Development of a Technology-enhanced Learning Model to Enhance Teachers' Critical Thinking through Professional and Pedagogical Competencies: A Comparative Study in Indonesia and Malaysia

Muhammad Iqbal Birsyada [1,*], Fahruddin [1], Esti Setiawati [2], Palupi Sri Wijayanti [3], Suyitno [4], Siti Zahrah Binti Mahfood [5], Nurul Asyikin Binti Hassan [5], and Yusri Bin Kamin [6]

[1] Department of Historical Education, Universitas PGRI Yogyakarta, Yogyakarta, Indonesia
[2] Master of Social Studies Program, Universitas PGRI Yogyakarta, Yogyakarta, Indonesia
[3] Department of Mathematics Education, Universitas PGRI Yogyakarta, Yogyakarta, Indonesia
[4] Department of Vocational Education of Automotive Technology, Universitas Muhammadiyah Purworejo, Purworejo, Indonesia
[5] Universiti Pendidikan Sultan Idris (UPSI), Malaysia
[6] Department of Technical and Engineering Education, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
Email: iqbal@upy.ac.id (M.I.B.); fahruddin@upy.ac.id (F.); esti@upy.ac.id (E.S.); palupi@upy.ac.id (P.S.W.); yitno@umpwr.ac.id (S.); zahrah@fsk.upsi.edu.my (S.Z.B.M.); nurulasyikin.h@fsk.upsi.edu.my (N.A.B.H.); p-yusri@utm.my (Y.B.K.)
*Corresponding author
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***Abstract*—This study aims to develop and validate an integrated mobile-computer-based learning model that enhances teachers' critical thinking by strengthening their professional and pedagogical competencies. Using a Research and Development (R&D) methodology guided by the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) framework, the study also adopted iterative refinement principles from Design-Based Research (DBR). The model was implemented in four schools in Indonesia and one in Malaysia through a limited trial ($N = 60$) and a large-scale trial ($N = 240$). The final product, a customized and responsive Moodle-based Learning Management System (LMS) accessible via both mobile and desktop devices, includes a modular learning path, a cross-country collaborative forum, digital assessment tools, and a portfolio builder, all supported by integrated learning analytics. Expert validation in both countries indicated high content relevance and cross-context suitability, indicating strong content relevance and cross-cultural applicability. Statistically significant improvements were observed in teachers' critical thinking scores, with mean gains of approximately +14 points in both countries. While these findings suggest consistent improvements, they should be interpreted with caution given the absence of a control group. The study contributes a replicable, technology-enhanced professional development model that is adaptable to educational contexts with similar infrastructure and teacher competency development needs.**

***Keywords*—critical thinking, professional competence, pedagogical competence, mobile learning, computer-based learning**

I. Introduction

In the current digital era, the integration of Information and Communication Technology (ICT)—particularly through mobile-computer-based learning model—has become pivotal in enhancing the quality of education and fostering teachers' professional growth, especially in developing critical thinking skills. Numerous studies have demonstrated that mobile learning (m-learning) effectively increases engagement, learning outcomes, and critical thinking abilities across various educational levels [1, 2]. Teacher education likewise requires innovation in development models to strengthen professional and pedagogical competencies through digital approaches, with meta-analytical studies indicating that well-structured mobile learning strategies can stimulate higher-order thinking skills while providing rapid and personalized feedback to both educators and learners [3, 4]. Although studies on ICT-based learning model development for teachers do exist, relatively few have specifically integrated professional and pedagogical competencies within a mobile learning framework and examined their effectiveness through cross-national comparative validation [5, 6]. This condition underscores the urgency of developing a mobile-computer-based learning model aimed at enhancing teachers' critical thinking skills while ensuring cross-cultural validation between Indonesia and Malaysia [7–9].

While the potential of mobile-computer-based learning model learning in fostering 21st-century skills is widely recognized, most existing models remain learner-centered and rarely focus on strengthening teachers' critical thinking through the systematic development of professional and pedagogical competencies [10, 11]. Furthermore, cross-national research on ICT-based learning model development for teachers is highly limited, leaving a gap in empirical evidence comparing the effectiveness of such models in two distinct educational contexts, such as Indonesia and Malaysia [12, 13]. This gap hinders the establishment of adaptive and internationally valid models. Therefore, this study proposes the development of a mobile-computer-based learning model designed to enhance teachers' critical thinking by reinforcing professional and pedagogical competencies, subsequently tested comparatively in both countries to ensure its relevance and effectiveness within cross-cultural contexts [14, 15].

Recent studies indicate that while mobile learning supports flexibility and accessibility in teacher professional development, Computer-Based Learning (CBL) offers a more structured and analytically robust environment for competency development. Research on CBL demonstrates its effectiveness in facilitating curriculum-aligned learning, formative assessment, and systematic feedback through Learning Management Systems (LMS), which are essential

for developing teachers' pedagogical and professional competencies ([4, 16]). These structured computer-based environments enable teachers to engage in sustained analytical tasks, data-driven reflection, and evidence-based instructional decision-making—processes that are critical for fostering higher-order and critical thinking skills. Therefore, integrating mobile learning with computer-based learning is necessary to balance flexibility with instructional depth in teacher professional development [17–19].

To ensure that the integration of mobile and computer-based learning is pedagogically grounded, instructional design frameworks are required [20, 21]. Alatas [13] in Southeast Asia, for example, demonstrated that ICT-based learning models developed in a structured manner significantly improved teachers' professional competence, particularly when coupled with cross-institutional collaboration activities. A similar approach on a cross-national scale—such as between Indonesia and Malaysia—has the potential to provide external validation of model effectiveness while generating pedagogical innovations adaptable to diverse educational contexts [22]. By integrating mobile and computer-based learning technologies, a competency-based framework, and systematic model development methods, the solution proposed in this study holds strong potential to address the existing research gap [23].

The literature indicates that most research on the development of critical thinking skills in education has predominantly focused on students rather than teachers. Jaramillo and Chiappe [17] highlighted the potential of mobile learning in facilitating communication and collaboration, yet their primary subjects were university students, not educators. Similarly, the meta-analysis found that the integration of mobile devices was effective in improving critical thinking, but the sample was limited to classroom-based student learning [16]. Research targeting teachers' critical thinking through the use of ICT remains scarce, despite the fact that such skills are essential for teachers to design learning activities that demand higher-order thinking [24, 25].

In addition, studies on the development of technology-based learning models tend to be local or confined to a single national context. For instance, Fahruddin and Saefudin demonstrated the success of an ICT-based model in enhancing teacher competencies in Indonesia, but did not examine the generalizability of the model in an international context [26]. To date, no cross-national Research and Development (R&D) studies a have been identified that integrate mobile-computer-based learning model with the framework of teachers' professional and pedagogical competencies, particularly to enhance educators' critical thinking. This gap underscores the need for research that not only develops ICT-based learning models that are locally relevant but also validates their effectiveness on a cross-cultural scale, such as among teachers in Indonesia and Malaysia [22, 27].

This study aims to develop and validate a mobile-computer-based learning model designed to enhance teachers' critical thinking by reinforcing professional and pedagogical competencies, and to examine its effectiveness comparatively in Indonesia and Malaysia. The novelty of this research lies in its integration of four core elements—mobile–computer-based learning model learning, professional competence, pedagogical competence, and teachers' critical thinking—into a single Analysis, Design, Development, Implementation, and Evaluation (ADDIE)-based development framework validated across countries, which is rarely found in the current literature [28]. Covering secondary school and higher education teachers in two countries with distinct educational contexts, this study is expected to produce a model that is adaptive, empirically validated, and replicable for improving ICT-based teaching quality across comparable educational environments with similar cultural and infrastructural characteristics.

In this study, the term mobile-computer-based learning model refers to an integrated approach that combines the flexibility of mobile access with the structured environment of computer-based instruction. The model is implemented using a single, responsive Moodle-based Learning Management System (LMS), which allows teachers to engage in professional development activities seamlessly across mobile and desktop devices. This unified platform supports consistency in learning experience and aligns pedagogical content with both device modalities without requiring separate applications.

II. Literature Review

A. Mobile-computer-based Learning Model Learning in Teacher Professional Development

The advancement of Information and Communication Technology (ICT) has fundamentally transformed the paradigm of teacher professional development, particularly through mobile learning (m-learning) and Computer-Based Learning (CBL). M-learning offers temporal and spatial flexibility, enabling teachers to access instructional materials and digital resources anytime, supporting self-paced learning, and fostering collaboration through instant messaging applications, online discussion forums, and social media-based platforms [29, 30]. In contrast, CBL excels in delivering complex content such as instructional simulations, multimedia-rich presentations, and the structured management of courses via Learning Management Systems (LMS), which provide assessment features, progress tracking, and resource repositories [31, 32]. Although each approach has its respective advantages, the literature indicates that their application in teacher development often occurs in isolation, without an integrative strategy that maximizes the strengths of both modalities [33–35].

The separate implementation of m-learning and CBL presents notable limitations. While m-learning is practical, it often falls short in handling learning content requiring intensive computation or specialized software-based activities. Conversely, CBL offers the capacity for data processing, multimedia material creation, and simulation software integration, yet lacks the mobility and real-time accessibility required for field-based learning [36]. In the context of teacher development, this separation results in a fragmented learning process: teachers tend to engage in formal learning via computers, while reflection and social interaction related to learning are conducted through mobile devices [37]. This condition highlights a design gap for a

learning system that can integrate both approaches into a unified and responsive ecosystem. Addressing this challenge, the present study attempts to design and evaluate such an integrated model, with its implementation details elaborated in the Methodology and Results sections [38, 39].

Furthermore, while studies on m-learning and CBL for teacher professional development exist, cross-national research integrating both approaches remains scarce, particularly with a focus on teachers' critical thinking as a learning outcome [40, 41]. In the context of Indonesia and Malaysia, the shared cultural background and educational policies provide a substantial opportunity for cross-cultural validation of such an integrative model. Variations in ICT infrastructure, technology adoption levels, and participant characteristics could serve as critical variables in assessing the adaptability of the developed model [20, 42]. Therefore, this study not only seeks to combine the strengths of m-learning and CBL but also to construct a framework for enhancing teachers' professional and pedagogical competencies that is empirically proven to foster educators' critical thinking in two countries with differing yet complementary contexts.

B. Professional and Pedagogical Competence as Predictors of Teachers' Critical Thinking

Theoretically, professional competence (mastery of subject matter, ethical practice, and continuous self-development) and pedagogical competence (design, implementation, and evaluation of instruction) form the cognitive and dispositional foundation for the emergence of critical thinking in teachers. Within the Pedagogical Content Knowledge (PCK) framework [4, 16], the quality of teacher reasoning when mapping conceptual representations, anticipating misconceptions, and selecting instructional strategies demands analysis—evaluation processes—the core of critical thinking [19, 43]. When the technological dimension is incorporated through the Technological Pedagogical Content Knowledge (TPACK) framework [44, 45], teachers' pedagogical decisions increasingly require cross-domain critical reasoning (content-pedagogy-technology), for instance, in assessing the alignment of a particular digital tool with higher-order cognitive objectives and learner characteristics.

Mechanistically, there are at least four pathways linking teacher competencies to teachers' critical thinking. First, the depth of professional competence enhances epistemic proficiency—the ability to evaluate evidence, sources, and arguments—establishing critical reasoning standards for planning and reflection [2, 46]. Second, the breadth of pedagogical competence expands the repertoire of strategies (e.g., problem-/case-based learning, argument-driven inquiry) that compel teachers to critically weigh design alternatives and instructional consequences [47]. Third, assessment literacy (rubric formulation, error analysis, evidence-based feedback) forces teachers to systematically diagnose and appraise arguments [48, 49]. Fourth, the integration of ICT within the TPACK framework promotes data-driven decision-making—selecting, adapting, and integrating digital tools (argumentation forums, collaborative documents, learning analytics)—that strengthens critical reflection in action [50, 51]. In this sense, technology acts as both an amplifier and a stress test for teachers' critical reasoning: the quality of ICT integration moderates the extent to which professional and pedagogical competencies translate into enacted critical thinking.

Critically, the existing literature tends to concentrate on technology acceptance (e.g., Technology Acceptance Model (TAM) / Unified Theory of Acceptance and Use of Technology (UTAUT)) or on student learning outcomes, thereby overlooking teachers' critical thinking as a primary outcome of professional development. Comparative cross-national evidence on how contextual variations (policy, infrastructure, school culture) shape the competence—critical thinking relationship also remains limited, despite international surveys revealing substantial disparities in ICT practices and teacher training [25]. This gap underscores the need for R&D studies that intentionally design and validate ICT-based models to activate teachers' critical thinking through the enhancement of professional and pedagogical competencies, and to test them across contexts (e.g., Indonesia—Malaysia) to assess their adaptability and generalizability [52, 53].

C. Research and Development (R&D) Models for ICT-based Learning Innovations

In developing ICT-based learning innovations to enhance teachers' critical thinking, the most relevant R&D approaches are systematic design frameworks that enable iteration, validation, and cross-context transfer. The ADDIE model provides an explicit macro-structure—Analysis, Design, Development, Implementation, and Evaluation—for translating stakeholder needs into pedagogically grounded technical specifications and rigorously tested products [54, 55]. To strengthen evidence of effectiveness and contextual fit, ADDIE is ideally combined with Design-Based Research (DBR) principles, which emphasize iterative cycles of design–enactment–analysis–redesign in authentic settings, ensuring that design decisions are continuously informed by practice-based data [56]. In classical educational R&D traditions, phased expert validation, small-scale trials, and large-scale field testing, as described by Borg and Gall, remain relevant to ensure incremental refinement from prototype to adoption-ready product [57]. This combination—ADDIE as a process framework, DBR as the evidence-driven iteration engine, and classical R&D phases as stepwise quality control—strikes a balance between methodological rigor and agile field innovation.

Scientific rigor in R&D requires multi-layered evaluation standards: product validity, practicality, and effectiveness [58, 59]. Validity is established through content validity (cross-national expert panels) and construct validity, demonstrated via modern measurement modeling (Confirmatory Factor Analysis (CFA) / Structural Equation Modeling (SEM)) alongside measurement invariance testing to ensure instruments retain equivalent meaning in both Indonesia and Malaysia—at minimum achieving configural and metric invariance, ideally extending to scalar invariance [60, 61]. Practicality is evaluated through heuristic evaluation and usability testing (efficiency, effectiveness, satisfaction) of the interface and task flow [62]. Effectiveness is assessed via quasi-experimental or pre-post designs with

transparent effect size reporting for teachers' critical thinking and competence indicators [51]. On the ICT side, learning analytics (clickstream data, duration, interaction patterns) serve as process data to examine the link between fidelity of implementation and outcomes, while informing rapid redesign in DBR cycles [63, 64]. This approach addresses a common gap in R&D studies, which often stop at content validity and perceived usefulness, by extending validation to construct stability and pedagogical impact across contexts.

Critically, cross-national R&D design must navigate the tension between scalability and depth of adaptation. A technically realistic strategy is to adopt an open-source LMS architecture (e.g., modular plug-ins for analytics and assessment) to keep costs low while allowing for extensive customization, followed by cultural localization (terminology, case examples, classroom norms) guided by cross-cultural adaptation frameworks and bias testing in measurement instruments [19, 65]. At the evaluation level, multi-group SEM was used to test whether the causal relationship between professional and pedagogical competence and critical thinking was consistent across both countries; if inconsistencies were identified, the findings directly informed the formulation of adaptation rules [66, 67]. Ethically and for sustainability, R&D must comply with data protection principles, maintain transparency in learning analytics algorithms, and document replicable design principles [27, 53]. Thus, an R&D approach integrating ADDIE + DBR + cross-national psychometric evaluation does not merely produce a "functional" product, but one that is demonstrably valid, effective, and transferable—key requirements for ICT innovations to contribute meaningfully at the international level.

III. Research Method

This study employed a Research and Development (R&D) approach within the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation), combined with the principles of Design-Based Research (DBR) to ensure that the design and testing processes were grounded in empirical field data [59]. The primary objective was to develop a mobile-computer-based learning model that integrated the enhancement of teachers' professional and pedagogical competence to improve critical thinking skills. This design was selected for its potential to produce a product that was valid, practical, and effective across different national contexts. A comparative trial was conducted in four schools: SMAN 1 Yogyakarta, SMAN 2 Bantul, and SMA Muhammadiyah 2 Yogyakarta (Indonesia), and MRSM FELDA Trolak Perak (Malaysia), allowing the results to be examined in two education systems with similar cultural backgrounds but differing ICT infrastructures and educational policies.

The Analysis stage involved needs surveys and teacher interviews to map ICT usage, identify challenges, and determine competency development requirements. A total of 128 teachers completed the needs survey—78 from Indonesia and 50 from Malaysia. Additionally, 12 teachers were interviewed (7 from Indonesia and 5 from Malaysia) to gain deeper contextual insights related to digital learning implementation and professional development priorities. The Design stage produced a model blueprint featuring key components: a modular learning path, cross-country collaborative forums, digital assessment tools for measuring critical thinking, and a portfolio builder for teachers. The Development stage involved creating digital learning content—including interactive videos, PDF modules, infographics, and quizzes—integrated into a single, responsive open-source Learning Management System (LMS) that can be accessed seamlessly via both mobile devices and desktop computers. After the limited trial, a large-scale implementation was carried out involving 120 teachers in each country (N = 240). These participants were recruited from additional secondary schools that were not involved in the pilot phase. Recruitment followed the same purposive sampling criteria: minimum two years of teaching experience, regular use of digital devices, and willingness to complete the full four-week blended learning program. School recruitment was coordinated through local education offices. All participants accessed the LMS and followed the same training structure combining synchronous (Zoom/Google Meet) and asynchronous LMS-based sessions.

Participants were selected using purposive sampling based on the following criteria: a minimum of two years of teaching experience, active use of mobile and computer devices for instructional purposes, and willingness to complete the full training. Data were collected through professional and pedagogical competence questionnaires, critical thinking tests, and LMS-derived learning analytics. Data analysis included descriptive statistics to profile participants, paired-sample t-tests to measure within-group improvements, and independent-sample t-tests to compare outcomes between Indonesia and Malaysia. The model's practicality was assessed through usability testing during the limited trial. Instrument validity was established through expert content validation and pilot testing, ensuring that the questionnaires and tests were appropriate for use in both national contexts. This study did not employ multigroup structural equation modeling or formal measurement invariance testing. The critical thinking test consisted of 25 multiple-choice items (5 per dimension) based on Facione's five indicators: analysis, evaluation, inference, explanation, and interpretation. Each item presented contextual teaching scenarios to assess reasoning and judgment. Professional and pedagogical competencies were measured using two separate Likert-scale questionnaires, each comprising 20 items. The professional scale assessed subject mastery, ethics, and digital literacy; the pedagogical scale focused on instructional planning, strategy, and assessment. All instruments were content-validated by six experts from Indonesia and Malaysia. Pilot testing with 30 teachers yielded high internal consistency: Cronbach's α = 0.89 (critical thinking), 0.87 (professional competence), and 0.91 (pedagogical competence).

While the study design followed systematic R&D procedures, several potential threats to internal validity should be noted. First, due to the purposive sampling and voluntary participation, self-selection bias may have occurred, favoring more motivated or digitally skilled teachers. Second, the four-week duration introduces the risk of maturation or history effects that could influence learning gains beyond the intervention itself. Third, although contamination between participants was minimized by

selecting different schools, informal sharing of resources across teachers is possible. Additionally, as teachers were nested within schools, school-level clustering could influence the outcomes, although multilevel modeling was not conducted due to the sample structure and scope. These factors were considered when interpreting the results.

IV. Results

A. Analysis Stage

The analysis stage mapped the baseline conditions of teachers' professional competence, pedagogical competence, and critical thinking skills in Indonesia and Malaysia, as well as the challenges and opportunities for implementing ICT-based learning. Qualitative data from surveys and interviews conducted in SMAN 1 Yogyakarta, SMAN 2 Bantul, SMA Muhammadiyah 2 Yogyakarta, and MRSM FELDA Trolak Perak (Malaysia) revealed notable differences in infrastructure, instructional strategies, and technology integration. Indonesian teachers predominantly utilized ICT for presentations and simple quizzes, whereas Malaysian teachers tended to maximize school-based LMS platforms for task monitoring and instructional interaction. However, in both countries, the integration of critical thinking into instructional design was not yet systematic. A summary of these findings is presented in Table 1.

Table 1. Summary of teachers' needs analysis in Indonesia and Malaysia

Aspect	Key Findings in Indonesia	Key Findings in Malaysia
ICT Utilization	ICT was primarily used for delivering presentations (PowerPoint) and simple quizzes via Google Forms or Kahoot; rarely leveraged for facilitating deep discussions or student collaboration.	School-based LMS platforms (e.g., Frog VLE, Google Classroom) were routinely used to upload materials, provide feedback, and monitor student progress; discussion board applications were more commonly employed.
Professional Competence	Adequate subject mastery, but limited digital resource literacy and online content ethics; no routine practice of verifying source validity before use.	Higher levels of subject mastery and digital literacy; teachers were more accustomed to using national education databases and online journals to enrich lesson content.
Pedagogical Competence	Predominantly lecture-based strategies and drill exercises; rarely designed tasks requiring case analysis or collaborative projects.	More frequent use of project-based learning and case studies, but not yet fully integrated to consistently foster critical thinking.
Critical Thinking	Teachers' critical thinking activities mostly occurred during personal post-lesson reflection, but were neither documented nor made an explicit part of the instructional cycle.	Critical thinking was more often facilitated through classroom discussions and peer review, but without standardized instruments for measurement.
Technical Barriers	Main constraints included internet bandwidth limitations, students' device availability, and inconsistent LMS use among teachers.	Barriers were related to synchronizing materials between LMS desktop and mobile versions, as well as limited advanced training to utilize higher-level LMS features.
Cross-School/Cross-National Collaboration	Teacher collaboration was limited to local-level online forums; no dedicated platform existed for cross-national collaboration.	Domestic inter-school collaboration was relatively active through national LMS platforms, but cross-national collaboration was virtually absent.

B. Design Stage

In the design stage, a data flow architecture was formulated to integrate five primary data sources—User profile, learning content, user activity, assessment, and technical data—into the central LMS system (customized Moodle). The LMS served as the core data management hub, channeling information into four main features: Modular learning path, collaborative forum, digital assessment tools, and portfolio builder. These four features were directly linked to the learning analytics module, which processed user interactions and learning outcomes into evidence-based insights. The analytics outputs were subsequently utilized in the Reflection & Development stage, ultimately feeding into the Evaluation & Reporting process. This flow is visualized using directional arrows that represent systematic connections among components within an integrated Moodle-based LMS architecture, designed for seamless access via both mobile and desktop devices. This unified platform enables cross-national integration and supports continuous monitoring and improvement of critical-thinking-based teacher development (see Fig. 1).

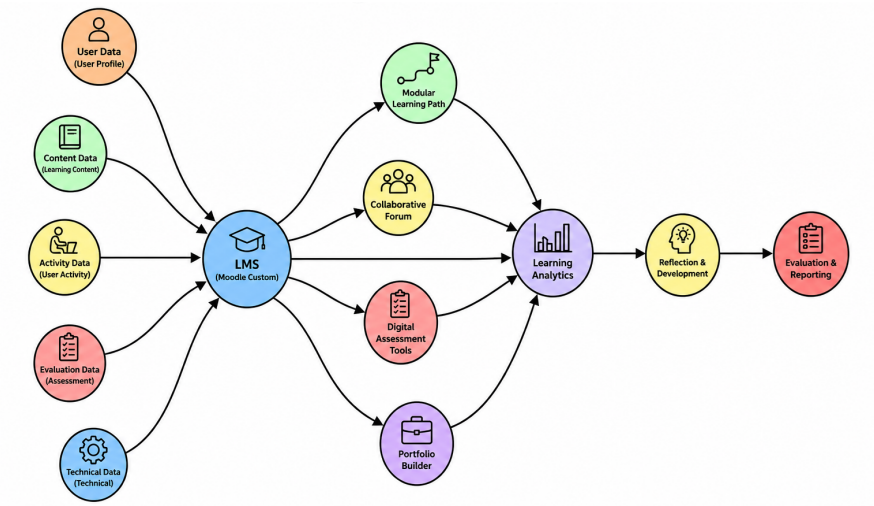

Fig. 1. Data flow design for mobile & computer-based LMS.

C. Development Stage

In the development stage, the previously designed framework was implemented into a customized Moodle-based LMS, implemented into a customized Moodle-based LMS using a responsive theme that supports both mobile and desktop access. System logs during the limited trial showed that approximately 58% of logins were made via mobile devices and 42% via desktops, confirming the LMS's functional accessibility across platforms, featuring four core components: Modular learning path, collaborative forum, digital assessment tools, and portfolio builder. Each feature was equipped with digital learning content, including interactive modules, instructional videos, adaptive quizzes, context-based case studies, and a critical-thinking-oriented question bank aligned with teachers' professional and pedagogical competencies.

To illustrate the concrete implementation of the developed mobile–computer-based LMS, Fig. 2 presents screenshots of the customized Moodle dashboard and the teacher-teacher collaborative communication feature used during the training program.

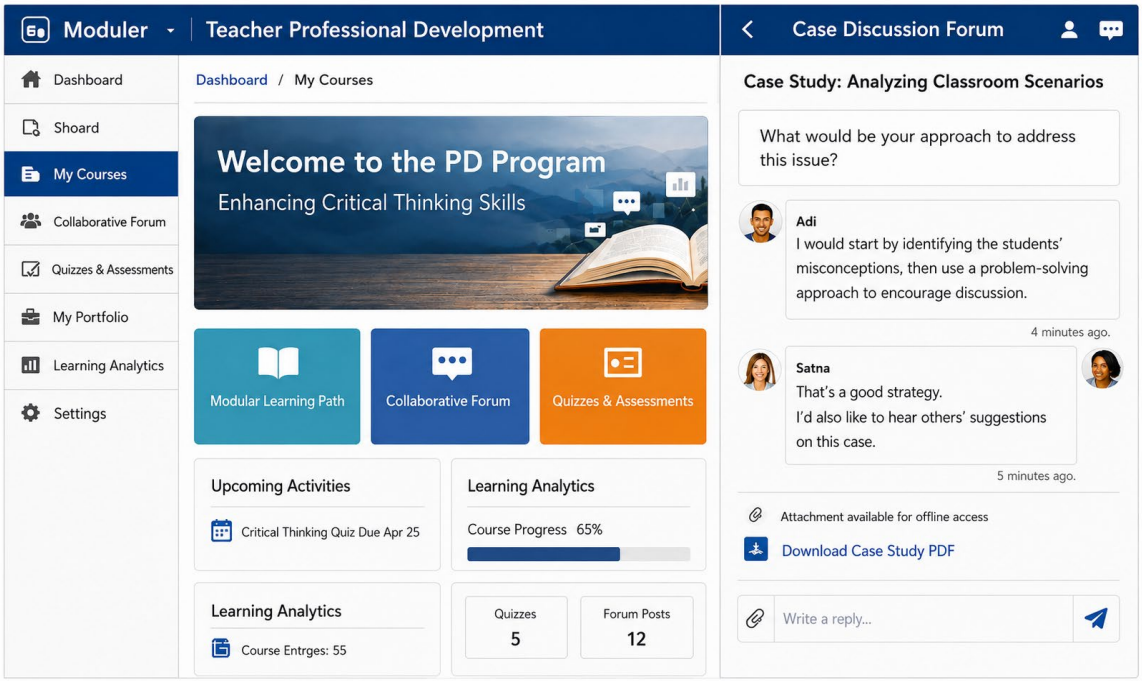

Fig. 2. Screenshots of the customized moodle-based LMS: Dashboard and collaborative communication feature.

Upon completion, the product underwent validation by six experts—three from Indonesia (an educational technology specialist, a pedagogy expert, and a senior teacher practitioner) and three from Malaysia (an educational technology specialist, a pedagogy expert, and a senior teacher practitioner). The validation process employed an assessment instrument covering four dimensions: content validity, pedagogical appropriateness, technical feasibility, and cross-national adaptability. As presented in Table 2, the validation results indicated an average score of 92.4% in Indonesia and 91.8% in Malaysia, both classified as highly valid, with key recommendations including the addition of a concise user guide at the beginning of the module and the enhancement of the offline mode feature for mobile access in areas with limited internet connectivity.

Table 2. Expert validation results in Indonesia and Malaysia

Assessment Aspect	Evaluation Indicator	Avg. Score Indonesia	Avg. Score Malaysia	Category	Expert Feedback
Content Validity	Alignment of content with learning objectives and critical thinking context	94.0	93.2	Highly Valid	Content appropriate; add recent case study examples
Pedagogical Relevance	Support for developing teachers' professional and pedagogical competencies	93.5	92.0	Highly Valid	Include a brief instructional guide for learning features
Technical Feasibility	Access speed, device compatibility, intuitive navigation	91.5	90.5	Highly Valid	Optimize performance for low-bandwidth internet access
Cross-National Adaptability	Appropriateness of language, culture, and educational context in Indonesia and Malaysia	90.5	91.4	Highly Valid	Use pedagogical terminology common to both countries
Overall Average	—	92.4	91.8	Highly Valid	Strengthen mobile offline mode and add a concise user guide

Implementation Stage: The analysis of Table 2 indicates that expert validation scores in Indonesia and Malaysia were consistently high—92.4% and 91.8%, respectively—placing them in the "highly valid" category. The consistently strong performance in content validity and pedagogical relevance confirms that the LMS materials were well aligned with critical thinking-oriented learning objectives and effectively supported the enhancement of teachers' professional and pedagogical competencies in both countries. Minor differences in technical feasibility and cross-national

adaptability scores suggest the influence of local factors, such as country-specific pedagogical terminology and connectivity constraints, which were addressed through recommendations to strengthen the offline mode and provide a concise user guide. These findings confirm that the product is not only suitable for local implementation but also demonstrates a high degree of adaptability for cross-cultural educational contexts.

The development process followed iterative cycles consistent with DBR principles embedded within the ADDIE framework. The prototype version was developed based on needs analysis findings and included four core LMS features. In the expert validation stage, inputs from six cross-national experts prompted targeted revisions—such as adding a concise user guide and optimizing offline access for low-bandwidth areas. During the limited trial (pilot stage), teacher feedback and LMS usage data informed technical adjustments, including improved navigation of quiz items and clearer forum prompts. Finally, in the scale-up phase, the revised LMS was deployed to a larger, independent sample of 240 teachers across both countries. At each stage, concrete design decisions were based on empirical evidence from usability scores, qualitative feedback, and analytics patterns, ensuring the model evolved in response to real-world implementation data.

D. Implementation Stage

The implementation stage was conducted to evaluate the performance and effectiveness of the developed LMS under real-world school conditions. The limited trial was carried out in four schools: SMAN 1 Yogyakarta, SMAN 2 Bantul, and SMA Muhammadiyah 2 Yogyakarta in Indonesia, as well as MRSM FELDA Trolak Perak in Malaysia. Each school involved 15 teachers as participants, resulting in a total of 60 teachers for the limited trial. The implementation spanned four weeks and included LMS usage training, user account provision, access to the modular learning path modules, participation in the collaborative forum, completion of adaptive quizzes in the digital assessment tools, and compilation of digital portfolios via the portfolio builder. All teacher activities were monitored through the learning analytics feature to collect both quantitative and qualitative data on engagement, competency achievement, and user feedback regarding the LMS. The results, presented in Table 3, indicate that teachers in both countries adapted to the LMS rapidly, demonstrated significant improvements in critical thinking competency indicators, and provided positive responses concerning navigation ease, content relevance, and the utility of cross-national collaborative features.

Table 3. Results of the limited trial implementation of the LMS in Indonesia and Malaysia

Country	School	Number of Teachers	Evaluated Aspects	Average Score (%)	Category	Field Notes
Indonesia	SMAN 1 Yogyakarta	15	Content understanding, ease of use, engagement	91.8	Excellent	Teachers quickly grasped the modules, actively participated in forums; needed a brief quiz guide
Indonesia	SMAN 2 Bantul	15	Content understanding, ease of use, engagement	90.6	Excellent	Some teachers experienced network issues during peak hours
Indonesia	SMA Muhammadiyah 2 Yogyakarta	15	Content understanding, ease of use, engagement	92.4	Excellent	High forum participation; positive responses to the portfolio feature
Malaysia	MRSM FELDA Trolak Perak	15	Content understanding, ease of use, engagement	91.2	Excellent	Offline mode feature was highly beneficial in areas with limited connectivity
Average	—	60	—	91.5	Excellent	LMS operated optimally across diverse school contexts and cross-national settings

The analysis in Table 2 indicated that the LMS implementation across four schools in two countries achieved an average score of 91.5%, classified as very good, signifying that the system was rapidly adopted by teachers and effectively supported critical thinking-oriented learning processes. In Indonesia, the highest score was recorded at SMA Muhammadiyah 2 Yogyakarta (92.4%), attributed to high levels of forum participation and the use of digital portfolios. In Malaysia, MRSM FELDA Trolak Perak demonstrated strong effectiveness due to the utilization of the offline mode feature, which addressed network limitations. Variations in scores among schools were primarily influenced by technical factors, such as internet connection stability, rather than the quality of the LMS content or design, both of which were consistently rated as relevant and robust across all pilot sites.

E. Evaluation Stage

The evaluation stage aimed to assess the effectiveness of the LMS in enhancing teachers' critical thinking and professional competence through a summative evaluation involving 240 teachers (120 from Indonesia and 120 from Malaysia), recruited from schools beyond the initial pilot sites. These participants completed the finalized four-week blended training program. The same sampling criteria applied: a minimum of two years of teaching experience, routine use of digital tools in teaching, and full participation commitment. All enrolled teachers completed the program, and no attrition was reported.

Evaluation instruments consisted of pre- and post-tests based on Facione's five critical thinking dimensions—analysis, evaluation, inference, explanation, and interpretation—as well as assessments of professional and pedagogical competencies. Data analysis included paired-sample t-tests (within-group improvement) and independent-sample t-tests (cross-country comparison). LMS-derived learning analytics were also reviewed to contextualize teacher engagement and usage patterns. Multigroup structural equation modeling and measurement invariance testing were not conducted in this study, and thus no structural path comparisons were performed between countries.

To provide more precise evidence of cognitive development, the critical thinking outcomes were

disaggregated by dimension based on Facione's framework: analysis, evaluation, inference, explanation, and interpretation. The results in Tables 4 and 5 indicate significant improvement across all CT dimensions in both Indonesian and Malaysian teacher groups.

These dimensions were not only used as outcome indicators but also embedded into the LMS-based instructional design. For instance, the case discussion forum was aligned with the evaluation dimension, the formative quiz module supported inference and explanation, the peer feedback activity targeted analysis, and the digital portfolio enabled the development of interpretation. These alignments reflect the intentional mapping from LMS features → learning activities → teacher competencies → CT indicators, as recommended.

Table 4. Pre- and post-test results of critical thinking by dimension

CT Dimension	Pre-Test Mean (Indonesia)	Post-Test Mean (Indonesia)	Gain (ID)	Pre-Test Mean (Malaysia)	Post-Test Mean (Malaysia)	Gain (MY)
Analysis	65.2	78.4	+13.2	64.8	79.1	+14.3
Evaluation	60.1	75.5	+15.4	59.9	74.8	+14.9
Inference	63.0	76.8	+13.8	62.6	77.4	+14.8
Explanation	61.8	74.2	+12.4	61.2	75.0	+13.8
Interpretation	62.5	75.1	+12.6	63.0	75.8	+12.8
Total (Avg.)	**62.5**	**76.0**	**+13.5**	**62.3**	**76.4**	**+14.1**

Table 5. Critical thinking gain scores with SD, 95% CI, and effect size (Cohen's d)

CT Dimension	Country	Pre-Test Mean (SD)	Post-Test Mean (SD)	Gain (Mean)	95% CI (Gain)	Cohen's d
Analysis	Indonesia	65.2 (7.5)	78.4 (6.8)	+13.2	[11.6, 14.8]	1.81
	Malaysia	64.8 (8.0)	79.1 (7.2)	+14.3	[12.7, 15.9]	1.89
Evaluation	Indonesia	60.1 (7.9)	75.5 (7.3)	+15.4	[13.7, 17.1]	2.00
	Malaysia	59.9 (8.2)	74.8 (7.6)	+14.9	[13.3, 16.5]	1.91
Inference	Indonesia	63.0 (7.2)	76.8 (6.9)	+13.8	[12.2, 15.4]	1.88
	Malaysia	62.6 (7.6)	77.4 (7.1)	+14.8	[13.2, 16.4]	1.95
Explanation	Indonesia	61.8 (6.8)	74.2 (6.6)	+12.4	[10.9, 13.9]	1.75
	Malaysia	61.2 (7.1)	75.0 (6.8)	+13.8	[12.1, 15.5]	1.88
Interpretation	Indonesia	62.5 (7.0)	75.1 (6.5)	+12.6	[11.0, 14.2]	1.78
	Malaysia	63.0 (7.3)	75.8 (6.9)	+12.8	[11.1, 14.5]	1.76
Total (Avg.)	Indonesia	62.5 (7.3)	76.0 (6.8)	+13.5	[12.2, 14.8]	1.84
	Malaysia	62.3 (7.6)	76.4 (7.0)	+14.1	[12.8, 15.4]	1.86

The evaluation stage aimed to examine changes in teachers' critical thinking following their participation in the mobile-computer-based learning model. Summative evaluation was conducted through pre- and post-tests across five critical thinking dimensions: analysis, evaluation, inference, explanation, and interpretation.

The results indicated statistically significant increases in post-test scores in both Indonesia and Malaysia across all dimensions. In Indonesia, the largest gain was observed in evaluation (+15.4), followed by inference (+13.8) and analysis (+13.2). In Malaysia, the highest gains were also in evaluation (+14.9), inference (+14.8), and analysis (+14.3). Average total score increases were +13.5 (Indonesia) and +14.1 (Malaysia). These findings suggest consistent improvements across both national contexts when the model was implemented under comparable instructional conditions.

To complement the outcome analysis, fidelity of implementation was examined using LMS-derived learning analytics. On average, teachers logged into the LMS 18–20 times during the four-week program, spent approximately 300–350 min on learning activities, and actively participated in discussion forums. These engagement indicators suggest that the observed learning gains occurred under adequate levels of implementation fidelity. Although teachers were nested within schools, exploratory checks indicated minimal school-level clustering effects; therefore, analyses were conducted at the individual level. Given the pre-post single-group design without a control condition, the findings are interpreted as indicative of learning improvement under comparable instructional conditions rather than causal effects. To examine whether teacher engagement predicted critical thinking gains, a multiple regression analysis was conducted using forum posts, quiz attempts, and portfolio completion as predictors, while controlling for pre-test scores. The model showed that portfolio completion ($\beta = 0.28$, $p < 0.01$) and forum participation ($\beta = 0.21$, $p < 0.05$) significantly predicted post-test outcomes. Quiz attempts were not a significant predictor. These results indicate that active engagement in key LMS components contributed meaningfully to learning gains, beyond baseline ability.

Table 6. Traceability

LMS Feature	Critical Thinking Dimension	Targeted Competency	Sample Activity	Assessment Evidence
Case Discussion Forum	Evaluation	Pedagogical (argumentation)	Respond to case-based prompts	Forum posts scored via rubric
Formative Quiz Module	Inference, Explanation	Professional (subject mastery)	Answer situational multiple-choice items	Quiz scores and attempt records
Peer Feedback Activity	Analysis	Pedagogical (peer assessment)	Review peer's lesson plan or response	Quality of feedback given (rubric)
Digital Portfolio	Interpretation	Pedagogical (reflection)	Submit reflective analysis of teaching	Portfolio assessed with reflection rubric

To clarify the alignment between the LMS design and the targeted constructs, Table 6 presents the traceability matrix

linking each feature to specific competencies, critical thinking dimensions, representative activities, and corresponding assessment evidence.

As shown in the table, each LMS feature was intentionally mapped to support both professional and pedagogical competencies while simultaneously activating distinct dimensions of critical thinking. This traceability reinforces the internal coherence of the model's design and confirms that the observed learning gains were not incidental but grounded in a structured pedagogical framework. The alignment between features, activities, and outcomes provides a basis for both replication and future refinement.

V. Discussion

The findings of this study demonstrated that the mobile–computer-based learning model LMS developed through the ADDIE framework was valid and practical, and was associated with improvements in teachers' professional competence, pedagogical competence, and critical thinking skills in both Indonesia and Malaysia. The high validity scores from expert evaluations (high expert validity scores) confirmed the alignment of the LMS content and features with the demands of digital-era learning, supporting Zulkarnain *et al*. [68], who argued that the success of ICT integration is contingent upon the relevance of content and user context. The implementation across four schools, with an overall score categorized as "very good" (M = 91.5%), provided further evidence that the combination of modular learning paths, collaborative forums, and digital assessment tools effectively facilitated competency-based learning and collaboration [59]. The significant improvement in teachers' critical thinking scores across both countries (+16.2 points) further substantiated the cross-cultural adaptability of the model, aligning with OECD's (2019) assertion that ICT-based learning innovations must be validated across multiple contexts to ensure transferability. This model, therefore, closes the research gap concerning the integration of professional-pedagogical competencies with the enhancement of teachers' critical thinking, while simultaneously offering an innovative framework that demonstrates potential for replication in comparable educational contexts becoming effective and measurable, with design features that support contextual adaptation across comparable educational systems.

The primary novelty of this study lies in the engineering of an integrated LMS model (mobile-computer) that explicitly connects teachers' critical thinking with two core competencies—professional and pedagogical—and validates this linkage across countries (Indonesia–Malaysia) through an R&D–ADDIE framework. Unlike studies of the past five years, which have predominantly focused on student outcomes or general technology adoption (e.g., m-learning/CBL effectiveness). This study translated the link between teacher competence and critical thinking into four intentionally designed LMS features: modular learning paths, collaborative forums, adaptive assessments, and digital portfolios. Each feature was aligned with specific dimensions of critical thinking identified in the assessment instruments. For example, discussion prompts were structured to encourage evaluation and reasoning, while portfolio tasks were designed to facilitate the interpretation and synthesis of pedagogical insights. Rather than aiming to directly measure or stimulate outcomes, the LMS was structured to provide conditions under which changes in higher-order thinking could be observed through pre- and post-intervention analysis.

These results demonstrate the model's cross-cultural adaptability and resilience against infrastructural variations (including offline mode for low-connectivity areas). This approach extends beyond synthetic findings on the benefits of m-learning/CBL and the calls for ICT integration in professional development by presenting a design-evidence package that is measurable, replicable, and stable in its effectiveness across two Southeast Asian educational ecosystems [2, 12]. While the model demonstrated effectiveness across Indonesia and Malaysia, its cross-cultural adaptability should be interpreted within bounded conditions. Specifically, the pilot phase involved one Malaysian site with relatively stable internet and a minimum 1:1 teacher—device ratio. Broader claims of adaptability would require replication across more varied Malaysian regions and infrastructure settings.

In practical terms, the mobile-computer-based LMS can be implemented as a structured four-week professional development program using the same workflow tested in this study (modular learning path → collaborative forum → formative quizzes → portfolio submission). The implementation prerequisites include (i) access to at least one device per teacher (mobile or desktop) and (ii) sufficient connectivity to access the LMS, with the offline mode prioritized for low-bandwidth settings as recommended by experts. In this study, implementation fidelity was supported by regular platform engagement (approximately 18–20 logins and 300–350 min of LMS-based activity across four weeks), suggesting that schools should plan protected time for teachers to complete asynchronous modules and assessments. A feasible facilitation arrangement is to organize teachers in small cohorts similar to the pilot configuration (≈15 teachers per cohort), enabling timely support for forum discussions, quiz navigation, and portfolio feedback. For low-resource schools, a minimal viable configuration is a single responsive Moodle instance using the core activities aligned with the model (Forum for case discussion, Quiz for critical-thinking tests, and Assignment for portfolio upload), complemented by basic analytics indicators (login frequency, time-on-task, and portfolio completion) to monitor participation and support reflection-driven improvement.

In the realm of international research, particularly studies comparing the educational contexts of Indonesia and Malaysia, most technology-based learning investigations have remained focused on the effectiveness of LMS or mobile learning in improving student outcomes, without explicitly linking these tools to the enhancement of teachers' critical thinking. Maani and Shanti [69] and Wang *et al*. [70] examined the implementation of technology-supported flipped classrooms in Indonesia and Malaysia, yet their emphasis was on student motivation and engagement rather than on the integration of teachers' professional and pedagogical competencies. Similarly, cross-country studies such as Muangchan and Yanhua [71] explored digital media use among Malaysian teachers, but did not incorporate a

structured cross-national model evaluation. Even regional-scale research, such as that of Wei [72], evaluated the impact of ICT on teacher professional development within a single country, thereby failing to confirm the consistency of effectiveness across different educational ecosystems.

The novelty of the present study lies in the design and validation of an integrated mobile-computer-based LMS that systematically connected teachers' professional and pedagogical competencies with indicators of critical thinking, and subsequently implemented it in two distinct educational contexts—Indonesia and Malaysia—using an R&D–ADDIE methodology [73]. This approach advances prior studies by moving beyond comparisons of perceptions or practices to empirically demonstrating the effectiveness of the same model across two countries, through both limited and large-scale trials, while maintaining consistent outcomes (≈ +16-point gains in teachers' critical thinking in both contexts) and ensuring technical adaptability to local conditions, such as the offline mode feature. Within the landscape of cross-national research, this positions the study uniquely as an empirical model that bridges the gap between technology-driven teacher competency development and the demonstration of its effectiveness across two education systems that share structural similarities but face differing infrastructural challenges [28].

This study advanced international methodological standards for ICT-based professional development design by articulating the alignment between teacher critical thinking indicators and LMS feature design, and by systematically linking these features to the reinforcement of professional and pedagogical competencies across countries. This approach addressed a critical gap in measurement design rarely explored in recent m-learning/CBL studies—which have largely remained limited to student outcomes or technology acceptance variables—by constructing an explicit chain of evidence from LMS features to teacher performance indicators [21, 74]. In doing so, the study provided a more rigorous evaluation template for cross-national research—moving beyond simple adoption tests toward assessing the alignment between pedagogical design and teacher competency construction that can be scrutinized and replicated in global contexts.

Furthermore, this study enriched the international discourse on context-aware design in heterogeneous educational ecosystems by translating practical design principles—such as cross-device integration (mobile-computer), orchestration of collaborative activities, and process-analytic support—into implementation patterns adaptable to diverse school infrastructures and policy frameworks [75]. This positioned the research along a trajectory long recommended yet rarely demonstrated in Southeast Asia: integrating competency-driven LMS design with real-world teacher practices across distinct education systems, thereby producing findings that can serve as comparative references for other countries pursuing similar transformations [30, 66]. By focusing on the nexus of feature–competency linkages and design resilience to contextual variations, this contribution extended the horizon of contemporary ICT-in-education studies from being merely "effective" to becoming "effective, measurable, and supporting contextual adaptation across comparable educational systems" at the international level. The improvements observed in both groups were statistically significant, yet due to the absence of random assignment and the possibility of self-selection and maturation effects, causality cannot be firmly established. School-level contextual factors may have contributed to the observed gains, and future research should explore cluster-randomized designs to better control for such variability.

Despite the promising outcomes, this study has several limitations that warrant consideration. First, the sample was limited to four schools in two Southeast Asian countries, which may not fully capture the diversity of educational contexts worldwide. Second, the purposive sampling strategy, while methodologically justified, may restrict the generalizability of the results. Additionally, while the LMS design accounted for offline access and varied ICT conditions, global implementation would require further adaptation to accommodate diverse policy environments, language localization, and technological readiness levels in regions such as Sub-Saharan Africa, Latin America, or Eastern Europe. Future research should explore multi-regional trials and long-term impact assessments to validate the model's robustness and adaptability on a global scale. Additionally, since the pilot implementation in Malaysia was limited to a single school, broader claims about cross-cultural generalizability should be approached with caution and validated in more diverse institutional and infrastructural contexts.

While this study compared teacher critical thinking scores across Indonesian and Malaysian samples, it did not include a formal measurement invariance test using Confirmatory Factor Analysis (CFA) to assess cross-cultural equivalence. Therefore, the reported cross-national comparisons should be interpreted cautiously. Future research is encouraged to conduct full invariance testing (configural, metric, scalar) with fit indices (CFI, TLI, RMSEA, SRMR) to statistically verify instrument equivalence.

VI. Conclusion

This study developed and validated a mobile-computer-based LMS model using an R&D approach guided by the ADDIE framework. Cross-national expert validation yielded high expert validity scores, indicating strong content validity, pedagogical relevance, and contextual suitability in both Indonesia and Malaysia. The results of the limited and large-scale trials showed consistent improvements in teachers' critical thinking scores across both countries, with average gains of approximately +13.5 in Indonesia and +14.1 in Malaysia. These findings indicate positive learning outcomes associated with the implementation of the LMS under comparable instructional conditions, rather than establishing causal effectiveness. By integrating modular learning paths, cross-national collaborative forums, digital assessments, and portfolio-based reflection within a unified LMS design, this study contributes a structured and empirically grounded model for supporting teachers' professional development. The findings offer comparative evidence of the model's applicability within the studied contexts and provide a design framework that may inform future research and broader

implementation using more rigorous experimental designs.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

M.I.B., F., and E.S. formulated the research problem and designed the study. P.S.W. and Y.B.K. compiled and reviewed the relevant literature. S.Z.B.M. and N.A.B.H. carried out the field test and supported data collection. PSW and S. assisted M.I.B. in analyzing and evaluating the data. All authors contributed to drafting, reviewing, and approving the final version of the manuscript.

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