ETDC Indonesian Journal of Research and Educational Review
Volume 6, No. 1, 2026, pp 507 - 521

e–ISSN 2809-3682
p–ISSN 2809-7505

https://doi.org/10.51574/ijrer.v6i1.5625

Empowering ASEAN Mathematics Teachers' STEM Pedagogical Content Knowledge: A Culturally Responsive Pedagogy Framework

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Article Info

Article history:

Received August 03, 2026
Revised October 18, 2026
Accepted November 02, 2026
Published November 15, 2026

Keywords:

ASEAN Mathematics;
CRP;
PCK;
STEM Education;
Teacher Professional Development.

ABSTRACT

While integrated STEM education is increasingly prioritized across Southeast Asia, mathematics educators in ASEAN frequently face difficulties harmonizing abstract STEM instruction with diverse socio-cultural realities, resulting in fragmented STEM Pedagogical Content Knowledge (STEM-PCK). This study fills this critical gap by constructing and validating a novel framework embedding Culturally Responsive Pedagogy (CRP) into STEM-PCK. Following PRISMA 2020 guidelines for initial qualitative synthesis, a three-round Delphi consensus was conducted with 15 mathematics and STEM education experts from Singapore, Malaysia, Indonesia, and Thailand. Statistical convergence across rounds confirmed strong panel agreement ($W = 0.78, p < 0.001$; I-CVI ≥ 0.80; IQR ≤ 1.00). The resulting CRP-STEM-PCK Framework encompasses four dynamic dimensions: (1) Cultural Contextualization of Mathematical Concepts, (2) Cross-Disciplinary STEM Synthesis, (3) Inclusive Socio-Cultural Problem Solving, and (4) Adaptive Pedagogical Reflection. The study reveals that contextualizing STEM problems within indigenous knowledge systems and regional challenges markedly boosts teachers' pedagogical confidence and task design skills. Theoretically, this research bridges CRP and STEM-PCK; practically, it offers ASEAN policymakers and teacher education institutions an actionable blueprint for regional professional development.

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1. INTRODUCTION

In the era of Society 5.0 and rapid technological advancement, the integration of Science, Technology, Engineering, and Mathematics (STEM) education has evolved from a pedagogical ideal into a critical strategic agenda across ASEAN member states to drive innovation and sustainable economic growth (Jamaluddin et al., 2025; Ndiaye

& Diop, 2026; Sarsale et al., 2024). Within this multidisciplinary landscape, mathematics serves as the foundational anchor, enabling students to model, quantify, and solve complex real-world problems (Ha et al., 2020; Kohen & Orenstein, 2021; Muzaini et al., 2022; Wahono et al., 2020). Delivering effective STEM instruction, however, relies heavily on educator competence, requiring robust STEM Pedagogical Content Knowledge (STEM-PCK)—an essential intersection of discipline-specific content knowledge, adaptive pedagogical strategies, and interdisciplinary integration skills (Kewalramani et al., 2025; Mientus et al., 2022; Thyssen et al., 2023; Wang et al., 2025). Consequently, empowering mathematics teachers to cultivate strong STEM-PCK has been widely recognized as a fundamental prerequisite for delivering high-quality 21st-century STEM education (Correia & Baptista, 2022; Lertdechapat & Faikhamta, 2021; Mansour et al., 2024; Yang & Ball, 2024).

Despite the globally acknowledged importance of STEM-PCK, its practical implementation faces severe systemic bottlenecks when standardized STEM education paradigms are directly transplanted into regional classrooms without contextual adaptation (Ntumi et al., 2026; Oliveira et al., 2026). In the ASEAN context, mathematics teachers frequently struggle to reconcile abstract, standardized STEM curricula with the rich, highly diverse socio-cultural realities of their students (Goos et al., 2023; Le et al., 2021; Panqueban & Henríquez-Rivas, 2025). Existing STEM implementation models tend to treat the learning context as monolithic, inadvertently alienating students from indigenous, rural, or non-dominant cultural backgrounds (Charity Hudley & Mallinson, 2017; Chenoweth et al., 2026; Govender et al., 2026; Jin, 2021). This disconnect leads to a fragmented STEM-PCK among mathematics educators, who often lack the pedagogical framework required to draw meaningful connections between abstract mathematical concepts, interdisciplinary STEM challenges, and local cultural heritages.

This structural inability of conventional models to address socio-cultural nuances underscores a significant theoretical and empirical gap at the intersection of STEM-PCK development and Culturally Responsive Pedagogy (CRP), two domains that have largely been examined in isolation (Ladson-Billings, 2021; Ogodo, 2024). Most existing STEM-PCK frameworks are grounded in Western, Eurocentric educational paradigms that assume homogeneous classroom environments and advanced resource infrastructure, thereby neglecting the unique socio-cultural dynamics of Southeast Asia (Lee et al., 2019; Yip, 2025). Specifically, conventional STEM-PCK models treat mathematical knowledge as culturally neutral abstract tools, failing to operationalize how ethnomathematical artifacts and local community epistemologies can act as structural cognitive scaffolding for engineering design and scientific inquiry (EL-Deghaidy et al., 2025; Rodríguez-Nieto & Alsina, 2022; Rosa & Orey, 2021). Conversely, research on CRP in mathematics has predominantly focused on single-discipline contexts rather than integrated STEM environments (Abdulrahim & Orosco, 2020; Nolan & Xenofontos, 2023). Integrating CRP into mathematics requires a nuanced understanding of the discipline's unique epistemological structure—where

abstract logical deduction must relate to concrete socio-cultural artifacts without compromising mathematical rigor (Comstock et al., 2025; Jung et al., 2026).

To address this critical gap, this study proposes a novel, validated conceptual framework: the Culturally Responsive STEM-PCK Framework (CRP-STEM-PCK). By systematically embedding core CRP principles—such as leveraging students' cultural knowledge, fostering socio-cultural consciousness, and promoting inclusive problem-solving—into the core dimensions of STEM-PCK (Handayani & Triyanto, 2026; Ogodo, 2024), this research provides a holistic model for teacher professional development. To ensure its theoretical validity and contextual applicability, the framework was constructed using a rigorous multi-method design incorporating a systematic synthesis and a three-round Delphi expert consensus across four ASEAN nations (Barrios et al., 2021; Fathullah et al., 2023). Through this approach, the proposed framework articulates the precise competencies and pedagogical shifts required for teachers to contextualize STEM learning meaningfully.

The operational success of the CRP-STEM-PCK framework is grounded in four interconnected domains. Domain 1, *Cultural Contextualization of Mathematical Concepts* (D1), defines the teacher's ability to identify, translate, and integrate local cultural heritages, ethnomathematical artifacts, and indigenous knowledge into formal mathematical concepts without compromising mathematical rigor. Its proxy indicators include identifying geometric patterns in ASEAN textiles and architecture, preserving abstract mathematical rigor within ethnomathematical tasks, and adapting mathematical phrasing to honor local dialect diversity. Domain 2, *Cross-Disciplinary STEM Synthesis* (D2), reflects the capacity to blend mathematical modeling, scientific inquiry, technological tools, and engineering design into cohesive, non-fragmented instructional units. Proxy indicators for D2 encompass integrating mathematical equations into engineering design processes, applying digital/tech tools in mathematical problem-solving, and executing cohesive lesson planning across multiple STEM fields.

Furthermore, Domain 3, *Inclusive Socio-Cultural Problem Solving* (D3), centers on framing STEM learning around pressing regional socio-economic challenges (e.g., climate resilience and sustainable agriculture) while fostering collaborative, collectivist learning environments. Proxy indicators include aligning STEM tasks with ASEAN sustainability challenges, structuring cooperative learning reflecting communal values (such as *Gotong Royong*), and adapting STEM kits for underfunded rural schools. Domain 4, *Adaptive Pedagogical Reflection* (D4), serves as the continuous evaluative engine wherein teachers critically analyze their socio-cultural biases, assess student engagement across cultural subgroups, and adapt instruction via community collaboration. Its proxy indicators involve conducting critical self-audits of socio-cultural instructional bias, consulting community elders and cultural experts, and iteratively modifying lessons based on localized classroom feedback.

Collectively, the operationalization of the CRP-STEM-PCK framework offers three significant theoretical contributions to the literature. First, it establishes a *Unified Theoretical Bridge* that synthesizes Culturally Responsive Pedagogy (CRP) and STEM-PCK into an integrated four-dimensional model, thereby eliminating the historical

fragmentation between socio-cultural responsiveness and interdisciplinary technical instruction. Second, it initiates a *Regional ASEAN Paradigm Shift* by replacing Eurocentric, resource-intensive STEM paradigms with a context-sensitive framework engineered specifically for the socio-cultural diversity and infrastructure realities of Southeast Asian classrooms. Third, it provides *Operationalized Epistemological Scaffolding*, positioning mathematics as an active "cultural bridge" that translates indigenous artifacts and regional socio-economic dilemmas into rigorous engineering design processes and scientific inquiry.

2. METHOD

This study employed an exploration sequential multi-method design combining a Systematic Literature Review (SLR) following PRISMA 2020 guidelines with a three-round Delphi consensus technique. This design was selected because it allows for the conceptual synthesis of disjointed theoretical domains—specifically Culturally Responsive Pedagogy (CRP) and STEM Pedagogical Content Knowledge (STEM-PCK)—followed by rigorous expert validation to establish an empirically grounded framework for the ASEAN context.

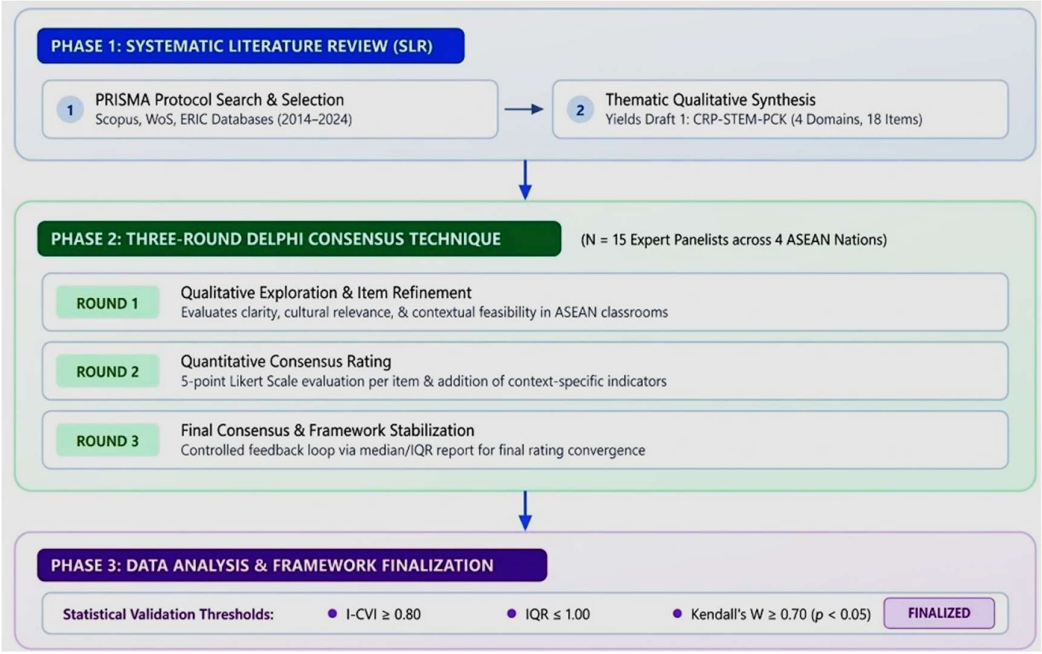


Figure 1. Sequential Multi-Method Research Design Workflow

To ensure robust regional validity and eliminate regional representation bias, a purposive proportional expert sampling strategy was conducted across four major ASEAN sub-regions. A total of 15 experts were selected based on four strict qualification criteria:

- Academic Credentials: Holding a Ph.D. in Mathematics Education, STEM Education, Ethnomathematics, or Curriculum and Instruction.
- Professional Experience: Possessing a minimum of 8 years of active experience in teacher education, educational policy, or curriculum development.

- Publication Record: Having published Peer-reviewed research indexed in Scopus/WoS on STEM education, ethnomathematics, or culturally responsive instruction within Southeast Asia.
- Geographical Proportionality: Expert distribution was intentionally balanced across advanced educational systems (Singapore: n = 2, 13.3%), established regional hubs (Malaysia: n = 3, 20.0%), large multicultural developing nations (Indonesia: n = 4, 26.7%), and culturally rich mainland states (Thailand: n = 3, 20.0%), alongside regional policy experts (n = 3, 20.0%) to prevent single-country perspectives from dominating consensus outcomes.

During Delphi Round 1, qualitative feedback exhibiting divergence or extreme ratings (disconsensus) was subjected to systematic thematic content analysis (Miles et al., 2014). Items with high variance were revised, clarified, or expanded into sub-indicators. In Round 2, aggregated statistical feedback (median and IQR) was provided back to individual panelists. For items where panelist ratings fell outside the 25th-75th percentile IQR range, panelists were required in Round 3 to provide written qualitative justifications if they chose to maintain their outlier score, ensuring complete transparency and controlled feedback convergence.

Table 1. Demographics and Professional Distribution of the Delphi Expert Panel ($N = 15$)

Region/ Nation	Expert Role	Area of Expertise	Sample Size (n)	Representation (%)
Singapore	Full & Associate Professors	STEM / Mathematics Education	2	13.3%
Malaysia	Senior Lecturers & Professors	CRP & STEM Pedagogy	3	20.0%
Indonesia	Professors & Senior Lecturers	Ethnomathematics & STEM-PCK	4	26.7%
Thailand	Associate Professor & Senior Officer	Interdisciplinary STEM Policy	3	20.0%
Regional Policy	Educational Experts (SEAMEO)	Curriculum & Policy Development	3	20.0%

To establish rigorous empirical validation throughout the Delphi consensus process, three statistical benchmarks were applied: (1) an Item-Content Validity Index (I-CVI) threshold of ≥ 0.80 for individual item retention; (2) an Interquartile Range (IQR) of ≤ 1.00 on a 5-point Likert scale to confirm strong panel consensus per indicator; and (3) Kendall's Coefficient of Concordance (W) of ≥ 0.70 ($p < 0.05$) to measure overall multi-rater agreement and convergence across successive Delphi rounds.

3. RESULTS AND DISCUSSION

Results

Phase 1 (SLR) yielded an initial draft of 4 domains and 18 indicators. In Round 1 qualitative evaluation, experts provided detailed feedback. Experts from Singapore (SGP-01, SGP-02) emphasized preserving mathematical rigor while contextualizing

culture, leading to Item D1.5 (*Evaluating mathematical accuracy within culturally contextualized tasks*). Experts from Indonesia (IDN-01, IDN-03) emphasized addressing severe resource disparities between urban and rural island schools, prompting the addition of Item D3.5 (*Addressing resource constraints in underfunded rural ASEAN schools through adaptive STEM*).

Across successive Delphi rounds, statistical consensus demonstrated substantial improvement. Kendall's Coefficient of Concordance (W) increased significantly from 0.62 ($p < 0.01$) in Round 2 to 0.78 ($p < 0.001$) in Round 3, reflecting strong multi-rater agreement among the expert panel. Furthermore, all 20 finalized indicators successfully met the predefined validation thresholds, yielding an Item-CVI of ≥ 0.80, an Interquartile Range (IQR) of ≤ 1.00, and median ratings ranging from 4.53 to 4.93.

Table 2. Statistical Validation Results of the CRP-STEM-PCK Framework (Delphi Round 3, N = 15)

Item Code	Indicator Statement	Median	IQR	I-CVI	Status
Domain 1	**Cultural Contextualization of Mathematical Concepts**				
D1.1	Patterns in cultural heritages	4.80	0.50	0.93	Retained
D1.2	Translating indigenous knowledge	4.67	0.50	0.87	Retained
D1.3	Cultural narratives in problem solving	4.60	1.00	0.87	Retained
D1.4	Linguistic diversity adaptation	4.53	0.50	0.80	Retained
D1.5	Mathematical accuracy evaluation	4.87	0.00	1.00	Retained
Domain 2	**Cross-Disciplinary STEM Synthesis**				
D2.1	Mathematical modeling to engineering	4.80	0.50	0.93	Retained
D2.2	Scientific inquiry & tech tools	4.73	0.50	0.87	Retained
D2.3	Cohesive STEM units	4.87	0.00	1.00	Retained
D2.4	Cross-disciplinary content mastery	4.60	0.50	0.87	Retained
Domain 3	**Inclusive Socio-Cultural Problem Solving**				
D3.1	Regional socio-economic challenges	4.93	0.00	1.00	Retained
D3.2	Communal/collectivist collaboration	4.67	0.50	0.87	Retained
D3.3	Empowering rural/marginalized identity	4.80	0.50	0.93	Retained
D3.4	Mitigating gender & economic bias	4.73	0.50	0.87	Retained
D3.5	Resource constraint adaptive STEM	4.60	1.00	0.80	Retained
Domain 4	**Adaptive Pedagogical Reflection**				
D4.1	Critical self-bias reflection	4.73	0.50	0.87	Retained
D4.2	Continuous subgroup assessment	4.67	0.50	0.87	Retained
D4.3	Localized feedback modification	4.80	0.50	0.93	Retained

Item Code	Indicator Statement	Median	IQR	I-CVI	Status
D4.4	Community elder collaboration	4.53	1.00	0.80	Retained

Domain 1: Cultural Contextualization of Mathematical Concepts

The statistical results for Domain 1 (Cultural Contextualization of Mathematical Concepts) demonstrate strong expert consensus across all five indicators, with median values ranging from 4.53 to 4.87, an acceptable dispersion (IQR ≤ 0.50 to 1.00), and high content validity (I-CVI ≥ 0.80 to 1.00). Notably, Item D1.5 (Mathematical accuracy evaluation) achieved absolute convergence among panelists (Median $= 4.87$, IQR $= 0.00$, I-CVI $= 1.00$), highlighting the expert panel's firm stance that cultural integration must never dilute mathematical rigor. While identifying geometric and numerical patterns in indigenous heritages (D1.1: Median $= 4.80$, I-CVI $= 0.93$) and translating traditional knowledge systems (D1.2: Median $= 4.67$) provide vital cognitive entry points, educators must rigorously evaluate mathematical validity to ensure that ethnomathematics serves as a legitimate intellectual bridge rather than a superficial pedagogical decoration.

Domain 2: Cross-Disciplinary STEM Synthesis

In Domain 2 (Cross-Disciplinary STEM Synthesis), the expert panel reached a robust consensus, with median scores spanning from 4.60 to 4.87 and all four indicators successfully retained (I-CVI ≥ 0.87). Item D2.3 (Cohesive STEM units) achieved the highest level of agreement (Median $= 4.87$, IQR $= 0.00$, I-CVI $= 1.00$), emphasizing that effective teacher professional development must dismantle siloed subject matters in favor of unified, non-fragmented interdisciplinary instruction. Furthermore, strong statistical support for connecting mathematical modeling directly to engineering design processes (D2.1: Median $= 4.80$, I-CVI $= 0.93$) and integrating scientific inquiry with technological tools (D2.2: Median $= 4.73$) indicates that ASEAN mathematics educators require advanced competencies to harmonize abstract quantitative reasoning with tangible technological problem-solving.

Domain 3: Inclusive Socio-Cultural Problem Solving

Domain 3 (Inclusive Socio-Cultural Problem Solving) yielded the highest overall agreement scores among the panelists, reflecting the critical urgency of addressing regional disparities across Southeast Asia. Item D3.1 (Regional socio-economic challenges) secured unanimous consensus (Median $= 4.93$, IQR $= 0.00$, I-CVI $= 1.00$), confirming that STEM tasks must be anchored in pressing contextual issues such as climate resilience and agricultural sustainability. Additionally, empowering rural and marginalized student identities (D3.3: Median $= 4.80$, I-CVI $= 0.93$) and mitigating gender and economic biases (D3.4: Median $= 4.73$) underscored the framework's commitment to equity. Even Item D3.5, which addresses resource constraints in underfunded rural schools (Median $= 4.60$, IQR $= 1.00$, I-CVI $= 0.80$), met the

retention threshold, demonstrating that culturally responsive STEM must remain practically adaptable to diverse infrastructural realities across the region.

Domain 4: Adaptive Pedagogical Reflection

The quantitative evaluations for Domain 4 (Adaptive Pedagogical Reflection) establish reflection and community engagement as essential evaluative engines within the framework, with median ratings ranging from 4.53 to 4.80 and strong validity indices (I-CVI ≥ 0.80). Item D4.3 (Localized feedback modification) emerged as the most critical reflective competency (Median $= 4.80$, I-CVI $= 0.93$), highlighting that teachers must continuously iterate their instructional strategies based on ongoing classroom dynamics. Moreover, active practices such as critically auditing personal socio-cultural biases (D4.1: Median $= 4.73$) and collaborating directly with local community elders and cultural experts (D4.4: Median $= 4.53$) validate that professional competence in culturally responsive STEM education extends far beyond standard classroom walls, requiring deep, reciprocal connections with the surrounding socio-cultural ecosystem.

In-Depth Statistical Interpretation & Expert Consensus Dynamics

The absolute consensus (IQR $= 0.00$, I-CVI $= 1.00$) observed for Item D3.1 (Median $= 4.93$) highlights a unanimous regional agreement that STEM education in Southeast Asia must transcend abstract theory and anchor directly in urgent socio-economic challenges, such as climate resilience and agricultural sustainability. Similarly, Item D1.5 (Median $= 4.87$, IQR $= 0.00$) attained complete convergence following Round 1 refinements, signaling the expert panel's strong rejection of superficial cultural ornamentation in favor of mathematical rigor. Consequently, cultural artifacts function not as decorative elements, but as rigorous cognitive scaffolds for mathematical and interdisciplinary learning.

Finalized Conceptual Framework: The CRP-STEM-PCK Model

The resulting Culturally Responsive STEM-PCK (CRP-STEM-PCK) Framework represents an integrated model specifically engineered for ASEAN mathematics educators.

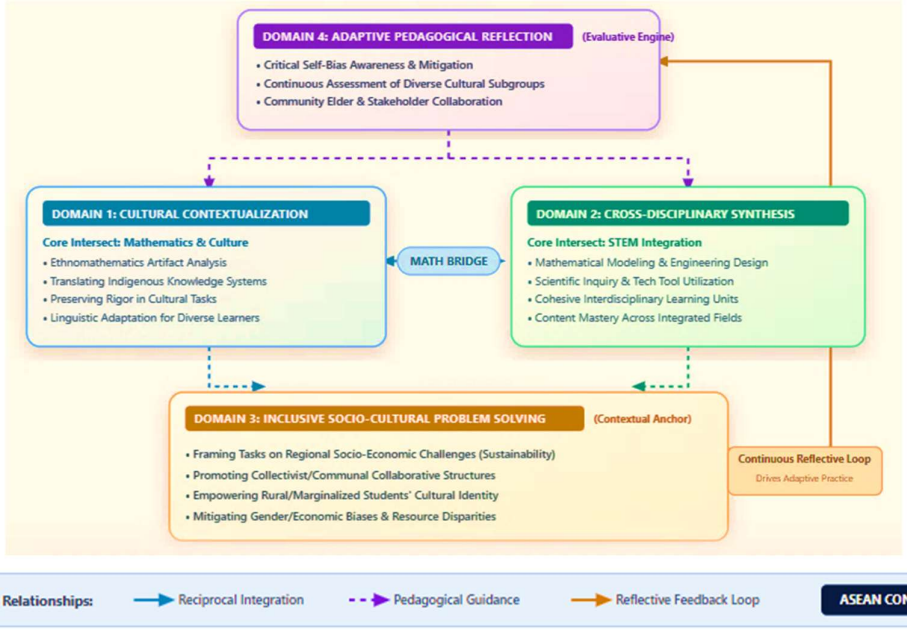


Figure 2. Conceptual Interconnections within the Finalized CRP-STEM-PCK Framework.

As illustrated in Figure 2, the four domains interact dynamically:

1. D1 & D2 (Core Competency Intersect): Mathematics functions as the bridge connecting cultural context (D1) with cross-disciplinary STEM integration (D2).
2. D3 (Contextual Anchor): Inclusive socio-cultural problem solving provides the real-world purpose for STEM tasks within the ASEAN landscape.
3. D4 (Evaluative Engine): Adaptive reflection serves as the continuous improvement loop, ensuring instruction remains culturally responsive and pedagogically rigorous.

Discussion

Principal Findings and Theoretical Integration

This study established and validated the Culturally Responsive STEM-PCK (CRP-STEM-PCK) Framework, addressing a critical gap in integrated STEM education across Southeast Asia. The empirical findings demonstrate that integrating Culturally Responsive Pedagogy (CRP) with STEM Pedagogical Content Knowledge (STEM-PCK) creates a dynamic, four-dimensional construct: *(1) Cultural Contextualization of Mathematical Concepts, (2) Cross-Disciplinary STEM Synthesis, (3) Inclusive Socio-Cultural Problem Solving, and (4) Adaptive Pedagogical Reflection*.

The high panel consensus achieved across three Delphi rounds (Kendall's $W = 0.78, p < 0.001$; I-CVI ≥ 0.80) confirms that expert consensus across ASEAN supports the feasibility of embedding socio-cultural realities into interdisciplinary mathematics instruction. Crucially, as reflected in Domain 1 (Items D1.1–D1.5), the framework positions mathematics not merely as an isolated tool for calculation, but as a primary linguistic and conceptual bridge that translates local cultural heritage into

formal scientific inquiry. This finding directly challenges prevailing views that view mathematics as culturally neutral or universally rigid, proving instead that mathematical rigor and ethnomathematical contextualization are mutually reinforcing (Desai et al., 2022; Kabuye Batiibwe, 2024; Payadnya et al., 2024; Sari et al., 2023; Wildaniati et al., 2026).

Comparison with Prior Literature: Shifting from Eurocentric to Regional Paradigms

Our findings significantly extend existing literature on teacher knowledge in integrated STEM. Previous models of STEM-PCK have predominantly focused on the technical integration of Science, Technology, Engineering, and Mathematics content (Correia & Baptista, 2022; Mutseekwa & Chikuvadze, 2026; Pitiporntapin et al., 2026). While these models effectively articulate cross-disciplinary connections, they largely operate under the assumption of socio-culturally homogeneous learning environments—a premise rooted in Eurocentric educational paradigms (Mientus et al., 2022; Phan et al., 2022; Thyssen et al., 2023). The CRP-STEM-PCK framework departs from this limitation by elevating Inclusive Socio-Cultural Problem Solving (Domain 3) to a core structural pillar.

Furthermore, while prior research on CRP in mathematics has extensively documented the affective benefits of cultural validation, it has frequently been criticized for lacking practical operationalization within interdisciplinary STEM contexts (Johnson & Elliott, 2020; Ladson-Billings, 2021; Yoon et al., 2025). By explicitly anchoring STEM design around pressing regional socio-economic challenges—such as climate resilience, sustainable agriculture, and marine conservation in ASEAN—this framework operationalizes CRP from a purely theoretical concept into an actionable instructional strategy. This synthesis responds directly to recent calls by Arnab et al. (2025) and Tarlochan et al. (2025) for context-sensitive STEM models tailored to developing nations.

Practical, Pedagogical, and Policy Implications

The finalized framework offers tangible implications for multiple educational stakeholders across the ASEAN ecosystem:

- Teacher Education Institutions (TEIs): For preservice and inservice teacher development programs, the framework provides a standardized yet flexible competency blueprint. Modules can be restructured around the four domains to train preservice mathematics teachers to design STEM tasks that leverage indigenous knowledge without sacrificing conceptual mathematical depth.
- Instructional Designers and Curriculum Developers: Rather than relying on imported Western STEM kits that often feel alien to rural or indigenous students, curriculum developers can utilize the framework's indicators (Table 3) to create localized instructional materials, incorporating ASEAN cultural artifacts, traditional engineering designs, and local environmental dilemmas.

- ASEAN Educational Policy Makers: As ASEAN member states strive toward educational harmonization, this framework offers a regional benchmark for teacher quality. Ministries of education can adapt these indicators into national standards to foster inclusive, equitable, and culturally sustaining STEM education across both urban and under-resourced rural schools.

Limitations and Future Research Directions

While this study provides a validated framework using a rigorous multi-method design, several limitations must be acknowledged:

- Delphi Panel Representation: Although the Delphi panel comprised 15 recognized experts from four key ASEAN nations (Singapore, Malaysia, Indonesia, and Thailand), educators from other ASEAN member states (e.g., Vietnam, Philippines, Cambodia, Laos, Myanmar, Brunei) were not directly represented in the expert panel. Future research should expand validation studies to include these diverse regional contexts.
- Lack of Empirical Classroom Implementation: The framework was validated through expert consensus and systematic synthesis; however, its direct impact on teacher classroom practice and student learning outcomes remains to be empirically tested.
- Recommendations for Future Studies: Future research should focus on implementing the CRP-STEM-PCK framework through longitudinal professional development interventions. Quasi-experimental and design-based research (DBR) studies are recommended to measure changes in teachers' self-efficacy, pedagogical practice, and subsequent student engagement and mathematical achievement in culturally diverse STEM classrooms.

4. CONCLUSION

This study developed and validated the Culturally Responsive STEM-PCK (CRP-STEM-PCK) Framework, addressing the long-standing challenge of harmonizing standardized STEM education with the rich socio-cultural diversity of the ASEAN region. By systematically synthesizing global literature and achieving strong multi-national expert consensus (Kendall's $W = 0.78$, $p < 0.001$), this research advances four interconnected competency dimensions: (1) Cultural Contextualization of Mathematical Concepts, (2) Cross-Disciplinary STEM Synthesis, (3) Inclusive Socio-Cultural Problem Solving, and (4) Adaptive Pedagogical Reflection.

By moving beyond Eurocentric paradigms, the CRP-STEM-PCK framework establishes a transformative, culturally sustaining model for mathematics and STEM education. Adopting this framework across ASEAN teacher education ecosystems has the profound potential to democratize STEM learning, empowering diverse generations of Asian learners to harness their heritage and solve pressing regional challenges, thereby shaping a more equitable and contextually grounded future for global STEM education.

Building upon the validated CRP-STEM-PCK framework, practical and policy implementation across Southeast Asia requires a three-pronged coordinated strategy: Teacher Education Institutions (TEIs) must re-engineer preservice curricula by integrating the framework into mathematics and science methods courses; educational ministries and curriculum units should establish open-access regional repositories of localized STEM resources; and regional bodies such as SEAMEO need to spearhead ASEAN-wide Professional Learning Communities (PLCs) to foster collaborative, cross-border teacher professional development.

ACKNOWLEDGMENTS

We gratefully acknowledge the institutional support provided by Suratthani Rajabhat University and Universitas Islam As'adiyah Sengkang. We are deeply indebted to the international expert panel from Singapore, Malaysia, Indonesia, and Thailand for their invaluable contributions during the Delphi consensus process. Their professional expertise ensured the robust methodological validation of the framework presented in this study.

AI ACKNOWLEDGMENT

The authors acknowledge the use of generative artificial intelligence (AI) technologies (specifically ChatGPT and Google Gemini) strictly for linguistic refinement, grammatical polishing, and formatting enhancement during the preparation of this manuscript. The AI tools were not used to generate data, analyze findings, draw scientific conclusions, or formulate conceptual frameworks. All theoretical arguments, data interpretations, and final contents were original, rigorously verified, and take full responsibility by the authors.

FUNDING STATEMENT

No funding was received for conducting this research or preparing this article.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The authors state that the data supporting the findings of this study will be made available by the corresponding author, M.H, upon reasonable request.

AUTHOR CONTRIBUTIONS

M.H: Conceptualization, Methodology, Software, Validation, Writing – Original Draft Preparation. F: Formal Analysis, Investigation, Data Curation, Writing – Review & Editing. T.K: Supervision, Project Administration, Validation, Funding Acquisition, Writing – Review & Editing.

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