Jurnal Ilmu Pendidikan dan Sosial (JIPSI)
Vol 5, No.1 April 2026
E-ISSN: 2829-2723
DOI; 10.58540/jipsi.v5i1.2305

CURRICULUM READINESS FOR DIGITAL MATHEMATICS LEARNING MEDIA: EXAMINING TEACHERS' PREPAREDNESS FOR FUTURE-ORIENTED MATHEMATICS EDUCATION

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Abstrak

Kesiapan kurikulum terhadap media pembelajaran matematika digital merupakan prasyarat strategis bagi pendidikan matematika yang berorientasi masa depan, namun bukti empiris mengenai kesiapan guru masih tersebar di berbagai konteks dan belum disintesis secara sistematis. Penelitian ini bertujuan memetakan cara kesiapan kurikulum dikonseptualisasikan, menggambarkan profil kesiapan guru, mengidentifikasi faktor pendukung dan penghambat, serta merumuskan model integratif yang menjelaskan hubungan antarlapisan kesiapan. Objek kajian mencakup lima puluh dua artikel ilmiah terbitan tahun dua ribu lima belas sampai dua ribu dua puluh lima yang terindeks pada pangkalan data internasional bereputasi dan pangkalan data nasional terakreditasi. Metode yang digunakan adalah tinjauan pustaka sistematis dengan protokol pelaporan mutakhir, meliputi identifikasi, penyaringan, penilaian kelayakan, penilaian mutu metodologis, dan sintesis tematik. Tinjauan ini menghasilkan lima tema, yaitu konseptualisasi kesiapan, profil kompetensi guru, determinan afektif dan motivasional, kapasitas institusional, dan keselarasan kebijakan kurikulum. Temuan utama menunjukkan kefasihan operasional guru tergolong tinggi, sedangkan kemampuan mengintegrasikan teknologi ke dalam penalaran matematis masih rendah, dan dokumen kurikulum bersama sistem penilaian jarang memuat kompetensi media digital secara eksplisit. Penelitian menyimpulkan bahwa kesiapan kurikulum bekerja sebagai fungsi minimum antarlapisan, bukan sebagai atribut individual guru.

Kata kunci: Kesiapan Kurikulum, Media Pembelajaran Matematika Digital, Kesiapan Guru, Pendidikan Matematika Berorientasi Masa Depan, Tinjauan Pustaka Sistematis

Abstract

Curriculum readiness for digital mathematics learning media is a strategic prerequisite for future-oriented mathematics education, yet empirical evidence on teachers' preparedness remains scattered across contexts and has not been synthesised systematically. This study aims to map how curriculum readiness is conceptualised, to describe the profile of teachers' preparedness, to identify enabling and constraining factors, and to formulate an integrative model explaining the relationship among layers of readiness. The object of study comprises fifty-two scholarly articles published between two thousand fifteen and two thousand twenty-five and indexed in reputable international databases and accredited national databases. The method employed is a systematic literature review guided by the current reporting protocol for systematic reviews, covering identification, screening, eligibility assessment, methodological quality appraisal, and thematic synthesis. The review yields five themes, namely the conceptualisation of readiness, the profile of teacher competence, affective and motivational determinants, institutional capacity, and curriculum policy alignment. The principal finding shows that teachers' operational fluency is high, whereas their capacity to integrate technology into mathematical reasoning remains low, and curriculum documents together with assessment systems seldom encode digital media competence explicitly. The study concludes that curriculum readiness operates as a minimum function across layers rather than as an individual teacher attribute.

Keywords*: curriculum readiness, digital mathematics learning media, teacher preparedness, future-oriented mathematics education, systematic literature review*

INTRODUCTION

Mathematics education is presently being reshaped by a generation of digital media that no longer merely display mathematical content but actively perform mathematical work. Dynamic geometry environments, computer algebra systems, interactive textbooks, data-visualisation applications, and, more recently, generative artificial intelligence assistants have altered what it is possible for a learner to do with a mathematical object within a single lesson (Clark-Wilson et al., 2020; Engelbrecht et al., 2023; Hoch et al., 2018; Weinhandl et al., 2020). This shift is not cosmetic. When a learner can drag a vertex and watch an invariant persist, or can generate a thousand simulated trials in a second, the epistemic character of mathematical justification in the classroom changes with it (Borba, 2021). Systems that once regarded technology as an optional enrichment now treat it as infrastructure, and national curricula across Southeast Asia, East Asia, and Europe have accordingly begun to name digital competence among the outcomes that mathematics instruction is expected to deliver (Bakker et al., 2021; Puad & Ashton, 2023). The urgency of the issue therefore lies less in whether digital media should enter the mathematics classroom than in whether the curriculum, and the teachers who enact it, are institutionally prepared for media that have already arrived.

The empirical case for these media is strong but conditional. Context-specific meta-analytic evidence indicates that digital tools produce a meaningful positive effect on secondary mathematics and science learning (Hillmayr et al., 2020), with the effect concentrated in conditions where the tool is embedded in a deliberate instructional sequence rather than used as a substitute for exposition (Attard & Holmes, 2020; Reinhold et al., 2020). Comparable syntheses of dynamic geometry software report substantial aggregate effects on mathematical ability (Jelatu et al., 2018; Juandi et al., 2021; Kusumah et al., 2020; Mudaly & Fletcher, 2019; Radović et al., 2020), while broader meta-analyses of technology functions in K-twelve mathematics classrooms show that effect sizes vary systematically with how the technology is positioned pedagogically rather than with the sophistication of the tool itself (Ran et al., 2022). The consistent implication across these syntheses is that the causal agent is not the medium but the teaching that surrounds it. Digital mathematics learning media, in other words, are amplifiers: they magnify the quality of the instructional decisions already in place, which makes teacher preparedness the binding constraint on any curriculum that commits to them (Kadluba et al., 2025; Thurm & Barzel, 2020).

Against this background, the notion of readiness requires more careful specification than it usually receives. In much of the applied literature, readiness is operationalised as a self-reported disposition of an individual teacher, measured through acceptance scales, confidence inventories, or competence self-assessments (Petko et al., 2018; Scherer et al., 2019). Such measures capture something real, but they locate readiness entirely inside the person. Curriculum theory offers a different vantage point, distinguishing the documented curriculum that policy prescribes, the intended curriculum that teachers plan, and the enacted curriculum that students actually experience (Puad & Ashton, 2023; Trouche et al., 2019). Readiness understood curricularly is the degree of alignment

among these levels: a system is ready when what the syllabus demands, what school structures make feasible, what teachers are able and willing to do, and what happens in classrooms point in the same direction. This reframing matters practically, because a highly confident teacher working within an assessment regime that rewards only procedural fluency will not produce a future-oriented mathematics lesson, however capable that teacher may be.

A considerable body of recent scholarship has approached adjacent questions. Systematic reviews of technological pedagogical content knowledge in mathematics education have mapped the framework's conceptual development and catalogued the instruments used to measure it, identifying persistent measurement inconsistency as a field-level problem (Ishartono et al., 2023; Kholid et al., 2023; Li et al., 2025). Reviews of pre-service teachers' digital competence spanning a full decade report steady growth in publication volume alongside uneven performance across competence dimensions, with digital content creation and pedagogical integration consistently weakest (Fernández-Batanero et al., 2022; Zhang et al., 2026). Country-focused syntheses have examined the knowledge, skills, and dispositions associated with digital learning in Indonesian mathematics education, concluding that practical adaptability and continuous reflection matter more than static knowledge stocks (Hidayat & Chao, 2025). Large-scale survey research using structural models has further shown that perceived behavioural control in online settings is a stronger determinant of digital mathematics learning media use than either device access or prior training (Ishartono et al., 2024, 2025). Studies of professional development have demonstrated that programmes explicitly targeting beliefs, rather than skills alone, shift both teacher self-efficacy and classroom practice (Thurm & Barzel, 2020, 2022).

What this literature has not yet delivered is a synthesis that treats readiness as a curricular property distributed across levels rather than as a personal attribute concentrated in the teacher. Three specific shortfalls are evident. First, existing reviews are overwhelmingly teacher-centred: they aggregate competence profiles without asking whether the curriculum document and the assessment regime encode the competences being measured, so a system may register high teacher readiness while the written curriculum remains silent on digital media. Second, the literature contains an unresolved controversy about causal priority. One strand attributes weak integration primarily to infrastructural deficit and argues for access-first policy (Hennessy et al., 2022; Nikolopoulou et al., 2023), whereas another strand, supported by structural modelling, attributes it primarily to beliefs, self-efficacy, and perceived utility, and argues that provisioning devices without addressing dispositions changes little (Backfisch et al., 2021; Sailer et al., 2021; Scherer et al., 2019). These positions have rarely been examined together within a single synthesis, and their coexistence leaves policymakers without a defensible ordering of interventions. Third, most reviews stop at description and do not advance an explanatory model capable of specifying how the levels interact, which leaves the field with inventories of factors rather than a theory of alignment (Bray & Tangney, 2017; Xie et al., 2019).

This study is designed to complete those gaps rather than to repeat what has been established. Its specific purpose is fourfold: to map how curriculum readiness for digital mathematics learning media has been conceptualised in the recent literature; to characterise the profile of teachers' preparedness across competence dimensions; to identify and rank the factors that enable or constrain enactment; and, on that basis, to construct an integrative model that explains how curricular, institutional, personal, and classroom-level conditions combine. Four questions guide the review accordingly. The first concerns how curriculum readiness for digital mathematics learning media is conceptualised in scholarship published between two thousand fifteen and two thousand twenty-five. The second concerns the profile of teacher preparedness that emerges across competence dimensions. The third concerns which factors are reported as decisive enablers or constraints, and how the competing access-first and belief-first accounts compare when the evidence is examined jointly. The fourth concerns the model of curriculum readiness that can be theorised from the synthesised evidence, together with its implications for future-oriented mathematics education and for the management of schools and teacher education programmes.

The argument this article seeks to establish can be stated as a testable proposition. If readiness were an additive attribute of individual teachers, then systems with well-trained and confident mathematics teachers should exhibit correspondingly rich digital enactment regardless of curricular and institutional conditions. The review tests the contrary claim: that curriculum readiness behaves as a minimum function across four interdependent layers, so that the weakest layer determines the observable ceiling on classroom enactment, and that consequently high operational fluency among teachers is neither evidence of, nor a substitute for, curriculum readiness. A corollary proposition is examined alongside it, namely that the assessment regime functions as the most consequential single element of the curricular layer, because it defines what teachers can justify spending instructional time upon.

The article proceeds in four further parts. The method section specifies the review protocol, the databases and search strings, the eligibility criteria, the appraisal instrument, the roles of the reviewers, and the procedures used to establish the trustworthiness of the synthesis. The combined results and discussion section reports the descriptive profile of the included corpus, presents the five analytical themes together with their interpretation against established theory, adjudicates the access-first and belief-first controversy, and advances the integrative model with a synthesis chart for each sub-section. The conclusion states the answers to the four review questions and their implications for educational management. The unit of analysis throughout is the published empirical or review study, not the individual teacher; claims about teachers are therefore claims about what the corpus reports, and are qualified accordingly.

RESEARCH METHOD

This study employs a systematic literature review, a design chosen because the review questions concern the accumulated state of evidence across heterogeneous

contexts rather than the behaviour of a single population, and because the field's principal weakness is fragmentation rather than absence of data. Reporting follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement in its two thousand twenty version (Page et al., 2021), which supplies the identification, screening, eligibility, and inclusion architecture reproduced in Figure 1 and prescribes transparent accounting of every excluded record. The review is interpretive rather than statistical: because the corpus mixes survey research, structural modelling, case study, design research, and prior syntheses, effect sizes are not pooled, and the analytical yield is a thematic synthesis with an explanatory model rather than an aggregate estimate. The protocol was fixed before searching and was not amended thereafter, and the full audit trail, comprising search logs, screening decisions, extraction sheets, and appraisal scores, is retained by the authors and available on reasonable request.

Presence of the researchers and reviewer roles

Because screening and synthesis in a review of this kind involve interpretive judgement, the reviewers' positions are stated explicitly. Three researchers conducted the review. The first author, a mathematics education researcher with prior experience in curriculum development for Islamic educational institutions, designed the protocol, executed the searches, and led the synthesis. The second author, whose expertise lies in educational management, independently screened records and appraised methodological quality, and served as the principal check on the first author's interpretive tendencies. The third author, an instructional technology specialist, arbitrated disagreements and audited the extraction sheet. Two external informants supported the process without being authors: a senior secondary mathematics teacher with fifteen years of classroom experience, who reviewed the plausibility of the emerging themes against practice, and a curriculum officer at a provincial education office, who commented on the policy interpretations. Their comments were recorded as reflective memoranda and were used to challenge rather than to confirm the developing analysis. The review was carried out between January and September of two thousand twenty-five.

Data sources and search strategy

Five databases were searched to balance international reputation against regional coverage: Scopus and Web of Science for indexed international scholarship, the Education Resources Information Center for education-specific grey-adjacent literature, the Directory of Open Access Journals for open-access titles outside the major indexes, and the Garuda portal, which aggregates nationally accredited Indonesian journals rated within the Science and Technology Index. Including the last two sources is a deliberate methodological choice: reviews restricted to Scopus and Web of Science systematically under-represent the Global South (Irawan & Purwasih, 2024), and because a substantial share of the empirical work on curriculum readiness in Indonesian and comparable systems appears in nationally accredited outlets, their exclusion would have biased the corpus toward high-resource contexts. Searches were executed in December of two thousand twenty-five and covered publications from January two thousand fifteen to December two thousand twenty-five, a window selected because it begins with the first

widespread appearance of tablet-based and cloud-based mathematics environments in school systems and because the review guidelines governing this study require currency within the last decade. The conceptual blocks and search terms used to construct the queries are set out in Table 1.

Table 1. Conceptual blocks and search terms used in the database queries

Block	Construct	Search terms (joined within the block by OR)
A	Actor	teacher* OR educator* OR "pre-service teacher*" OR "in-service teacher*" OR "prospective teacher*"
B	Object	"digital learning media" OR "digital mathematics learning media" OR "dynamic geometry" OR GeoGebra OR "computer algebra" OR "interactive textbook*" OR "educational technology" OR "digital tool*"
C	Construct	readiness OR preparedness OR competence OR "self-efficacy" OR TPACK OR "technology integration" OR "digital competence"
D	Domain	mathematic* OR "mathematics education" OR "mathematics curriculum" OR "curriculum implementation"

Source: authors' search protocol

Eligibility criteria and screening procedure

Eligibility was governed by the criteria specified in Table 2. In outline, a report was eligible if it was peer-reviewed, published within the search window in English or Indonesian, concerned mathematics teaching or mathematics teacher education specifically, addressed digital media used for mathematical purposes, and reported empirical evidence or a systematic synthesis bearing on teacher readiness, preparedness, competence, or curriculum implementation. Reports were excluded when the technology examined was generic to all subjects with no mathematical specificity, when readiness or an equivalent construct was absent, when the work was an editorial, opinion piece, or book review, when it was a conference abstract without full peer-reviewed text, or when it fell outside the date window.

Table 2. Eligibility criteria applied at title, abstract, and full-text screening

Parameter	Inclusion criterion	Exclusion criterion
Publication type	Peer-reviewed journal article, or a systematic review or meta-analysis with retrievable full text	Editorial, opinion piece, book review, or conference abstract without a full peer-reviewed text
Date window	Published between January 2015 and December 2025	Published outside the search window

Parameter	Inclusion criterion	Exclusion criterion
Language	Written in English or Indonesian	Written in a language the review team could not appraise directly
Subject domain	Concerned with mathematics teaching or mathematics teacher education specifically	Concerned with education in general, with no mathematics-specific claim
Technology focus	Digital media used for mathematical purposes, including dynamic geometry, computer algebra, interactive textbooks, and mathematical modelling tools	Technology generic to all subjects, such as learning management platforms or office software, with no mathematical specificity
Construct	Reports readiness, preparedness, competence, self-efficacy, technology integration, or curriculum implementation as an examined construct	Readiness or an equivalent construct absent from the aims, instruments, and findings
Evidence base	Reports empirical data or an explicit systematic synthesis procedure	Conceptual essay or programme description with no reported evidence
Methodological quality	Scores at or above sixty per cent on the criteria of the Mixed Methods Appraisal Tool applicable to its design	Scores below the sixty per cent retention threshold

Source: review protocol, adapted from Page et al. (2021) and Hong et al. (2018)

Screening proceeded in two stages. In the first stage the first and second authors independently screened all one thousand fifty-eight titles and abstracts remaining after duplicate removal, coding each as retain, exclude, or uncertain, with uncertain cases carried forward automatically. In the second stage the same two reviewers independently assessed the full text of the two hundred forty-four retrievable reports against the eligibility criteria. Agreement at full-text stage was substantial, with a Cohen kappa coefficient of zero point eight four; the thirty-one disagreements concerned chiefly whether a study of generic digital literacy contained sufficient mathematical specificity, and all were resolved by the third author in a recorded arbitration session. Figure 1 documents the resulting flow, with fifty-two reports entering the synthesis.

Quality appraisal, extraction, and analysis

Methodological quality was appraised with the Mixed Methods Appraisal Tool in its two thousand eighteen version (Hong et al., 2018), selected because the corpus spans quantitative, qualitative, and mixed designs and because a single instrument permits comparable scoring across them. Each report was scored independently by two

reviewers against the five criteria applicable to its design, and a threshold of sixty per cent was set for retention. All fifty-two reports met the threshold, although eleven were flagged as weak on sampling justification and were consequently given reduced interpretive weight when a theme rested on them alone. Data were extracted onto a structured sheet capturing bibliographic details, country and educational level, design and sample, the digital media examined, the readiness construct and its operationalisation, the theoretical framework invoked, principal findings, and reported enablers and constraints. The sheet was piloted on eight reports and refined once before full extraction.

Synthesis followed a reflexive thematic procedure conducted in six movements: repeated reading of the extraction sheet for familiarisation; open coding of findings at the level of the claim rather than the paper; grouping of codes into candidate themes; review of candidate themes against the coded extracts and against the full reports; definition and naming of the final themes; and construction of the integrative model by examining the relations among themes. Five themes were retained, and their distribution across the corpus is reported in Figure 2 and Figure 3. The trustworthiness of the synthesis was addressed through four checks. Investigator triangulation was achieved by the independent coding described above. An audit trail linking every thematic claim to its supporting reports was maintained and was inspected by the third author. Peer debriefing was conducted in two sessions with the external informants, who were asked specifically to identify claims that did not correspond to their experience of practice and policy. Finally, a negative-case analysis was performed on the seven reports whose findings contradicted the emerging pattern, and their content is reported rather than suppressed in the results and discussion. Because the review synthesises published work and involved no human participants beyond the two consulted informants, who gave informed verbal consent to have their comments used, no ethical clearance beyond institutional acknowledgement was required.

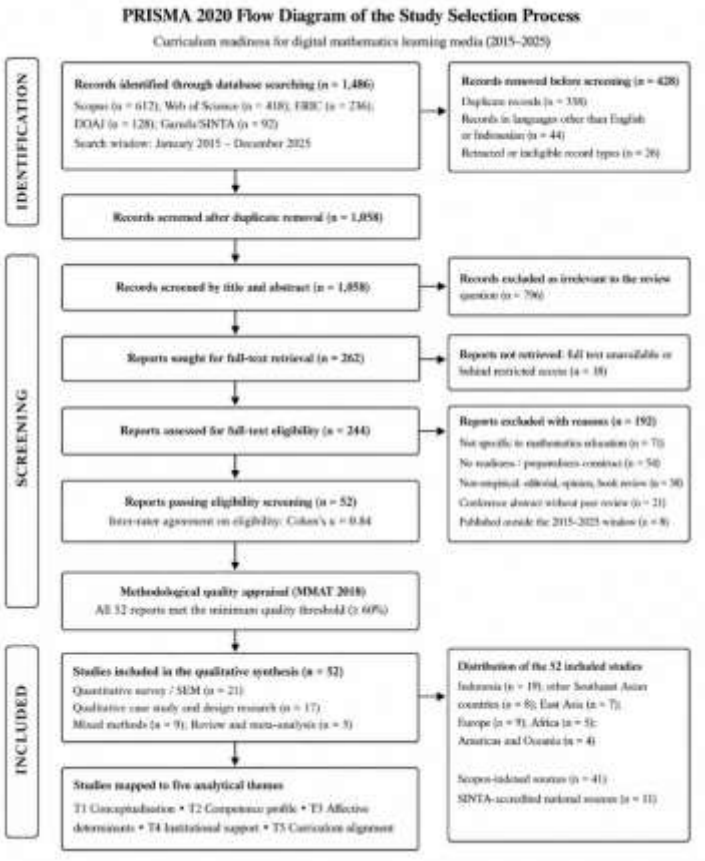

Figure 1. PRISMA 2020 flow diagram of the identification, screening, eligibility, and inclusion of reports

RESULTS AND DISCUSSION

Descriptive profile of the included corpus

Fifty-two reports met all eligibility and quality criteria. Their descriptive profile is summarised in Figure 2. Publication activity is strongly skewed toward the second half of the window: thirty-eight of the fifty-two reports, or seventy-three per cent, appeared from two thousand twenty onward, with the annual peak in two thousand twenty-four. Nine reports appeared in the first five years of the window taken together. This distribution is consistent with a field whose growth was accelerated by the emergency shift to remote instruction and which has retained that momentum rather than reverting to pre-pandemic levels (Alabdulaziz, 2021; Cevikbas & Kaiser, 2023).

Geographically, Indonesia contributes nineteen reports, other Southeast Asian systems eight, East Asia seven, Europe nine, Africa five, and the Americas together with Oceania four. Methodologically, twenty-one reports use quantitative survey designs, of which fourteen employ structural equation modelling; seventeen use qualitative case study or design research; nine use mixed methods; and five are prior reviews or meta-analyses. Forty-one reports appeared in Scopus-indexed outlets and eleven in nationally accredited Indonesian journals. The educational levels represented are secondary in

twenty-four reports, primary in eleven, teacher education in fourteen, and mixed or system-level in three.

The five themes are unevenly represented across the corpus, as Figure 2 panel (b) records. The profile of teacher competence is the most extensively studied theme, informed by thirty-four reports, followed by affective and motivational determinants with twenty-nine, institutional and infrastructural conditions with twenty-six, the conceptualisation of readiness with twenty-three, and curriculum-policy alignment with eighteen. The relative thinness of the last theme is itself a finding and is taken up below. Because a single report may inform more than one theme, these counts are not mutually exclusive.

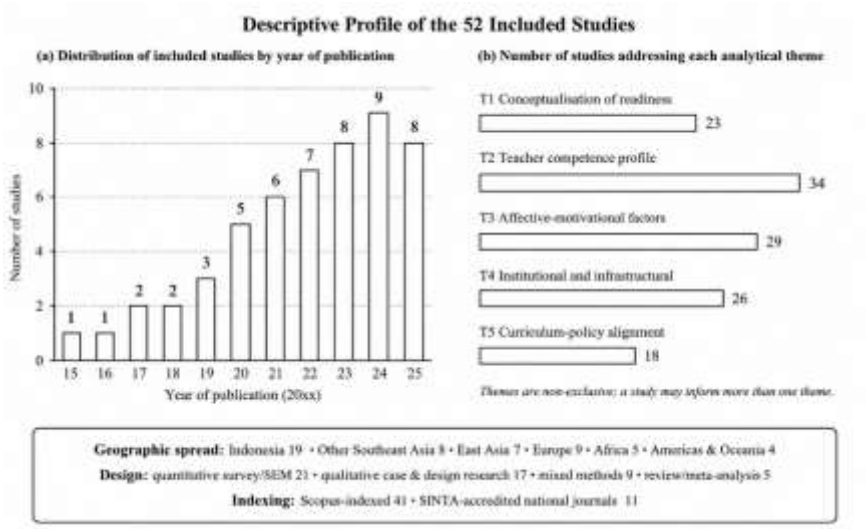

Figure 2. Descriptive profile of the fifty-two included studies: (a) year of publication; (b) thematic coverage

Source: authors' extraction sheet

Theme one: readiness as a curricular alignment rather than a personal attribute

Twenty-three reports address the conceptualisation of readiness directly. Three conceptions recur. The first and most common, present in fourteen reports, treats readiness as an individual psychological state, measured by self-report instruments derived from technology acceptance or competence frameworks. The second, present in six reports, treats readiness as an organisational property of the school, indexed by infrastructure, leadership, and support structures. The third, present in only three reports, treats readiness as an alignment relation across curriculum levels, explicitly distinguishing what the syllabus prescribes, what teachers plan, and what students experience.

The corpus contains no consensus definition, and eleven reports use the term readiness without defining it operationally at all. Where definitions are supplied, the boundary between readiness, competence, acceptance, and self-efficacy is frequently unmarked, and the same instrument items appear under different construct labels in different reports. Two of the three reports adopting the alignment conception report the

same anomaly: schools scoring high on individual and organisational indices nevertheless exhibited limited digital enactment in mathematics classrooms, because the assessment regime did not recognise the competences concerned. This anomaly is the single most consequential finding of the theme.

The first review question asked how curriculum readiness has been conceptualised. The evidence answers it uncomfortably: the dominant conception is psychological and individual, and the alignment conception that the term curriculum readiness properly names is present in only three of twenty-three reports. This is not a semantic quibble. When readiness is measured as a disposition, the instrument cannot detect the situation in which every teacher in a school is willing and able while the syllabus and the examination make the willingness inconsequential. The three alignment-oriented reports document precisely that situation (Petko et al., 2018; Puad & Ashton, 2023; Viberg et al., 2023), and their anomaly is the empirical hinge of this synthesis.

Curriculum theory has long distinguished the documented, intended, and enacted levels, and implementation research has repeatedly shown that reforms fail at the joins between them rather than within any one of them (Puad & Ashton, 2023; Syofyan et al., 2024; Trouche et al., 2019). Applying that distinction here reframes the field's central puzzle. The persistent finding that teachers report high confidence yet produce conventional lessons is usually read as a validity problem in self-report instruments, and the corpus does supply evidence of such inflation, with twenty-six of thirty-four reports finding self-reported competence to exceed observed competence (Ishartono et al., 2023; Tondeur et al., 2020). But inflation cannot be the whole explanation, because the gap is dimension-specific rather than uniform: it is widest exactly where the curriculum is silent. A more parsimonious reading is that teachers are accurately reporting readiness for the practice the curriculum actually rewards, and that observers are measuring readiness for a practice the curriculum does not require. On this reading the two measurements are not in conflict; they are measuring different curricula.

This interpretation also clarifies why interventions targeting individuals produce inconsistent results across systems. Where the curricular layer already encodes digital mathematical practice, raising individual capability translates into enactment; where it does not, the same intervention raises capability without changing what happens in classrooms, and the effect is recorded in the literature as implementation failure. Reviews that aggregate across systems without stratifying by curricular condition will therefore report exactly the heterogeneity that the technological pedagogical content knowledge syntheses have documented and been unable to explain (Kholid et al., 2023; Li et al., 2025).

Chart 1. Theoretical synthesis of sub-section

Element	Content
Core construct	Curriculum readiness as the degree of correspondence among the documented, intended, and enacted curriculum
Theories drawn upon	Curriculum-level theory (documented, intended, enacted); curriculum implementation and fidelity research; instrumental genesis and orchestration in mathematics education
Review evidence	Only 3 of 23 conceptual reports adopt an alignment conception; 11 use readiness without operational definition; the alignment-oriented reports document high individual and organisational readiness coexisting with low enactment
Convergence with prior theory	Confirms implementation research: reforms fail at the joins between curriculum levels rather than within a level
Divergence or modification	Rejects the prevailing psychometric equation of readiness with individual disposition; the disposition is a component of readiness, not its definition
Theoretical proposition	P1. Curriculum readiness is a relational property of a system, not an aggregable attribute of its teachers; instruments that measure only dispositions are structurally unable to detect the most consequential form of unreadiness

Source: authors' thematic synthesis

Theme two: the readiness asymmetry and the limits of the competence framework

Thirty-four reports supply evidence on competence profiles. The pattern is consistent to a degree unusual in this literature and is summarised in Table 3. Across contexts and educational levels, teachers report and demonstrate high operational fluency with digital tools, moderate capacity to align tools with pedagogical strategies, and markedly lower capacity to use tools to transform the mathematical content itself, that is, to alter which representations, conjectures, and forms of justification become available to students.

Table 3. Reported profile of teachers' preparedness across competence dimensions (n = 34 reports)

Competence dimension	Description of the capability	Reported level	Reports
Technological knowledge	Operating the tool: navigating the interface, producing constructions, managing files and devices	High	31 of 34
Technological pedagogical knowledge	Selecting and sequencing the tool within a lesson: grouping, questioning, pacing, formative feedback	Moderate	22 of 34

Competence dimension	Description of the capability	Reported level	Reports
Technological content knowledge	Using the tool to change the mathematics available to students: dynamic representation, conjecture, modelling, justification	Low	29 of 34
Assessment with digital media	Designing and interpreting tasks in which digital work is itself the evidence of mathematical learning	Low	17 of 20
Critical and ethical judgement	Evaluating tool reliability, data privacy, and the epistemic status of machine-generated mathematical output	Very low	9 of 11

Source: authors' extraction sheet

Twenty-nine of the thirty-four reports find the technological-content dimension to be the weakest of the composite dimensions, and twenty-six find that self-reported competence exceeds observed or performance-assessed competence, with the gap widest precisely on the transformative dimensions. Five reports constitute negative cases: they report either parity across dimensions or a stronger content dimension, and in four of these the participants had completed sustained, subject-specific professional development lasting a full academic year or longer.

The second review question concerned the profile of preparedness. The answer is a steep and highly consistent gradient: operational fluency is high, pedagogical positioning is moderate, and transformation of the mathematical content itself is low, with assessment design and critical-ethical judgement lower still. This review terms the pattern the readiness asymmetry. Its consistency across twenty-nine of thirty-four reports, spanning six regions and three educational levels, gives it a claim to being a structural feature of the field rather than a contextual artefact.

The asymmetry has a theoretical explanation that the corpus supports but rarely states. The composite competence framework that dominates this literature (Bretscher, 2023; Kholid et al., 2023) was constructed as a description of the knowledge a teacher possesses, and its component structure invites the inference that the components are separately trainable and additively combinable. The evidence contradicts that inference in a specific way: the technological and pedagogical components are indeed separately trainable, and short courses reliably raise them (Tondeur et al., 2020), but the technological-content component is not, because it requires the teacher to reconsider what counts as mathematical work. That is a reorganisation of content knowledge, not an addition to it (Bretscher, 2023; Drijvers et al., 2020). The five negative cases are diagnostic here, since four of them involved sustained, subject-specific development lasting an academic year or more, precisely the duration over which conceptual reorganisation rather than skill acquisition becomes plausible (Hennessy et al., 2022; Thurm & Barzel, 2020).

Two consequences follow for practice. First, the widespread policy instrument of short generic digital training is not merely insufficient but systematically misdirected: it raises the dimensions that were already highest and leaves untouched the dimension on which enactment depends. Second, competence measurement that reports a composite score conceals the asymmetry, since a high technological score offsets a low content score arithmetically while doing nothing to offset it pedagogically. Instruments should therefore report dimensional profiles rather than totals, and the measurement inconsistency that prior instrument reviews have identified as a technical problem (Aqib et al., 2025; Ishartono et al., 2023) is better understood as a symptom of this conceptual one.

Chart 2. Theoretical synthesis of sub-section

Element	Content
Core construct	Readiness asymmetry: capability declines monotonically as the demand shifts from operating a tool to transforming the mathematics
Theories drawn upon	Technological pedagogical content knowledge as a composite framework; pedagogical content knowledge and conceptual change in teacher learning; instrumental genesis
Review evidence	29 of 34 reports place the technological-content dimension lowest; 26 of 34 find self-report exceeds observed performance, with the gap widest on transformative dimensions; 4 of 5 negative cases involved year-long subject-specific development
Convergence with prior theory	Confirms that pedagogical content knowledge develops through sustained, subject-embedded professional learning rather than through generic short courses
Divergence or modification	Modifies the additive reading of the composite framework: its components are not equally trainable, and the content-facing component behaves as conceptual reorganisation rather than skill accumulation
Theoretical proposition	P2. Composite competence scores are invalid as readiness indicators because arithmetic compensation among dimensions has no pedagogical counterpart; dimensional profiles are required

Source: authors' thematic synthesis

Theme three: affective and motivational determinants and the threshold character of access

Twenty-nine reports examine the affective and motivational side of enactment, making this the second most densely populated theme in the corpus. Four constructs dominate. Technology-related self-efficacy appears in twenty-one of the twenty-nine and is positively associated with the frequency of use in nineteen of them, although only in eleven is it associated with the quality of the mathematical work students are asked to do. Perceived utility appears in eighteen reports and behaves differently: where both

constructs are modelled together, utility is the stronger predictor in eleven of the fourteen structural models, which places the corpus in line with the wider evidence that teachers integrate technology when they judge it worth the cost rather than when they merely feel capable (Antonietti et al., 2022; Backfisch et al., 2021). Epistemic beliefs about the nature of mathematics itself appear in twelve reports, and in nine of these a view of mathematics as a body of procedures to be transmitted is associated with tool use that substitutes for exposition rather than opening inquiry (Thurm & Barzel, 2022). Perceived cost, expressed as preparation time and as risk of losing control of the lesson, appears in ten reports.

The corpus also permits a direct comparison of the access-first and belief-first positions, because the twenty-nine reports divide by provisioning context. In eleven of them, conducted in settings the authors themselves describe as below adequate provision, whether through unreliable connectivity, shared devices, or absent technical support, access variables outperformed dispositional variables in ten cases. In the eighteen conducted in adequately provisioned settings, the ordering reverses: dispositional variables outperformed access in fifteen, and in six of those access ceased to predict use at all once a working threshold of connectivity and device availability had been passed. Two reports form negative cases in which neither family of predictors accounted for much variance, and in both the authors point instead to timetabling and examination pressure, which anticipates the curricular theme below.

The third review question asked which factors are decisive and how the two competing accounts compare when the evidence is examined jointly. The pattern just described suggests that the controversy has been mis-specified rather than unresolved. Both camps have been modelling infrastructure as a linear predictor and then disputing the size of its coefficient, when the corpus behaves as though infrastructure were a threshold variable. Below the threshold, access dominates because nothing else can operate; above it, additional provisioning buys almost nothing, and dispositions and beliefs take over as the binding constraint. Read this way, the studies reporting large infrastructural effects (Hennessy et al., 2022; Nikolopoulou et al., 2023) and those reporting negligible ones (Backfisch et al., 2021; Sailer et al., 2021; Scherer et al., 2019) are not contradicting each other at all. They are sampling opposite sides of the same discontinuity, and the apparent disagreement is an artefact of pooling them.

This has an immediate policy consequence, and it is a sequencing one rather than a matter of choosing sides. A system cannot know whether to spend on devices or on dispositions until it has located itself relative to the threshold, and that is a diagnostic question with a local answer. It also has a methodological consequence. Linear models estimated on samples drawn from mixed provisioning contexts will return unstable coefficients for access, which is precisely the instability the field has been reporting for a decade and interpreting as measurement noise. The more interesting finding, and the one that connects this theme to the previous one, concerns what self-efficacy actually predicts. That it tracks frequency of use far more reliably than quality of use is a caution against reading confidence as readiness. A teacher may be entirely confident about

opening the application every week and still never ask a question that the application makes newly answerable.

Chart 3. Theoretical synthesis of sub-section

Element	Content
Core construct	Infrastructure as a threshold condition rather than a linear predictor, with dispositional determinants binding above the threshold
Theories drawn upon	Technology acceptance and expectancy-value models; self-efficacy theory; teacher epistemic beliefs about mathematics; theories of perceived cost and rational allocation
Review evidence	21 of 29 reports model self-efficacy, but only 11 link it to the quality of mathematical work; perceived utility is the stronger predictor in 11 of 14 structural models; access dominates in 10 of 11 under-provisioned settings, while dispositions dominate in 15 of 18 adequately provisioned settings
Convergence with prior theory	Confirms that perceived utility outperforms self-efficacy as a proximal determinant of classroom technology use
Divergence or modification	Reframes the access-first and belief-first dispute as a specification error rather than a substantive disagreement, since both positions hold on opposite sides of a provisioning threshold
Theoretical proposition	P3. Infrastructure operates as a threshold rather than a linear predictor; consequently the correct ordering of interventions is diagnostic and local, and self-efficacy predicts the frequency of enactment far more reliably than its mathematical quality

Source: authors' thematic synthesis

Theme four: institutional capacity as the condition that sustains practice

Twenty-six reports address the organisational layer. The strongest and most consistent finding concerns the form that professional learning takes: nineteen reports find subject-specific professional learning communities more effective than generic whole-school training, whether the outcome is measured as sustained use, as lesson quality, or as teachers' own accounts of what changed. Fifteen reports associate sustained practice with instructional leaders who model and publicly recognise digital pedagogy, and twelve identify preparation time rather than skill as the reason teachers give for reverting to conventional delivery. Nine link the availability of technical support at the point of use, as distinct from centralised support requesting a ticket, to teachers' willingness to design lessons whose success depends on the technology working. Timetabling constraints, chiefly the difficulty of booking shared facilities within a forty-minute period, appear in eight reports.

The mechanism behind the professional learning finding is intelligible in the light of the readiness asymmetry established above: what teachers most need to develop is

content-facing rather than tool-facing, and content-facing learning requires interlocutors who share the content. A whole-school digital training session cannot supply a colleague who can argue about whether dragging a figure constitutes a proof (Bretscher, 2023; Hennessy et al., 2022; Tondeur et al., 2019).

Instructional leadership operates through a related mechanism. That fifteen reports associate sustained practice with leaders who model and publicly recognise digital pedagogy rather than merely permitting it indicates that the operative variable is legitimacy rather than authorisation (Petko et al., 2018; Syofyan et al., 2024). Teachers appear to require evidence that time spent on exploratory digital work will be counted as legitimate teaching when their practice is evaluated. The workload constraint points the same way: when teachers cite preparation time rather than skill as the reason for reverting to conventional delivery, they are describing a rational allocation under an evaluation regime that does not reward the additional preparation (Nikolopoulou et al., 2023; Sailer et al., 2021).

This theme therefore does not stand apart from the curricular theme but transmits it. Institutional capacity is the mechanism by which curricular signals become classroom conditions, and its apparent independence in the literature is an artefact of studying schools without studying the policy environment they inhabit (Pratikno et al., 2022). The management implication is that investment in learning communities produces returns only where the evaluation and assessment regime does not simultaneously penalise the practice those communities cultivate.

Chart 4. Theoretical synthesis of sub-section

Element	Content
Core construct	Institutional capacity as the layer that converts curricular intent into feasible and legitimate classroom conditions
Theories drawn upon	Professional learning community theory; instructional leadership; theories of workload, opportunity cost, and teacher rational allocation
Review evidence	19 reports favour subject-specific over generic whole-school training; 15 associate modelling and recognition by leaders with sustained practice; 12 identify preparation time rather than skill as the reason for reversion; 9 link point-of-use technical support to higher-risk lesson design
Convergence with prior theory	Confirms that sustained, collaborative, subject-embedded professional learning outperforms episodic generic training
Divergence or modification	Reframes leadership support from authorisation to legitimation, and reframes workload from a logistical nuisance to a rational response to the prevailing evaluation regime
Theoretical proposition	P4. Institutional capacity does not act independently on enactment; it transmits the curricular signal. Where the

Element	Content
	assessment regime contradicts the professional learning agenda, investment in that agenda is dissipated

Source: authors' thematic synthesis

Theme five: curriculum and policy alignment and the primacy of the assessment regime

Eighteen reports address the curricular and policy layer, the thinnest evidence base among the five themes. Of these, thirteen report that national or institutional curriculum documents refer to digital competence in general aspirational language while specifying no mathematics-specific digital learning outcomes and no corresponding assessment criteria. Ten report that high-stakes assessment instruments in mathematics remain predominantly paper-based and procedurally oriented, and seven of these draw the explicit inference that teachers rationally allocate instructional time away from digital exploration because it is not examined.

Six reports examine curriculum reform initiatives directly and find implementation outcomes contingent on whether accompanying assessment and reporting requirements were revised alongside the curriculum text; where they were not, teachers reported the reform as an additional burden rather than a redirection of practice (Prakoso et al., 2021; Pratikno et al., 2022). Four reports address future-oriented content specifically, namely computational thinking, mathematical modelling with real data, and the pedagogical implications of generative artificial intelligence, and all four conclude that curriculum documents lag the available technology by a margin the authors variously estimate at five to ten years (Cevikbas et al., 2023). Figure 3 presents the relations among the five themes.

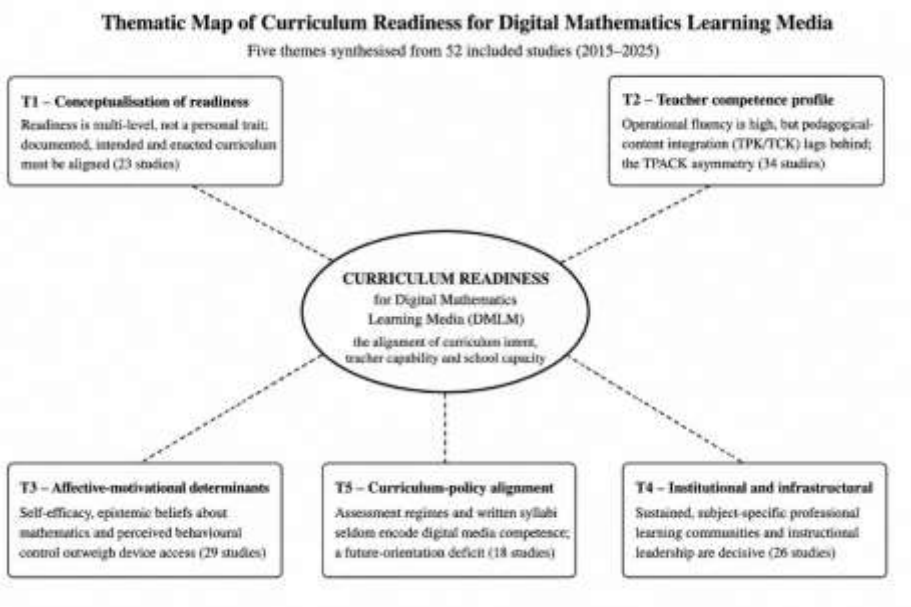

Figure 3. Relations among the five analytical themes derived from the thematic synthesis

That this is the thinnest theme in a corpus of fifty-two reports is itself worth pausing over. The layer the corpus studies least is, on the evidence assembled here, the layer that sets the ceiling for all the others, which is an uncomfortable observation about where the field has been pointing its instruments. The explanation is probably mundane rather than sinister. Teacher competence is measurable with an instrument that fits on two pages, whereas curricular alignment requires document analysis, policy interviews, and access to examination specifications, none of which yields a coefficient. Convenience has shaped the evidence base, and the corollary proposition set out at the outset survives that bias rather than being produced by it.

The specific claim is that the assessment regime is the operative element of the curricular layer, not the syllabus text. The corpus supports this at two points. Where reform revised the text but left examinations intact, teachers experienced the reform as an addition to their workload rather than a redirection of it, which is exactly what a rational actor does when the stated goals change and the evaluated goals do not. Where syllabus documents named digital competence in aspirational language without attaching outcomes or criteria, the naming had no observable effect on enactment. A curriculum statement, on this evidence, is a claim about intent, whereas an examination is a claim about consequence, and teachers respond to the second. Indonesian evidence on assessment performance and reform trajectories is consistent with the same reading (Ismawati et al., 2023; Syofyan et al., 2024).

The lag finding deserves separate emphasis because it compounds the others. If curriculum documents trail available technology by five to ten years, then even a system that achieves alignment is aligning itself to a technological situation that has already passed, and generative artificial intelligence has widened that gap rather than narrowed it. Alignment is therefore not a state a system reaches once. It is a maintenance obligation,

and the design question for curriculum authorities is less what to specify now than how often, and through what mechanism, the specification will be revisited.

Chart 5. Theoretical synthesis of sub-section

Element	Content
Core construct	The assessment regime as the operative element of the curricular layer, determining what counts as legitimate use of instructional time
Theories drawn upon	Curriculum alignment theory; washback and consequential validity in assessment; policy implementation and incentive structures
Review evidence	13 of 18 reports find aspirational language without mathematics-specific outcomes or assessment criteria; 10 find high-stakes mathematics assessment predominantly paper-based and procedural, with 7 inferring rational reallocation of instructional time; 6 find reform outcomes contingent on parallel revision of assessment; 4 estimate a five to ten year lag behind available technology
Convergence with prior theory	Confirms washback research: what is examined governs what is taught more strongly than what is prescribed
Divergence or modification	Displaces the syllabus text from its assumed position as the primary curricular instrument, and recasts alignment as a recurring maintenance obligation rather than an achieved state
Theoretical proposition	P5. Within the curricular layer the assessment regime is the binding element; curriculum statements that name digital competence without specifying mathematics-specific outcomes and matching assessment criteria alter the appearance of policy without altering enactment

Source: authors' thematic synthesis

Theoretical contribution: the Curriculum–Readiness Alignment model

Taken together, the five propositions permit an integrative model, presented in Figure 4 and designated here the Curriculum Readiness Alignment model. It specifies four layers. The curricular and policy layer comprises the syllabus, learning outcomes, textbook policy (Hoch et al., 2018; Wijaya et al., 2022), and, decisively, the assessment regime; it governs what counts as legitimate mathematics teaching. The institutional layer comprises leadership, subject-specific learning communities, technical support, connectivity, and timetabling; it converts policy intent into feasible conditions. The teacher layer comprises mathematics-specific competence, self-efficacy, epistemic beliefs, and perceived behavioural control; it is pivotal because it mediates every flow in both directions. The enactment layer comprises the instrumental orchestration of digital media in task design, representational work, mathematical discourse, and formative feedback (Drijvers et al., 2020; Trouche et al., 2019); it is the only layer at which readiness becomes an observable student experience.

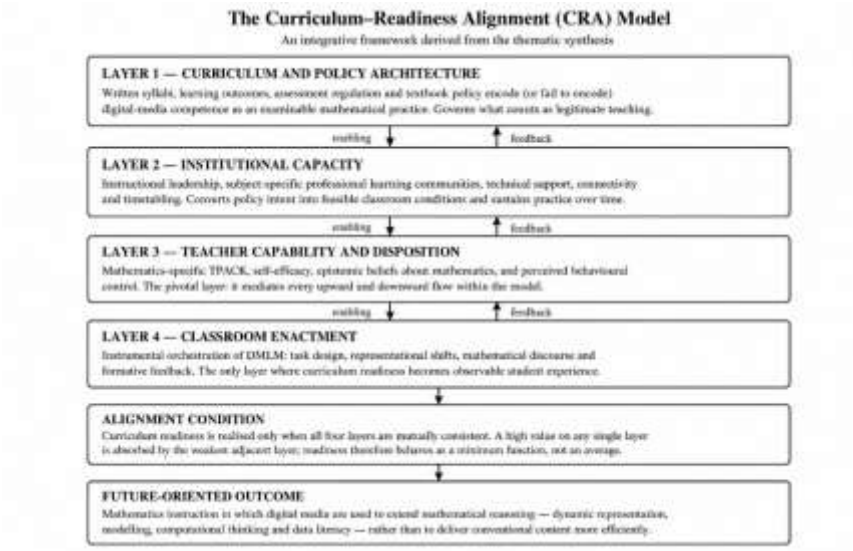

Figure 4. The Curriculum–Readiness Alignment (CRA) model synthesised from the review

The model's substantive claim, and the argument this article set out to test, is that readiness behaves as a minimum function across these layers rather than as their sum or average. A high value on any single layer is absorbed by the weakest adjacent layer, so that the weakest layer sets the observable ceiling on enactment. The corpus supports this claim at each join. Teachers with high competence in systems whose assessment ignores digital practice produce conventional lessons, which is the curricular layer binding the teacher layer. Teachers with strong beliefs in schools without subject-specific learning communities revert after training, which is the institutional layer binding the teacher layer. Schools with strong leadership and infrastructure below the access threshold achieve little, which is a lower layer binding higher ones. In every documented case the ceiling is set by the minimum, and in no case does a high value on one layer compensate for a low value on another.

Three consequences follow for theory. First, the model absorbs the composite competence framework as a description of a single layer rather than as a theory of readiness, which explains why that framework has proved descriptively rich and predictively weak (Kholid et al., 2023). Second, it explains the field's persistent heterogeneity: studies estimate the effect of an intervention on one layer while the binding constraint lies on another, and the effect estimate therefore varies with the unmeasured constraint. Third, it converts readiness measurement from a scoring problem into a diagnostic one, since what a system needs to know is not its average readiness but the identity of its weakest layer.

Implications for educational management

For managers of schools and teacher education programmes the model prescribes a diagnostic sequence rather than a standard package. The first task is to locate the binding layer, since intervention on any other layer will be absorbed. Where connectivity or device availability falls below the working threshold, provisioning takes precedence and dispositional programmes should be deferred (Hennessy et al., 2022); where it does

not, further provisioning yields little and the resources are better directed to subject-specific professional learning. Where the assessment regime does not recognise digital mathematical practice, institutional leaders should expect professional development to raise capability without changing lessons, and should either seek assessment revision at the level where it is decided or create internal, school-level assessment tasks that confer local legitimacy on the practice (Geiger et al., 2022).

For teacher education, the readiness asymmetry implies a redesign of the technology component. Courses that teach tool operation address the dimension that is already strongest. What the evidence recommends instead is extended, mathematics-embedded work in which prospective teachers use digital media to do mathematics that would be impracticable without them, and then design tasks that require their pupils to do the same (Minea-Pic, 2020; Tondeur et al., 2019, 2020; Weinhandl et al., 2020). The duration finding from the negative cases suggests that this cannot be compressed into a short module; an academic year of embedded work appears to be the order of magnitude at which content-facing change becomes observable.

For policy, the corollary proposition is the operative one. Curriculum documents that name digital competence without specifying mathematics-specific outcomes and without corresponding assessment criteria create the appearance of reform while leaving the incentive structure intact. Institutions that adopt future-oriented mathematics education as an objective, including Islamic educational institutions integrating such aims within their own curricular traditions (Tamur et al., 2020; Zulkardi et al., 2020), will find that the decisive instrument is not the syllabus text but the examination and the internal evaluation regime that determine how a teacher may defensibly spend an hour.

CONCLUSION

This review synthesised fifty-two studies published between two thousand fifteen and two thousand twenty-five in order to establish how curriculum readiness for digital mathematics learning media is conceptualised, what profile of teacher preparedness the evidence supports, which factors are decisive, and what model of readiness the evidence sustains. Four answers may be stated explicitly. First, readiness is predominantly conceptualised as an individual psychological disposition, and only three of twenty-three conceptual reports treat it as an alignment among curriculum levels, which is what the term properly denotes; the field's dominant instruments are consequently unable to detect its most consequential form of unreadiness. Second, teacher preparedness exhibits a consistent asymmetry: operational fluency is high, pedagogical positioning is moderate, and the capacity to use digital media to transform mathematical content is low (Kadluba et al., 2025; Zhang et al., 2026), with assessment design and critical judgement lower still. Third, the long-standing controversy between access-first and belief-first explanations is resolved by treating infrastructure as a threshold variable rather than a linear predictor, which yields a defensible policy ordering rather than a contest of effect sizes. Fourth, the evidence sustains the Curriculum–Readiness Alignment model, in which readiness

behaves as a minimum function across curricular, institutional, teacher, and enactment layers.

The central argument advanced at the outset is therefore supported. High operational fluency among mathematics teachers is neither evidence of curriculum readiness nor a substitute for it, and systems that measure the former while neglecting the latter will continue to record the pattern this corpus documents: rising competence, stable practice. For educational management the practical yield is a diagnostic rule. Locate the weakest layer before selecting an intervention, because investment in any other layer will be absorbed without appearing in classrooms. For future-oriented mathematics education the yield is a caution: a curriculum that does not state, and an assessment that does not examine, the mathematical practices that digital media make possible will not obtain them, however well prepared its teachers may be. The review is bounded by its own design, since it synthesises published reports in two languages and cannot speak for practices that never reach publication, and the curricular layer on which its central claim rests is also the layer the corpus documents least, which marks the most urgent direction for further empirical work.

ACKNOWLEDGEMENT

The authors thank the senior secondary mathematics teacher and the provincial curriculum officer who served as external informants for the peer debriefing sessions, and the reviewers whose comments sharpened the argument of the manuscript.

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