

Indigenous Knowledge-Responsive Blended Learning in Mathematics Teacher Education: A Conceptual Framework for Engagement and Learning

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Abstract. This conceptual review examines how Indigenous Knowledge Systems (IKS) can strengthen blended learning in mathematics teacher education. It synthesises 30 peer-reviewed and policy sources through a structured narrative review guided by four questions concerning pedagogical orchestration, culturally grounded mathematical meaning-making, student engagement and enabling conditions. The review finds that effective blended learning depends on purposeful connections between online and face-to-face activity; IKS contributes when community practices generate mathematically rigorous inquiry rather than decorative examples; engagement is behavioural, emotional, cognitive and agentic; and learning benefits remain conditional on equitable access, lecturer capability, multilingual participation and ethical knowledge governance. Drawing on social constructivism, culturally responsive pedagogy, ethnomathematics and the Community of Inquiry, the article proposes an integrated framework linking theoretical foundations, pedagogical design, engagement processes and learning outcomes. The framework indicates that culturally grounded hybrid pedagogy can strengthen mathematical reasoning, learner voice, belonging, and transferable problem-solving skills. Its principal limitation is conceptual status; multi-institutional empirical testing is required before claims of effectiveness or achievement can be established.

Keywords: Blended Learning, Culturally Responsive Pedagogy, Indigenous Knowledge Systems, Mathematics Teacher Education, Student Engagement

1 Introduction

Blended and hybrid learning have become central to the redesign of higher education because they redistribute teaching, interaction and assessment across physical and digital spaces. Their educational value, however, does not arise automatically from combining classroom meetings with a learning-management system. Hybrid environments become educationally productive when each mode performs a complementary function and when students can move coherently among explanation, practice, dialogue,

feedback and independent reflection [1]-[4]. This requirement is especially important in mathematics teacher education, where preservice teachers must learn to coordinate symbolic, graphical, numerical, verbal and contextual representations while also developing the pedagogical judgement needed to teach these relationships to diverse learners [5], [6].

A technology-centred approach can reproduce rather than reduce inequality. Students may experience unstable connectivity, costly data, shared devices, power interruptions, and unsuitable study spaces, while lecturers must prepare multiple formats and maintain interaction across platforms. South African policy, therefore, positions digital learning within broader responsibilities for institutional capacity, academic support and student success [7], [8]. Usable access is consequently more important than nominal access: resources are educationally available only when students can reach, understand and use them under their actual material and linguistic conditions.

The challenge is also epistemic. Mathematics is often presented as culturally neutral and detached from the knowledge practices of learners' families and communities. Ethnomathematics and culturally responsive pedagogy challenge this assumption by recognising that patterning, measurement, spatial design, games, trading, environmental observation and collective problem-solving contain mathematically significant relationships [9]-[13]. Studies of Morabaraba, Kgati and Alikoto show that indigenous games can support serious inquiry into geometry, number, probability, strategy and mathematical communication [14]-[16]. Such practices should not be appended as illustrations after formal content has been defined; they should help generate the problem, representation and argument through which formal mathematics is developed.

Although blended learning and IKS are potentially complementary, the two literatures remain insufficiently integrated. Blended mathematics studies commonly emphasise platform use, technology acceptance or achievement, whereas IKS-oriented studies often describe culturally grounded activities without examining the distinctive affordances and inequalities of hybrid learning [2], [11], [17], [18]. The central problem is therefore how to design blended mathematics teacher education that is simultaneously pedagogically coherent, culturally rigorous, equitable and ethically responsible. This review addresses four questions: (1) Which design principles make blended mathematics teacher education transformative rather than supplementary? (2) How can IKS support rigorous mathematical meaning-making? (3) How should engagement and learning outcomes be conceptualised in these environments? and (4) Which institutional and ethical conditions shape implementation? The objective is to develop an integrated IKS-responsive framework that aligns theory, course design, engagement processes and defensible learning outcomes.

2 Literature Review

2.1 Blended learning as pedagogical orchestration

The literature consistently distinguishes pedagogical redesign from digital supplementation. Uploading notes, recordings, or quizzes may increase access to content, but it does not necessarily improve learning quality. Strong hybrid designs assign

complementary purposes to different modes: asynchronous resources support preparation, replay, and reflection; synchronous online or face-to-face sessions support questioning, modelling, strategy comparison, and immediate feedback; and follow-up tasks consolidate explanation and transfer [1]-[6]. The important unit of analysis is therefore not the individual platform or activity but the sequence through which students encounter, discuss, represent, test and revise mathematical ideas.

For mathematics teacher education, orchestration has two related purposes. First, it supports students' own mathematical learning by allowing repeated movement among concrete contexts, diagrams, symbols and verbal explanations. Second, it makes pedagogy visible by requiring preservice teachers to explain why a particular representation, mode or feedback strategy is appropriate. Social interaction and mediated tool use are central to the development of higher mental functions in social constructivism [19]. Similarly, the Community of Inquiry framework explains purposeful online and blended learning through the interaction of teaching presence, social presence and cognitive presence [20]. These perspectives imply that technology is educationally meaningful when it supports guided participation, collaborative inquiry and progressive independence.

2.2 IKS, ethnomathematics and culturally responsive mathematics teacher education

IKS refers to bodies of knowledge, practices, values and interpretive resources developed through long-term relationships between communities and their social and ecological environments. In mathematics education, ethnomathematics provides a language for recognising the mathematical dimensions of cultural practices. At the same time, culturally responsive pedagogy focuses on how curriculum, relationships and instruction can sustain academic rigour, cultural competence and critical awareness [9]-[13]. The contribution of IKS is therefore not to replace disciplinary mathematics with cultural description. It is to create epistemic bridges through which learners can investigate formal relationships from meaningful practices and critically examine the assumptions embedded in mathematical models.

Authentic integration requires mathematical and cultural integrity. Beadwork may support transformation geometry and sequences; indigenous architecture may support ratio, measurement, and spatial reasoning; games may support combinatorics, probability, and strategic thinking; and community data may support statistics, estimation, and modelling [14]-[18]. Yet the use of cultural material can become tokenistic when a practice is simplified, detached from its purpose or presented as representative of a homogeneous community. Knowledge holders should be acknowledged, variation within communities should be recognised, and restricted or collectively owned knowledge should not be digitised without appropriate consent. These responsibilities are consistent with South Africa's Indigenous Knowledge legislation, which emphasises protection, recognition, development and responsible management [21].

2.3 Student engagement and learning outcomes in hybrid environments

Engagement is frequently treated as participation in online activity, but logins, clicks and task completion provide only partial evidence. The literature identifies behavioural engagement in participation and persistence; emotional engagement in confidence, belonging, and reduced anxiety; cognitive engagement in reasoning, reflection, and strategic effort; and agentic engagement in questioning, proposing examples, and influencing the learning process [3], [4]. These dimensions are particularly important in mathematics, where visible participation can coexist with procedural compliance and where students may require time, language support and multiple representations before contributing publicly.

Blended environments can widen participation when they offer asynchronous thinking time, multimodal explanation and repeated access to feedback. Voice notes, diagrams, worked examples, collaborative forums and face-to-face discussion can operate as complementary entry points. The Community of Inquiry further clarifies that meaningful engagement depends on interaction among teaching, social and cognitive presence [20]. Within an IKS-responsive design, cultural recognition adds a transversal quality to these presences: it shapes which problems are deemed worthy, whose explanations are heard, and whether students experience mathematics as connected to identity and place. The most defensible outcomes are therefore deeper explanation, flexible representation, persistence, belonging, learner agency and transfer. Claims of improved achievement require validated assessment evidence and comparative empirical designs.

2.4 Equity, lecturer capability and ethical knowledge governance

Hybrid flexibility is uneven when participation assumes continuous connectivity, personal devices, academic English and quiet study environments. Inclusive design consequently requires low-bandwidth files, downloadable resources, flexible participation windows, meaningful offline alternatives and institutional support for devices and data [7], [8], [17], [18], [24]. Hybrid learning should be evaluated by students' conversion of resources into actual learning opportunities, rather than by the mere existence of a platform. Theorising hybrid lifelong learning likewise emphasises continuity across settings, temporal flexibility and the purposeful integration of formal and informal learning spaces [22].

Lecturer capability is equally consequential. IKS-responsive blended teaching requires integrated knowledge of mathematics, pedagogy, culture, technology, assessment and facilitation. The epistemological-bridge approach assists teachers in connecting community knowledge with disciplinary concepts without reducing either knowledge system [23]. Research in resource-constrained schools and on digital game-based mathematics learning further indicates that implementation depends on teacher confidence, infrastructure, leadership and sustained professional learning [24], [25]. Culturally responsive constructivist preparation [26] and culturally grounded technology use for diverse learners [27] reinforce the need for inclusive design expertise. Ethical governance must also address attribution, consent, collective ownership, digital

permanence and the risks associated with generative artificial intelligence or automated content production [21], [28].

2.5 Theoretical Framework

The study is guided by an integrated theoretical framework that combines social constructivism, culturally responsive pedagogy, ethnomathematics, and the Community of Inquiry. The four perspectives are complementary rather than interchangeable. Social constructivism explains learning as mediated participation in which language, cultural tools and interaction support movement from assisted activity towards independent reasoning [19]. In a blended mathematics course, this lens directs attention to scaffolding, collaborative problem-solving, dialogic feedback and the deliberate movement between contextual experience and formal representation.

Culturally responsive pedagogy explains why the recognition of students' knowledge, language and identities is central to academic rigour rather than separate from it [10], [11]. It requires teacher educators to select tasks that connect disciplinary goals with learners' cultural resources, maintain high expectations and create participation structures in which diverse forms of explanation can develop towards mathematical precision. Ethnomathematics complements this perspective by identifying the mathematical relationships embedded in cultural practices and by questioning narrow accounts of what counts as legitimate mathematical knowledge [9], [12], [13]. Together, these lenses define epistemic inclusion as the rigorous connection of community knowledge and formal mathematics, not the uncritical celebration of culture.

The Community of Inquiry provides the framework for a hybrid-learning architecture [20]. Teaching presence concerns purposeful design, facilitation, and feedback; social presence concerns trust, recognition, and the capacity to participate as a real person; and cognitive presence concerns the movement from a problem or puzzling event through exploration, integration, and resolution. The present review treats cultural responsiveness as a transversal condition that shapes all three presences. It affects teaching presence through task and language choices, social presence through belonging and recognition, and cognitive presence through the contexts that make inquiry meaningful.

The integrated framework therefore proposes a directional relationship: theoretical foundations inform pedagogical design; pedagogical design creates opportunities for behavioural, emotional, cognitive and agentic engagement; and these engagement processes support deeper mathematical meaning-making, participation, culturally affirmed identity and transferable problem-solving. Equity and ethical governance operate as conditioning factors rather than background variables. When connectivity, devices, lecturer support, multilingual participation or knowledge permissions are inadequate, the proposed mechanisms are weakened. This theoretical alignment also structures the review method and the presentation of findings: each research question corresponds to a layer of the framework, enabling consistency across the problem, literature synthesis, analysis, and conclusions.

Table 1. Theoretical lenses and their alignment with the review

Theoretical lens	Core proposition	Analytical role	Design implication
Social constructivism	Learning develops through mediated participation, language and scaffolding.	Explains collaborative reasoning and movement from supported to independent activity.	Connect contextual tasks, representations, dialogue and feedback across modes.
Culturally responsive pedagogy	Academic rigour is strengthened when learners' identities, languages and knowledge are recognised.	Examines belonging, participation, high expectations and inclusive curriculum choices.	Use multilingual and culturally meaningful tasks that develop formal mathematical precision.
Ethnomathematics	Mathematical relationships are embedded in culturally situated practices.	Identifies epistemic bridges between community knowledge and disciplinary mathematics.	Generate inquiry from authentic practices while maintaining mathematical and cultural integrity.
Community of Inquiry	Meaningful hybrid learning emerges through teaching, social and cognitive presence.	Organises the analysis of design, interaction and sustained inquiry across settings.	Coordinate purposeful facilitation, social recognition and progressive problem resolution.

3 **Methods**

A structured narrative review was selected because the purpose was to integrate theoretical and empirical insights across four intersecting fields rather than to estimate an intervention effect. The unit of analysis was the published source, and the review was organised around the four research questions stated in the Introduction. Searches used combinations of the terms blended learning, hybrid learning, mathematics teacher education, Indigenous Knowledge Systems, ethnomathematics, culturally responsive pedagogy, student engagement, Community of Inquiry, digital equity and South African higher education. Sources were located through scholarly search engines and publisher websites, with backward reference tracing used to identify influential works cited in the initial set.

The review prioritised peer-reviewed empirical studies, theoretical papers and reviews published from 2016 to 2025 that addressed at least two focal domains: blended or hybrid design; mathematics or teacher education; IKS, ethnomathematics or culturally responsive pedagogy; engagement and learning outcomes; or digital equity and institutional conditions. Earlier publications were retained when they established the theoretical foundations of ethnomathematics, culturally relevant pedagogy, social constructivism and the Community of Inquiry [9], [10], [19], [20]. Policy and legislative documents were included when they clarified responsibilities for digital learning or indigenous knowledge governance [7], [8], [21]. Sources were excluded when they treated technology only as a technical platform, lacked a clear educational focus, or could not inform mathematics teacher education. Thirty sources were retained.

A source matrix was used to record publication type, context, focal construct, methodological orientation, principal argument or finding, and relevance to the review questions. Analysis proceeded through thematic synthesis. Initial codes reflected the four

questions: orchestration of learning modes, epistemic and cultural inclusion, engagement and learning outcomes, and enabling conditions. Codes were compared across sources, refined through attention to convergences and tensions, and interpreted through the integrated theoretical framework. The analytical process drew on the iterative logic of thematic analysis [29]. At the same time, quality was strengthened through transparent selection criteria, conceptual coherence, attention to contradictory claims, and a clear separation between evidence-supported propositions and untested causal claims [30].

The review does not claim exhaustive database coverage and is not presented as a systematic review or meta-analysis. Its purpose is analytical generalisation: to develop transferable design propositions that can be tested in future empirical work. The Results section, therefore, reports the four synthesis themes in the same sequence as the research questions, and the Discussion evaluates how these themes extend theory, teacher education practice, and future research.

4 Results and Discussion

4.1 Results

The synthesis produced four findings that correspond directly to the four review questions and to the analytical layers of the theoretical framework.

Finding 1: Purposeful orchestration transforms blended mathematics pedagogy.

Across the reviewed literature, the strongest distinction was between the addition of technology and the redesign of learning. Digitised notes, recordings and quizzes can improve convenience, but they remain supplementary when students encounter the same transmission-oriented pedagogy in another medium. Transformative designs distribute complementary work across modes. Before contact sessions, low-bandwidth materials and contextual prompts prepare students to notice patterns and formulate questions. During synchronous or face-to-face activity, students compare strategies, justify representations, model relationships, and receive dialogic feedback. After contact, reflective or application tasks require consolidation and transfer [1]-[6].

For mathematics teacher education, purposeful orchestration also makes teaching decisions available for examination. Preservice teachers should not only solve a contextualised problem; they should also explain how the sequence supports conceptual development, which misconceptions it anticipates, why a particular representation was selected, and how feedback will move learners forward. The first finding, therefore, confirms that the pedagogical contribution of blending lies in continuity among tasks, representations, dialogue and feedback. The relevant design question is not whether technology is used, but how activity across spaces strengthens mediated participation and mathematical reasoning.

Finding 2: IKS is an epistemic resource when it generates rigorous mathematical inquiry.

The second finding is that IKS contributes most strongly when community practices carry substantive mathematical structure and initiate inquiry. Patterned artefacts can support sequences, symmetry and transformation; architecture and land practices can support scale, ratio, area and spatial reasoning; games can support counting, probability, combinatorics and strategic reasoning; and community datasets can support estimation, statistics and modelling [11]-[18]. These contexts make mathematical relationships culturally legible while creating opportunities to examine the limits, assumptions and consequences of formal models.

The synthesis also identifies clear boundaries. Cultural references become tokenistic when they decorate an otherwise unchanged lesson, when practices are treated as static or homogeneous, or when mathematical claims are imposed without demonstrating their connection to the practice. Rigorous integration requires verification of mathematical content, respect for variation, attribution of knowledge and consultation where use may affect collective rights or restricted knowledge [21], [23]. The second finding, therefore, positions IKS as a knowledge-generating resource and an ethical relationship, not simply a motivational device.

Finding 3: Engagement is multidimensional and supports broader learning outcomes.

The third finding is that engagement in blended mathematics cannot be inferred solely from platform activity. Behavioural engagement is visible in attendance, participation and persistence; emotional engagement concerns confidence, belonging and willingness to take intellectual risks; cognitive engagement concerns explanation, reflection, strategy selection and conceptual connection; and agentic engagement appears when students ask questions, introduce examples and influence the direction of inquiry [3], [4]. A coherent blended design can support these dimensions through asynchronous thinking time, multilingual contributions, multimodal explanation, peer dialogue and repeated access to feedback.

The literature supports cautious claims about outcomes. Culturally meaningful problems and flexible participation may strengthen explanation, representational fluency, persistence, identity, learner voice and transfer. These outcomes are educationally important in teacher education because future teachers must develop both mathematical understanding and the capacity to design inclusive instruction. However, perceived usefulness, participation or qualitative reports of confidence should not be treated as proof of achievement gains. Causal claims require validated mathematics assessments, appropriate comparison conditions and evidence that changes are attributable to the design rather than to access or selection effects.

Finding 4: Equity, lecturer capability and ethical governance condition implementation.

The fourth finding is that the proposed benefits are conditional. Students cannot use flexibility when resources require continuous connectivity, large downloads, personal

devices or uninterrupted home study. Low-bandwidth formats, downloadable materials, offline pathways, flexible submission windows and access to devices and data are therefore components of pedagogy rather than peripheral support [7], [8], [24]. Multilingual participation is similarly important: home-language speech, diagrams and gestures can provide bridges towards formal mathematical language without lowering disciplinary expectations.

Lecturer capability and institutional support determine whether these principles can be enacted. Designing culturally grounded hybrid inquiry requires integrated knowledge of mathematics, pedagogy, technology, assessment, language and community context [17], [18], [25]-[27]. Institutions should provide professional learning, instructional design support, and recognition of the labour involved in producing accessible resources and sustaining feedback. Ethical governance must address permissions, attribution, collective ownership, digital permanence, and the use of artificial intelligence to represent community knowledge [21], [28]. The final finding is therefore that equity and ethics are not implementation details; they determine whether the framework's engagement and learning mechanisms can operate.

Table 2. Thematic findings and aligned design implications

Finding	Design emphasis	Educational contribution	Critical condition
Purposeful orchestration	Connected asynchronous, synchronous and contact tasks	Reasoning, dialogue, feedback continuity and pedagogical judgement	A clear complementary purpose for each mode
Epistemic inclusion	Authentic IKS-grounded mathematical inquiry	Cultural relevance, conceptual connection and mathematical identity	Rigour, attribution, consent and non-tokenistic use
Multidimensional engagement	Voice, collaboration, reflection and co-design	Persistence, belonging, agency, flexible representation and transfer	Multilingual and multimodal participation
Conditional implementation	Low-bandwidth access, lecturer support and ethical governance	More equitable participation and sustainable inclusive design	Devices, data, professional learning, workload recognition and knowledge permissions

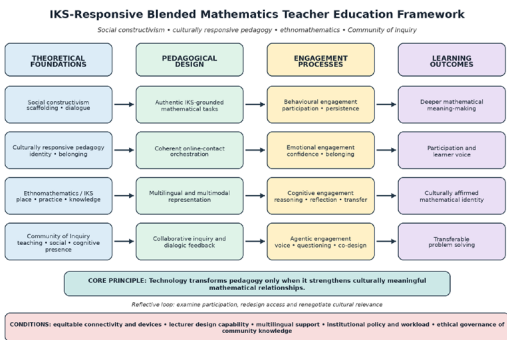


Fig. 1. IKS-responsive blended mathematics teacher education framework (developed by the authors)

4.2 Discussion

The synthesis shows that the educational contribution of blended learning is pedagogical and epistemic before it is technological. Social constructivism explains why connected activity, dialogue and tool-mediated representation can move students from supported participation towards more independent reasoning [19]. The Community of Inquiry explains how purposeful design, social recognition and sustained inquiry must operate together across online and contact spaces [20]. The findings extend these perspectives by showing that cultural responsiveness influences all three presences. It shapes teaching presence through task, language and assessment choices; social presence through recognition and belonging; and cognitive presence through the contexts in which mathematical problems become meaningful.

The framework's principal theoretical contribution is the connection of cultural presence with engagement processes. Cultural presence is not proposed as a separate fourth presence to be mechanically added to the Community of Inquiry. It is a transversal condition in which students' languages, experiences, and community knowledge are treated as legitimate starting points for disciplined inquiry. This interpretation aligns culturally responsive pedagogy and ethnomathematics with hybrid-learning design [9]-[13]. It also clarifies why the same platform can produce different outcomes: learning depends on the relationships among knowledge, participation, representation, feedback and material access rather than on the technology alone.

The findings provide a practical sequence for mathematics teacher educators. Design should begin with a mathematically productive community practice or problem, clarify the formal concepts and ethical permissions involved, and allocate complementary work to asynchronous and contact modes. Students should investigate the context, develop and compare representations, receive feedback, formalise relationships and return to the context to test the usefulness and limitations of the model. Assessment should reward explanation, strategy comparison, questioning, reflection and the capacity to design inclusive teaching, not only the production of correct answers.

The framework also disciplines claims about achievement. The review supports plausible mechanisms linking coherent design and cultural relevance to engagement, meaning-making, and transfer, but it does not establish a causal link to improved marks. Future research should test the framework through comparative case studies, design-based research and mixed-methods studies across institutions and mathematical domains. Interviews and observations should be triangulated with learning artefacts, validated engagement measures and mathematics assessments. Studies should also examine which framework components are essential, how multilingual practices operate over time, and how community knowledge holders experience digital representation.

The review is limited by its structured narrative design, reliance on English-language accessible literature and concentration on mathematics and South African educational contexts. The source set does not permit exhaustive coverage or statistical generalisation, and the integrated framework has not been empirically validated. These limitations do not invalidate the synthesis, but they require treating the framework as a testable conceptual model rather than a proven intervention.

5 Conclusions And Suggestions

IKS-responsive blended learning can advance mathematics teacher education when technology, culture and pedagogy are treated as an integrated design problem. The review answers the four research questions by identifying four aligned requirements: the purposeful orchestration of online and contact activity; the mathematically rigorous and ethically grounded use of community knowledge; support for behavioural, emotional, cognitive, and agentic engagement; and institutional conditions that make participation materially equitable. The resulting framework links these requirements to deeper mathematical meaning-making, learner voice, belonging, culturally affirmed identity and transferable problem-solving, while avoiding unsupported claims of achievement.

Five suggestions follow. First, teacher educators should co-design culturally grounded tasks with students and, where appropriate, community knowledge holders. Second, every hybrid sequence should provide low-bandwidth and offline participation pathways. Third, multilingual and multimodal explanations should serve as a bridge to formal mathematical communication. Fourth, institutions should recognise inclusive course design and dialogic feedback through professional development, instructional design support, and workload allocation. Fifth, future studies should empirically test the framework across institutions, year levels, and mathematical domains, using designs that connect engagement processes to validated learning outcomes.

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