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CRITICAL NUMERACY BASED ON MAJAPAHIT ETHNOMATHEMATICS: SYNTHESIZING CRITICAL THINKING AND NUMERACY LITERACY

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ABSTRACT
Critical thinking and numeracy literacy have largely been studied as two standalone competencies, so their integration in mathematics learning remains limited. This conceptual article aims to synthesize critical thinking and numeracy literacy into the construct of critical numeracy, and to position digital ethnomathematics as a contextual vehicle for its development. The study employed a narrative review method of literature published between 2015 and 2026, retrieved through the Scopus, Web of Science, and Google Scholar databases. The synthesis shows that critical numeracy is a capacity that integrates the dimensions of critical thinking (FRISCO) with numeracy literacy through four key capabilities Understanding, Criticality, Community, and Creativity which are explicitly distinguished from earlier versions of the critical numeracy construct through their mapping onto the FRISCO framework. This construct aligns with the principles of Deep Learning (Meaningful, Mindful, and Joyful Learning) within the Merdeka Curriculum, while digital ethnomathematics grounded in Majapahit culture is proposed as an authentic context that connects mathematical reasoning with real-life problems. This article produces a Conceptual Model of Critical Numeracy Based on Majapahit Ethnomathematics as a theoretical foundation for developing assessment instruments, instructional models, and empirical research at the junior high school level in Indonesia.

Introduction

The ability to reason mathematically within real-life contexts is one of the most strategically important competencies for twenty-first-century learners. The PISA 2022 results placed Indonesia's mathematics score at 366 points, far below the OECD average of 472 points, with only 18% of Indonesian students reaching Level 2, compared with 69% of OECD students (OECD, 2023). This figure is not merely a statistical note; it indicates a systemic gap between the mathematical competencies developed in classrooms and the demands of learners' civic, professional, and personal lives today.

Behind this gap lies a problem of conceptual fragmentation: critical thinking and numeracy literacy have largely been researched and taught as two separate domains. Research on critical thinking in mathematics tends to focus on higher-order reasoning processes-analysis, evaluation, and inference that are often detached from real-world quantitative contexts. Conversely, numeracy literacy research, particularly within the PISA framework and Indonesia's Minimum Competency Assessment, places greater emphasis on functional mathematical capability and pays less attention to the critical-evaluative dimension required for deeper understanding (Geiger & Schmid, 2024). Kaize et al. (2024) and Zetriuslita et al. (2025), who examined the integration of critical thinking and numeracy literacy within the Indonesian education context, assert that this integrated capacity which they term ‘critical-

numeracy thinking'-remains underdeveloped and requires more targeted pedagogical intervention.

At the same time, the Indonesian government, through the Ministry of Primary and Secondary Education, has since 2025 launched the Deep Learning policy as a new orientation for implementing the Merdeka Curriculum, emphasizing learning that is meaningful, mindful, and joyful, in line with the national Asta Cita agenda (Suyanto, 2025). This principle aligns with the deep learning conceptualization proposed by Fullan, Quinn, and McEachen (2018), which emphasizes students' deep cognitive and emotional engagement with meaningful content as a prerequisite for twenty-first-century competencies, including critical thinking. Within the context of Indonesian mathematics education, Feriyanto and Anjariyah (2024) show that these three principles are relevant to mathematics learning oriented toward conceptual understanding and critical thinking, consistent with Wiryanto et al.'s (2025) finding that deep learning strategies are an effective mechanism for developing critical numeracy skills aligned with the goals of Indonesia's Asta Cita development agenda. This Deep Learning policy thus serves as a relevant policy context for the development of critical numeracy, without needing to be structurally synthesized into a separate pedagogical framework in this article.

In parallel, a number of ethnomathematics studies in Indonesia demonstrate the substantial potential of local cultural contexts as a bridge between mathematical abstraction and cultural meaning, including at the level of developing numeracy literacy instruments grounded in specific cultural contexts such as Banten culture (Wirawan et al., 2024) and local Jambi culture (Dewi & Defitriani, 2024), which confirm the pedagogical feasibility of local-culture-based approaches for developing junior high school students' numeracy literacy more broadly, not limited to any single cultural context. Specifically within the context of Majapahit cultural heritage in Mojokerto, the first author's research program has uncovered mathematical structures in traditional market transactions using gobog coins (Khapsari et al., 2025), in the architectural geometry of Brahu Temple (Anjariyah, Imanah, et al., 2025), and in the development of Majapahit-themed digital games to support numeracy literacy (Ermawan et al., 2025). These local findings, read alongside evidence from other Indonesian cultural contexts noted above, strengthen the argument that digital ethnomathematics can serve as a contextual vehicle that is pedagogically feasible for developing critical numeracy, particularly in Mojokerto and regions with similarly rich cultural heritage.

The novelty of this article lies not in introducing the term critical numeracy itself-which was introduced by Stoessiger (2002) and elaborated by Jain and Rogers (2019) and O'Keeffe and Paige (2021) but in two specific contributions not yet explicitly advanced in that literature. First, this article operationally maps critical numeracy onto the FRISCO framework, which has been validated in the Indonesian context, so that the construct can potentially be assessed empirically using existing instruments rather than instruments that must be built from scratch. Second, this article articulates digital ethnomathematics grounded in Majapahit cultural heritage as a contextual vehicle that specifically links the four critical numeracy capabilities with local cultural practices a combination not yet proposed in either the international critical numeracy literature or the Indonesian ethnomathematics literature, which to date have proceeded as two relatively separate research traditions.

Based on the foregoing, this article aims to (1) synthesize critical thinking and numeracy literacy into a theoretically grounded construct of critical numeracy; (2) position this critical numeracy construct within the policy context of Deep Learning in the Merdeka Curriculum; and (3) propose digital ethnomathematics, particularly within the context of Majapahit culture in Mojokerto, as a contextual vehicle for developing critical numeracy among junior high school students.

Based on the literature synthesis outlined above, this article develops a conceptual framework that integrates critical thinking, numeracy literacy, critical numeracy, the Deep Learning policy, and digital ethnomathematics grounded in Majapahit culture. This conceptual framework forms the basis for the synthesis presented in the results and discussion section, as shown in Figure 1.

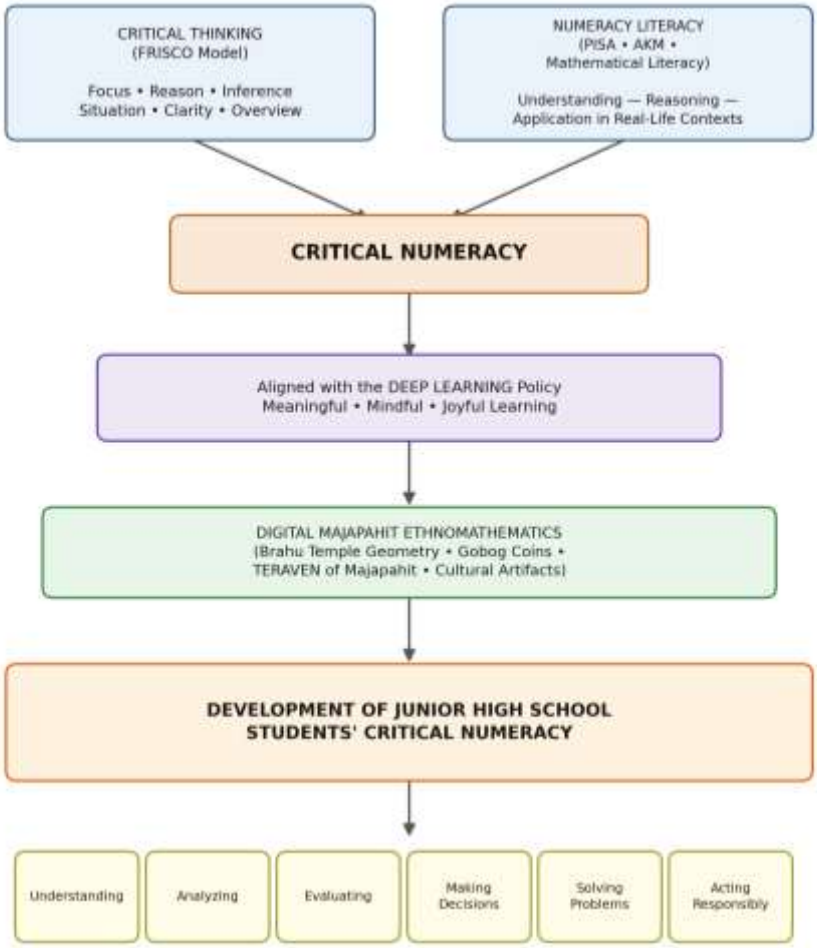


Figure 1. Conceptual Framework for Developing Critical Numeracy Based on Majapahit Ethnomathematics

Methods

This article was prepared using a narrative review approach. This approach was chosen because it allows for the synthesis of diverse theoretical traditions, the identification of conceptual gaps across strands of literature, and the construction of a new integrative argument tasks that require interpretive judgment rather than mere systematic aggregation.

Literature searches were conducted through the Scopus, Web of Science, and Google Scholar databases, using three keyword clusters: (1) critical numeracy, numeracy literacy, mathematical critical thinking; (2) deep learning, Merdeka Curriculum, meaningful mindful joyful; and (3) digital ethnomathematics, Indonesian critical numeracy, FRISCO critical thinking. The search was limited to publications from 2015 - 2026, with the exception of foundational theoretical works, which were included regardless of publication date. The searches across these three keyword clusters yielded a number of initial records, which were then screened in stages through title and abstract review to remove duplicates and irrelevant records; articles that passed this screening stage were subsequently read in full, and only those meeting the inclusion criteria below were included as synthesis sources in this review.

The inclusion criteria comprised: (1) reputable articles, operationalized as articles indexed in Scopus/Web of Science or accredited under SINTA 1 - 4, with the exception of a small number of SINTA 5 articles that constitute the only published sources on Majapahit ethnomathematics, given the specificity of this local topic; (2) availability in Indonesian or English; and (3) direct relevance to junior high school mathematics education or to the theoretical constructs under review.

Publications by the author were included insofar as they provided empirical grounding not available from other sources particularly ethnographic data on Majapahit ethnomathematics

and their proportion was kept from dominating the overall literature review; independent publications outside the author's own body of work were prioritized for any claim that could be supported by the broader literature, in keeping with common practice in conceptual review methodology.

The construction of the argument followed three stages: (1) thematic synthesis of the theoretical foundations of critical thinking and numeracy literacy, carried out through independent thematic coding followed by discussion to reach consensus; (2) identification of points of convergence and complementarity between the two as the basis for the critical numeracy construct; and (3) articulation of the position of digital ethnomathematics as a contextual vehicle and its relationship to the Deep Learning policy.

Results and Discussion

Critical Thinking in Mathematics Learning

Critical thinking is one of the competencies most consistently cited in twenty-first-century education frameworks, yet its operationalization in mathematics classrooms remains contested and inconsistently applied. In mathematics education, critical thinking generally encompasses higher-order cognitive processes: the ability to analyze complex problems, evaluate the validity of mathematical arguments, draw evidence-based inferences, and apply reasoning flexibly to novel situations.

The FRISCO model, developed within the author's own research program and tested through doctoral study, outlines six interrelated dimensions of critical thinking: Focus (identifying the core of the problem), Reason (providing logical justification), Inference (drawing valid conclusions), Situation (considering contextual factors), Clarity (expressing ideas with precision), and Overview (reflecting holistically on the reasoning process) (Anjariyah et al., 2018, 2023). Empirical applications of this framework across multiple studies consistently show that Indonesian junior high school students have particular weaknesses in the Inference and Clarity dimensions-indicating that students are able to identify problems but struggle to reason toward valid conclusions and to communicate their thinking clearly.

A systematic review by Wang and Abdullah (2024) identifies three shared characteristics of successful critical thinking interventions in mathematics learning: embedding mathematical reasoning in authentic problem contexts, providing structured metacognitive scaffolding, and creating opportunities for collaborative discourse. The first characteristic authentic problem contexts constitutes an important point of convergence with numeracy literacy, discussed in the following section.

Numeracy Literacy: From Functional to Critical

Numeracy literacy, as conceptualized within international assessment frameworks such as PISA, refers to the capacity to access, use, interpret, and communicate mathematical information in order to function effectively in real-world situations (OECD, 2023). In Indonesia, the AKM operationalizes numeracy as a cross-curricular competency, yet empirical research consistently shows a gap between students' procedural competence and their capacity to reason mathematically in context (Ayuningsih et al., 2024).

Recent theoretical developments propose a more critical orientation toward numeracy. Geiger and Schmid (2024), who document what they term a ‘critical turn’ in numeracy education, show how numeracy theory has evolved from a purely functional perspective toward a model that incorporates the evaluative and decision-making capabilities required for informed citizenship. Their four-dimensional model-context, mathematical knowledge, tools, and disposition is unified by a critical orientation that enables learners not merely to use mathematics but also to question whose mathematics is treated as valid and what assumptions are embedded in numerical representations. A comprehensive review of numeracy research in the Australasian region by Goos et al. (2024) further confirms that this shift represents a broader regional trend, not one confined to the European context examined by Geiger and Schmid (2024).

Critical Numeracy as a Synthesis Construct

The construct of critical numeracy outlined in this article is built upon three foundational theoretical contributions. Stoessiger (2002) introduced critical numeracy alongside critical literacy, identifying four core aspects: the ability to critique or make critical interpretations of mathematics; the ability to decode mathematical situations; using mathematics self-reflectively; and using mathematics to act more empoweredly in the world. O'Keeffe and Paige (2021), drawing on the Australian curriculum context and Freirean critical pedagogy, reaffirm the potential of critical numeracy, arguing that the construct challenges teachers to connect students' lifeworlds, their communities, and social issues through mathematical reasoning. Jain and Rogers (2019), working with adult learners at the University of Tasmania, operationalize numeracy as a form of critical thinking using the Four Resources Model of Luke and Freebody (1999), showing that framing numeracy as the critical evaluation of real-world mathematical information is both pedagogically effective and motivationally meaningful.

This construct also intersects with the critical mathematics education tradition developed by Skovsmose (2023), which emphasizes that school mathematics should empower students to question how mathematics helps to format social and political decisions, rather than serving merely as a neutral procedural tool. This perspective underscores that Criticality within critical numeracy is not merely a technical evaluation of the validity of mathematical arguments, but also a question of power and interest embedded in numerical representations consistent with Gal's (2002) conceptualization of statistical literacy, which positions critical disposition as a core component, not an addendum, of quantitative literacy.

Building on this foundation, this article defines critical numeracy as four interrelated capabilities: (1) Understanding - comprehending mathematical content and its interconnection with cultural context; (2) Criticality - questioning the validity, assumptions, and social implications of mathematical information; (3) Community - constructing mathematical understanding collaboratively through shared inquiry; and (4) Creativity - producing new mathematical representations, arguments, or products that demonstrate transformative understanding. This four-dimensional construct can be meaningfully mapped onto the FRISCO framework: Focus and Situation align with Understanding; Reason, Inference, and Clarity align with Criticality; while Overview connects with both Community and Creativity. This mapping allows critical numeracy to be operationalized pedagogically and assessed empirically using FRISCO-based instruments already validated in the Indonesian context (Anjariyah et al., 2023). The full mapping is presented in Table 1.

Table 1. Mapping of Critical Thinking and Numeracy Literacy onto Critical Numeracy

Critical Numeracy Capability	Contribution from Critical Thinking / Numeracy Literacy	Related FRISCO Dimension
Understanding	Understanding of mathematical content and real-world quantitative context (Numeracy Literacy)	Focus, Situation
Criticality	Evaluation of the validity, assumptions, and logical inferences of mathematical arguments, including the power and interests embedded in numerical representations (Critical Thinking)	Reason, Inference, Clarity
Community	Collaborative construction of mathematical understanding through shared discourse	Overview
Creativity	Production of new, authentic, and reflective mathematical representations or arguments	Overview

Deep Learning as a Policy Context

The Deep Learning policy launched by the Ministry of Primary and Secondary Education since 2025 within the framework of the Merdeka Curriculum emphasizes learning that is meaningful, mindful, and joyful (Suyanto, 2025). This article does not position these principles as a pedagogical framework structurally synthesized with critical numeracy, but rather as a policy context that legitimizes and supports the development of critical numeracy in Indonesian classrooms today.

Feriyanto and Anjariyah (2024), through a systematic literature review, show that the meaningful-mindful-joyful principle aligns with mathematics learning that fosters conceptual understanding and critical thinking, particularly when learning tasks are embedded in contexts that are personally and culturally meaningful to students. More concrete empirical evidence from jigsaw-based statistics learning (Anjariyah et al., 2025) further shows that deep learning principles can be effectively translated into specific mathematical content areas, although this finding originates from the statistics domain and its relevance to critical numeracy specifically requires further testing. Wiryanto et al. (2025) further establish that deep learning strategies are an effective mechanism for developing critical numeracy skills aligned with the goals of Indonesia's Asta Cita development agenda.

Accordingly, critical numeracy need not be constructed as a structural derivative of Deep Learning, but rather as a substantive goal whose relevance and policy support are strengthened as the Deep Learning orientation is implemented within the Merdeka Curriculum.

Ethnomathematics as a Vehicle for Critical Numeracy

Ethnomathematics, introduced by D'Ambrosio (1985) and elaborated by Rosa and Orey (2011), refers to mathematical practices embedded within cultural communities. In mathematics education, the ethnomathematical approach positions cultural context not as decorative background, but as the principal medium through which mathematical concepts are explored, questioned, and understood. Digital ethnomathematics extends this tradition by integrating digital technology as a tool for representing, exploring, and communicating mathematical ideas embedded in cultural artifacts and practices.

The author's research program in Mojokerto has established an empirical foundation for digital ethnomathematics within the context of Majapahit cultural heritage. Khapsari et al. (2025) identified mathematical concepts embedded in traditional market transactions at Pasar Keramat-including circle geometry in gobog coin transactions, algebraic variables, and social arithmetic. Anjariyah, Imanah, et al. (2025) analyzed the geometry embedded in the architectural structure of Brahu Temple, revealing cylinders, quadrilateral prisms, symmetry, and transformational geometry within the temple's design. Ermawan et al. (2025) developed TERAVEN of Majapahit, a digital educational game integrating Majapahit cultural content with trigonometry learning, achieving an average mastery score of 80% on the numeracy literacy instrument developed in that study.

Within the framework of this article, digital ethnomathematics is positioned not as a structural component standing alongside critical numeracy, but as a vehicle a contextual medium through which the four critical numeracy capabilities (Understanding, Criticality, Community, Creativity) operate and are tested. When students engage mathematically with cultural practices they recognize and value such as the geometry of Brahu Temple or the algebra of gobog coin transactions learning becomes personally meaningful (Understanding); students gain a natural opportunity to question how mathematical concepts are embedded within cultural practices and whose knowledge is treated as valid (Criticality); exploration of cultural artifacts naturally fosters shared inquiry and discussion (Community); and digital representations of ethnomathematical findings open space for authentic mathematical products (Creativity).

It should be noted that the effectiveness of this Majapahit ethnomathematics vehicle may vary for students without a direct cultural connection to Majapahit heritage for example, migrant students or students in regions with different cultural traditions. The Understanding principle, which relies on personal meaningfulness, requires that applications of this approach outside the Mojokerto context be adapted using local cultural artifacts relevant to the local student

population as similarly demonstrated by the success of comparable approaches in the Banten (Wirawan et al., 2024) and Jambi (Dewi & Defitriani, 2024) cultural contexts rather than applied uniformly using Majapahit content throughout Indonesia.

Implications for Secondary Mathematics Learning

For junior high school mathematics teachers implementing the Deep Learning dimension of the Merdeka Curriculum, the synthesis of critical thinking and numeracy literacy into critical numeracy, with ethnomathematics as its vehicle, offers directly applicable guidance. Teachers in Mojokerto and surrounding regions are uniquely positioned to implement this approach, as Majapahit cultural heritage provides a ready-made ethnomathematical context from temple geometry to traditional market arithmetic that has already been empirically documented. Digital tools developed within this research program, including TERAVEN of Majapahit (Ermawan et al., 2025), provide ready-to-use resources for implementing digital ethnomathematics as a vehicle for critical numeracy in the classroom. For teachers outside Mojokerto, the same principles can be applied by substituting Majapahit content with local cultural artifacts relevant to their own students' contexts.

Based on the conceptual synthesis outlined above, this article proposes the Conceptual Model of Critical Numeracy Based on Majapahit Ethnomathematics as its principal conceptual contribution. This model shows that digital ethnomathematics functions as a contextual vehicle that facilitates the development of the four critical numeracy capabilities (Understanding, Criticality, Community, and Creativity), which are further supported by Deep Learning principles to produce learners capable of using mathematics critically in real life. The model is presented in Figure 2.

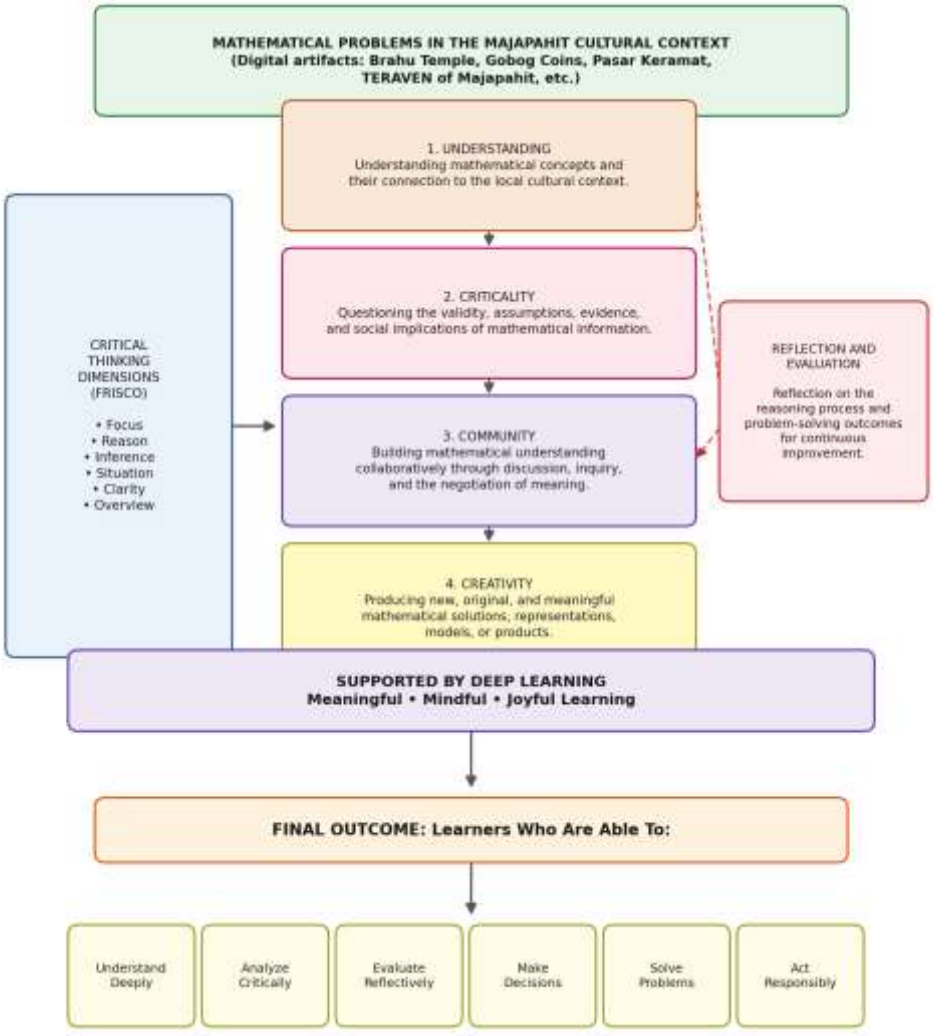


Figure 2. Conceptual Model of Critical Numeracy Based on Majapahit Ethnomathematics

As a conceptual review, this article has limitations: the proposed synthesis has not been empirically tested, and claims regarding the relationships between components remain theoretical propositions. Further research is needed to develop and validate a FRISCO-based critical numeracy instrument and to test the effectiveness of digital-ethnomathematics-based learning at the junior high school level in Mojokerto, as a continuation of this conceptual review.

Conclusion

This article proposes critical numeracy as a conceptual construct that synthesizes critical thinking and numeracy literacy. This construct is built upon the foundational contributions of Stoessiger (2002), Jain and Rogers (2019), O'Keeffe and Paige (2021), and Skovsmose (2023), and is then operationally mapped onto the FRISCO dimensions already validated within the Indonesian context. This synthesis produces the Conceptual Model of Critical Numeracy Based on Majapahit Ethnomathematics, which positions digital ethnomathematics as a contextual vehicle connecting critical reasoning with the use of mathematics in real-life situations. The model also shows that the development of critical numeracy aligns with the principles of Deep Learning (Meaningful, Mindful, and Joyful Learning) within the Merdeka Curriculum.

Critical numeracy is not merely the sum of critical thinking and numeracy literacy, but an emergent capacity that develops when learners engage in mathematical inquiry grounded in cultural context. Through the processes of understanding, evaluating, collaborating, and producing mathematical solutions, learners are expected to be able to use mathematics reflectively, critically, and responsibly in daily life. This article thus offers a theoretical contribution in the form of a conceptual model that can serve as a foundation for the development of instructional practice, assessment instruments, and empirical research on ethnomathematics-based critical numeracy.

As a conceptual review, this article has limitations, since the proposed synthesis has not been empirically tested and remains grounded in an interpretive narrative review. The proposed conceptual model should therefore be regarded as a theoretical proposition requiring further validation. Future research is recommended to develop and validate a FRISCO-based critical numeracy instrument, to test the effectiveness of digital-ethnomathematics-based instructional models among junior high school students, and to explore its application within other cultural contexts in Indonesia.

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