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Ethnomathematics as a Pillar of Ethnopedagogy in STEM: A Case Study of Mathematics Education Students' Critical Understanding

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Abstract: Ethnomathematics as a Pillar of Ethnopedagogy in STEM: A Case Study of Mathematics Education Students' Critical Understanding. Objectives: This research aims to analyze students' critical understanding of the role of ethnomathematics as a fundamental pillar of ethnopedagogy, particularly in the context of Science, Technology, Engineering, and Mathematics (STEM) education. Specifically, this analysis focuses on dissecting the structural components and argumentation patterns that constitute students' conceptual framework. **Methods:** This research used a descriptive qualitative approach. Primary data consisted of five sets of written arguments from students in the mathematics education program who had completed the ethnomathematics course. The study involved five undergraduate students as the primary participants. This textual data was analyzed using thematic analysis to identify, examine, and report systematically emerging patterns of understanding. **Findings:** This analysis shows that students develop structured patterns of understanding. First, they position ethnomathematics as the philosophical foundation for ethnopedagogy by rejecting the assumption of universalism in science and mathematics. This perspective goes beyond mere cultural appreciation, framing ethnomathematics as a decolonizing force that challenges the hegemony of Western knowledge systems. Second, they identify ethnomathematics as the primary pedagogical mechanism for contextualising STEM, serving to address students' alienation from abstract subject matter. Third, they validate local wisdom as an authentic source of STEM content, recognizing cultural practices as valid scientific knowledge. Uniquely, students conceptualize this not as supplementary content, but as the core epistemic bridge that unifies the separate disciplines of STEM within a single cultural activity. **Conclusion:** The data indicate that students in mathematics education conceptualize ethnomathematics as a central element for the effective implementation of ethnopedagogy in STEM education. This implies that students have successfully internalized a transformative pedagogical framework, viewing indigenous knowledge not as peripheral but as a legitimate and necessary foundation for rigorous STEM learning.

Keywords: ethnomathematics; ethnopedagogy; STEM education; critical understanding; teacher education.

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INTRODUCTION

Science, Technology , and Mathematics (STEM) education is prioritized worldwide as a response to the need for innovation and a technology-based economy in the 21st century (Suparman et al., 2025; Fajrina et al., 2020; Aboudahr et al., 2024). In Indonesia, the development of STEM education is a priority to improve national competitiveness. However, STEM education faces several obstacles, especially in engaging students in learning activities and ensuring the relevance of the materials. Many students find STEM disciplines, especially mathematics, to be abstract, complex, and far removed from their daily lives (Bursal & Ages, 2025; Umo & George, 2025; Drakatos & Stompou, 2023). This feeling of separation may make it more difficult for educators to achieve the general goals of STEM education. Standard pedagogical interventions often fall short of addressing this separation because they tend to treat it as merely a cognitive hurdle, while ignoring the more profound cultural dissonance that alienates students from STEM disciplines.

Previous empirical research has extensively documented the persistence of this dissonance, highlighting that conventional STEM curricula often inadvertently marginalize students whose cultural backgrounds do not align with the examples and logics typically prioritized in Western-centric instruction (Yeldell et al., 2024; Vacano et al., 2022). Studies indicate that while integrating cultural contexts into STEM, often termed culturally responsive teaching, shows promise for increasing student engagement and identity formation, the results are often inconsistent. Some researchers report that without a deep, structural connection to the content, cultural integration remains at a superficial 'celebratory' level, failing to improve rigorous conceptual understanding or to challenge the underlying student alienation. The challenge, therefore, is not merely to add culture to STEM but to fundamentally reframe how STEM concepts are accessed through cultural lenses.

To overcome this challenge, a more contextual and student-centered pedagogical approach is crucial. Specifically, an approach is needed that does not merely contextualize content superficially but re-cultures the learning process itself to resonate with students' identities. Ethnopedagogy, an approach to teaching and learning that incorporates cultural values and community knowledge into the educational process, offers a feasible solution (Rexhepi & Bajrami, 2025; Fatih et al., 2022; Hidayati et al., 2022). In STEM, ethnopedagogy helps students recognize that scientific and mathematical ideas are realized and applied in their own cultural homes, thereby connecting and rooting what is being learned in something students find valuable (Shih, 2024; Rahmawati et al., 2020). By validating local knowledge systems, ethnopedagogy offers a unique solution to the problem of alienation that generic teaching methods cannot address, effectively transforming students' backgrounds from a potential barrier into a critical learning resource. However, for ethnopedagogy to be successfully implemented in STEM, a robust disciplinary backbone must exist that integrates culture-based ways of knowing with the formalized content of the academies. This is where the general principles of ethnopedagogy require a specific operational foundation to bridge abstract STEM concepts with concrete cultural practices.

In this context, ethnomathematics, or the inquiry into the mathematics embedded in cultural practices, is central (Sari et al., 2022; Pradhan et al., 2021; Charitas & Prahmana, 2019). Ethnomathematics is a foundational aspect of ethnopedagogy, especially when enhancing the 'M' (Mathematics) in STEM. However, this integration remains a subject of intense academic debate centered on conflicting epistemological stances regarding the nature of mathematics. Scholars point out that the dominant STEM framework often adheres to a universalist epistemology that marginalizes non-Western mathematical systems, creating a theoretical tension between standardized curriculum and culturally situated knowledge.

This debate juxtaposes 'universalism,' which posits that mathematical truths are absolute, acultural, and independent of human context, against 'pluralism,' which argues that all mathematics is a cultural product generated by specific groups to solve specific problems. In the context of STEM education, this is not merely a philosophical abstraction but a practical conflict: the universalist view tends to present science and mathematics as elite, foreign domains that require students to shed their cultural identities to succeed (Simpson et al., 2023; Davis & Wilson-Kennedy, 2023). Conversely, the pluralist or ethnomathematical perspective seeks to democratize access to scientific literacy by validating diverse ways of knowing. The tension lies in how to honor local wisdom without compromising the rigorous standards required in STEM fields. Critics of ethnomathematics often argue that it may dilute the curriculum. At the same time, proponents counter that it provides the necessary scaffolding for deep conceptual understanding by linking abstract logic to tangible reality.

Ethnomathematics offers a philosophical foundation and the actual subject matter for linking mathematics and science, technology, and engineering from a cultural perspective (Rosa & Shirley, 2016; El-Deghaidy & Mansour, 2015). Therefore, the inclusion of ethnomathematics is not merely a methodological adjustment but a critical disruption of the positivist traditions that historically separate 'academic' mathematics from 'everyday' cultural practices. For instance, the Science and Engineering of the geometry and physics inherent in traditional home architecture, or the way algorithms and logic (Technology) are embodied in traditional weaving patterns, are among many mathematical practices that find expression in ethnomathematics (Jaizul & Putra, 2025; Dominikus et al., 2017).

Although the conceptual relationship among ethnomathematics, ethnopedagogy, and STEM appears strong, the success of their future implementation depends heavily on educators' readiness. Prospective teachers, especially mathematics education students who will become STEM educators, must have a deep critical understanding of how ethnomathematics functions as that pillar. In this study, the term 'pillar' is rigorously defined to encompass three distinct but interrelated dimensions: the philosophical basis for challenging epistemic hegemony, the pedagogical framework for mediating cultural context, and the substantive source for authentic scientific inquiry. Although some studies have confirmed prospective teachers' positive perceptions of ethnomathematics (Milambo & Sakala, 2019; Sylvia et al., 2022; Purwanto et al., 2025; Utami, 2025). There is still a gap in understanding how they critically conceptualise the role of ethnomathematics as a foundation for broader pedagogical approaches such as ethnopedagogy in STEM. While prior research effectively maps the landscape of 'willingness' to adopt these methods, it rarely investigates the 'critical architecture' of the underlying philosophical and pedagogical justifications that students must build to navigate the tensions between local wisdom and standardized STEM education.

This disconnect is best understood through the theoretical framework of the 'perception-practice gap' in teacher education. This framework describes a pervasive phenomenon in which pre-service teachers frequently demonstrate high levels of critical awareness and positive attitudes toward culturally responsive pedagogy (perception), yet fail to translate these egalitarian beliefs into enacted classroom practices (Singh & Akar, 2021; Pevec-Zimmer). In the specific domain of ethnomathematics, this gap is exacerbated by the subject's cognitive demands; teachers may philosophically agree that culture is important, but lack the structural knowledge to convert cultural artifacts into rigorous mathematical models. Consequently, without a clear cognitive map or 'critical architecture' to guide them, teachers often revert to traditional, decontextualized methods when faced with the complexities of curriculum design.

This structural insight is critical because a teacher's deep conceptualization is a prerequisite for moving beyond superficial cultural integration.

If this cognitive structure remains unexamined, teacher education programs risk producing graduates who possess the willingness but lack the epistemic competence to prevent the trivialization of indigenous knowledge within the rigorous demands of the STEM curriculum.

Therefore, this study aims to conduct an in-depth analysis of the structure of students' critical understanding of the role of ethnomathematics as an ethnopedagogical pillar in STEM education. This research formally seeks to map the argumentative patterns students use to legitimize the integration of cultural knowledge into the standardized STEM curriculum. Knowing the logic behind their thinking, the programs that prepare teachers would be a stronger alternative to simply finishing educator preparation in a way that allows them to impose culture within STEM learning as an authentically transformative process, not as an "add-in" (culture), as the title of this article suggests.

METHOD

Participants

The subjects of this study were students of Mathematics Education at FKIP Unmas Denpasar, Indonesia. All participants have taken the Ethnomathematics course, so they possess basic knowledge of the subject, its philosophical foundation, and its applicability in education. This 3-credit compulsory course was structured around Ubiratan D'Ambrosio's Ethnomathematic Program as its core theoretical framework, aiming to deconstruct the Eurocentric narrative of mathematics history. The curriculum encompassed three main modules: (1) The Philosophical Foundations, exploring the relationship between culture and mathematical cognition; (2) Ethnomodeling, focusing on the technical decoding of cultural artifacts (e.g., weaving, architecture, calendars) into mathematical systems; and (3) Pedagogical Application, where students were trained to design culturally responsive learning activities for the Indonesian national curriculum. This is important in context because it means their arguments are grounded in ordered academic knowledge rather than general opinion. The population included all students enrolled in the final year of the program, and a purposive sample of five students was selected to identify those demonstrating the highest depth of reflective capability.

Specifically, participants were recruited from the cohort of students who achieved an 'A' grade in the Ethnomathematics course, establishing a baseline of content mastery. From this academic pool, the final five were selected based on their voluntary willingness to participate and a preliminary assessment of their written communication skills, ensuring they possessed the necessary articulateness to engage in deep critical discourse.

The limitation to five participants is methodologically grounded in the study's design as an exploratory multiple case study, where the priority is not statistical generalization but the generation of high 'information power' from a focused group. This sample size allows for a micro-analytic investigation of each student's unique cognitive structure, permitting a depth of idiographic inquiry that would be diluted in a broader survey.

Research Design and Procedures

This research was designed using a descriptive qualitative approach. Specifically, this study was grounded in a collective case study tradition, designed to explore the shared and distinct cognitive structures of a bounded group of prospective teachers regarding a specific phenomenon. In accordance with the aim of the research to provide a detailed description of students' reasoning structures, this strategy was selected to investigate the "what" and "how" of their critical awareness of understanding rather than to seek to test hypotheses or to make statistical generalisations (Tarnoki & Puentes, 2019; Kouam & William, 2024). The focus is on a holistic understanding of participants' thinking within their specific context. The research procedures were carried out over 4 months, comprising four main stages: the preparation phase, the data collection phase using written prompts, the practical simulation phase, and the data analysis phase. In the added practical phase, participants were tasked with developing concrete teaching materials based on their designs and performing a micro-teaching simulation to allow for the observation of their pedagogical enactment.

Instruments

The research data consists of five sets of written documents produced by the students. This information was gathered in the context of a structured activity, in which students wrote answers to the question "In what sense is ethnomathematics a critical response?" This method of data collection enabled the researcher to document, in the students' words, authentic arguments, yielding high-quality textual data for analysis. To capture the practical dimension of student understanding, a 'STEM-Ethnomathematics Lesson Design Sheet' was utilized, requiring participants to translate their critical arguments into a concrete learning activity.

However, to overcome the limitations of purely perception-based data and to capture authentic pedagogical practice, three additional instruments were employed. First, a 'Micro-Teaching Performance Protocol' was used to video-record and analyze participants' teaching of a 20-minute segment of their lesson design, focusing on their verbal explanations and instructional gestures. Second, a 'Teaching Artifact Rubric' was utilized to evaluate the concrete quality of the developed learning materials, including student worksheets, media, and assessment instruments. Third, a 'Scenario-Based Interview Guide' was introduced to simulate real-time classroom challenges, asking participants to respond to specific pedagogical dilemmas (e.g., "How would you respond if a student claims this is history, not math?") to assess their spontaneous decision-making skills.

To acquire richer, more valid data on complex critical understanding, semi-structured follow-up interviews were conducted with the five students to explore their arguments in greater depth. The main instrument used was a reflective essay prompt sheet adapted from D'Ambrosio's theoretical framework, which was validated through expert review to ensure the credibility and dependability of the qualitative data obtained.

Data Analysis

Data were analyzed using thematic analysis, following a systematic series of steps to ensure accuracy and reliability (Oliver, 2011; Vaismoradi & Snelgrove, 2019). The analysis did not employ inferential statistical techniques but rather used inductive coding to categorize textual data into meaningful thematic hierarchies. Complementing the thematic analysis of essays, the lesson design artifacts and the micro-teaching video recordings were analysed using a comparative framework to evaluate the depth of cultural integration against the students' own critical arguments. Specifically, the micro-teaching performances were assessed using a structured rubric to identify discrepancies between the students' intended curriculum (design) and their enacted curriculum (practice), providing empirical evidence for the perception-practice gap.

Data from the interviews were also transcribed and coded to triangulate the findings from the written essays and lesson designs. To ensure the rigour of the qualitative inquiry, the coding process was performed independently by two researchers to establish inter-coder reliability, with potential interpretive conflicts resolved through peer debriefing and consensus. Additionally, the credibility of the findings was validated through member checking, in which participants reviewed the emerging themes to verify that the analysis accurately captured their lived experiences. These steps were as follows:

1. Data Familiarization: The researcher copied and pasted the five student records multiple times and read the records over to familiarise herself with the data.
2. First Coding: The entire record was reviewed to identify chunks (phrases or sentences) that expressed specific concepts or points of view. These ideas were coded (e.g., "rejecting universalism," "mathematics as alien," "validating local knowledge"). Crucially, this coding process was rigorously inductive, ensuring that categories emerged directly from the participants' narratives rather than being imposed by a pre-existing theoretical framework. To illustrate this trajectory, the raw excerpt "mathematics is often considered to originate only from European civilisation" was initially assigned the descriptive label "questioning historical origins," which was subsequently refined into the analytical code "challenging Eurocentrism," and then synthesized into the broader theme of "Rejecting Universalism."
3. Searching for themes. The resulting codes were then clustered based on semantic similarity to form potential themes. For instance, codes related to the beginnings of Western mathematics and its universal character were combined under the potential theme "Critique of Universalism."
4. Reflecting upon and refining themes: Candidate themes are then reviewed in relation to the entire data set, to check that they work in relation both at this level and that they have the appropriate level of conceptual depth. Similar themes were combined, and those with insufficient data support were excluded.
5. When Defining and Naming Themes. After we finalized the themes, each theme was assigned an indicative label, and a description was generated for it. This definition captures the spirit and boundaries of each theme and is used as a lens through which to present the research findings.
6. tructural Analysis of Thematic Relationships: To move beyond a flat categorization of themes and to investigate the hierarchical nature of students' understanding, a structural analysis was performed. This involved tracing the logical dependencies and causal connectors (e.g., "because," "leads to," "therefore") within the participants' arguments. Specifically, the researchers examined whether the emergence of practical pedagogical themes was contingent upon the presence of specific philosophical critiques, thereby establishing the structural order visualized in the study's figures.

■ RESULT AND DISCUSSION

Analysis of textual data from the five participants shows that their arguments are not random or fragmented. Conversely, within the specific context of this micro-case study, the data suggest that these students developed a structured and critical understanding of the role of ethnomathematics. This understanding can be mapped into three main themes that describe how they view ethnomathematics as an ethno-pedagogical pillar in the STEM context: (1) Critical Foundations of Ethno-pedagogy: Rejecting Universalism in Science and Mathematics, (2) Pedagogical Mechanisms: Ethnomathematics as a Bridge for Contextualising STEM, and (3) STEM Content Sources: Validating Local Wisdom as Scientific Knowledge.

Results: The Structure of Students' Critical Understanding

This understanding structure evolves from a philosophical foundation to pedagogical mechanisms, culminating in the identification of authentic content sources for STEM learning. Table 1 presents a thematic matrix that visualises how these three themes are manifested in each student's arguments. To allow for independent verification of these interpretations, Table 1 provides comprehensive and representative excerpts from the participants' raw data, illustrating the depth and nuance of their critical argumentation for each identified theme.

Table 1. Thematic matrix of students' critical understanding of ethnomathematics as a pillar of ethnopedagogy

Participant	Theme 1: The Critical Foundation of Ethnopedagogy: Rejecting Universalism in Science & Mathematics	Theme 2: The Pedagogical Mechanism: Ethnomathematics as a Bridge for STEM Contextualization	Theme 3: The Source of STEM Content: Validating Local Wisdom as Scientific Knowledge	Conceptual Analysis & Pedagogical Implications
Student 1	"It is a misconception to view mathematics as a culture-free zone. We must reject the notion that only Western science holds the truth; mathematics is a universal human activity, not a European invention. Recognizing this is the first step to decolonizing our curriculum."	"Ethnomathematics acts as a pedagogical bridge. By integrating cultural context, we transform abstract symbols into meaningful tools, making STEM education not just about memorizing formulas, but about understanding our own reality and finding relevance in every equation."	"This is a process of decolonization. We are not just adding 'flavor' to the curriculum; we are validating indigenous knowledge systems like traditional farming algorithms as legitimate scientific methodologies that are equal in value to Western science."	This argument reframes mathematics from a neutral subject to a cultural product, establishing decolonization as a necessary prerequisite for authentic learning. Conceptually, the 'bridge' metaphor shifts the focus from content delivery to meaning-making, connecting abstract syntax with lived reality. Furthermore, this perspective moves beyond appreciation to epistemological validation, elevating indigenous practices to the status of rigorous scientific methodology.
Student 2	"I deny that mathematics has only one form belonging to the West. Every civilization, including ours, has developed sophisticated mathematical thinking. Accepting a single form of math limits our	"Students feel detached because math feels foreign. Ethnomathematics builds a bridge between the concepts in textbooks and the reality of their daily lives, turning 'alien' numbers into familiar cultural friends."	"Look at Torajan architecture or the Mayan system. These are not just art or history; they are complex geometrical and numerical systems that rival any Western construct, proving that rigorous math exists in our heritage."	Challenging the singularity of Western mathematics empowers students to reclaim their agency as producers rather than just consumers of knowledge. This perspective addresses the affective dimension of learning by proposing ethnomathematics as a

	students' potential to see themselves as creators of knowledge."			remedy for the psychological alienation caused by decontextualized curricula. Finally, it uses comparative validation to dismantle the hierarchy of knowledge, proving that local heritage contains the same mathematical rigor as canonical Western examples.
Student 3	"We must question the neutrality of mathematics. Knowledge is socially constructed, and accepting universalism blindly erases our social identity. Math is not just numbers; it is a reflection of how a society organizes its world."	"It fosters cultural pride. When students solve problems using their own cultural context, they build an identity as capable STEM learners, not just consumers of foreign knowledge."	"We need to valorize local wisdom. Weaving patterns are not just crafts; they are algorithms and logic materialized in cloth. These practices deserve a place in the STEM classroom as valid sources of content."	Highlighting the social construction of knowledge reveals that 'universalism' often masks cultural erasure, necessitating a pedagogy that affirms identity. By connecting cultural context to self-efficacy, this view suggests that identity formation is intrinsic to cognitive success in STEM learning. Moreover, redefining artifacts like cloth as algorithmic manifestations challenges the separation between 'craft' and 'technology', effectively broadening the definition of STEM.
Student 4	"History books say math comes from Europe. We must correct this narrative to show that mathematics is a global human endeavor. Our students need to know that their ancestors were mathematicians too."	"For example, teaching the area through *Batik* patterns makes the concept tangible. It transforms a boring formula into an appreciation of cultural aesthetics, linking the logic of math with the beauty of art."	"Local knowledge is scientific. The *Baduy* use astronomy for agriculture, which is Science and Technology in practice, recognized and valid. It is proof that our people have always practiced STEM."	The correction of historical narratives is posited as essential for inclusivity, shifting the student's self-concept from an outsider to an inheritor of a global mathematical tradition. This interdisciplinary integration of aesthetics and logic demonstrates how ethnomathematics humanizes STEM, making abstract concepts tangible and emotionally resonant. Additionally,

				identifying functional survival practices as 'Science' effectively decolonizes the definition of STEM, proving the existence of indigenous scientific literacy.
Student 5	"The current curriculum is too Eurocentric. To truly engage students, we must shift the philosophical stance to value diverse sources of knowledge and admit that our way of knowing is just as valid."	"The goal is to bring ideas closer to life. Ethnomathematics demystifies complex concepts by rooting them in familiar activities like sailing or building, making the abstract accessible."	"Math is a cultural product used to control reality. Traditional navigation is not magic; it is the application of precise mathematical relations to survive and thrive in our environment."	The call for 'epistemological pluralism' critiques the curriculum's bias and demands a structural shift to recognize multiple valid ways of knowing. In this framework, demystification serves as a cognitive strategy to reduce the cognitive load of abstract concepts by anchoring them in prior cultural knowledge. Furthermore, framing traditional practices as tools for 'controlling reality' emphasizes the utilitarian and sophisticated nature of indigenous mathematics to counter the myth of primitivism.

To illustrate how these themes are interconnected within the students' arguments, Figures 1-5 visualize the structural progression of their critical understanding from philosophical critique to pedagogical application. Figure 1 Analysis: Rejecting Western hegemony (Theme 1) is a prerequisite for validating farming algorithms (Theme 3) as equivalent science. Figure 2 Analysis: Psychological focus. Critiquing singular mathematics (Theme 1) transforms math from 'alien' to 'friend' (Theme 2). Figure 3 Analysis: Math as a social mirror (Theme 1) builds identity pride (Theme 2), evidenced by weaving logic (Theme 3). Figure 4 Analysis: Correcting history (Theme 1) shifts math from abstract to tangible/beautiful (Theme 2) and scientific (Theme 3). Figure 5 Analysis: Emphasizes the validity of local ways of knowing (Theme 1) to demystify math (Theme 2) into a survival tool (Theme 3).

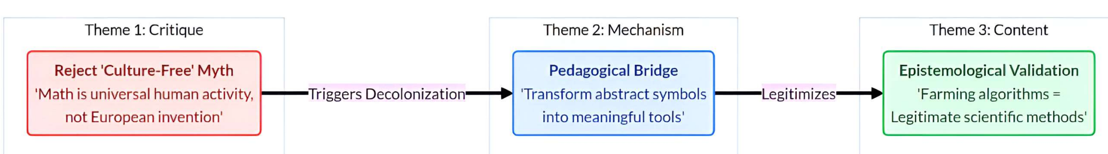

Figure 1. Student 1: decolonization perspective

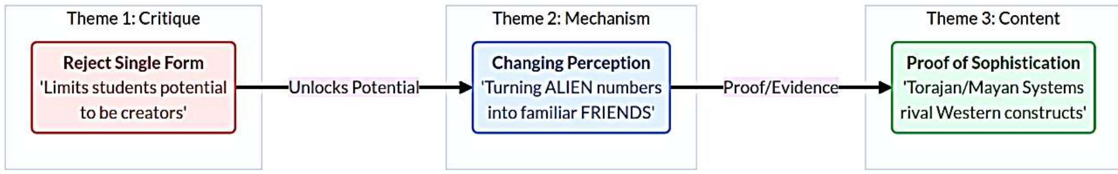

Figure 2. Student 2: epistemic ownership

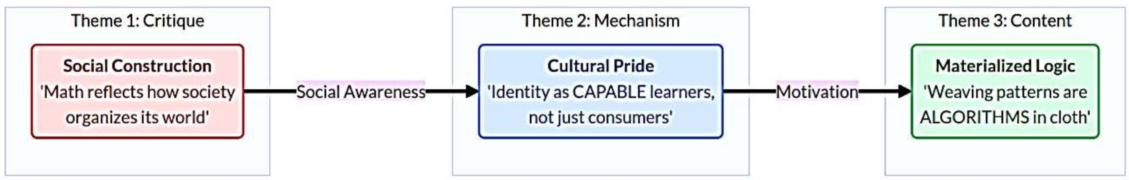

Figure 3. Student 3: social identity

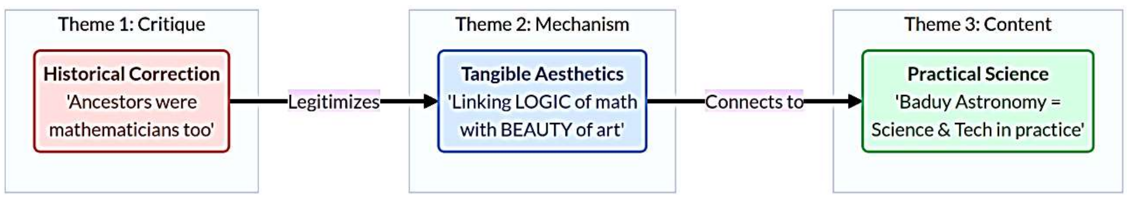

Figure 4. Student 4: historical narrative

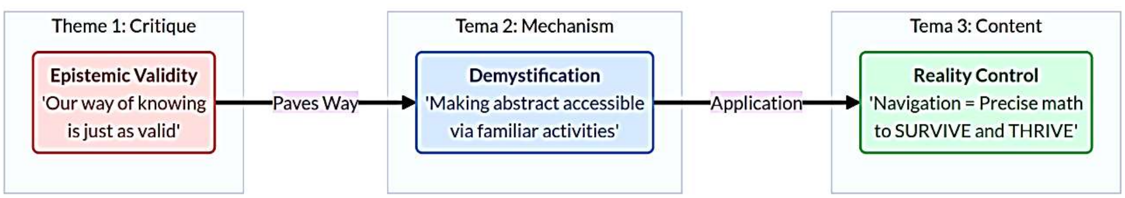

Figure 5. Student 5: demystification & utility

Theme 1: The Critical Foundation of Ethnopedagogy: Rejecting Universalism in Science and Mathematics

The criticality of students' thinking is rooted in a fundamental critique of the assumption of universalism that often undergirds traditional STEM education. The five students repeatedly conveyed that the storyline frames mathematics as a "universal, neutral, and culture-free science" (Student 1, Student 3, Student 5), but this framing is neither complete nor neutral. Student 5 identified this view as "too Eurocentric," while Student 4 directly criticised the narrow historical narrative that "mathematics is often considered to originate only from European civilisation." This rejection serves as an essential philosophical foundation: if mathematics (and its implications, science) is not universal, then space is opened for alternative pedagogical approaches that recognise diverse knowledge systems, namely ethnopedagogy. Student 2 affirmed this by stating that ethnomathematics "rejects the idea that mathematics has only one form and belongs only to the West." **As** Student 1 forcefully articulated, "It is a misconception to view mathematics as a culture-free zone... recognizing this is the first step to decolonizing our curriculum." By deconstructing this myth, the five students built a justification for why ethnopedagogy is an important and valid approach.

A comparative nuance is evident here: while Student 5 critiques Eurocentrism primarily as a historical oversight regarding the origins of mathematics, Student 1 advances a more complex argument, framing it as an active epistemological exclusion. By explicitly linking ethnomathematics to 'decolonization,' Student 1 demonstrates a higher level of critical sophistication, moving beyond a plea for inclusion to a demand for the restructuring of power dynamics in knowledge validation.

Furthermore, in-depth interviews revealed that this critical perspective was not solely derived from the course material but was significantly amplified by students' lived experiences of cultural marginalization during their secondary education, indicating that their critical consciousness is personally situated. This finding clarifies that the critical architecture of their understanding is constructed through a dual process: the academic deconstruction of universalism provided by the course, and the personal reconstruction of their cultural identity, suggesting that meaningful engagement with ethnomathematics is inherently autobiographical.

Theme 2: The Pedagogical Mechanism: Ethnomathematics as a Bridge for STEM Contextualization

After establishing a philosophical foundation, the students identified ethnomathematics as a concrete pedagogical mechanism for applying ethnopedagogy in STEM learning. They understand that the main challenge in STEM education is students' alienation from abstract material. Student 2 stated that in conventional education, students often "feel mathematics is 'foreign' and irrelevant to life." In their understanding, ethnomathematics serves as a "bridge" or "link" (Student 2) that overcomes this problem. The goal is to "bring mathematical concepts closer to everyday life" (Student 5). Student 2 elaborated on this mechanism, noting that "Ethnomathematics builds a bridge between the concepts in textbooks and the reality of their daily lives, turning 'alien' numbers into familiar cultural friends." When we relate mathematical ideas to cultural situations that students can identify with- "teaching areas and patterns using *batik* patterns" (Student 4), for example, learning STEM becomes "more relevant and meaningful" (Student 1). It is a cognitive development, but it also aims to "develop a sense of identity and cultural pride" (Student 3), which can lead to increased long-term interest and engagement in STEM disciplines.

Theme 3: The Source of STEM Content: Validating Local Wisdom as Scientific Knowledge

With a view to practical understanding, they situate ethnomathematics as a means to recognize popular knowledge as a valid content of the STEM disciplines. They now understand culture not just as a context for science, but also as a source of scientific knowledge. The case of Student 4 is the most obvious, because they "declare that local knowledge is also scientific" when referring to the *Baduy* community's practice of using astronomical knowledge (Science) to decide when to plant (Technology/ Engineering). Student 4 explicitly argued, "Local knowledge is scientific... The *Baduy* use astronomy for agriculture, which is Science and Technology in practice, recognized and valid." Student 5 supports this by acknowledging mathematics as a "cultural product" used to "manage reality." Another example, such as Toraja architecture and the Mayan number system (Student 2), as well as weaving patterns (Student 3), is recognised as a manifestation of complex mathematical and engineering principles. By validating these practices, ethnomathematics is seen as a "decolonising" movement (Student 1) that "recognises the value of local wisdom" (Student 3), thus providing authentic raw materials for project-based or problem-based STEM learning.

It is pertinent to distinguish the nature of these examples. At the same time, Toraja architecture is a canonical instance often cited in ethnomathematics literature focusing on geometry, and the exploration of the *Baduy* agricultural calendar represents a distinct, original inquiry into less conventional indigenous scientific practices. This shift from tangible geometric objects to intangible astronomical systems illustrates a deeper capability to identify complex STEM concepts embedded within cultural behaviors. When pressed for specific instructional strategies during interviews, participants demonstrated the capacity to transcend superficial integration; for instance, one student detailed how the curved structure of the Toraja roof could be transformed from a mere visual context into a rigorous engineering challenge requiring students to calculate vector loads and static equilibrium. They explicitly distinguished this approach from using culture as a mere 'sweetener' or ice-breaker, advocating instead a deep integration in which the cultural object serves as the central epistemological anchor for the entire STEM inquiry process.

Discussion

These findings indicate that mathematics education students have developed a layered and critical understanding of how ethnomathematics functions as an ethnopedagogical pillar within the STEM context. They can move beyond the definition of ethnomathematics as "mathematics in culture" and articulate it as a framework with philosophical underpinnings, pedagogical mechanisms, and content sources relevant to modern STEM education.

The hierarchical progression observed in this study, from rejecting universalism (Theme 1), to establishing pedagogical bridges (Theme 2), and finally to validating specific content (Theme 3), suggests that critical understanding in this domain operates as a developmental trajectory rather than a static collection of beliefs. This structural ordering implies a theoretical model in which the philosophical deconstruction of epistemological hegemony is a necessary prerequisite for authentic pedagogical innovation; without the initial rejection of universalism, the integration of cultural content risks becoming mere tokenism rather than rigorous scientific validation. Consequently, this finding offers a new theoretical perspective for teacher education: the development of critical ethnopedagogical competence follows a specific 'epistemic-pedagogical-content' sequence, requiring teacher training programs to prioritize disrupting philosophical beliefs before introducing instructional strategies or curriculum design techniques.

This distinct structural trajectory offers a significant refinement to established frameworks such as Shulman's Pedagogical Content Knowledge (PCK) and the TPACK model, which typically conceptualize teacher knowledge domains as intersecting components that develop concurrently. In contrast, our findings argue for the 'foundational primacy' of the philosophical domain in culturally responsive STEM; specifically, critical epistemological awareness serves as the gatekeeper to the effective acquisition of pedagogical content knowledge. Furthermore, this structure aligns with and extends Mezirow's theory of transformative learning into the realm of mathematics teacher education, demonstrating that the 'perspective transformation' regarding the nature of mathematics (Theme 1) is the critical antecedent required to unlock the 'behavioral integration' of culture in teaching practice (Themes 2 and 3).

Furthermore, the analysis highlights a sophisticated cognitive negotiation regarding the potential contradiction between rejecting universalism and integrating ethnomathematics into the historically universalist STEM canon. Students do not perceive this as an impasse; instead, they offer a mechanism of 'epistemological broadening' to reconcile the two.

By redefining STEM not as a closed Western enterprise but as a global heritage of problem-solving, they effectively create a 'third space' where local and academic knowledge systems can coexist and interact without hierarchy, thereby resolving the tension through synthesis rather than displacement.

Alignment of Student Understanding with Modern STEM Education Frameworks

The students' understanding is very much in line with the principles of contemporary STEM education, which emphasises interdisciplinary, contextual, and problem-based learning (Olatunbosun Bartholomew Joseph & Nwankwo Charles Uzondu, 2024). When students argued that local wisdom is a source of scientific knowledge (Theme 3), they intuitively connected ethnomathematics with place-based STEM education, where the local environment and culture serve as learning laboratories (Nakashi Kawa Miuka & Jamila Tufu, 2025; Marzuki et al., 2024). Examples such as traditional architecture or local farming systems represent authentic technical and scientific problems that can be solved using mathematical modelling.

However, a critical interrogation of this alignment reveals a profound tension between the students' valorization of local wisdom and the structural realities of the national education system. The validation of indigenous knowledge as legitimate scientific content (Theme 3) fundamentally challenges the hegemony of the standardized STEM curriculum, which prioritizes universalist, abstract scientific principles over localized epistemologies. This creates a significant implementation risk where the 'local science' advocated by students may be marginalized as mere folklore or non-examinable enrichment within a high-stakes testing regime that values global standardization over cultural contextualization.

Additionally, students' emphasis on the role of ethnomathematics in overcoming student alienation (Theme 2) is consistent with the literature on the importance of identity and belonging in increasing participation in STEM fields, particularly for students from underrepresented groups (Shih, 2024; Bursal & Ages, 2025). By treating culture as an asset in learning, ethnopedagogy supported by ethnomathematics can create a more inclusive and motivating STEM learning environment.

Critical Implications: Bridging Critical Understanding with STEM Pedagogical Practice

Although students' critical understanding is already strong, the real challenge lies in applying this understanding to the practical design of effective STEM learning. The literature consistently shows a "perception-practice gap," in which prospective teachers' positive attitudes and theoretical understanding do not always align with their ability to develop high-quality, culturally relevant learning materials (Utami, 2025; Norlizam et al., 2024).

In the STEM context, this gap could be compounded. Pre-service teachers might develop a critical awareness that traditional home construction incorporates STEM ideas (Theme 3). However, they find it challenging to develop a learning progression that systematically guides students in deriving mathematical (e.g., the golden ratio, the Pythagorean theorem), physical (e.g., force and structural analysis), and engineering (e.g., earthquake-resistant design) principles from this cultural tradition. Often, cultural integration is shallow, with cultural contexts used as 'lead-ins' and not meaningfully connected to particular STEM learning outcomes (Utami, 2025; Akintoye et al., 2023).

This gap is exacerbated by structural challenges, including a dense curriculum, a lack of teaching resources, and inadequate training in culturally responsive instructional design (Kyeremeh et al., 2024; Kyeremeh et al., 2025). Moreover, interview data revealed a pragmatic layer to this gap: participants candidly articulated fears that the dense national curriculum would leave little room for time-intensive cultural inquiries, framing the implementation challenge not just as a lack of skill but as a systemic conflict between culturally responsive pedagogy and standardized accountability. In anticipation of real classroom dynamics, they argued that without explicit policy support to allocate time for such explorations, teachers would be forced to revert to conventional methods to meet the dense curricular targets.

This observation is not merely a theoretical inference but was empirically substantiated by the video critique data. When analyzing the instructional video, all five participants successfully identified the 'cultural vacuum' in the lesson (aligning with Theme 1), yet when asked to propose alternatives, their suggestions predominantly focused on aesthetic modifications such as changing the visual setting to a traditional house rather than restructuring the core mathematical problem to leverage the structural properties of that architecture. This discrepancy provides concrete evidence that, while their evaluative critical eye is sharp, their generative pedagogical design skills remain nascent, confirming a functional gap between perception and practice.

Therefore, the findings of this study underscore the urgent need for teacher education programs to move beyond simply fostering critical awareness. These programs must explicitly equip prospective teachers with STEM pedagogical design competencies. Consequently, teacher education must pivot from general 'awareness-raising' to a 'pedagogical reconstruction' approach. Specifically, curricula should introduce 'cultural translation labs' where students practice the granular mechanics of decoding cultural artifacts into variable-based mathematical problems, ensuring the culture is the *source* of the variables, not just the background scenery. Furthermore, the findings necessitate the implementation of 'dual-coding' assessments in teacher training, where prospective teachers are evaluated not only on their philosophical essays but equally on their ability to re-engineer standard textbook problems into culturally situated STEM inquiries that maintain mathematical rigor. Without this bridge between critical understanding and practical skills, the potential of ethnomathematics as a pillar of ethnopedagogy in STEM risks not being fully realised in the classroom.

CONCLUSION

This study concludes that prospective mathematics teachers have developed a structured critical understanding of ethnomathematics, visualizing it not as a supplemental 'add-on' but as a fundamental pillar of ethnopedagogy within the STEM context. Specifically, the findings reveal a hierarchical cognitive trajectory where students first deconstruct the myth of universalism in science, then establish ethnomathematics as a pedagogical bridge to overcome student alienation, and finally validate indigenous wisdom as an authentic source of rigorous scientific content. This structural insight is profoundly important for the field of education as it demonstrates that prospective teachers are capable of constructing a sophisticated 'critical architecture' that challenges the epistemological hegemony of Western-centric curricula, a prerequisite for fostering truly inclusive and culturally responsive learning environments.

Ultimately, the defining contribution of this research is the empirical delineation of this 'critical architecture,' which establishes that the effective implementation of ethnopedagogy in STEM is strictly contingent upon a foundational philosophical shift. Without first dismantling the epistemic hierarchy that privileges Western science, any pedagogical attempt at cultural integration remains superficial.

The educational implications of this study underscore an urgent need to reorient teacher preparation programs from theoretical exposure to practical competency. Curriculum designers must introduce specific 'cultural translation laboratories' where pre-service teachers can practice the granular mechanics of converting cultural artifacts into variable-based mathematical problems, ensuring that culture serves as the epistemological core rather than a superficial background. However, these conclusions must be interpreted within the constraints of specific methodological limitations. Reliance on a small, purposively selected sample of five high-achieving students limits the generalizability of the findings to a broader, more diverse population of teacher candidates. Furthermore, while the use of written arguments, interviews, and lesson designs provided insight into students' cognitive structures, the lack of longitudinal classroom observations means that the study captures declared competence rather than enacted performance in real-world teaching scenarios. To rigorously address this gap, future research should adopt a longitudinal design that follows pre-service teachers into their first years of teaching to observe the enactment of ethnomathematics in real classrooms directly. Furthermore, intervention studies are needed to test specific teacher training modules such as the proposed cultural translation labs to quantify their impact on bridging the gap between critical perception and pedagogical practice.

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