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Designing a Technology Integration Competency Framework for Mathematics Teachers Through Reflective Practice: A Design-Based Research Approach

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Abstract

Although reflective practice is recognised as a driver of instructional change, technology-focused professional development—particularly one-shot tool workshops—often lacks systematic analysis of student evidence, prioritising technical skills over evidence-based reflection. This study aimed to empirically develop and refine a technology integration competency framework for mathematics teachers by investigating how structured reflective practice serves as a mechanism for longitudinal development. Adopting a design-based research (DBR) approach, the study was conducted over 18 months with 21 in-service mathematics teachers in northern Thailand through two iterative cycles of design, enactment, analysis, and redesign. The intervention utilised structured tools, including guided reflective journals, classroom video reflection, and reflective dialogue, enabling teachers to connect pedagogical intentions with evidence of student response. Thematic analysis indicated that the initial framework required reconfiguration into a dynamic model characterised by three structural shifts: the merger of technological knowledge and tool proficiency into a single fundamental technology competency; the reclassification of teacher confidence as a transversal element; and the central positioning of flexible learning design for blended orchestration. These thematic findings were validated through data triangulation of journals, video reflections, and interviews. The study contributes an empirically warranted framework with actionable implications for designing professional development that fosters sustained instructional improvement in mathematics.

Keywords: reflective practice; professional development; mathematics teaching; technology integration; teacher competency; design-based research

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Academic Editors: Remigijus Bubnys, Jordi Colomer Feliu and Aušra Kazlauskienė

Received: 5 January 2026
Revised: 6 February 2026
Accepted: 8 February 2026
Published: 10 February 2026

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1. Introduction

The landscape of mathematics education has undergone a profound transformation, accelerated by recent global disruptions that necessitated an immediate shift toward technology-mediated instruction. These disruptions underscored a critical reality. Effective mathematics teaching in contemporary environments must remain resilient even when traditional face-to-face classroom routines are constrained (Mukuka & Alex, 2025). In contactless, blended, and asynchronous settings, the efficacy of learning depends significantly on the capacity of students to engage in self-paced activities (Mshayisa & Ivala, 2022) and the ability of teachers to adapt their pedagogical strategies beyond the confines of physical explanations and real-time monitoring.

Within these complex contexts, the quality of educational systems is increasingly defined by teachers' capacity to utilise digital tools not merely as supplementary resources but as fundamental cognitive reorganisers that fundamentally reshape mathematical thinking and knowledge acquisition processes (Ince-Muslu & Erduran, 2021). This requirement for situational adaptability establishes the immediate context for the current research, demanding a rigorous analysis of teacher competency within evolving technological learning ecologies.

Despite substantial international attention to digital infrastructure and hardware procurement, persistent challenges in technology adoption indicate that access alone is insufficient to catalyse pedagogical reform (Ogwu et al., 2023). This suggests the bottleneck is not infrastructure but teachers' integration competency and the learning mechanisms that sustain it. A primary barrier to effective integration lies in the disparity between a teacher's technical proficiency with a tool and their pedagogical capacity to use that tool in ways that reshape mathematical understanding rather than simply modernising presentation styles (Akram et al., 2022). Moving from tool-focused instruction to pedagogy-driven integration requires teachers to interpret complex evidence from classroom enactments, such as digital interaction traces, student participation patterns, and conceptual artefacts, and to make principled, adaptive adjustments to their instruction.

However, existing frameworks for mathematics teachers' technology integration competency provide a fragmented understanding of how teachers develop and enhance these abilities in practice. While the Technological Pedagogical Content Knowledge (TPACK) framework, proposed by Mishra and Koehler in 2006 (Koehler & Mishra, 2009), offers a useful conceptual lens, it has faced significant empirical critique regarding its lack of operational specificity and the difficulty of measuring its overlapping domains (Priyanda et al., 2025; Abebe & Trainin, 2024). Critics argue that TPACK often remains too theoretical, failing to provide actionable guidance for teachers in diverse contexts or to explain the longitudinal developmental pathways of integrated knowledge.

Similarly, the Pedagogical Technological Knowledge (PTK) framework, proposed by Thomas and Hong, incorporates personal orientations and beliefs (Thomas & Hong, 2013) but provides limited understanding of the iterative nature of teacher learning in technology-rich environments. Current models exhibit a pronounced lack of empirical anchoring; they do not clearly explain what existing frameworks overlook based on classroom findings, particularly how teachers transition from using tools instrumentally to orchestrating blended learning in a sophisticated manner. This study identifies a specific gap in the literature regarding the mechanisms that facilitate the transformation of teacher competency through sustained, practice-based evidence.

To address these gaps, reflective practice is theorised as the primary professional learning mechanism that supports instructional transformation. Reflective practice allows educators to make sense of complex classroom events, connect professional knowledge to situated action, and refine subsequent decisions based on student evidence (Agnihotri et al., 2024). Grounded in the ALACT model comprising action, looking back, awareness, creating alternatives, and trial, reflection is positioned as a structured, scaffolded process rather than an individual disposition (Anand & Gangmei, 2023).

By systematically examining their pedagogical intentions against the evidence of student response, teachers can identify bottlenecks in their practice and iteratively redesign their instruction. Recent research indicates that when reflection is supported by structured tools, such as guided journals, video analysis, and reflective dialogue, it can move beyond surface description toward deeper analytic engagement with technological affordances (Ahmad et al., 2025).

Therefore, this study reconceptualises the development of technology integration competencies as an outcome of reflective practice embedded within a sustained, 18-month professional development programme. This study used a design-based research (DBR) approach because of its iterative cycles of design, enactment, analysis, and redesign, which allow for the investigation of learning in authentic messy classroom contexts. DBR, proposed by Brown and Collins during 1990s, is the iterative process designed to develop knowledge for practices of quality, and focused on designing relevant interventions that can impact where the study is being performed (Tinoca et al., 2022). It enables both framework refinement and the articulation of design principles for reflective professional development (PD), ensuring that the resulting outputs are both empirically grounded and practically actionable. By conducting research over two complete iterative cycles, the study captures the complex interactions between teachers, students, and digital tools.

The aim of this study is to empirically develop and validate a framework of technology integration competency for mathematics teachers. Accordingly, the study is guided by the research question of how an empirically grounded framework for technology integration competency in mathematics teachers can be developed through structured reflective practice.

2. Backgrounds

The theoretical background of technology integration in mathematics education has evolved from instrumental conceptions of technology as computational aids toward more sophisticated understandings of technology as cognitive reorganisers that fundamentally reshape mathematical thinking processes (Hegedus & Moreno-Armella, 2009; Korobkova et al., 2025). This evolution necessitates a critical re-examination of teacher professional knowledge, shifting the focus from the mere acquisition of technical skills to the development of situated, adaptive competencies (Lu, 2014).

For the contemporary mathematics educator, technology integration is not a static state of knowledge but a dynamic, transactional relationship between content, pedagogy, and digital affordances (Priyanda et al., 2025). As educational environments increasingly transition toward contactless, blended, and asynchronous configurations, the capacity of teachers to adapt their pedagogical strategies based on student evidence has become the defining characteristic of instructional quality (Lee et al., 2022).

2.1. Existing Frameworks Relating to Technology Integration

In the effort to categorise the knowledge required for effective technology use, two paradigms have dominated the literature, which are the Technological Pedagogical Content Knowledge (TPACK) framework and the Pedagogical Technological Knowledge (PTK) framework. While both have provided essential taxonomic clarity, their limitations in modelling the longitudinal and iterative development of teacher competence provide the primary rationale for the current study.

The TPACK framework, first developed by Mishra and Koehler, is a well-established paradigm for understanding the critical knowledge necessary for technology integration in teaching practices (Koehler & Mishra, 2009), as depicted in Figure 1.

By extending Shulman's pedagogical content knowledge (PCK), referring to the unique integration of subject-matter expertise and pedagogical strategy (Koehler & Mishra, 2009), TPACK identifies seven knowledge domains that converge to form the specialised knowledge required to teach effectively with technology.

In mathematics education, TPACK emphasises how digital tools, such as dynamic geometry software or statistical visualisation programmes, can reshape mathematical concept communication (Kholid et al., 2023). However, while the TPACK framework

provides a conceptual foundation for integrating technology into mathematics education, its transition from theory to classroom practice is hindered by several structural and operational hurdles. These limitations can be categorised into five primary dimensions including operational specificity, measurement bias, static nature, contextual resilience, and AI integration.

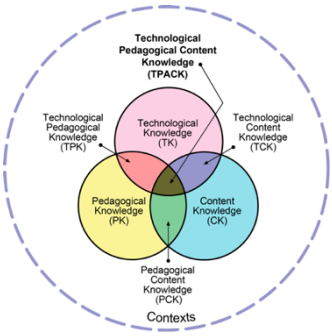

Figure 1. TPACK framework (Koehler & Mishra, 2009).

Firstly, the primary critique of TPACK involves its fuzzy boundaries. In practice, teachers often struggle to distinguish between overlapping domains, such as technological pedagogical knowledge (TPK) and technological content knowledge (TCK). Because these definitions remain vague, it becomes difficult to develop objective metrics to observe or evaluate these knowledge types during actual classroom instruction (Priyanda et al., 2025).

Secondly, data regarding TPACK often suffers from a lack of objective verification. The current research relies heavily on self-reporting surveys, which measure a teacher's perception of their own skills rather than their actual enactment of those skills. This gap between what a teacher believes they know and how they actually perform in a live educational setting creates a significant bias in educational research (Priyanda et al., 2025; Aqib et al., 2025).

Moreover, TPACK functions as a static taxonomy, capturing a snapshot of knowledge at a single point in time. This fails to account for the fluid nature of teaching. Effective mathematics instruction requires knowledge structures to shift and evolve in response to real-time classroom evidence and student feedback, e.g., a dynamic process that the traditional TPACK model does not adequately represent (Priyanda et al., 2025; Aqib et al., 2025).

Additionally, the framework frequently overlooks the real-world environment of the school system. TPACK tends to focus on individual teacher knowledge while ignoring external factors such as institutional constraints, lack of resources, or technostress. So, the psychological burden placed on educators by rapidly changing technology. Without accounting for these pressures, the framework lacks the resilience needed to guide professional development in diverse or under-resourced contexts (Aqib et al., 2025).

Finally, the emergence of artificial intelligence presents a unique challenge to the TPACK model. Unlike traditional digital tools, such as calculators or static software, AI is adaptive and autonomous. The current TPACK framework struggles to account for tools that can independently generate content or adapt to student needs, suggesting that the model may need to be updated to remain relevant in the age of generative AI (Eyal, 2025).

Moreover, research suggests that simply acquiring technological skills is insufficient. Teachers must understand how to utilize tools in ways that specifically enhance mathematical thinking. TPACK, while identifying what knowledge is needed, provides little insight into the reasoning process through which a teacher aligns these domains during the messy, unpredictable moments of classroom orchestration. This situated reasoning gap is a primary driver of the current study's efforts to reconfigure framework dimensions around evidence-based practice (Kurniawan et al., 2025).

The PTK framework attempted to bridge the gaps in TPACK by incorporating personal orientations and personal instrumental genesis as illustrated in Figure 2.

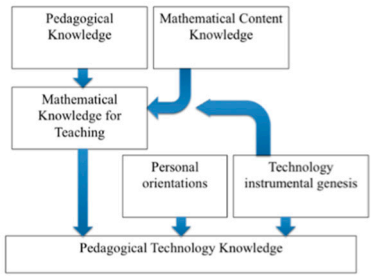

Figure 2. PTK framework (Thomas & Hong, 2013).

PTK is notably more practice-oriented, emphasising that technology integration is driven by a teacher's beliefs, attitudes, and their personal history of using a specific tool. This inclusion is critical in mathematics, where a teacher's orientation toward the subject, e.g., viewing mathematics as a set of rules or an exploration of patterns, dictates how they deploy technology (Thomas & Hong, 2013).

However, a fundamental tension persists in the PTK model regarding the representation of professional growth. Although PTK acknowledges beliefs and implementation, it does not model the iterative reflective pathway through which competencies transform. It provides a snapshot of teacher characteristics but fails to articulate the mechanism by which a teacher with a transmission-oriented belief system evolves into a transformative practitioner through successive cycles of action and reflection. This study identifies a specific lack of empirical anchoring in current models, which fail to explain how teachers navigate the transition from instrumental tool use to sophisticated orchestration (Ruiz-López, 2018).

The development of technology integration competency in mathematics is inseparable from the teacher's underlying mathematical knowledge. Ball (2000) proposed mathematical knowledge for teaching (MKT) to describe the specialised knowledge needed for explaining concepts, interpreting student strategies, and analysing errors. MKT serves as a prerequisite for technological adoption; without a deep understanding of mathematical structures, a teacher cannot properly select tools for abstract concepts.

This relationship is operationalized through the theory of instrumental genesis (IG), which describes the process through which a technical artefact, e.g., software, transforms into a cognitive instrument. This involves two concurrent processes, including instrumentalisation and instrumentation. The instrumentalisation refers to the subject, as teacher or student, learning to use the artefact and may transform it for specific uses, while the instrumentation focuses on the subject's cognitive schemes that are shaped by the affordances and constraints of the artefact (Ruiz-López, 2018).

In the actual classroom, the teacher's role is defined as instrumental orchestration, that is, the intentional organisation of artefacts to guide the collective instrumental genesis of the class. However, professional development policies are often too general, failing to acknowledge that personal instrumental genesis is a spontaneous and individual process that requires ongoing support. There is a pronounced need for frameworks that account for how teachers develop these orchestration schemes iteratively.

2.2. Professional Development for Technology Integration

Traditional approaches to professional development for technology integration have been largely criticised for being linear and tool-focused (Ertmer & Ottenbreit-Leftwich, 2012). These isolated training sessions or one-shot workshops prioritise technical proficiency over evidence-based reflection, often leading to superficial adoption rather than

deep pedagogical reform (Seufert et al., 2020). Mathematics teachers engaged in traditional professional development frequently utilise technology as a support to established teaching methods, failing to fundamentally reconsider mathematical content or pedagogical strategies (Ertmer & Ottenbreit-Leftwich, 2012).

Moreover, research indicates that mathematics teachers require continuous, contextual support to develop the sophisticated skills needed for transformational technology integration (Aguirre-Muñoz et al., 2020). The contextual aspect of technology integration issues necessitates that professional development addresses the particular mathematics content, student characteristics, and institutional limitations that teachers encounter in their practice (Cullen et al., 2020).

The design-based research (DBR) intervention required participating teachers to develop custom materials using the open-source platform. The materials were essential as tools for student learning, facilitating active knowledge construction by students instead of serving only as static aids for teachers.

This methodological requirement fulfilled two purposes. It facilitated the development of interactive media that overcame the constraints of existing one-way media. The effective development of these complicated student learning tools significantly improved teacher self-efficacy. The practical use of these tools resulted in a particular change in students' behaviour. Teachers observed that students progressed from passively receiving mathematical information to demonstrating greater enthusiasm and initiating profound conceptual explorations, a change infrequently observed in conventional lecture-based classrooms. This outcome confirms the fundamental idea of adopting IG as a requisite element of technology-orientated professional development.

2.3. Reflective Practice as a Causal Mechanism for Professional Growth

To address the limitations of static frameworks, this study theorises reflective practice not merely as a disposition but as the primary professional learning mechanism for instructional transformation. Reflection is defined as the active, persistent, and careful consideration of any belief or supposed knowledge considering the grounds that support it (Mohamed et al., 2022).

The causal power of reflection is rooted in the transition from routine action to reflective action. It was argued by Dewey that reflection emancipates the practitioner from impulsive activity, enabling them to plan according to ends-in-view (Mohamed et al., 2022). Additionally, Schön further refined this by distinguishing between reflection-on-action, referring to looking back after the event, and reflection-in-action, which included adjusting in the moment (Mohamed et al., 2022; Qvortrup, 2019).

Korthagen's ALACT model, consisting of action (A), looking back on the action (L), awareness of essential aspects (A), creating alternatives (C), and trial (T), serves as the structural framework for the study's intervention, utilising a spiral approach to teacher reflection (Do Anh, 2016). The model's core strength lies in its ability to facilitate core reflection, which bridges the gap between a teacher's theoretical knowledge and their actual cognitive structures. By moving through the following five distinct phases of competency development, educators develop the ability to learn independently from their own classroom experiences.

From the action phase, the cycle begins with direct engagement. In the context of this study, this involves the practical integration of technology within the classroom. This phase is crucial because it generates the raw experiential data, that is, the real-world successes and challenges, forming the basis for all subsequent reflection.

In looking back on the action phase, teachers perform a structured review of the event. This is often supported by objective data such as video recordings or reflective logs. The

goal here is to identify salient moments, which are specific instances where things went particularly well or poorly, and to acknowledge the emotions felt during those moments.

The awareness of essential aspects phase moves beyond description into analysis. Teachers begin to identify underlying patterns in their behaviour, surface-level misconceptions about technology, or specific technostress triggers. By gaining awareness of these essential aspects, the teacher transitions from simply recounting an event to understanding the cognitive and emotional drivers behind their instructional choices.

Once the teacher understands why certain moments were salient, they begin to develop new instructional strategies in the creating alternatives phase. This is a creative phase where the educator uses their newfound awareness to brainstorm alternative approaches to technology integration, specifically designed to address the challenges identified in the previous phases.

The final phase involves the implementation of these revised strategies in a live classroom setting. The trial in this phase is not an end point but a beginning. It initiates a new cycle of growth. Successes and failures in this phase become the action for the next iteration of the ALACT spiral, leading to continuous professional improvement (Do Anh, 2016).

While the ALACT model describes the process, Clarke and Hollingsworth proposed the interconnected model of teacher professional growth, providing the architecture for understanding how change occurs across different domains of a teacher's professional world. The model suggests that professional growth is a non-linear process involving external, personal, practice, and consequence domains (Muir et al., 2021). All domains include (1) information sources or stimuli outside daily context, (2) teacher knowledge, beliefs, and attitudes, (3) professional experimentation within the classroom, and (4) salient outcomes, particularly student learning and engagement.

The model identifies reflection and enactment as the specific mediating mechanisms that translate change from one domain to another. For example, enactment involves putting a new idea or belief into action in the classroom. If this action results in salient outcomes, the teacher's subsequent reflection on those outcomes reinforces or shifts their knowledge and beliefs. This change sequence is the causal engine of competency development.

By using the interconnected model of teacher professional growth model as a lens, we can see that existing frameworks fail because they focus on teacher knowledge, positioned in personal domain, without modelling the reflective loops that link practice and consequence. Therefore, the contribution of this study is the articulation of these loops through a sustained, 18-month DBR trajectory.

From a teacher education perspective, reflective practice is not only a desirable disposition but also a set of learnable and assessable competencies. Empirical work has operationalised reflection, detailing how reflective depth can be examined in written accounts (Zhang et al., 2023). Recent work has also argued that reflection quality is strengthened when it is supported by structuring prompts and examined through multidimensional indicators rather than treated as a single, undifferentiated construct (Arendt et al., 2025).

A further implication is that reflective practice can be intentionally scaffolded through structured routines and digital tools. For example, video-mediated approaches have been used to promote individual and collaborative reflection. In addition, pre-service teachers can select and analyse short lesson clips and receive mentor feedback that supports reflection on practice, with video platforms making feedback episodes visible and analysable (Liesa et al., 2023).

Beyond initial teacher education, reflective video-based professional development models have also been implemented as iterative cycles to support educators' self-reflection and community learning (Simpson et al., 2025).

3. Materials and Methods

Treating reflective practice as a mechanism for teacher learning implies that reflection should be designed and scaffolded, not simply encouraged. This study employed the DBR approach to develop and refine a technology integration competency framework for mathematics teachers. DBR is an iterative, collaborative, and situated approach that aims to solve practical educational problems (Tinoca et al., 2022) while simultaneously advancing theoretical understanding of learning and instruction (McKenney & Reeves, 2021). By conducting research within the authentic, messy context of real-world classrooms rather than controlled laboratory environments, the study captures the complex interactions between teachers, students, technological tools, and mathematical content (Scott et al., 2020).

3.1. Design-Based Research and Intervention Design

The adoption of DBR was motivated by the need to develop a framework that is not only descriptively accurate but also practically actionable for teacher professional development. This study adapted the DBR paradigm to the four canonical steps, including design, enactment, analysis, and redesign, encompassing two complete iterative cycles to ensure that the final competency framework was progressively refined based on practice-based evidence.

3.1.1. Structure of the Professional Development

The intervention was designed as a sustained learning trajectory rather than a series of isolated workshops. Grounded in the principle that technology integration requires a fundamental shift in pedagogical reasoning, the programme positioned reflection as a designed work mechanism. The design drew upon the existing framework as a knowledge base and utilised a design approach to active engagement.

The 18-month professional development programme was structured into three distinct stages of intervention intensity comprising foundational workshops, collaborative lesson design, reflective cycles, and validation as summarised in Table 1.

Table 1. A professional development programme.

Stage	Timeline	Activities for Participants
Foundational workshops	Month 1–2	- Workshops focused on technical instrumental genesis.
Collaborative lesson design	Month 3–4	- Community of inquiry groups to co-design technology-enhanced tasks in a simulated school setting.
Reflective cycles 1	Month 5–10	- Instructional planning according to authentic school settings. - Implementation of the designed plan in classrooms. - Evaluation of the effectiveness of the enacted designs on student learning. - Reflection 1 (Competency development of themselves).
Reflective cycles 2	Month 11–16	- Instructional planning (can be a different unit of learning/content) according to teachers' reflective cycle 1. - Implement the refine plan in classrooms. - Evaluation of the effectiveness of the enacted designs on student learning. - Reflection 2 (Competency development of themselves).
Validation stage	Month 17–18	- Community of inquiry groups to validate the framework for technology integration competencies developed by researchers.

According to Table 1, foundational workshops focused on technical instrumental genesis, where teachers moved from exploring software functionality to understanding how specific tools mediate mathematical concepts. In collaborative lesson design practice, teachers worked in community of inquiry groups to co-design technology-enhanced tasks in a simulated school setting.

Both reflective cycles stage started from instructional planning including task design. The tasks were explicitly mapped to curriculum goals and student-centred orchestration modes. This session of the professional development programme focused on encouraging teachers to consider interconnections between technology, content, and pedagogy. Participants engaged in experiential learning actively by exploring instructional planning.

Each cycle utilised journals, video feedback cycles, and peer-led reflective dialogue sessions to evaluate the effectiveness of the designs enacted on student mathematical learning. In this session, they discussed complex strategies in technology-enhanced pedagogy, strategies for maximising learner engagement, and strategies for establishing a technology-enabled learning environment. Additionally, this phase focused on assessing learning and development and refining their technology integration.

The validation stage allowed the participants validate the technology integration competency framework developed by researchers according to their experiences. The iterative feedback cycles made it easier for participants to progress toward a broader rollout, especially in pedagogy practices, for the integration of technology.

3.1.2. Research Paradigm: DBR

The ontological stance of this study is interpretivist, acknowledging that teacher competency is not a fixed attribute but is constructed through social interaction, professional experience, and critical reflection. Methodologically, this required a flexible approach where the research procedures could evolve in response to emerging data. Table 2 outlines the temporal progression of the research phases, DBR cycles, and the focal objectives of each phase.

Table 2. Research procedures and DBR cycles.

PD Session	DBR Phase	Timeline	Core Activities of Researcher	Research Outputs
	DBR Phase 1. Initial Design and Framework Development Phase			
1. Foundational workshops	Analysis and Exploration	Month 1–2	Literature review on TPACK/PTK; expert consultations; baseline surveys of teacher needs; planning of the PD curriculum.	Identification of primary generators for the design; PD workshop materials.
2. Collaborative lesson design	Initial Design	Month 3–4	Foundational workshops: development of the draft framework.	First version of draft framework: co-design technology-enhanced tasks.
3. Reflective cycles	*DBR Phase 2. Implementation and Iterative Refinement Phase*			
	Reflective Cycle 1	Month 5–10	Implementation of the first draft; monthly workshops; first round of classroom video reflection.	Preliminary thematic map: identification of functional overlaps.
	Reflective Cycle 2	Month 11–16	Refinement of the framework based on Cycle 1 data; focus on adaptive teaching and blended orchestration.	Final framework: design principles for reflective PD.
4. Validation	*DBR Phase 3. Final Evaluation and Validation Phase*			
	Validation	Month 17–18	Validation of the framework	Final validated framework: design principles for reflective PD.

From Table 2, this study comprised iterative cycles in which data were collected using reflective journals, classroom video reflection, and reflective dialogue via semi-structured interviews. The methods were chosen in an effort to accumulate rich, detailed data that captures the experiences, understanding, and ongoing feedback of the participants in relation to developing and using the framework.

Phase 1: Initial Design and Framework Development

The study started with a thorough literature review for the purposes of establishing rudimentary principles for constructing the framework. This phase further involved consultations with experts in technology in education and experienced mathematics teachers for the purpose of getting insights on existing concerns in relation to technology integration. The first draft of the framework was developed using the TPACK, PTK, and tried-and-tested teaching practices.

Phase 2: Implementation and Iterative Refinement

In accordance with this developed structure, implementations were integrated in a cyclical planning process, and the teachers participated in workshops on a monthly basis in both small and full groups. Qualitative data was collected while the teachers used the lessons they developed in their schools. The process involved mechanisms for collecting feedback, making it possible for participants to evaluate progress and suggest adjustments to the framework.

Phase 3: Final Evaluation and Validation

The framework improved based on input given by teachers and subsequently rechecked by expert opinion and further critique. The process of data generation consisted of iterative cycles, in which in-service teaching sessions played a major role in supporting professional growth.

3.2. Participants

The study involved 21 in-service mathematics teachers from schools in Northern Thailand. A purposive sampling strategy was employed to ensure that the participants were key informants who could provide rich, relevant data regarding the intersection of technology integration and reflective practice. This non-probability sampling method prioritises the depth of insight over statistical representativeness, which is essential for theory-building in DBR.

Participants were selected based on a weighted ranking system designed to identify teachers with the requisite dedication and readiness for a long-term, intensive DBR project. The criteria were operationalised to minimise convenience bias and ensure methodological rigour. The operational definition and verification of each criterion are detailed in Table 3.

Table 3. Operational definition and verification of criteria.

Criterion	Weighting	Operational Definition and Verification
Professional Dedication	40%	Commitment to attend 100% of the 18-month workshop; prior history of engaging in school-based peer learning communities.
Implementation Fidelity	30%	Willingness to implement at least four technology-integrated lessons and record them for review.
Reflective Capacity	20%	Capability to articulate pedagogical rationales in a pre-screening interview; readiness to share problems of practice openly.
Technical Readiness	10%	Basic proficiency in core educational software for measuring pre-intervention skills.

The final sample of 21 teachers represented a diversity of experience levels and school contexts, allowing the researchers to observe how the competency framework functioned across a range of learning ecologies. To ensure transparency and facilitate generalisation, the baseline characteristics of the analytic sample are summarised in Table 4.

Table 4. Participant Demographics.

Participant	Teaching Experience (Years)	Grade Level	Primary Technology Utilised
T01–T04	6–15	Primary	GeoGebra, Google Classroom, Microsoft Teams
T05–T07	6–15	Lower Secondary	GeoGebra, Google Classroom, Microsoft Teams
T08–T09	6–15	Upper Secondary	GeoGebra, Google Classroom, Microsoft Teams, mixed-level Excel, interactive whiteboards
T10–T13	Over 15	Primary	GeoGebra, Geometer's Sketchpad, Google Classroom, Microsoft Teams, Mixed Levels Excel
T14–T17	Over 15	Lower Secondary	GeoGebra, Geometer's Sketchpad, Google Classroom, Microsoft Teams, Mixed Levels Excel
T18–T21	Over 15	Upper Secondary	GeoGebra, Geometer's Sketchpad, Google Classroom, Microsoft Teams, Mixed Levels Excel, Interactive Whiteboards

According to Table 4, the participants comprised mid-career teachers with 6–15 years of experience and veteran teachers with 16 or more years of experience who taught across mixed grade levels. The mid-career teachers primarily used GeoGebra, Google Classroom, Microsoft Teams, mixed-level Excel, and interactive whiteboards, while the veteran teachers reported using GeoGebra, Geometer's Sketchpad, Google Classroom, Microsoft Teams, mixed-level Excel, and interactive whiteboards as their primary tools.

3.3. Data Collection

The obtained framework was validated by a systematic data triangulation strategy employed across both DBR cycles. Data was gathered from three complementary sources to capture subjective belief, observable practice, and pedagogical justification, demonstrated in Table 5.

Table 5. Data sources across DBR iterative cycles.

Data Source	Purpose in DBR	Key Data Captured
Reflective Journals (n = 252)	Capturing self-reflection and longitudinal shifts in affective factors	Shifts in attitudes and confidence/perceptions towards technology, reflections on what worked/what did not, intended revisions
Classroom Video Reflection (n = 42)	Capturing instructional practice (action) and evidence of technology integration fidelity	Enacted technology integration, teaching methods, and evidence of adaptive teaching
Individual and Group Interviews (Reflective dialogue) (n = 42 and n = 12)	Qualitative insight into pedagogical rationale and empirical justification for changes	Teacher goals, perception changes, justification for using technology vs. traditional methods

For reflective journals, teachers completed a guided reflection journal after each implementation. The journaling questions were designed to elicit evidence-based reflection rather than general impressions. Questions focused on (a) lesson goals and technological

choices, (b) observed student responses and evidence of learning, (c) points of difficulty, and (d) concrete revisions for next lessons.

Classroom video reflection provided teachers with opportunities to review their teaching through classroom videos and structured observation records, which supported their awareness of student thinking, teacher questioning, representations, and orchestration decisions. Reflection was guided by an analysis protocol aligned to lesson goals and student evidence, such as moments where technology supported conceptual understanding and required adaptive decisions.

Reflective dialogue was gathered when teachers participated in facilitated debrief sessions and both individual and group interviews in which they shared evidence from lessons and journals, compared interpretations, and co-developed revisions. Facilitation prioritises evidence-based discourse and the linking of instructional decisions with student learning evidence.

This study utilised a triangulation strategy that corroborated self-reported data with observable actions and collaborative justifications. Table 6 illustrates how these sources were triangulated to validate the framework's core dimensions.

Table 6. Data source triangulation strategy.

Framework Dimension	Primary Data Sources	Secondary Data Sources	Triangulation Logic
Fundamental Tech Competency	Video Recording	Individual Interview	Corroborating technical proficiency with actual classroom operation.
Transversal Confidence	Reflective Journal	Individual Interview	Mapping longitudinal shifts in self-efficacy to qualitative justifications.
Adaptive Orchestration	Video Recording	Group Interview	Observing real-time adjustments and the teacher's subsequent rationale for them.

3.4. Data Analysis and Validation

The qualitative data was analysed, focusing on identifying changes and recurring patterns related to the development of technology integration competencies. Data, including all notes and quotations, were transcribed and reviewed at the beginning of the data analysis process for contextualisation.

This study adopted the reflexive thematic analysis approach originated and defined by Braun and Clarke (2006). The reflexive thematic analysis is a method, providing a theoretically flexible tool that is compatible with the study's interpretivist and social constructionist stance. This stance acknowledges that the researcher's subjectivity and interpretative framework are central to the identification and construction of meaning-based themes. The analysis followed the standardised six-step protocol proposed by Braun and Clarke (2006) to ensure replicability and credibility.

Step 1: The researchers engaged in multiple readings of all transcripts and journals. Initial thoughts were recorded in reflexivity journals to track how the researchers' perspectives shaped early interpretations.

Step 2: An initial codebook was developed, combining deductive codes derived from the literature, e.g., tool selection or pedagogical strategy, with inductive codes emerging from the data, e.g., crisis adaptation and teacher fear. Systematic coding was conducted using a hybrid deductive and inductive approach since coding and analysis never adhere strictly to a single approach and frequently employ a hybrid of both methods (Braun &

Clarke, 2019). Open coding was applied to text chunks, assigning descriptive labels to capture the essence of each segment.

Step 3: Codes were grouped into potential themes based on conceptually related patterns around a central organising concept. This step involved moving from descriptive categories to interpretive themes that captured shared patterns of meaning. For example, codes relating to software crashes, student engagement, and real-time adjustment were clustered into the candidate theme of adaptive orchestration.

Step 4: Reviewing and refining themes involved quality control to ensure the themes accurately represented the entire dataset. The team organises themes into a thematic map to visualise hierarchical relationships between core competencies and sub-competencies. This facilitated the identification of conceptual tensions, such as the intersection between technological fluency and pedagogical risk-taking.

Step 5: Themes were refined to ensure they were distinct and directly addressed the research question. Definitions were established to set clear boundaries between themes, ensuring that each captured a unique aspect of the teachers' experiences. During this stage, the team determined that confidence was not a separate stage of competency but a transversal dimension that interacted with all other components.

Step 6: The final report weaves together the themes and sub-themes into a narrative, supported by thick descriptions and illustrative quotes from the data. This narrative tells a coherent story about the development of technology integration competencies, highlighting the systemic and personal factors that influence mathematical teaching in digital environments.

3.5. Iterative Evolution of the Framework

A defining feature of this study is the transparency regarding how the technology integration competency framework evolved across the DBR cycles. This evolution was not random but was driven by empirical criteria derived from the triangulation of data.

The initial draft was influenced by the primary issue in practice, which is that technology is often used as a supplement rather than as a core tool for constructing mathematical knowledge. The initial framework presented competency as a linear progression that moves from technical skills to the classroom environment.

Data from Cycle 1 implementation revealed that the linear model failed to capture the messy reality of teacher competency development. Table 7 provides the schematic overview, detailing the specific evidence that necessitated changes between Cycles 1 and 2.

The final iteration represents an unassuming theory of technology integration. It is grounded in context-specific practice but offers transferable design principles for other mathematics educators. The emergence of adaptive teaching based on technology-mediated evidence became the core theoretical contribution, shifting the focus from using technology to orchestrating learning with digital evidence.

Trustworthiness was strengthened through methodological triangulation across three data sources, iterative comparison of evidence across cycles, and peer debriefing with the researcher and experts. To enhance credibility, preliminary interpretations and the evolving framework were shared with participants for comment, and revisions were made where clarifications were warranted. An audit trail was maintained, including coding memos, versions of the codebook, and records of framework revisions across DBR iterations.

Table 7. Schematic overview of changes between two cycles.

Framework Level	Draft Component (Cycle 1)	Final Component (Cycle 2)	Empirical Criterion for Revision
Foundation	TK + Tool Proficiency	Fundamental Tech Competency	Functional Overlap - Qualitative data showed teachers did not practically distinguish between knowing a tool and using it effectively. - Codes for these two components were redundant in 88% of cases.
Affective	Confidence	Transversal Dimension	Cyclical Relationship - Journal data showed that success in adaptive orchestration fuelled confidence, which in turn improved lesson design. - Confidence was an outcome and a driver.
Instruction	(Static) Lesson Design	Flexible Learning Design	Situational Adaptability - Emerged from the need for crisis-resilient teaching. Teachers' accounts highlighted the importance of managing asynchronous and self-paced mathematical exploration.
Environment	Interactive Exercises	Blended Orchestration	Redundancy/Output - Analysis revealed that exercises were the output of effective management, not a distinct competency. - The framework was streamlined to focus on the orchestration process.

4. Results

Across iterative cycles, the DBR process generated empirical evidence that enabled progressive refinement of the draft framework for technology integration competencies. The results are reported as framework learning produced through structured reflective routines, including teachers' reflective journals, classroom video review, and reflective dialogue through which participants connected instructional intentions, enacted decisions, and student responses. This section first reports the initial draft framework and the preliminary thematic structure derived from early-cycle reflective evidence. It then details the empirically grounded revisions that resulted in the final framework.

4.1. Initial Draft Framework and Preliminary Themes

The initial draft framework conceptualised technology integration competency as a three-stage developmental progression comprising (1) technology skills, (2) technology integration in lesson design, and (3) technology-enhanced learning environment. This staged logic was adopted based on the model drew from Rogers' diffusion of innovation theory, which posits that individuals move through stages of knowledge, persuasion, decision, implementation, and confirmation (Toledo, 2005). Furthermore, the model of computer technology integration provided the rationale for assuming that teachers first focus on entry and adoption (technical skills) before moving toward adaptation, appropriation, and invention (pedagogical transformation in lesson and learning environment design).

This linear assumption was initially considered appropriate because baseline surveys indicated that 18 out of 21 participants (85.7%) reported significant technostress and a perceived lack of software mastery. Therefore, the PD intervention was designed to first shore up technology skills before addressing lesson design. However, as the DBR cycles progressed, empirical evidence from classroom videos and reflective journals revealed that technical proficiency did not always precede pedagogical innovation, necessitating a shift toward a more dynamic, transactional model where these domains co-evolved.

Early-cycle analysis of triangulated reflective evidence reveals critical insights into how mathematics teachers integrate technologies into their classrooms. Table 8 presents the key codes identified within each theme and sub-theme, capturing how teachers described their developing capability, for example, tool selection and operation, intentional planning, and management of technology-mediated learning activity.

Table 8. Key codes of the preliminary themes in the initial draft framework.

Theme	Sub-Theme	Key Codes
1. Technology Skills	Technological Knowledge (TK)	Tool selection (TS); successful application (SA); knowledge of tool operation (TO)
	Technological Tool Proficiency	Device familiarity (DF); software functional mastery (SM); specific software feature utilisation (sSU); variable manipulation skill (VM)
2. Technology Integration in Lesson Design	Technology-Enhanced Pedagogy	Intentional planning (IP); technology blending (TB); shift to integration (IC)
	Confidence in utilising technology	Self-efficacy (S-E); reduction in fear/hesitation (HR); personal orientation (PO); reinforcement of belief (B)
3. Technology-Enhanced Learning Environment	Technology-Driven Learning Management	Using technology to organise group work (GW); Tracking student progress through technology (Track); Adjusting instruction based on real-time feedback (R-F); Classroom culture of exploration/collaboration (Coll)
	Interactive Learning Exercise Development	(Student learning) instrument design (IDe); dynamic concept manipulation (Dym); self-paced student exploration (S-P Ex); knowledge construction (KnowCon)

Figure 3 illustrates the initial draft framework that informed the beginning of the DBR intervention. This initial conceptual model was structured in a consequential manner, positioning technology integration as a developmental process that includes three stages of competence.

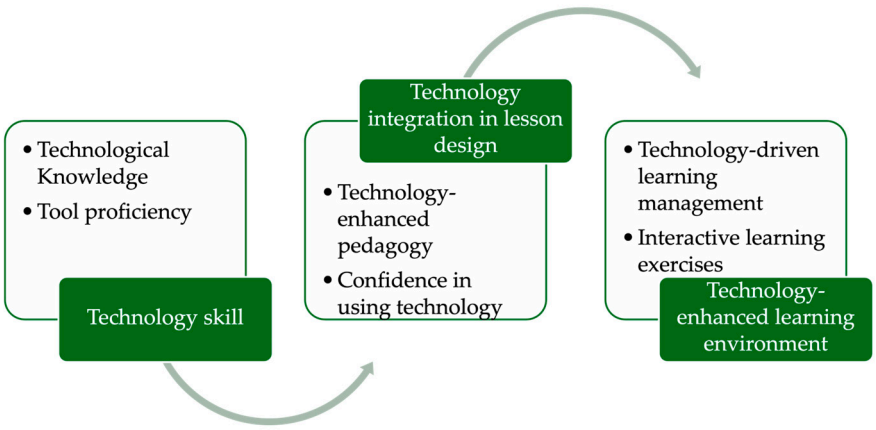

Figure 3. The initial framework from the first cycle.

Conceptually, the foundational stage was technological skill development, focusing on the necessary technical prerequisites for successful integration. The draft separated "knowing about technology" from "being able to use specific tools". Therefore, this stage comprised two separate components, including technological knowledge, which involved the theoretical understanding of technology principles mentioned in the literature, and tool proficiency, which denoted the practical mastery and functional ability to operate specific software tools.

The intermediate stage, technology integration in lesson design, focused on applying these skills to instructional planning. This stage included technology-enhanced pedagogy, defining the systematic and intentional blending of technology with teaching methods, and confidence in using technology, which was initially classified as a siloed component within lesson design that influenced a teacher's willingness to integrate technological tools.

This final stage, the technology-enhanced learning environment, represented the most specific application of competence, focusing on transforming the classroom atmosphere. This stage comprised technology-driven learning management, referring to the organisational and monitoring aspects of student activity using digital media, and interactive learning exercises, which were defined as the design and creation of dynamic materials to facilitate student knowledge construction.

However, this initial framework served as the analytic starting point, providing the initial analytical frame against which the qualitative data collected during the iterative cycles was tested and subsequently refined. As detailed in the following sections, the analysis revealed misalignment between the draft's conceptual separations and how competence was enacted and justified in practice, mandating the revisions that led to the final, empirically grounded framework.

4.2. Empirical Refinement and Framework Reconfiguration

Reflective evidence across cycles revealed that several elements of the draft framework did not adequately represent teachers' lived integration work. Therefore, the analysis focused on how teachers observed their practices through journals and video reviews, as well as how they justified changes during reflective dialogues, which led to the following key structural changes.

Table 9 presents the frequency and distribution of codes identified through thematic analysis of 252 reflective journals, 42 classroom video reflections, and 54 interviews conducted over 18 months. The shift in frequencies between Cycle 1 and Cycle 2 illustrates the longitudinal developmental pathway of the participants as the following.

The data in Table 9 demonstrates a profound upward shift in code density from Cycle 1 to Cycle 2. In Cycle 1, 48% of coded segments were related to technology skills, reflecting the participants' initial preoccupation with hardware and software functionality. However, by Cycle 2, these codes dropped to only 7.2%, while adaptive teaching and affective factors became the dominant themes, representing 49.3% of the total analytical focus. This trajectory empirically confirms that teacher growth in DBR is not a post hoc relabelling but a demonstrable shift in instructional priority from the tool to students.

The draft framework treated technological knowledge and technological tool proficiency as distinct foundational elements. However, empirical analysis demonstrated that teachers did not meaningfully separate these in practice. Knowing about a tool was only educationally consequential when it was operationalised through successful use in authentic lessons. Accordingly, these two elements were consolidated into fundamental technology competency, a performance-orientated foundation that better captures the enacted nature of teachers' technological readiness.

In the initial draft, confidence in utilising technology was treated as a component located within lesson design. Across iterative reflective cycles, however, confidence and perceptions towards technology functioned as both an outcome of successful enactment and a driver of subsequent pedagogical ambition. Teachers' reflective accounts indicated a cyclical relationship that participants achieved more competent use of dynamic software and developed technology-mediated materials, confidence increased. As a result, increased confidence supported more sophisticated instructional design and broader engagement with technology integration demands. This pattern warranted reclassifying

confidence as a transversal competency operating across the framework rather than as a single bounded component.

Table 9. Example of frequency and trajectory of competency codes.

Theme	Code	Cycle 1 Frequency	Cycle 2 Frequency	Trajectory Description
Technology Skills	Tool selection (TS)	148	22	Shift from "finding tools" to "justifying tool affordances" for specific math concepts.
	Software functional mastery (SM)	92	34	Rapid decline as technical operation became subconscious and automated.
Technology Integration in Lesson Design	Intentional planning (IP)	58	112	Increased focus on linking technology to specific mathematical learning goals.
	Flexible Learning Design (FD)	14	86	Emergence of planning for asynchronous, self-paced, and hybrid environments.
Affective Factors	Self-Efficacy (S-E)	42	98	Growth in belief that tech-enhanced pedagogy improves student outcomes.
	Reduced Hesitation (RH)	12	74	Observable shift from cautious, scripted use to fluid, impromptu tech adjustments.
	Risk-Taking (RT)	8	62	Willingness to relinquish teacher control and allow student-led exploration.
Technology-Enhanced Learning Environment	Adaptive Teaching (AT)	11	145	Core shift in Cycle 2: using digital data traces to adjust instruction in real time.
	Blended Orchestration (BO)	26	94	Sophisticated management of simultaneous online and face-to-face activities.
	Exercise Output (EO)	88	42	Reclassified as an output; codes shifted to the management of these materials.

A further revision emerged from contextual pressures associated with contactless and blended instruction. Reflective evidence indicated that some teachers moved towards more flexible designs, which required competence in managing learning without continuous real-time teacher presence. In this context, teachers' reflections highlighted the importance of using technology-mediated evidence, such as interaction traces or results from dynamic software activities, to inform formative decisions and adjust instruction. This led to the addition of flexible learning design as a core dimension within technology integration in lesson design, as illustrated in Figure 4.

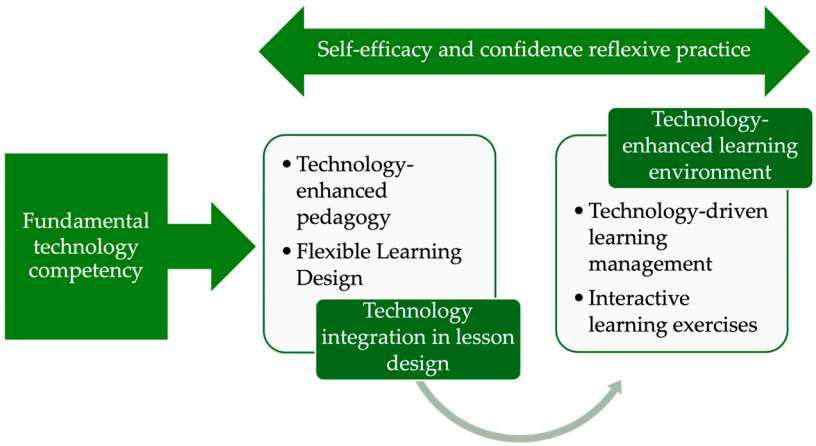

Figure 4. The structural revisions from iterative cycles.

Moreover, there exists the competency reflecting the teacher's essential ability to observe and adjust teaching suitable for their class based on data collected directly through interviews. The inclusion confirms that the framework is uniquely responsive to the demands of self-paced learning and adaptive teaching environments. These additions shift the framework's focus from only integration to orchestration, acknowledging the teacher's role in managing self-paced learning environments. Therefore, according to the emerging sub-themes, adaptive teaching for blended learning orchestration was defined under the theme of technology-enhanced learning environment design.

Additionally, the interactive learning exercise development was discarded as a core component and redefined as an instructive activity, acknowledging that it represents an observable implication rather than a fundamental ability, thereby refining the framework's emphasis on transferable competences. Collective data also confirmed that creating exercises is an outcome of effective technology-driven management rather than a standalone competency. Therefore, self-directed learning media design represents a refinement in which interactive learning exercises are reclassified as specific outputs for asynchronous and pre-class materials development. Separating this as a final stage clarifies that the ultimate goal of the adaptive pedagogy is to produce materials that support student autonomy and crisis-resilient learning.

The transition from the draft framework to the final validated model was driven by qualitative evidence that surfaced during cross-cycle analysis. To fulfil the requirement for demonstrably grounded findings, Table 10 provides representative excerpts from the data that catalysed each major structural shift.

Table 10. Representative data excerpts ground the framework evolution.

Framework Shift	Participant	Data Source	Representative Excerpt	Analytical Significance
Merging TK and Tool Proficiency	T05	Reflective Journal (C2)	"I don't think about 'how' to use GeoGebra sliders anymore. The slider is the ratio y/x."	Technical skills became invisible as they fused with mathematical content knowledge.
Confidence as Transversal	T12	Interview (C2)	"In the first lesson, I was terrified if the internet failed. Now, if a student breaks the model, I use it as a 'teaching moment.' Confidence isn't a stage. It's what lets me try new things every day."	Confidence functions as a continuous amplifier of all other competencies, not a siloed stage.
Adding Adaptive Teaching	T18	Video Reflection (C2)	"I saw on the Google Classroom dashboard that half the class was struggling with the domain restriction $x > 0$. I stopped the individual work to do a quick mini-lesson on why the graph disappeared."	Using technology-mediated evidence to inform formative assessment and instructional axes.
Reclassifying Exercise Development	T09	Reflective Dialogue (C1)	"Designing the Quizizz was easy, but managing 40 students as they explored it was the real challenge. The Quizizz is just a tool. The organisation is the skill."	Material creation is an output of successful orchestration, not a standalone core competency.
Flexible Learning Design	T21	Reflective Journal (C2)	"The flipped model required me to design tasks where students could struggle productively at home. I had to anticipate their errors in the digital task design."	Response to the contextual demands of blended and contactless mathematics instruction.

Table 10 provides a direct empirical link between teacher experiences and the resulting framework architecture. For instance, the comment from T05 led to the consolidation

of technological knowledge and tool proficiency into a single, performance-orientated fundamental technology competency.

Figure 5 illustrates the final framework, validated through triangulation and expert review, and foregrounds two defining features of the empirically grounded model, including a consolidated foundational competence and a transversal affective dimension that interacts with competence development over time.

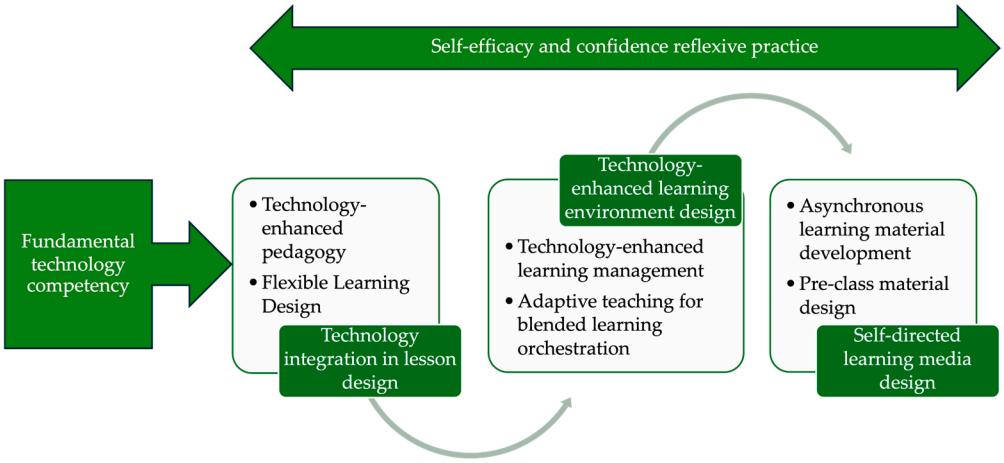

Figure 5. The final framework of technology integration competency.

To address the conceptual ambiguity surrounding confidence, we have established rigorous analytical boundaries between the four primary affective constructs coded in this study. Self-efficacy was coded as the teacher's domain-specific judgement of their ability to achieve student learning outcomes using technology; for example, "I can help students understand fractions using this GeoGebra." In contrast, confidence was operationalised as a broader behavioural trait characterised by the absence of anxiety and the presence of risk-taking.

Confidence was coded by three observable behavioural indicators: reduced hesitation, pedagogical risk-taking, and willingness to try new orchestration. Reduced hesitation entails the speed and confidence with which a teacher tackles technical issues or student requests without returning to standard methods, while pedagogical risk-taking denotes the readiness to engage in open-ended, student-centred tasks where the results are not definitively foreseeable. Furthermore, the willingness to explore new orchestration is characterised by the proactive search of new methods for structuring classroom interactions, such as flipped models.

However, perception was coded as the teacher's subjective view of the classroom environment, such as the excerpt of "the students are more engaged". Attitude was defined as a relatively stable predisposition toward the value of technology in education, for example, as in the excerpt "Technology is essential for 21st-century learners."

Table 11 illustrates how these indicators were used to validate the framework's "transversal confidence" dimension. To make the empirical logic behind these changes transparent, Table 11 also summarises the critical, empirically driven revisions that transitioned the draft framework into its final, validated form, demonstrating the rigour of the iterative process.

Table 11 summarises the empirical trajectory of the framework's development, detailing the specific refinements mandated by iterative cycles. By cross-referencing classroom video review with teacher interviews, the initial conceptual model was adjusted to resolve functional overlaps and incorporate emergent phenomena. Specifically, the table justifies the transition of confidence to a transversal driver and the introduction of adaptive teach-

ing as the framework's core theoretical response to the demands of digitally mediated mathematics education.

Table 11. Empirical justification for the framework's evolution.

Draft Components (Figure 3)	Final Components (Figure 5)	Structural Revision Type	Evidence Source(s)	Quote Label	Empirical Justification
TK + Tool proficiency (2 elements)	Fundamental technology competency (merged)	Consolidation	Video, Interview	Software skill is math skill (Ref: T05-I-C2)	High functional overlap; teachers did not separate knowing from using in practice.
Confidence (Siloed stage)	Transversal confidence and risk-taking	Reclassification	Journal, Interview	Fuel for the engine (Ref: T12-I-C2)	Recursive relationship: success in practice drives confidence, which enables more complex design.
Static learning exercise	Flexible learning design	Expansion	Journal	Planning for the struggle (Ref: T21-J-C2)	Need for crisis-resilient teaching in blended/asynchronous settings.
Learning management	Adaptive teaching based on digital evidence	Redefinition	Video, Interview	Digital eyes to see (Ref: T18-V-C2)	Shift from monitoring behaviour to using data traces to adjust mathematical pacing.
Exercise development	Self-directed media (outcome)	Reclassification	Journal, Interview	Orchestration byproducts (Ref: T09-I-C1)	Determined to be a specific output of effective management, not an independent core competency.

5. Discussion

Drawing on evidence from structured reflective journalling, classroom video reflection, and reflective dialogue, this section explains how reflective practice functioned as the mechanism through which the technology integration competency framework was empirically developed and refined across iterative cycles. The central argument is that the study's contribution is not only the resulting competency framework but also the empirically documented pathway through which it was developed.

5.1. Contributions and Significance of Reflective Practice Research to Theoretical Novelty

This study extends current scholarship on technology-focused professional development by demonstrating that technology integration competency can be developed empirically through structured reflective practice, rather than being treated as a set of predefined knowledge domains to be transmitted. The principal novelty, lying in specifying an evidence-based developmental pathway, adds three distinct dimensions, including the transversal confidence factor, the focus on adaptive orchestration, and the DBR-based validation rule.

The transversal confidence dimension is perhaps the most significant departure from traditional models. In our framework, confidence is not only an entry requirement or a final stage; it is also an amplifier that operates across all dimensions. As T12 noted in an interview, "Confidence isn't a stage. It's what lets me try new things every day." This recursive relationship, where success in adaptive teaching fuels confidence, which in turn permits pedagogical risk-taking, is modelled as a converging spiral (Bueno et al., 2021).

This positioning addresses the psychological burden, or technostress, identified in the literature by showing that affective resilience is a co-dependent variable in the growth of technological pedagogical content knowledge.

Moreover, the orchestration focus shifts the unit of analysis from the teacher's knowledge to the teacher's reasoning in action. Orchestration involves the intentional organisation of artefacts to guide the collective instrumental genesis of the class (Mariotti, 2009). In our framework, adaptive teaching for blended learning orchestration replaces learning management, emphasising that the teacher's core competency is the ability to adjust instruction based on digital feedback loops.

Finally, the DBR validation rule ensures that the developed framework's dimensions are only accepted when they are corroborated by three distinct data sources comprising subjective belief from reflective journals, observable practice from video, and pedagogical justification from interviews. This rigorous triangulation logic, summarised in Table 6, provides a warranted model that balances theoretical rigour with practical applicability.

Rather than treating reflection as an individual and largely unstructured add-on, we show that reflective activity becomes professionally productive when it is scaffolded, evidence-informed, and explicitly oriented towards revising subsequent instruction. This positioning aligns with prior work showing that reflective tasks can help teachers make their technology-integration reasoning more explicit and transferable, particularly when reflection is framed to unpack the complexity of teaching with technology and to plan modified action (Lu, 2014).

A second contribution is methodological and practical. Reflective practice was operationalised as a sequence of designed routines, structured prompts, artefacts of practice, and dialogic feedback that can be embedded into professional learning. Evidence from teacher education indicates that structured supports can move reflection beyond surface description towards more theory-informed, analytic engagement, especially when teachers work with concrete representations of practice (Rothe & Göbel, 2024; Rogge & Herzig, 2025). Building on the literature, the findings of this study indicate that the value of reflection in technology integration is realised most clearly when teachers reflect on evidence of students' mathematical thinking and participation, not only on tool operation. In a technology-enhanced context, mathematical thinking refers to the wide range of cognitive processes that students engage in while constructing or applying mathematical knowledge, which is often demonstrated through various forms of technology, such as online artefacts, student traces, or responses.

Thirdly, this study advances the field by producing an empirically grounded framework for technology integration competency that is not only descriptive but also actionable for professional learning design. The emergence of flexible learning design and adaptive teaching based on technology-mediated evidence indicates that teachers' reflective learning increasingly involved interpreting student responses and redesigning instruction accordingly. Therefore, the obtained framework specifies what teachers learn to notice, justify, enact, and evaluate when reflection is structured around teaching goals and evidence, making reflective practice a practical force for sustained instructional improvement (Liesa et al., 2023; Vogelsang et al., 2025).

5.2. Reflection as a Mechanism for Changing

A central interpretive insight is that teachers' development progressed when reflection functioned as a mechanism for instructional reasoning, not as a compliance activity. In line with research on video-supported and collaborative reflection, teachers benefited when they could (i) identify salient moments in practice, (ii) justify pedagogical decisions using evidence and professional knowledge, and (iii) generate testable revisions for subsequent

lessons (Rothe & Göbel, 2024). Importantly, the mechanism was strengthened when reflection was socially mediated through structured dialogue, because uncompetitive talk supported explanation, challenge, and refinement of teachers' interpretations of evidence (Rothe & Göbel, 2024; Liesa et al., 2023).

The findings also indicate that reflective practice becomes more meaningful when feedback is designed to be collaborative and role-complementary, as peer or facilitator feedback, rather than unidirectional advice. Prior evidence shows that video-based feedback can structure collaborative reflection across different roles and help participants focus on both emotional support and task assistance, which together can sustain engagement in iterative improvement (Liesa et al., 2023). In this study, the literature helps explain why reflection influenced not only teachers' planning but also their willingness to revise instructional moves and assessment practices based on student evidence.

5.3. Emergent Themes as Reflection on Evidence

The most educationally consequential extension of the framework involves adaptive teaching within blended environments. Teachers' competency was strengthened when reflective practice was explicitly orientated towards how evidence, such as student work, participation traces, and classroom interaction data, could inform decisions about pacing, scaffolding, representations, and task sequencing. This resonates with evidence that structured supports can help teachers connect observed events to theory-informed explanations and to alternatives for future action (Rogge & Herzig, 2025; Vogelsang et al., 2025).

For mathematics teaching, adaptive orchestration is particularly important because instructional quality often depends on how teachers respond to students' partial conceptions and emergent misconceptions in the moment. In this study, reflection enabled teachers to treat blended tools not as ends in themselves but as resources for making students' thinking visible and for planning targeted follow-up. When reflection was linked to evidence, teachers were better able to justify why a given technology-supported move was pedagogically warranted, rather than simply engaging or modern.

Additionally, confidence and perception remain relevant, but we interpret them as enabling conditions that shape whether reflective insights translate into enacted change. Reflection can support teachers' sense-making about technology integration and strengthen their readiness to act, particularly when reflective routines help teachers articulate reasoning and anticipate classroom contingencies (Lu, 2014). However, the findings of this study are not only confidence itself but also the way confidence operates within a designed reflective system. Particularly, when reflection is evidence-informed and scaffolded, teachers' confidence becomes more tightly coupled with pedagogical justification and adaptive enactment, rather than with tool familiarity alone.

This framing is also consistent with research suggesting that structured reflection, especially when tied to concrete artefacts of practice and collaborative dialogue, can support deeper analytic engagement and more robust connections between observation, interpretation, and instructional alternatives (Rothe & Göbel, 2024; Rogge & Herzig, 2025). Thus, confidence is better positioned as a cross-cutting amplifier of reflective-to-enactive coherence, not the primary contribution of the framework.

5.4. Implications for Professional Development

Consistent with critiques in previous research that highlight the limitations of isolated, tool-focused training, the reflective practice and iterative process of DBR demonstrate the value of sustained, design-orientated professional learning and simultaneously cultivate technology-integrative competency.

A critical component of this operationalisation is the facilitation move protocol. Successful PD facilitators do not only set the context, but they also use back-pocket questions to nudge teachers toward deeper noticing. For example, during a video review session, a facilitator might ask, "I see the student struggled at 05:12. What mathematical idea where they are grappling with when they clicked that button?" This focused responsiveness starts with the premise that teachers bring valuable possessions and helps them bring those possessions into conversation with research-based approaches. Table 12 provides a ready-to-use set of prompts and timelines for PD designers.

Table 12. Professional development phases and protocols.

PD Phase	Core Activity	Timeline	Recommended Facilitation Move	Prompt for Teacher Reflection
Phase I: Technical Genesis	Exploring software affordances	Months 1–4	Modelling digital collaboration in PD sessions.	Which specific mathematical representation does this tool make more accessible?
Phase II: Collaborative Design	Co-planning tasks in Community of Inquiry groups	Months 5–8	Challenging the view of students as "reproducers" of knowledge.	What is your plan for assessing student thinking in this lesson?
Phase III: Enactment and Feedback	Implementing plans; classroom video capture	Months 9–14	Providing "formative, non-evaluative feedback" on teacher uptake.	What did you notice about the relationship between your question and the student's digital drag?
Phase IV: Validation and Scaling	Sharing products (TMLS); revising the local theory	Months 15–18	Facilitating post-lesson dialogue that balances support with challenge.	How has your understanding of this concept changed through watching the students' errors?

The implications of this study are the following. First, the usage of structured questions that require teachers to (i) identify a pedagogical problem of practice, (ii) interpret evidence, (iii) justify decisions, and (iv) specify a concrete revision to test in the next lesson treats reflection as designed work. Evidence from teacher education suggests that structured reflection improves the quality of video reflection and supports movement beyond descriptive accounts (Vogelsang et al., 2025).

Moreover, the incorporation of artefacts such as annotated lesson videos, student work, and participation traces was used to deepen reflection so that reflection is anchored in observable events rather than impressionistic recall. Structured video annotation and guided protocols can support deeper and theory-aligned reasoning about teaching episodes and alternatives for action (Rogge & Herzig, 2025; Vogelsang et al., 2025).

Finally, facilitating post-lesson dialogue allows teachers and facilitators to jointly examine artefacts of practice and provide feedback that balances support with task-focused questioning, making reflective dialogue more evidence-based and feedback-rich. Classroom video review and feedback systems have been shown to structure collaborative reflection and can sustain engagement in iterative improvement (Liesa et al., 2023).

These implications clarify how reflective practice can be enacted as a coherent design for professional learning that systematically improves technology-integrated mathematics teaching while also producing transferable knowledge for educators who seek to make reflection consequential for instructional change.

5.5. Limitation and Future Research

While this study provides an empirically warranted framework, several limitations must be acknowledged. First, the sample comprised 21 in-service teachers within a specific

regional context. While the DBR approach offers deep, qualitative insights, the generalisability of the framework to different cultural or institutional ecologies requires further investigation. Second, although the 18-month duration captured longitudinal shifts, the rapid evolution of generative AI occurred during the latter stages of the study. While the framework accounts for adaptive tools, future research should specifically investigate how AI-driven adaptive learning systems fundamentally change the fundamental technology competency domain. Finally, the reliance on classroom video for reflection, while powerful, may introduce a performance bias among participants. Future studies could explore more naturalistic data collection methods, such as automated interaction logging, to corroborate teacher self-reflections.

6. Conclusions

This study successfully developed and validated a technology integration competency framework for mathematics teachers through an 18-month design-based research trajectory. By utilising structured reflective practice as the primary causal mechanism for change, the research demonstrates that teacher competency is not a linear progression of skills but a dynamic, transactional process. The final framework highlights three critical shifts in our understanding of teacher knowledge, including the integration of tool proficiency into a singular fundamental competency, the recognition of confidence as a transversal amplifier of pedagogical risk-taking, and the central positioning of adaptive teaching based on digital evidence.

In conclusion, this research moves beyond the static "what" of teacher knowledge to the dynamic "how" of teacher growth. By grounding competency development in the evidence of student response, we provide a resilient pathway for mathematics teachers to navigate the complexities of contemporary, technology-mediated learning environments.

Author Contributions: Conceptualisation, N.J.-o.; methodology, N.J.-o. and C.S.; validation, N.J.-o.; formal analysis, N.J.-o. and C.S.; investigation, N.J.-o.; data curation, N.J.-o.; original draft preparation, N.J.-o.; review and editing, N.J.-o. and C.S.; project administration, N.J.-o.; funding acquisition, N.J.-o. All authors have read and agreed to the published version of the manuscript.

Funding: This research project was funded by the National Research Council of Thailand (NRCT), grant number N42A670856. The APC was funded by Lampang Rajabhat University.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Chiang Mai Rajabhat University (protocol code IRBCMRU, 29 August 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: N.J.-o. would like to acknowledge Suthep Suantai for his initiatives and supervision of this research.

Conflicts of Interest: The author declares no conflicts of interest.

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