments included expert validation questionnaires, user response questionnaires, learning interest questionnaires, and mathematical concept understanding tests. The results showed that M-learning was highly feasible according to media expert validation (average 3.84) and material expert validation (average 3.9), and it was rated as very practical by teachers (average 3.96) and practical by students (average 3.36). The M-learning implementation increased learning interest by 20.2% and mathematical concept understanding by 72.70%. M-learning flipped classroom proved effective in enhancing interest and understanding of mathematical concepts.



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## INTRODUCTION

The contemporary educational landscape is experiencing an unprecedented digital transformation that fundamentally reshapes pedagogical approaches and learning methodologies across global educational systems. Digital technologies have become essential catalysts for educational innovation, enabling personalised learning experiences and expanding access to quality education (UNESCO, 2020). Indonesia, as one of the world's largest developing nations, is actively participating in this digital revolution, implementing comprehensive strategies to integrate technology into its educational framework. The Indonesian Ministry of Education, Culture, Research, and Technology has highlighted the critical importance of digital literacy and technological integration in achieving the nation's educational goals outlined in the National Education System Law No. 20/2003. This transformation encompasses not merely the adoption of digital tools but represents a paradigmatic shift toward learner-centered pedagogical approaches that underline critical thinking, collaboration, creativity, and communication skills. The Association of Educational and Communication Technology (AECT) defines educational technology as "the study and ethical practice of facilitating learning and improving performance through the creation, use, and management of appropriate technological processes and resources" (Januszewski & Molenda, 2008). This definition underscores the ethical responsibility of educators to leverage technology effectively for enhancing student learning outcomes. Educational institutions worldwide are increasingly recognising that successful digital transformation requires comprehensive teacher training programs, robust technological infrastructure, and systematic curriculum integration strategies. The integration of mobile learning (m-learning) technologies has emerged as a particularly promising approach, offering unprecedented flexibility and accessibility in educational delivery. Modern educational paradigms demand that teachers possess 21st-century skills, including digital literacy, adaptability, and the ability to facilitate collaborative learning environments that prepare students for an increasingly interconnected global economy (Qarkaxhja et al., 2021).

Mathematics education in Indonesia faces significant challenges that directly impact students' academic achievement and conceptual understanding, creating substantial barriers to effective learning outcomes. The Programme for International Student Assessment (PISA) 2022 results reveal that Indonesian students' mathematical literacy scored 366 points, representing a concerning decline of 13 points from the 379 points achieved in 2018 (OECD, 2023). This downward trend is particularly alarming considering that Indonesia has consistently failed to reach the international average PISA score of 500 points throughout the assessment period from 2000 to 2022. These statistics indicate systemic deficiencies in mathematics education that extend beyond individual student performance to encompass broader pedagogical and structural issues within the Indonesian education system. Mathematical conceptual understanding is the foundational cornerstone for students' success in mathematics, enabling them to comprehend abstract concepts, apply problem-solving strategies effectively, and develop procedural fluency in mathematical operations (Ningrum et al., 2022). Research consistently demonstrates that students who lack solid conceptual foundations struggle significantly with advanced mathematical topics due to the hierarchical and interconnected nature of mathematical knowledge structures. Hussein (2022) emphasised that conceptual understanding constitutes the fundamental cognitive framework that enables students to approach mathematical problems with confidence and accuracy. The systematic nature of mathematics requires students to master basic concepts thoroughly before progressing to more complex topics, as each new concept builds upon previously acquired knowledge and skills. Ho (2020) argued that comprehensive conceptual mastery provides students with cognitive tools to select appropriate problem-solving approaches and demonstrate procedural fluency in mathematical calculations and analyses.

Direct observational data collected from SMA Negeri 1 Cawas on March 13, 2024, through structured interviews with mathematics teachers revealed significant evidence of learning loss and pedagogical ineffectiveness in current mathematics instruction practices. Learning loss, defined as the suboptimal learning conditions that result in students' inability to achieve expected academic progress, has become a pervasive issue affecting mathematics education quality across Indonesian secondary schools. The interviewed mathematics teacher reported that students

consistently found it challenging to answer questions requiring higher-order thinking skills, particularly those involving application and analysis-level cognitive processes. This finding aligns with Bloom's taxonomy framework, which emphasises the importance of progressing from basic knowledge recall to higher-order cognitive skills, including analysis, synthesis, and evaluation. The prevalence of conventional teaching methods, characterised by teacher-dominated lecture formats and passive student participation, has been identified as a primary contributing factor to student disengagement and poor conceptual understanding. Students frequently exhibit signs of boredom, lack of motivation, and academic anxiety during mathematics lessons, creating negative learning environments that impede effective knowledge acquisition. The teacher further noted that students often feel overwhelmed by academic workloads without possessing sufficient foundational understanding of basic mathematical concepts, creating a cycle of academic frustration and declining performance. A study [Alali & Al-Barakat \(2023\)](#) corroborates these observations, indicating that current learning models remain predominantly direct instruction approaches where educational activities follow unidirectional communication patterns. In such traditional pedagogical frameworks, teachers assume primary responsibility for content delivery while students maintain passive roles as information recipients, resulting in monotonous learning experiences that fail to promote active student engagement. This pedagogical approach contradicts contemporary educational research, emphasising the importance of student-centered learning environments that encourage active participation, collaborative problem-solving, and critical thinking skill development.

The flipped classroom model represents a pedagogical innovation that addresses the limitations of traditional instructional approaches by redistributing learning activities between the classroom and home environments to optimise educational effectiveness. [Weiß & Friege \(2021\)](#) defines the flipped classroom as an instructional approach that relocates traditional classroom activities to home-based learning contexts, enabling face-to-face classroom time to focus on interactive discussions, collaborative problem-solving, and individualised support. [Huanhuan & Chi \(2017\)](#) expand this definition by emphasising that flipped classroom methodology is specifically designed to maximise the quality of teacher-student interactions while providing students with greater autonomy in managing their learning schedules and pace. The successful implementation of flipped classroom approaches requires comprehensive integration of digital media platforms, systematic content organisation strategies, and robust assessment mechanisms that accurately measure student learning progress and engagement levels. Mobile learning (m-learning) technology emerges as an ideal complementary solution for flipped classroom implementation, offering the technological infrastructure necessary to support flexible, accessible, and personalised learning experiences. M-learning utilises mobile devices and wireless communication technologies to enable learning activities that transcend traditional spatial and temporal limitations, allowing students to access educational content anytime and anywhere. [UNESCO \(2020\)](#) identifies numerous benefits of m-learning implementation, including expanded equitable access to education, support for individualised learning approaches, provision of immediate feedback and assessment, facilitation of anytime-anywhere learning opportunities, optimisation of classroom time utilisation, creation of collaborative learning communities, and support for field-based learning experiences. The integration of m-learning technologies within flipped classroom frameworks creates synergistic educational environments that address both pedagogical and technological requirements for effective mathematics instruction. M-learning implementation within flipped classroom contexts significantly improves students' conceptual understanding and creates positive correlations between learning interest and academic achievement in mathematics education.

The convergence of identified pedagogical challenges and available technological solutions creates a compelling rationale for investigating the development and implementation of m-learning technologies within flipped classroom learning models, specifically targeting mathematics conceptual understanding and student engagement enhancement. This research addresses critical gaps in current educational practice by proposing innovative pedagogical approaches that leverage technological capabilities to overcome traditional instructional limitations while maintaining focus on fundamental mathematical learning objectives. The

proposed integration of m-learning and flipped classroom methodologies represents a systematic response to the documented challenges in Indonesian mathematics education, offering potential solutions for improving student conceptual understanding, increasing learning motivation, and developing 21st-century skills essential for academic and professional success. The research recognizes that effective educational innovation requires careful consideration of technological capabilities, pedagogical principles, student learning characteristics, and institutional implementation requirements to ensure sustainable and impactful educational improvements. By focusing specifically on mathematics conceptual understanding and student interest development, this study aims to provide empirical evidence regarding the effectiveness of technology-enhanced pedagogical approaches in addressing persistent challenges in mathematics education. The investigation seeks to contribute valuable insights to the growing body of research on educational technology integration while providing practical guidance for educators, administrators, and policymakers interested in implementing innovative learning approaches. The ultimate goal is to demonstrate how thoughtful integration of mobile learning technologies within flipped classroom frameworks can create engaging, effective, and accessible mathematics learning environments that support improved student outcomes and enhanced educational quality in Indonesian secondary education contexts.

## METHOD

This research and development (R&D) study employs the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) instructional design model, which originated from Florida State University in the 1970s and was later elaborated (Branch, 2009), in his comprehensive framework for creating learner-centered learning environments. The ADDIE model is integrated with the Software Development Life Cycle (SDLC) approach to systematically manage the complex development process of mobile learning applications (Spatioti, Kazanidis, & Pange, 2022). This integration ensures that the Analysis phase of ADDIE aligns with the Requirements Gathering in SDLC, the Design phase corresponds to System Design, the Development phase integrates with Implementation and Coding, while Implementation and Evaluation phases synchronise with Testing and Maintenance phases of SDLC. The developmental sequence is illustrated in Figure 1, which demonstrates the systematic integration of both methodologies.

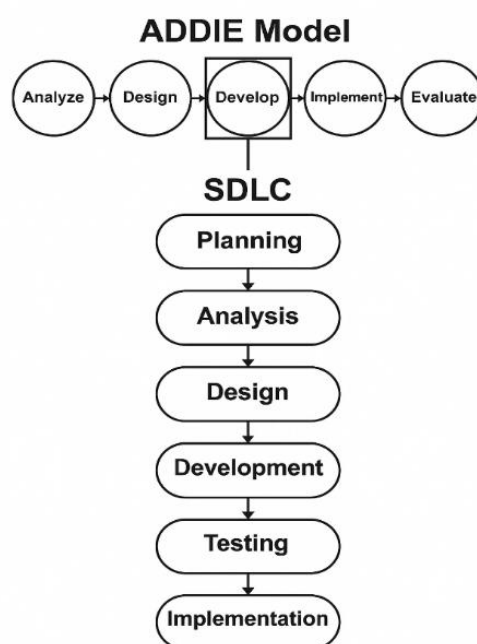


Figure 1. ADDIE Model Steps with SDLC Approach

The R&D process follows a structured validation approach encompassing multiple stages: expert validation by media and subject matter specialists, small-group testing with limited participants, and comprehensive field testing. The study was conducted at SMA Negeri 1 Cawas during the 2024/2025 academic year, involving 36 students from class XI A (experimental group) and 33 students from class XI B (control group). A quasi-experimental design with pretest-posttest nonequivalent control group configuration was implemented, where the experimental group experienced the flipped classroom m-learning model while the control group received conventional instruction focusing on advanced mathematics matrix concepts.

Data collection utilised multiple instruments, including media validation questionnaires, material validation questionnaires, user response questionnaires, learning interest questionnaires, and mathematics concept comprehension tests. Quantitative descriptive analysis techniques were applied to evaluate feasibility through expert assessments, practicality through teacher and student evaluations post-implementation, and effectiveness through learning interest measurements and concept understanding assessments.

The questionnaire grids for media expert feasibility, material expert feasibility, practicality, student learning interest, and mathematics concept comprehension are listed in [Tables 1, 2, 3, 4, and 5](#), respectively. The expert media feasibility questionnaire was used to obtain quality data in terms of the technical aspects of the product.

**Table 1. Media expert eligibility questionnaire grid**

Aspects	Indicators
Media display	Clarity of material presentation
	Harmony of content layout
	Aesthetics and clarity of display
Font usage	Appropriateness of font size for the device
	Consistency of font type throughout the application
	Contrast between font and background
Visual design	Comfortable background color selection
	Harmony of visual elements such as images and animations
	Clarity of images, graphics, and animations
Navigation	Ease of use of menus and buttons
	Simplicity of interface navigation
	Responsiveness of navigation on various devices
Interactivity	Responsive to user input
	Presence of interactive features
Privacy and data storage	User privacy protection
	Storage of user learning progress
Availability of access on various devices	Support for various operating systems
	Availability of support for low-speed internet connections
Accessibility features for users with special needs	Alternative tests in images
	Support for screen readers
	Support for keyboard/voice controls

The expert material feasibility questionnaire was used as a tool to obtain data regarding the quality of the learning content.

**Table 2. Questionnaire grid for material expert feasibility**

Aspects	Indicators
Content feasibility	Relevance of material to learning objectives
	Suitability of material to student needs
	Timeliness of material
Depth of subject matter	Comprehensive presentation of concepts
	Level of understanding required of students
	Simple explanations for difficult concepts
	Consistency of subject matter with Competency Standards (SK) and Basic Competencies (KD)
Relevance of subject matter	Relationship of subject matter with applicable curriculum
	Consistency of examples and exercises with subject matter
	Accuracy of examples for explanations
Sample questions	Sufficiency of examples provided
	Clarity of instructions for exercises/quizzes
Evaluation	Variety of evaluation types/forms
	Provision of feedback

The practicality questionnaire aims to measure how practical the use of M-learning based flipped classroom learning media is for teachers and students.

**Table 3. Practicality questionnaire grid**

Aspects	Indicators
Ease of use	Ease of navigation
	Ease of access to materials
Flexibility of use	Flexibility of time of use
	Flexibility of place of use
Availability of features	Interactive facilities
	Completeness of materials
Effectiveness of use	Support for Learning
	Effectiveness in Improving Learning
User engagement	Student Engagement in Learning
	Teacher Participation in Learning
Time efficiency	Time Savings in the Learning Process
Overall user experience	User Satisfaction
	Recommendations for Further Use

This questionnaire aims to identify the students' interest in learning mathematics before and after using m-learning based on the flipped classroom learning model.

**Table 4. Student interest questionnaire grids**

Aspects	Indicators
Feeling happy	Students find learning math interesting and fun
Student interest	Desire to understand and learn math
Student attention	Students show return focus during the lesson
Student engagement	Students are actively involved in learning math
Effort to learn	Students seek additional ways to understand math

The mathematics concept understanding test is used to measure students' understanding levels before and after the implementation of M-learning with the flipped classroom model. The

form of the test is tailored to the needs of current education, designed in the form of mathematical literacy to reflect students' abilities in understanding and applying concepts in real-life contexts.

**Table 5. Math concept understanding test grid**

Indicators	Question topic
Restate a concept	Intercity distance
Classify objects according to certain properties in accordance with the concept	Production of goods at the factory
Giving examples and non-examples of a concept	Customer survey at branch stores
Presenting concepts in various forms of mathematical representations	Cake shop
Develop necessary or sufficient conditions of a concept	Equipment prices at each branch of the company
Select, use, and utilize certain procedures or operations	Aircraft type
Apply concepts or algorithms to problem solving	Types of bacteria

The feasibility and practicality criteria were measured using Likert scale interpretations as presented in Table 6, mathematics learning interest was evaluated according to criteria in Table 7, while effectiveness was determined using Hake's (1999) N-Gain Score formula with criteria outlined in Table 8.

**Table 6. Feasibility/practicality criteria**

Interval	Likert Score	Criteria Interpretation
$X > 3,00$	4	Very suitable/practical
$2,50 < X \leq 3,00$	3	Suitable/practical
$2,00 < X \leq 2,50$	2	Not suitable/practical
$X < 2,00$	1	Not very suitable/practical

(Mardapi, 2008)

Next, the results of the assessment of interest in learning mathematics are calculated using the criteria in Table 7.

**Table 7. Criteria for interest in learning mathematics**

Interval	Criteria
$< 35$	Low
35 - 45	Insufficient
46 - 56	Adequate
$> 3,00$	High

Meanwhile, the effectiveness was assessed using the N-Gain Score formula developed by Hake (1999), by processing pretest and posttest data on mathematical concept understanding. The effectiveness criteria are shown in Table 8.

**Table 8. Effectiveness criteria**

Interval	Criteria
$< 40$	Not effective
40 - 55	Less effective
56 - 75	Moderately effective
$> 76$	Effective

(Hake, 1999)

## RESULTS

### M-learning development process

The development of M-learning in the flipped classroom model followed a systematic approach combining the ADDIE model with the Software Development Life Cycle (SDLC) methodology. This integration ensured comprehensive product development from conceptualisation to implementation.

### Analysis phase

The analysis phase revealed significant challenges in mathematics education based on direct field observations and teacher interviews. Students demonstrated low comprehension levels in mathematics and exhibited diminished interest in the subject, resulting in minimal engagement during learning activities. These findings align with Indonesia's consistently low performance in international assessments, as evidenced by PISA reports from 2000 to 2022, where Indonesia has failed to achieve the average PISA score of 500 (OECD, 2023). Student characteristic analysis informed the selection of appropriate learning media. The research focused on matrix topics, covering fundamental concepts to practical applications across six integrated learning sessions designed for self-directed learning within the flipped classroom framework.

### Design phase

The design phase established a comprehensive flowchart mapping the learning flow from initial student access through feature navigation to task completion and evaluation. This systematic approach ensured logical progression and an intuitive user experience throughout the learning process.

### Development phase

The development phase employed the SDLC approach across six stages: planning, analysis, design, development, testing, and implementation. The planning and analysis stages identified development needs and user requirements. The design stage focused on system architecture, dashboard layout for students and teachers, platform navigation, and content presentation strategies. The development and testing phases involved media creation, system configuration, and comprehensive validation processes.

### Validation results

Expert validation assessed both media and material quality through systematic evaluation. Media validation, conducted by technical experts, yielded a score of 96 with an average of 3.84, categorising the system as "Very Good" quality. Material validation by subject matter experts of 78, with an average of 3.9, also falls within the "Very Good" category. These high validation scores indicate that the M-learning system meets established technical and pedagogical standards.

### Implementation phase

The implementation phase involved practical application in experimental classes, followed by comprehensive practicality and effectiveness testing. This stage provided empirical evidence of the system's real-world applicability and impact on learning outcomes.

### Practicality test results

Practicality assessment evaluated user experiences from both teachers and students directly involved in the learning process. The evaluation measured ease of use, appropriateness to learning needs, and effectiveness in supporting the educational process (see Table 9).

**Table 9. Practical test results**

Number of Subjects	Number of Scores	Average Score	Percentage of Scores	Quality Criteria
1	99	3.96	99%	Very Practical
36	3.028	3.36	84.11%	Practical

Teacher evaluation resulted in a score of 99 with an average of 3.96, meeting "Very Practical" criteria. This high score indicates excellent system usability, interface design, and administrative functionality from the educator's perspective. The single teacher participant's overwhelmingly positive response suggests strong system stability and content management simplicity. Student

evaluation from 36 participants yielded a score of 3028 with an average of 3.36, categorised as "Practical." The student score of 84.11% suggests general system effectiveness while indicating areas for potential improvement, particularly in user interface intuitiveness for technology-novice users. The difference between teacher and student scores likely reflects varying levels of technological familiarity and system complexity from different user perspectives.

**Effectiveness test results**

Effectiveness testing measured M-learning's impact on student learning interest and mathematical concept understanding through pre- and post-implementation assessments.

**Learning interest assessment**

Learning interest evaluation demonstrated significant improvement following M-learning implementation. The mean score before implementation was 41.86. After M-learning integration, the mean score increased to 50.31. This improvement of 8.45 points represents a 20.2% increase, categorised as "sufficient" according to established assessment criteria.

**Mathematical concept understanding assessment**

Mathematical concept understanding underwent comprehensive statistical analysis including normality testing, homogeneity testing, and t-test analysis to ensure robust and reliable results.

**Normality Test Results**

The Shapiro-Wilk normality test confirmed normal data distribution across all groups, validating subsequent parametric statistical analyses (see [Table 10](#)).

**Table 10. Results of normality test of mathematical concept understanding**

Class	Statistic	df	Sig.
<b>Students' Understanding of Mathematical Concepts</b>			
Pre-Test Experiment	956	36	158
Post-Test Experiment	950	36	102
Pre-Test Control	971	33	509
Post-Test Control	952	33	150

All significance values exceeded 0.05, confirming normal distribution in both control and experimental groups for pre-test and post-test data. This validation supports the null hypothesis ( $H_0$ ) and satisfies normality assumptions for subsequent statistical analyses.

**Homogeneity Test Results**

Homogeneity testing using one-way ANOVA assessed variance uniformity between groups.

**Table 11. Results of homogeneity test of mathematical concept understanding**

Class	Levene Statistic	df1	df2	Sig.
<b>Students' Understanding of Mathematical Concepts</b>				
Based on Mean	879	1	67	352
Based on Median	790	1	67	377
Based on Median and with adjusted df	790	1	63.663	378
Based on Trimmed Mean	830	1	67	366

The homogeneity test results (Sig. 0.352 > 0.05) confirmed homogeneous variance between control and experimental groups, validating the appropriateness of comparative statistical testing (see [Table 11](#)).

**Independent sample t-test results**

Independent sample t-test compared mean differences between control and experimental groups.

**Table 12. results of independent sample t-test for understanding mathematical concepts**

Class	F	Sig.	t	df	Sig. (2-tailed)
<b>Ngain_Persen</b>					
Equal variances assumed	3.874	53	3.615	67	1
Equal variances not assumed	-	-	3.571	59.253	1

The significance value (2-tailed) of  $0.001 < 0.05$  indicates statistically significant differences between groups (Table 12). These results demonstrate that M-learning integration with the flipped classroom model significantly enhances students' mathematical concept understanding.

The experimental group achieved a 72.70% improvement in mathematical concept understanding, evidenced by substantially higher post-test scores compared to pre-test results. This substantial improvement indicates M-learning's considerable potential for enhancing mathematical concept comprehension.

#### **Evaluation summary**

Comprehensive evaluation confirms that the developed M-learning system is both effective and practical for improving student learning interest and mathematical concept understanding. The product demonstrates suitability for implementation as a learning instrument within the flipped classroom framework, providing empirical evidence of its educational value and practical applicability.

## **DISCUSSION**

### **M-learning development and implementation**

The development of Moodle-based M-learning represents a significant advancement in digital mathematics education, combining modern interface design with comprehensive content management capabilities (Ostrovskaya et al., 2023). The application was specifically engineered to facilitate advanced mathematics learning, particularly matrix concepts, through interactive Android-based delivery. As a Learning Management System (LMS), M-learning provides structured content delivery and intuitive navigation, empowering students to engage in independent learning with comprehensive access to digital resources. This development aligns with Zidoun et al. (2020) theoretical framework, which defines M-learning as education utilising mobile technology, including phones, tablets, and similar devices to support flexible and distributed learning processes. The integration of mobile technology in mathematics education addresses contemporary students' technological expectations while accommodating diverse learning preferences and schedules. The implementation of Moodle as the underlying platform significantly enhances the learning management process, as supported by a study (Alotaibi, 2024), which demonstrated that LMS integration in M-learning development substantially improves mathematics learning outcomes through enhanced navigation ease and material accessibility. Consequently, Moodle implementation not only streamlines administrative processes but also creates a responsive digital environment aligned with 21st-century educational demands and contemporary student expectations.

### **Validation and quality assurance**

The comprehensive validation process involved two expert categories: media specialists and subject matter experts, ensuring thorough assessment of both technical and pedagogical aspects. Media experts evaluated interface design, system functionality, and user experience elements, while subject matter experts assessed content accuracy, pedagogical appropriateness, and alignment with learning objectives (Peláez et al., 2025). Both expert categories awarded high scores, indicating that visual design, layout organisation, and content structure meet established pedagogical standards. These validation results corroborate findings (Putro et al., 2023), which concluded that M-learning incorporating flipped classroom models receives high suitability

ratings from both media and material experts. Digital learning products are essential for determining feasibility based on content and media presentation alignment. The systematic expert evaluation from both technical and pedagogical perspectives confirms the M-learning application's validity and feasibility as an educational medium. This multi-dimensional validation approach ensures comprehensive quality assurance, addressing both technological functionality and educational effectiveness.

### **Practicality assessment and user experience**

The practical evaluation revealed contrasting perspectives between teachers and students regarding system usability and accessibility. Teachers rated the application as highly practical, emphasising system stability and content administration simplicity. This positive teacher response indicates successful integration with existing educational workflows and administrative requirements (Rebollo & Oliveira, 2024). Student evaluation, while generally positive, revealed lower practicality scores, suggesting challenges in system comprehension and navigation. These difficulties likely stem from limited prior exposure to LMS technology in academic contexts, particularly among students unfamiliar with digital learning environments. The variance between teacher and student responses highlights the importance of comprehensive user training and gradual technology integration. Despite these challenges, the overall practical assessment indicates successful transition facilitation from conventional to digital learning methodologies. The system's practical value supports effective M-learning implementation in mathematics classroom environments, though additional user support and training may enhance student adoption and engagement.

### **Learning interest enhancement**

The quantitative analysis of learning interest demonstrated significant positive changes in student attitudes toward mathematics learning. The mean score increased from 41.86 to 50.31, representing a substantial improvement, indicating enhanced student motivation and engagement. This finding aligns with research (Alan & Yurt, 2024), which demonstrated that flipped model implementation through M-learning leads to considerable enhancement in student motivation and curiosity toward mathematics. The flipped classroom strategy, where students access materials independently through applications before face-to-face sessions, provides stimulation encouraging active participation and intellectual curiosity. This pre-class preparation allows students to engage more meaningfully during classroom discussions, as they arrive with foundational knowledge and specific questions. The observed learning interest enhancement substantiates the efficacy of digital strategies in creating substantial positive changes in mathematics learning dynamics. Research lends further support to this finding, asserting that the implementation of the flipped model through M-learning leads to a substantial enhancement in students' motivation and curiosity towards mathematics (Amad, et al., 2023). The interest improvement also reflects the engaging nature of interactive digital content compared to traditional textbook-based approaches. M-learning's multimedia capabilities, including videos, animations, and interactive exercises, cater to diverse learning styles and preferences, contributing to increased student engagement and sustained interest in mathematical concepts.

### **Mathematical concept understanding enhancement**

The implementation of M-learning demonstrated remarkable effectiveness in enhancing students' mathematical conceptual understanding, particularly in matrix topics. The pre-test and post-test comparison following the blended learning approach revealed substantial learning outcome improvements, indicating students' development of deeper comprehension of abstract mathematical concepts. The 72.70% improvement in mathematical conceptual understanding represents a significant educational achievement, demonstrating M-learning's capacity to facilitate meaningful learning rather than superficial knowledge acquisition. This substantial improvement suggests that students developed genuine conceptual understanding rather than mere procedural knowledge, indicating the effectiveness of the flipped classroom approach in promoting deep learning.

The integration of M-learning with the flipped classroom model provides students opportunities to explore materials independently at their own pace, subsequently engaging in interactive classroom discussions that reinforce and extend their understanding. This approach

accommodates different learning speeds and styles, allowing students to revisit challenging concepts multiple times before classroom engagement. These findings align with research (Yosiana et al., 2021), which demonstrated superior mathematical conceptual understanding performance using M-learning media compared to conventional learning methods. Additionally, mobile learning has some strong positive impacts on conceptual understanding in mathematics topics, as reinforced by the findings (Egara & Mosimege, 2024), which state that learners taught mathematics utilising a flipped classroom approach had higher mathematics achievement and interest scores than their peers taught using the conventional approach. The consistent evidence across multiple studies supports M-learning's effectiveness in enhancing mathematical concept comprehension across diverse educational contexts and student populations.

### **Implications for mathematics education**

The successful development and implementation of M-learning in the flipped classroom model has significant implications for mathematics education reform. The research demonstrates that technology integration, when properly designed and implemented, can address persistent challenges in mathematics learning, including low student engagement and conceptual understanding difficulties. The findings suggest that M-learning can serve as a bridge between traditional and modern educational approaches, providing familiar content delivery methods while incorporating innovative technological tools. This hybrid approach may be particularly effective in educational contexts where complete technology integration is challenging due to infrastructure or resource limitations. Furthermore, the research indicates that M-learning's effectiveness extends beyond the simple digitisation of traditional materials. The interactive nature of the platform, combined with the flipped classroom model's self-paced learning opportunities, creates a fundamentally different educational experience that promotes deeper engagement and understanding (Agyeman & Venessa, 2024).

The study's results also highlight the importance of comprehensive validation and testing processes in educational technology development. The systematic approach to validation, practicality assessment, and effectiveness testing provides a robust framework for future M-learning development projects, ensuring that technological innovations translate into meaningful educational improvements. The development of M-learning in the flipped classroom model represents a successful integration of modern educational technology with proven pedagogical approaches. The comprehensive development process, validated through expert assessment and empirical testing, demonstrates the system's effectiveness in enhancing both student interest and mathematical concept understanding. While challenges remain in ensuring universal user adoption and technological proficiency, the overall results indicate significant potential for M-learning to transform mathematics education through increased engagement, improved understanding, and enhanced learning outcomes. In line with this, research by Uy (2022) stated several challenges noted for the flipped classroom approach, including creating a digital divide among learners, dependence on preparation and trust, and an increase in computer screen time instead of people and places.

Theoretically, this study contributes to the development of learning technology by presenting an M-learning media model that combines the flipped classroom approach and mobile-based learning, specifically designed to support the understanding of mathematical concepts at the secondary level. This study strengthens the theoretical framework for interactive subject-based media design and demonstrates how instructional development models such as ADDIE and SDLC can be synergised in the production of media aligned with pedagogical objectives. While practically, this research provides concrete implementation steps and design guidelines for educators seeking to enhance mathematics learning through digital technology. The validated media products can serve as a reference for teachers and instructional designers aiming to integrate mobile learning into classroom activities, particularly in settings with limited face-to-face instruction time (Torres-Martín, et al., 2022). The application of the flipped classroom

methodology is more effective in achieving an improvement in the performance of students with this prolonged experience in time.

## CONCLUSION

This study successfully demonstrated that the development and implementation of M-learning educational media integrated with the flipped classroom model is effective in increasing students' interest in learning and understanding mathematical concepts, particularly in matrix material. The systematic development process, combining the ADDIE model and the SDLC approach, resulted in a valid, practical, and pedagogically sound learning platform, contributing theoretically to the design of mobile-based digital media in mathematics education. The main limitations of this study lie in the narrow scope of the topic, confined to matrix material, and the low technological literacy of some students, which hinders the optimal use of the media. Therefore, further research is recommended to expand the application of this media to various other mathematics topics to test the generalisation of its effectiveness, as well as to include mentoring strategies that support the improvement of students' and teachers' digital literacy. Additionally, comprehensive teacher training programs need to be developed to ensure consistent implementation quality across various educational contexts with varying levels of technological infrastructure.

## Author contributions

The authors made significant contributions to the study's conception and design. The authors was in charge of data analysis, interpretation, and discussion of results. The final manuscript was read and approved by the authors.

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## Conflict of interest

The authors declare that there is no potential conflict of interest.

## Data availability statement

All data are available from the authors.

## REFERENCES

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