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Digital Library-Based LMS with TRINGO Strategy: Cross-Tradition Approach for Technological Content Knowledge Development

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Abstract: Indonesian faith-based educators lack structured digital environments that integrate pedagogical strategies with the development of Technological Content Knowledge. This Research and Development study, following the Lee and Owens model, developed and validated a digital library-based Learning Management System operationalizing Ki Hadjar Dewantara's TRINGO strategy (*Ngerti*, *Ngrasa*, *Nglakoni*) as a cross-tradition learning architecture for Muhammadiyah educators. 45 educators from 21 Malang City schools completed a 4-week training cycle. Expert validation across media (95%), content (90%), and learning strategy (100%) domains classified the LMS as Highly Valid. A focus group discussion with 21 school principals revealed an institutional appetite for structured teacher development and a resonance between TRINGO's tripartite structure and Muhammadiyah's *Pendidikan Berkemajuan* commitments. Class-level Technological Content Knowledge improved by eighteen percentage points from pre-test (42%) to post-test (60%). Critically, post-test performance plateaued below the seventy-percent mastery threshold, with the affective *Ngrasa* dimension showing the smallest gains, suggesting that four weeks suffice for procedural learning but not for deeper reflective engagement. The study contributes a validated cross-tradition prototype for faith-based teacher development while identifying the boundary conditions of its application. Future research requires multi-site replication, extended training cycles, and deeper integration of Muhammadiyah's own pedagogical sources to address the affective dimension.

Keywords: Technological Content Knowledge, TRINGO strategy, learning management system, faith-based education, teacher professional development.

INTRODUCTION

The intersection of technology and pedagogy has become a defining challenge for twenty-first-century education systems. The UNESCO Global Education Monitoring Report on technology in education underscored that digital tools serve learning only when integrated with a pedagogical purpose rather than treated as ends in themselves, a framing that gains particular urgency in low- and middle-income contexts where infrastructure and professional development resources remain unevenly distributed (Timotheou et al., 2023). In Indonesia, this imperative intersects with persistent gaps in teacher digital competency: national

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assessment data indicate that many educators lack the capacity to integrate technology in ways that meaningfully advance subject-matter learning, a gap magnified within private religious educational networks that serve millions of students yet often receive less systemic support for digital transformation than public schools (Mintasih et al., 2024; Purwanto et al., 2023). Recent reviews of teacher digital competence further document that classroom technology integration depends less on hardware access than on educators' Technological Content Knowledge, that is, the capacity to discern how specific digital tools shape, constrain, and enable particular forms of subject-matter learning (Zhang et al., 2025; Cabero-Almenara et al., 2023). For faith-based school networks, this challenge is compounded by the need to integrate digital pedagogies with religiously grounded content and character formation, an integration that generic LMS deployments rarely provide an explicit pedagogical scaffold for.

Central to this conceptual landscape is Technological Content Knowledge (TCK), the component of the Technological Pedagogical Content Knowledge framework developed by Mishra and Koehler (2006) that describes educators' understanding of how technology and subject matter mutually influence and constrain one another. Bibliometric and systematic reviews published since 2022 confirm that TCK remains the least empirically developed component of the TPACK framework, with most TPACK research concentrated on the pedagogical knowledge dimensions (Cabero-Almenara et al., 2023; Kholid et al., 2023; Su, 2023). Schmid et al. (2021) further note that validated instruments for measuring TPACK components in non-Western contexts remain scarce, prompting calls for context-sensitive instrument development and culturally located implementation studies. Muhammadiyah, founded in 1912 by K.H. Ahmad Dahlan, operates one of the world's largest faith-based educational networks, comprising over 10,000 schools and approximately 5 million students across Indonesia. A preliminary needs assessment conducted in Malang City suggested that the majority of Muhammadiyah educators in the city possessed basic technology-operation skills but lacked the capacity to integrate digital tools into content-specific pedagogical approaches, the essence of TCK as theorized by Mishra and Koehler. This local pattern aligns with broader Indonesian findings in which technology access has outpaced pedagogical readiness (Hamami & Nuryana, 2022; Imran & Mardhiah, 2023).

Learning Management Systems represent a well-established mechanism for delivering scalable teacher professional development, particularly when supported by structured pedagogical design. Recent empirical and review literature on LMS-based teacher development indicates that effectiveness depends critically on the instructional strategy embedded within the platform rather than on technological features alone (Al-Fraihat et al., 2025; Elmunsyah et al., 2023; Fütterer et al., 2025). Studies of Moodle-based teacher training across Indonesian contexts, including Madrasati LMS adoption in faith-based schools and hybrid LMS development at Islamic universities, have documented modest but inconsistent gains in teacher digital competency, with the most positive outcomes appearing in programs that combined platform deployment with structured pedagogical scaffolding (Alzahrani et al., 2023; Anam & Asyhar, 2023; Susanti et al., 2023). The integration of digital libraries within LMS architectures remains comparatively underexplored as a mechanism for enriching content resources and supporting self-directed professional learning among educators in resource-constrained settings, particularly in faith-based educational networks where organizational culture, religious values, and pedagogical traditions shape technology acceptance in distinctive ways (Aflalo et al., 2024; Morris, 2025; Suharsiwi et al., 2024). Recent culturally responsive technology research argues that the design of digital learning environments for Indigenous and minority-tradition contexts must account for the

pedagogical heritage of those communities rather than treating them as content-neutral users of generic platforms (Yip & Chakma, 2024).

Building on this gap, this study developed and evaluated a digital library-based Learning Management System that operationalizes the TRINGO strategy, that is, *Ngerti*, *Ngrasa*, and *Nglakoni*, as a learning architecture for enhancing TCK among Muhammadiyah educators. A critical clarification is required at the outset: TRINGO originates in Ki Hadjar Dewantara's pedagogical philosophy and the Taman Siswa tradition established in 1922, and is not native to Muhammadiyah's own pedagogical lineage, which traces its foundations to K.H. Ahmad Dahlan's principles of *Pendidikan Berkemajuan* (progressive education) and the integration of religious and secular knowledge through the *Al-Islam Kemuhammadiyahan* curriculum (Akhyar et al., 2024; Hamami & Nuryana, 2022; Mulkhan & Abror, 2019). The decision to operationalize TRINGO within a Muhammadiyah context is therefore framed in this study as a cross-tradition application of indigenous Indonesian pedagogical wisdom, drawing on its tripartite cognitive, affective, and behavioral structure and its established uptake in Indonesian instructional design research, while recognizing that the substantive religious content of the LMS remains anchored in Muhammadiyah's own curricular tradition. Three research questions guided the inquiry: (1) What is the validity of the digital library-based LMS with TRINGO operationalization as assessed by media, content, and learning strategy specialists? (2) How do Muhammadiyah educators and Muhammadiyah school principals evaluate the usability of the LMS during a focus group discussion and a full-scale implementation? (3) To what extent does the LMS-based training program affect class-level TCK performance from pre-test to post-test, and what patterns emerge at the item level across the *Ngerti*, *Ngrasa*, and *Nglakoni* dimensions?

METHOD

Research Design

This study adopted a Research and Development approach following the five-phase instructional development model proposed by Lee and Owens (2004): Assessment and Analysis, Design, Development, Implementation, and Evaluation. Three alternative R&D frameworks were considered before selection. The ADDIE model (Analysis, Design, Development, Implementation, Evaluation) shares a similar phase structure but is more general and less explicitly focused on multimedia-based learning artifacts. The 4D model (Define, Design, Develop, Disseminate) emphasizes the dissemination of teaching tools rather than the iterative refinement of digital learning environments.

Design-Based Research operates over longer cycles and assumes embedded researcher-practitioner partnerships, which are not feasible within the four-week training window available for this study. Lee and Owens' model was selected because it was explicitly developed for multimedia-based instructional design, accommodates iterative formative evaluation across each phase, and has an established record of application in Indonesian instructional design research, including LMS, multimedia, and e-module development across primary, secondary, and higher education contexts (Ariyanti, 2022; Dewi et al., 2023). The five phases of Lee and Owens were cross-mapped to the three dimensions of the TRINGO strategy, with each phase incorporating cognitive understanding (*Ngerti*), affective engagement (*Ngrasa*), and behavioral practice (*Nglakoni*) as design principles. The cross-mapping is presented in Table 1, and the overall research flow is depicted in Figure 1.

Table 1. Operationalization of TRINGO across the Five Phases of the Lee and Owens R&D Model

Phase	*Ngerti* (Understanding)	*Ngrasa* (Internalizing)	*Nglakoni* (Practicing)
Assessment / Analysis	Needs assessment survey of digital literacy and TCK gaps	Interviews to surface educators' affective stance toward technology	Observation of current classroom technology practice
Design	Conceptual design of theoretical modules and content map	Design of reflection forums and discussion spaces	Design of practical assignments and project briefs
Development	Production of e-books, video explanations, and digital library content	Construction of synchronous and asynchronous mentoring channels	Construction of peer-review and project-submission features
Implementation	Delivery of theoretical sessions through LMS modules	Facilitation of reflective dialogue in moderated forums	Implementation of project-based assignments with peer assessment
Evaluation	Pre-test and post-test assessment of conceptual knowledge	Satisfaction questionnaire and reflective writing	Rubric-based evaluation of final projects and observation of LMS log activity

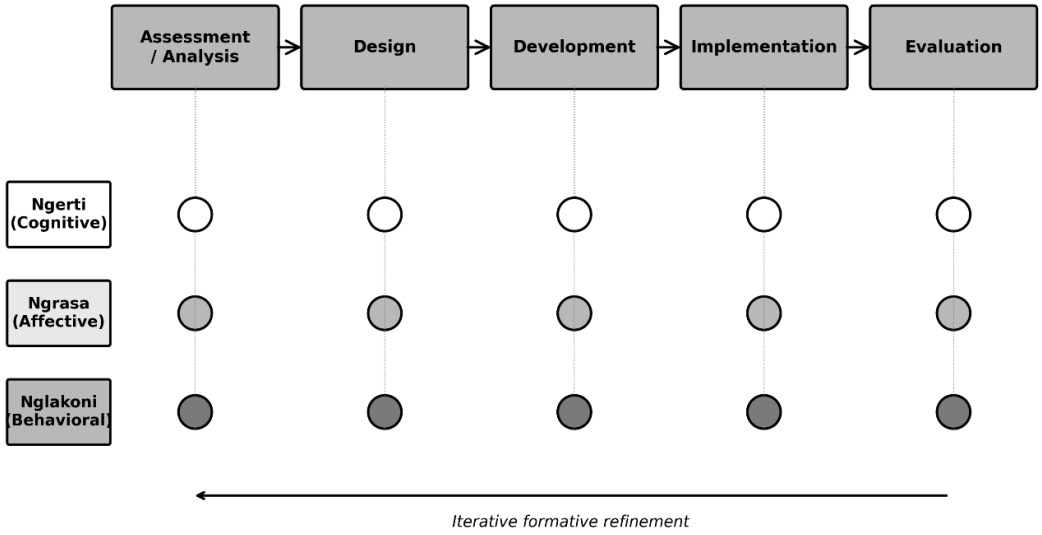

Figure 1. Lee & Owens R&D Model with TRINGO Strategy Integration

Participants and Setting

The study was conducted in Malang City, East Java, Indonesia. Forty-five Muhammadiyah educators participated, drawn from twenty-one Muhammadiyah schools across the city, spanning elementary, junior secondary, senior secondary, vocational, and *madrasah* levels. The training venue was the auditorium of the Pimpinan Daerah Muhammadiyah Kota Malang (Malang City Regional Board of Muhammadiyah). All participants were active educators with at least 2 years of teaching experience and were affiliated with the Muhammadiyah Primary and Secondary Education Council (Dikdasmen) of Malang City. A separate focus group discussion involved 21 Muhammadiyah school principals, who served as institutional stakeholders and provided perspectives on organizational uptake

and sustainability. Basic digital literacy among participants was operationalized as the capacity to operate a smartphone, access the internet, and use at least one cloud-based platform, such as Google or WhatsApp. It was verified by self-report at the recruitment stage. The pre-test performance distribution observed during implementation suggested that this screen captured only the lower bound of digital readiness, an issue revisited in the limitations. Participant characteristics and validator profiles are summarized in Table 2.

Table 2. Participants, Validators, and Discussion Group Composition

Group	*n*	Role	Recruitment	Affiliation
Training cohort	45	Muhammadiyah educators (teachers and administrators)	Purposive across 21 Muhammadiyah schools	Dikdasmen Muhammadiyah Kota Malang
Focus group discussion	21	Muhammadiyah school principals	Purposive (institutional leaders)	Dikdasmen Muhammadiyah Kota Malang
Media expert validator	1	Lecturer in Educational Technology	Purposive by expertise	Dept of Educational Technology, Universitas Negeri Malang
Content expert validator	1	Senior cadre of Pimpinan Daerah Muhammadiyah	Purposive by expertise	Pimpinan Daerah Muhammadiyah Kota Malang
Learning strategy expert validator	1	Lecturer in Educational Technology	Purposive by expertise	Dept of Educational Technology, Universitas Negeri Malang

Product Development

The LMS was built on the Moodle 4.2 framework and deployed at muhammadiyahdikdasmenmalang.org. The architecture was designed to be responsive across desktop and mobile devices, with hosting and bandwidth specifications calibrated for the educational sector's resource constraints. The platform integrated a digital library containing electronic books, journal articles, instructional videos, and supplementary teaching materials, all curated to align with Muhammadiyah educational priorities and *Al-Islam Kemuhammadiyahan* content. The TRINGO strategy was operationalized through three corresponding feature clusters within the LMS interface.

The *Ngerti* cluster delivered theoretical modules, downloadable materials, and recorded videos explaining LMS pedagogy and TCK concepts. The *Ngrasa* cluster enabled threaded discussion forums, reflection prompts, and both synchronous and asynchronous mentoring channels. The *Nglakoni* cluster facilitated the submission of practical assignments, project-based tasks, collaborative work, and peer assessment. Additional features included user management, a quiz and evaluation module integrated with the Quizizz platform for pre-test and post-test administration, a notification system, a progress-monitoring dashboard, and an examination proctoring extension, available as an opt-in feature for educators who prefer proctored assessment of their own students. The proctoring extension is discussed further in the research ethics section.

Instruments and Validation

Three expert validation instruments were developed for the LMS, each using a Likert-type rating scale with open-ended feedback sections. The media validation instrument comprised ten items covering interface usability, visual layout, system functionality, loading speed, cross-device compatibility, multimedia support, feature completeness, content relevance, interaction facilitation, and overall learning effectiveness. The content validation instrument comprised fifteen items covering material relevance to curriculum standards, alignment with TCK development, integration with the TRINGO strategy, support for technology-enhanced pedagogy, and adequacy of supporting resources. The learning strategy validation instrument comprised 10 items covering clarity of training objectives, instructional sequencing, adequacy of materials, fit of the evaluation tool, and pedagogical coherence. Validity was computed using the formula $P = (F / A) \times 100\%$, where P is the validity percentage, F is the obtained score, and A is the maximum possible score. Results were classified using the four-category rubric established by Arikunto (2010), which is widely used in Indonesian instructional design research: 76 to 100% indicates Highly Valid, 51 to 75% indicates Valid, 26 to 50% indicates Less Valid, and 0 to 25% indicates Invalid.

TCK was measured through a twenty-item multiple-choice instrument administered before and after the training via the Quizizz platform. Items spanned three TCK competency domains corresponding to the TRINGO dimensions: *Ngerti* items measured conceptual understanding of LMS features and TCK constructs; *Ngrasa* items measured perception of and reflective engagement with technology features; and *Nglakoni* items measured procedural knowledge of LMS implementation steps. The distribution of items across dimensions is presented in Table 3, and instrument specifications appear in Table 4. The Minimum Competency Achievement (*Kriteria Ketuntasan Minimal*, KKM) threshold was set at 70%, in line with the internal performance standard of Muhammadiyah Dikdasmen Malang for in-service training programs.

Table 3. Item Distribution of the Twenty-Item TCK Test by TRINGO Dimension

Dimension	Items	Item IDs	Domain Focus
Ngerti (cognitive understanding)	11	1, 2, 3, 5, 8, 10, 11, 13, 14, 15, 17	Conceptual knowledge of LMS features and TCK constructs
Ngrasa (affective engagement)	5	6, 7, 12, 16, 18, 19	Perception, evaluation, and reflective engagement
Nglakoni (behavioral application)	4	4, 9, 13, 20	Procedural execution of LMS implementation tasks

Table 4. Specifications of the TCK Pre-Test and Post-Test Instrument

Specification	Detail
Platform	Quizizz, integrated within the Moodle LMS course module
Format	Multiple choice with four answer options per item
Total items	20 (pre-test) and 25 (post-test, which added 5 extension items not used in pre-post comparison)
Administration time	Approximately 7 min 33 sec (pre-test mean) and 7 min 32 sec (post-test mean)
Scoring	Percentage of correct responses; class-level item statistics generated by Quizizz
Mastery threshold (KKM)	70%, set by Muhammadiyah Dikdasmen Malang for in-service training
Content alignment	TPACK framework (Mishra & Koehler, 2006), with items mapped to *Ngerti*, *Ngrasa*, *Nglakoni*

Data Collection and Analysis

Quantitative data were generated from the validation instruments, the pre-test and post-test TCK scores at the class level, and LMS log activity. Qualitative data were generated from the focus group discussion with twenty-one Muhammadiyah school principals, semi-structured interviews with selected participants, and open-ended sections of the validation instruments. The focus group discussion was conducted on 6 July 2024, prior to the full-scale training implementation, and was structured around three guiding questions: institutional perceptions of LMS-based teacher development; perceived alignment between the TRINGO strategy and Muhammadiyah educational priorities; and anticipated implementation challenges at the school level. The discussion was audio-recorded with participant consent, transcribed verbatim, and analyzed using thematic coding. Two researchers independently coded an initial subsample to develop a preliminary thematic map, then collaboratively revised it before applying it to the full transcript. Representative quotations are reported in the Results section to illustrate principal themes.

Quantitative analysis was descriptive. Validity percentages and item-level pre-test and post-test means were computed directly from instrument scores and Quizizz platform-generated class statistics. Because the available pre-post data consist of class-level item statistics and aggregated participant scores rather than individual paired raw scores, inferential analyses such as paired-samples t-test and Cohen's *d* were not performed; the methodological implications of this design choice are discussed in the limitations and revisited in the future research directions. Class-level changes from pre-test to post-test are reported as percentage-point gains; item-level changes are reported alongside item difficulty distributions to enable readers to evaluate the magnitude and pattern of learning gains independently of any single summary statistic.

Research Ethics

The Research Ethics Committee of Universitas Negeri Malang approved the study. Informed consent was obtained from all participants prior to data collection, and participants were assured of confidentiality and the voluntary nature of participation, with the right to withdraw at any time without consequence. A specific clarification is warranted regarding the LMS proctoring feature. During the training, several participants asked whether the LMS could deter cheating during student assessments at their own schools. In response, the LMS was equipped with an optional proctoring extension that, when activated by an instructor,

requires test-takers to enable webcam and screen-sharing during examinations. In this study, the proctoring extension was demonstrated as a feature available to participating educators for future use with their students. However, it was not activated during the research participants' pre-test and post-test administrations. Pre-test and post-test data for the present study were collected without webcam or screen-sharing surveillance, and participants were informed of this distinction during the consent process. Where the proctoring extension is deployed by participating educators in their schools, the LMS documentation directs them to apply institutional policies on consent, recording storage, and retention.

RESULTS

This section presents findings from three streams of evidence: expert validation, focus group discussions with school principals, and pre-test and post-test learning outcomes. Each stream contributes complementary information about the LMS as a developmental product.

Expert Validation Results

Three domains of expert validation yielded the results presented in Table 5. All three domains were classified in the highest validity category according to Arikunto's (2010) four-tier rubric. The media specialist returned a score of 95% (38 out of 40), with full marks across interface usability, layout, system functionality, loading speed, cross-device compatibility, multimedia support, feature completeness, content relevance, and overall learning effectiveness, and a half-mark deduction on interaction facilitation and feedback features that the specialist suggested could be strengthened. The content specialist returned 90% (54 out of 60), with full marks on curriculum alignment, relevance to Technological Content Knowledge development, alignment with the TRINGO strategy, accessibility through the LMS, support for practical application, integration with related materials, support for current educational technology, and motivational design, and partial marks on depth of material, accessibility for less digitally literate participants, supplementary resources, inclusion of worked examples, interactive teaching methods, and currency with the latest scholarship. The learning strategy specialist returned a perfect 100% score (50 out of 50) across all ten items. The interpretive significance of this perfect score, particularly given that only a single rater was used for this domain, is taken up in the Discussion subsection.

Table 5. Expert Validation Results across Three Domains

Validation Domain	Items	Validator(s)	Score	Maximum	Validity (%)	Category (Arikunto, 2010)
Media	10	1 (Educational Technology lecturer, UM)	38	40	95	Highly Valid
Content	15	1 (senior cadre, PDM Kota Malang)	54	60	90	Highly Valid
Learning Strategy	10	1 (Educational Technology lecturer, UM)	50	50	100	Highly Valid
Aggregate (unweighted mean)	—	—	—	—	95	Highly Valid

Qualitative feedback from the media specialist suggested that learning content should be packaged with richer multimedia elements, such as narrative, video, and imagery. This led to the inclusion of additional video explanations and infographic-based summaries during the development phase. Meanwhile, the content specialist recommended expanding supplementary resources and incorporating more worked examples. These suggestions were partially addressed by adding curated digital library entries linked to each module. Both types of feedback were integrated into iterative product refinement prior to full-scale implementation. The final product of the Digital Library-Based LMS is shown in Figure 2.

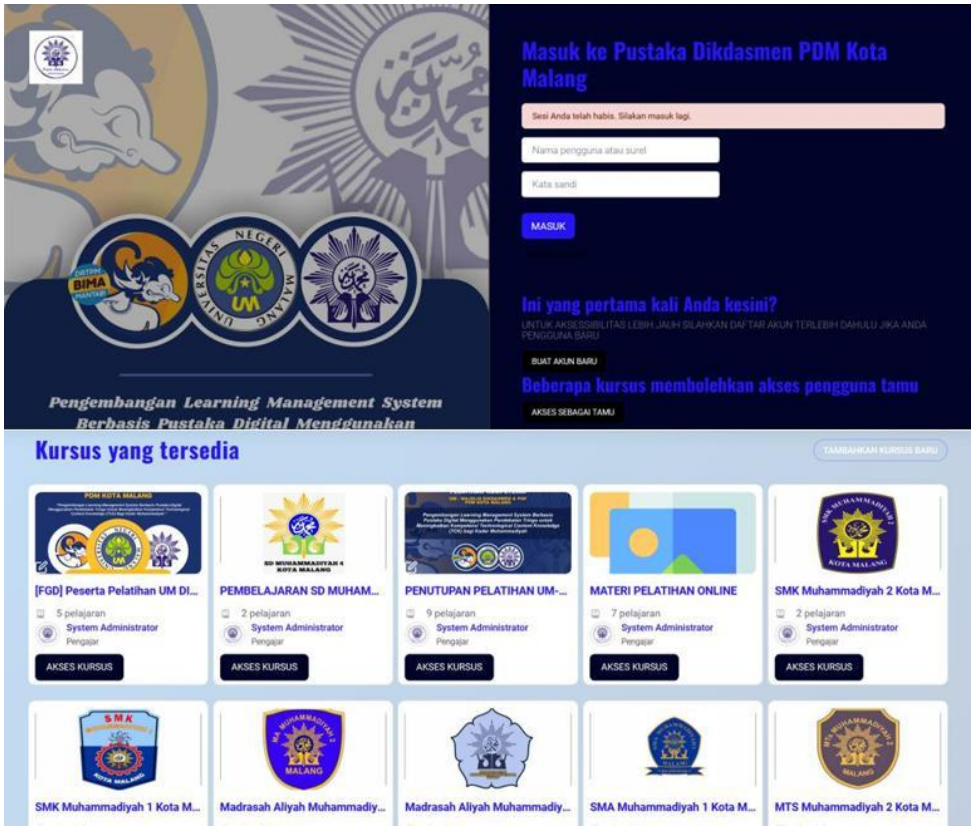

Figure 2. Product of the Digital Library-Based LMS

Focus Group Discussion with School Principals

The focus group discussion was held on 6 July 2024 at the Pimpinan Daerah Muhammadiyah Kota Malang auditorium with twenty-one school principals representing elementary, junior secondary, senior secondary, vocational, and *madrasah* levels across the city. Thematic analysis of the verbatim transcript surfaced four principal themes: (1) institutional appetite for structured teacher digital development; (2) the perceived fit between the TRINGO framework and Muhammadiyah educators' professional identity; (3) anticipated implementation challenges; and (4) requests for sustained post-training support. Within the first theme, principals expressed strong institutional support for LMS-based teacher development, with many noting that fragmented, ad hoc training initiatives across their schools had not produced durable improvements in teachers' technology integration. A principal from a vocational school observed that prior trainings had reached individual teachers without producing institutional knowledge that could be sustained when those teachers transferred or retired, an observation that aligns with the broader research literature

on the sustainability problems of one-off teacher professional development (Fütterer et al., 2025).

Within the second theme, principals reported that the explicit framing of TRINGO as Ki Hadjar Dewantara's pedagogical contribution was experienced as both intellectually clarifying and pedagogically resonant. Several principals explicitly noted that they had previously assumed TRINGO to be part of Muhammadiyah's tradition and welcomed the historical clarification. A senior principal commented that the tripartite emphasis on *Ngerti*, *Ngrasa*, and *Nglakoni* mapped naturally onto Muhammadiyah's own emphasis on the integration of cognition, character, and practice as articulated in *Pendidikan Berkemajuan* (Akhyar et al., 2024; Mulkhan & Abror, 2019), even though the conceptual vocabulary itself originated outside Muhammadiyah. Within the third theme, principals raised concerns about bandwidth limitations at outlying schools and about the heterogeneity of teachers' baseline digital literacy. Within the fourth theme, principals requested that the LMS continue to serve as an institutional repository of pedagogical resources after the training concluded, beyond its initial role as a delivery platform for the four-week intervention. This request directly supported the decision to keep the LMS live as a continuing digital library for Muhammadiyah educators in Malang City.

Pre-Test and Post-Test Learning Outcomes

Pre-test and post-test data were collected through the Quizizz platform integrated within the LMS course module. Class-average performance rose from 42% on the pre-test to 60% on the post-test, an eighteen percentage-point gain. The number of participants whose post-test performance reached or exceeded a functional competency threshold equivalent to the lower bound of the four-tier learning success rubric (Arikunto, 2010) reached thirty-six out of forty participants who completed both assessments, while none of the forty completers reached the seventy-percent Minimum Competency Achievement threshold set by the Muhammadiyah Dikdasmen Malang standard. This pattern, in which substantial improvement was observed. However, mastery was not attained, which is one of the most analytically significant findings of the study and is taken up at length in the Discussion subsection.

Item-level class statistics generated by the Quizizz platform are summarized in Table 6 and show substantial heterogeneity in item difficulty both before and after the intervention. The least successfully answered pre-test item (item 18: "To create an assignment in Moodle, which feature must we use?") was correctly answered by 15% of the class at pre-test and by 42% at post-test, a 27 percentage-point gain on a procedural *Nglakoni* item. The most successfully answered pre-test item (item 14: "Example of TPACK application in MBR pedagogy") was correctly answered by 63% of the class at pre-test and 79% at post-test, a comparatively modest 16 percentage-point gain that may reflect a ceiling effect on an item already familiar to a substantial proportion of participants. Items at the middle of the difficulty range showed gains in the 15 to 30 percentage-point band.

Table 6. Class-Level Pre-Test and Post-Test Performance with Item Difficulty Distribution

Measure	Pre-Test	Post-Test	Gain
Class-average accuracy	42%	60%	+18 percentage points
Average completion time	7 min 33 sec	7 min 32 sec	≈ 0
Item difficulty range (class %)	15% to 63%	30% to 79%	Floor lifted, ceiling lifted
Lowest-performing item	Item 18 (*Nglakoni*, procedural)	Item 18 (*Nglakoni*, procedural)	15% to 42% (+27 pp)
Highest-performing item	Item 14 (*Ngerti*, conceptual)	Item 24 (*Nglakoni*, applied)	63% to 79% (+16 pp)
Participants meeting functional threshold (≥56%)	—	36 of 40	—
Participants meeting Muhammadiyah Dikdasmen Malang KKM (70%)	—	0 of 40	—

Disaggregated by TRINGO dimension, the largest mean class-level improvements were observed on *Nglakoni* items (procedural knowledge), where the average gain across items ranged from twenty to twenty-seven percentage points. *Ngerti* items (conceptual knowledge) showed mean gains of approximately sixteen to twenty percentage points. In contrast, *Ngrasa* items (affective and reflective engagement) showed smaller and more variable gains in the eight to fifteen percentage-point range. This pattern suggests that the LMS-mediated intervention was most effective at developing procedural fluency with LMS features and least effective at cultivating the affective and reflective engagement that the TRINGO framework treats as the bridge between knowing and doing.

Beyond test outcomes, the implementation phase revealed several strengths and limitations of the LMS, as observed by participants and documented in the log activity. Identified strengths included an intuitive user interface that reduced navigation barriers for first-time Moodle users. This comprehensive digital library provided flexible resource access, effective TRINGO-aligned structuring that enabled participants to locate cognitive, affective, and practical resources within a coherent navigational architecture, and cross-device responsiveness across desktop and mobile devices. Identified limitations included bandwidth-dependent performance affecting participants in less-connected schools, limited automated feedback mechanisms within the assessment module, forum discussion threading that required improvement for sustained asynchronous dialogue, and an assignment upload process that several participants found cumbersome on mobile devices. These limitations informed the iterative refinement of the LMS and the recommendations developed in the Discussion subsection.

DISCUSSION

Convergence of Evidence Across Three Streams

Three streams of evidence, that is, expert validation across media, content, and learning strategy domains; focus group discussion with school principals; and class-level pre-test and post-test performance, each contribute partial information about the LMS as a developmental

product, and their convergence supports a modest set of claims. The expert validation scores of 95%, 90%, and 100% across the three domains were uniformly classified as Highly Valid under the Arikunto rubric and suggest that the LMS, as a technical and instructional artifact, meets the design quality thresholds that Indonesian instructional design research has historically applied to multimedia-based teaching products (Ariyanti, 2022; Dewi et al., 2023). The focus group discussion contributed a different and complementary form of evidence. Principals' explicit recognition of the historical clarification that TRINGO's origin lies in the Taman Siswa tradition rather than in Muhammadiyah's own canon supports the framing decision made in the Introduction and suggests that institutional stakeholders are receptive to cross-tradition pedagogical adoption when its provenance is openly disclosed. The pre-test and post-test data complete the triangulation by indicating that, beyond the technical validity of the artifact and the institutional appetite for it, class-level Technological Content Knowledge did move in the expected direction. The three streams converge most strongly on the claim that the LMS is a validated, institutionally welcomed developmental prototype with measurable formative effects. They converge less strongly and indeed reveal a clear tension on the more ambitious claim of effectiveness.

The triangulation reported here is consistent with a broader methodological pattern in recent TPACK and digital readiness research, in which multi-source evidence (expert judgement, stakeholder perception, and learner performance) yields a more defensible warrant than any single indicator. Madanat et al. (2024), in a study of Jordanian English educators' readiness for virtual learning environments, demonstrate the value of combining self-report, infrastructure audit, and instructor perception when readiness claims must travel beyond a single site; Mahler and Arnold (2022) reach a parallel conclusion in their validation of the MaSter-Bio instrument for prospective biology teachers, in which expert and field procedures were sequenced to produce a defensible technology-related self-concept measure. Su (2023), in a bibliometric review of pre-service TPACK research between 2017 and 2023, further confirms that the most credible TPACK validation studies couple instrument-level evidence with implementation-level evidence. Read alongside that comparative literature, the convergence reported in the present study should be taken as adequate for a developmental-prototype warrant rather than as a substitute for the larger-N effectiveness trial that would establish causal claims.

Four Competing Hypotheses

The most analytically valuable observation in this study is not that class-average performance improved by eighteen percentage points. However, that post-test performance plateaued at 60%, a level below the 70% Minimum Competency Achievement threshold set by the Muhammadiyah Dikdasmen Malang standard and well below the 80% threshold conventionally associated with mastery-level learning in Arikunto's (2010) classification of learning success. None of the forty participants who completed both assessments reached the Muhammadiyah Dikdasmen Malang KKM. This finding is not buried in the data; it sits at the centre of the data, and a paper that takes its evidence seriously must take this question seriously. Four hypotheses, each with different implications for the field, can be considered. The first hypothesis is that the four-week training cycle was too short for the targeted construct. Recent literature on technology-integrated teacher development consistently finds that durable changes in TPACK and its sub-components require sustained engagement over many months rather than weeks (Çam & Koç, 2024; Fütterer et al., 2025). The differentially larger gains observed on *Nglakoni* (procedural) items relative to *Ngrasa* (reflective) items are

consistent with this hypothesis. What changes fastest in a short cycle is precisely what is most procedural. The second hypothesis is that the twenty-item TCK instrument was more difficult than participants' prior digital experience allowed them to complete within a single training cycle. The third hypothesis is that the participant population was more heterogeneous in baseline digital literacy than the recruitment-stage self-report screen captured. The fourth hypothesis is that aspects of TCK, as theorized by Mishra and Koehler (2006), are not addressable within a four-week LMS-based intervention, regardless of design quality. These four hypotheses are not mutually exclusive, and disentangling them is a task for future research.

Two additional considerations help situate the 60% ceiling against the recent literature on learner readiness and reception of new digital pedagogies. Alanoglu et al. (2025) show that university students' self-directed online learning in the context of emergency remote teaching is mediated jointly by online learning readiness and digital literacy, with each factor placing a ceiling on what platform features alone can deliver. Their finding maps onto the Muhammadiyah cohort here: the recruitment-stage digital-literacy screen verified basic operational fluency. However, it did not measure self-directed learning readiness, the very disposition the *Ngrasa* and *Nglakoni* dimensions of TRINGO ask participants to enact. Siregar (2023), examining perceived usefulness and perceived ease of use of online learning among Islamic religious education teachers in Indonesia, reports that acceptance is contingent on prior exposure to platform-mediated pedagogy rather than on hardware alone, a pattern consistent with the slower gains observed on the affective *Ngrasa* items in the present data. Chan and Hu (2023) similarly document, in their survey of student perceptions of generative AI in higher education, that acceptance and meaningful integration lag behind exposure even when access is unconstrained. Together, these studies suggest that the 60% plateau is unlikely to be closed by extending the training cycle alone; rather, it points to a deeper readiness-and-reception layer that future iterations of the LMS will need to address directly.

Implications and Boundary Conditions

Implications drawn from a single-city feasibility study with forty-five participants must be calibrated against the warrant that the data can bear. The Muhammadiyah educational network operates over 10,000 schools nationwide, and any responsible discussion of the implications must distinguish between what this study can plausibly contribute and what it cannot. The study cannot, on its own, support claims about scaling to the full Muhammadiyah network or about implications for Indonesian national education policy. What it can support is a more modest, more defensible set of claims about pathways warranting further investigation and replication. The validated LMS provides a deployable platform for the Muhammadiyah Dikdasmen Malang council to continue using as an institutional digital library beyond the training cycle, a use case explicitly requested by the school principals in the focus group discussion. The Moodle-based architecture offers cost-effective scalability, open-source flexibility, and an established institutional support ecosystem that lowers the barrier to extending it to other Muhammadiyah regional councils, particularly those with comparable infrastructure and educator profiles. The cross-tradition operationalization of TRINGO offers a transferable design pattern for other faith-based educational networks in Indonesia that face the same conjunction of conditions: a strong religious educational identity, an underdeveloped digital pedagogical infrastructure, and a national educational heritage that offers indigenous pedagogical wisdom as a design resource.

The implications outlined above are reinforced by a small but growing body of Indonesian work on LMS integration in faith-based and Muhammadiyah-affiliated settings. Nafiah et al. (2026), in a bibliometric analysis of LMS as a digital transformation in elementary schools covering the period from 1989 to 2025, document a clear acceleration of LMS-related research after 2020 but a continuing scarcity of validated, context-sensitive implementation studies in Indonesian faith-based contexts; the present study contributes one such exemplar to that underdeveloped evidence base. Suharsiwi et al. (2024), in their development of technology-based teaching materials for Islamic religious education subjects, similarly underline that durable uptake depends on the alignment between digital content and the religious-pedagogical commitments of the host institution rather than on platform features in isolation. Most directly, Kuswandi et al. (2021) report a TRINGO-based digital learning literacy programme for teachers at SMP Wahid Hasyim Malang that anticipates several design choices made here, providing a local precedent for the cross-tradition operationalization of Ki Hadjar Dewantara's framework in a Muhammadiyah network school within the same city. The convergence of these studies strengthens the case that the LMS reported in the present study is one node in a wider, though still under-theorized, Indonesian trajectory of LMS-mediated faith-based teacher development.

Theoretical Contribution: A Cross-Tradition Pathway

The principal theoretical contribution of this study is to articulate and operationalize a cross-tradition pathway for the development of Technological Content Knowledge within faith-based teacher development. Three elements of this contribution warrant explicit statement. First, the study demonstrates that an indigenous Indonesian pedagogical strategy originating in one religious and cultural tradition (Ki Hadjar Dewantara's Taman Siswa) can be operationalized, with explicit acknowledgment of its provenance, within a different religious educational network (Muhammadiyah) when the structural compatibility of the strategy with the host network's pedagogical commitments is theorized rather than assumed. The framework underlying this argument is depicted in Figure 3.

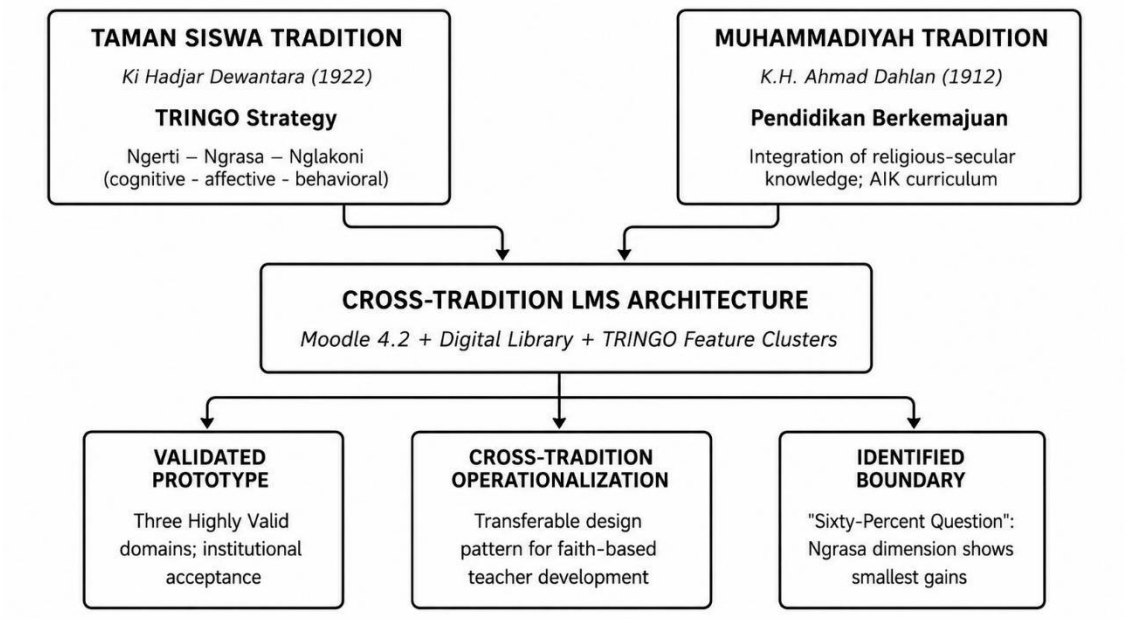

Figure 3. Cross-Tradition Contribution Framework

Second, the study contributes a validated developmental prototype that operationalizes the tripartite *Ngerti*, *Ngrasa*, and *Nglakoni* structure within a digital library-based LMS architecture, providing an empirical example that other instructional designers can adapt and extend. Recent reviews of TPACK instrument development and of digital instructional design for underserved teacher populations have repeatedly noted the absence of validated, context-sensitive design exemplars (Gonscherowski & Rott, 2025; Sofyan et al., 2023). Third, the study identifies the boundary at which cross-tradition pedagogical adoption alone is insufficient: while the TRINGO structure proved compatible with Muhammadiyah educator priorities and produced measurable class-level improvement on procedural *Nglakoni* items, the affective *Ngrasa* dimension, precisely the dimension most theoretically connected to the religious-identity formation that distinguishes faith-based educational networks, showed the smallest gains. This pattern suggests that the substantive religious content of any successor LMS for Muhammadiyah educators may need to be more deeply grounded in Muhammadiyah's own pedagogical sources, that is, *Al-Islam Kemuhammadiyahan*, *Pendidikan Berkemajuan*, and the institutional documents of the Muhammadiyah educational tradition, rather than relying on the cross-tradition framework alone to carry the affective work. The cross-tradition pathway is therefore best understood not as a substitute for engagement with Muhammadiyah's own pedagogical canon but as a learning architecture that can host and structure that engagement.

The cross-tradition argument advanced here can be located within two further bodies of work that warrant explicit acknowledgement—the first concerns Ki Hadjar Dewantara's framework as a transferable Indonesian pedagogical grammar. Qadri et al. (2023) demonstrate the operationalization of Ngarti and *Ngrasa* in accounting education, showing that the tripartite structure travels productively across disciplinary domains when the host pedagogy and the framework are theorized together rather than juxtaposed. Read against Nashir (2023) on Islam berkemajuan as the doctrinal and pedagogical foundation of Muhammadiyah's educational mission, the present study's framing of TRINGO as a learning architecture that hosts, rather than substitutes for, Muhammadiyah's own canon receives a more precise theoretical anchor. The *Ngerti*, *Ngrasa*, and *Nglakoni* progression also resonates with the cognition, reflection, practice cycle articulated in Kolb's (2014) classic theorization of experiential learning, providing a transnational point of theoretical contact without dissolving the indigenous specificity of the Indonesian formulation. The second body of work concerns the broader literature on integrating indigenous knowledge into teacher education and STEM curricula. Yip and Chakma (2024), in their scoping review of empirical studies on indigenous knowledge and perspectives in initial teacher education, identify a persistent gap between policy-level commitment and classroom-level uptake; Matindike and Ramdhany (2025) reach a comparable conclusion in their systematic review of indigenous knowledge in integrated STEM education. The cross-tradition pathway operationalized here offers one workable response to that gap in the Indonesian faith-based context, by treating an indigenous pedagogical structure as a design substrate for a contemporary digital learning environment.

Limitations and Future Research Directions

Several limitations of the study should be acknowledged. The single-group pre-test and post-test design, without a control group, precludes definitive causal attribution of class-level improvement to the LMS intervention specifically. The available pre-test and post-test data were class-level item statistics generated by the Quizizz platform rather than individual-level paired raw scores, precluding inferential analyses. The panel of expert validators included a

single rater in each of the three domains, limiting inter-rater reliability assessment. The sample was drawn exclusively from Muhammadiyah educators in Malang City, limiting generalizability to other regional councils. The four-week training cycle, while sufficient for the present feasibility study, is probably too short to produce mastery-level Technological Content Knowledge. The affective *Ngrasa* dimension showed the smallest gains, suggesting the need for design refinements that engage more deeply with Muhammadiyah's own pedagogical sources. Each of these limitations corresponds to a direction for future research: quasi-experimental or randomized controlled designs to strengthen causal inference; retention of individual-level data to enable inferential reporting; expansion of validation panels to three to five raters per domain with Content Validity Index and Cohen's kappa reporting; multi-site replication across Muhammadiyah regional councils and comparable faith-based networks; longer training cycles of three to six months with periodic follow-up; and integration of *Al-Islam Kemuhammadiyahan* content and the documentary tradition of *Pendidikan Berkemajuan* into the LMS substantive content layer.

Beyond the directions outlined above, future iterations would benefit from an extended cognitive-outcome measurement strategy of the kind used by Muharram et al. (2023) in their R&D development of an IoT-supported learning artifact, in which cognitive ability was tracked alongside affective and behavioural outcomes through staged data collection rather than through a single pre-post comparison. Adapting that multi-wave R&D measurement logic to the present LMS would allow the *Ngerti*, *Ngrasa*, and *Nglakoni* dimensions to be tracked separately over time. It would help disentangle the four hypotheses considered earlier in the discussion of the 60% plateau.

CONCLUSION

This Research and Development study produced a validated digital library-based Learning Management System that integrates Ki Hadjar Dewantara's TRINGO strategy as a cross-tradition learning architecture for the development of Technological Content Knowledge among Muhammadiyah educators in Malang City, Indonesia. Three streams of evidence, that is, expert validation scores of 95% (media), 90% (content), and 100% (learning strategy); a focus group discussion with twenty-one Muhammadiyah school principals; and class-level pre-test to post-test performance gains of eighteen percentage points, support the claim that the LMS functions as a Highly Valid developmental prototype that institutional stakeholders are prepared to host and that produced measurable formative effects on participant performance. The study explicitly clarifies that TRINGO originated in the Taman Siswa tradition rather than within Muhammadiyah's own pedagogical canon, and frames its operationalization as a cross-tradition pathway that draws on the structural compatibility between TRINGO's tripartite cognitive, affective, and behavioral architecture and Muhammadiyah's *Pendidikan Berkemajuan* commitments. The most analytically significant finding is that post-test performance plateaued at 60%, below the seventy-percent Minimum Competency Achievement threshold and well below the conventional mastery threshold, with the affective *Ngrasa* dimension showing the smallest improvement. The study positions the LMS as a developmental prototype warranting further investigation rather than as a fully evaluated effectiveness trial. It articulates a cross-tradition contribution to the literature on faith-based teacher development, indigenous pedagogical adoption, and Technological Content Knowledge development in Indonesian educational contexts.

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