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Ethnomathematics-Based Deep Learning Model in Enhancing Numeracy Literacy and Integrity Character among Prospective Elementary School Teacher Education Students

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Abstract
Preparing prospective elementary teachers requires mathematics learning that develops conceptual understanding alongside numeracy literacy and professional integrity. Although ethnomathematics and deep learning have been widely investigated independently, limited empirical evidence explains the pedagogical mechanisms through which culturally grounded learning integrates these dimensions within mathematics teacher education. This study explored how ethnomathematics-based deep learning functioned as a culturally situated pedagogical process in an Elementary School Teacher Education Program. A qualitative interpretive single-case study was conducted in one Elementary Mathematics Education course at Universitas Mandiri Subang, Indonesia. Fourteen participants, comprising one lecturer, twelve prospective elementary teachers, and one head of programme, were selected through purposive sampling. Data were collected through classroom observations, semi-structured interviews, and document analysis and analysed using an interactive hybrid deductive–inductive coding approach. The findings revealed an interconnected pedagogical mechanism in which cultural contextualisation initiated mathematical meaning construction through reflection, inquiry, mathematical representation, and collaborative dialogue. Within this process, cultural experiences served as epistemic resources for interpreting quantitative relationships before formal mathematical abstraction. Simultaneously, numeracy literacy and professional integrity developed through contextual reasoning, evidence-based justification, critical evaluation, and collaborative learning. The study contributes an empirically grounded explanation of the pedagogical mechanism linking cultural contextualisation, mathematical meaning construction, numeracy literacy, and professional integrity, extending current understandings of ethnomathematics-based deep learning in mathematics teacher education.
Keywords: ethnomathematics; mathematical meaning construction; numeracy literacy; professional integrity

INTRODUCTION

Teacher education is undergoing profound transformation in response to rapid technological advancement, evolving educational priorities, and increasingly complex expectations regarding teachers' professional competence and ethical responsibility. Contemporary teacher education is expected not only to develop disciplinary expertise but also to cultivate critical thinking, reflective practice, adaptability, and professional judgement. These expectations are particularly relevant to Elementary School Teacher Education Programs (PGSD), where prospective teachers are prepared not only to facilitate children's learning but also to model responsible and ethical professional practice. Consequently, effective teacher preparation requires learning experiences that integrate academic competence with reflective and professional development rather than treating them as separate educational objectives.

Within this context, numeracy literacy and professional integrity have become essential dimensions of prospective teachers' preparation. Numeracy literacy extends beyond computational proficiency to encompass the ability to interpret quantitative information, reason mathematically, evaluate evidence, and make informed decisions across diverse contexts (Gal et al., 2020). Professional integrity similarly involves honesty, accountability, responsibility, and ethical judgement that shape how future teachers make instructional decisions and fulfil their professional responsibilities. Nevertheless, mathematics instruction in many teacher education programmes continues to privilege cognitive achievement while giving comparatively limited attention to the development of these broader professional capabilities. As a result, mathematics learning remains an underutilised context for fostering reflective reasoning, evidence-based judgement, and responsible professional practice alongside mathematical competence.

This limitation is reflected in the dominant instructional approaches reported in mathematics teacher education. Previous studies have shown that learning frequently relies on procedural instruction, routine exercises, and assessment-oriented practices (Sari et al., 2024). Although such approaches may strengthen procedural fluency, they provide relatively few opportunities for prospective teachers to explain mathematical ideas, justify their reasoning, evaluate alternative solutions, or connect mathematical concepts with authentic situations. Similarly, Wijaya et al. (2021) argued that procedure-oriented instruction constrains learners' capacity to apply mathematical knowledge in unfamiliar contexts because classroom activities often prioritise obtaining correct answers rather than developing conceptual understanding. Consequently, mathematics learning in teacher education has largely been examined in terms of achievement and conceptual mastery, while its potential contribution to developing reflective judgement, professional competence, and ethical responsibility remains comparatively underexplored.

One pedagogical perspective that offers opportunities to address these limitations is deep learning. In this study, deep learning is understood as a learning orientation that emphasises conceptual understanding, reflective inquiry, meaningful knowledge construction, and the application of knowledge in authentic contexts. Unlike surface learning, which primarily focuses on memorisation and procedural completion, deep learning encourages learners to establish conceptual relationships, critically examine ideas, and transfer knowledge across different situations. Within mathematics education, this perspective positions learning as a process of reasoning and meaning construction rather than the execution of procedures alone (Fauzan et al., 2024). Although deep learning has been increasingly recognised for promoting higher-order thinking, existing discussions have largely emphasised cognitive outcomes, providing comparatively limited explanation of how cultural contexts shape conceptual development during mathematical learning.

A complementary perspective is provided by ethnomathematics, which conceptualises mathematics as knowledge embedded in community practices, cultural traditions, and everyday experiences (Prahmana & D'Ambrosio, 2020; Rosa & Orey, 2023). Rather than serving merely as contextual illustrations, cultural practices provide meaningful resources through which learners interpret, represent, and negotiate mathematical ideas. Recent scholarship has further demonstrated that ethnomathematics strengthens cultural identity, promotes mathematical creativity, and supports the integration of local knowledge into contemporary mathematics education (Alsina & De Freitas, 2025; Batiibwe, 2025). Empirical studies likewise indicate that culturally contextualised mathematics learning enhances conceptual understanding, student engagement, and appreciation of local knowledge (Kamid et al., 2021; Risdiyanti & Prahmana, 2021; Juniarti et al., 2022). Collectively, these perspectives suggest that culturally grounded learning environments provide productive conditions for developing both mathematical understanding and broader professional capabilities. Nevertheless, most empirical evidence has been generated in elementary and secondary school settings, leaving mathematics teacher education comparatively underexplored despite its central role in preparing future teachers to design culturally responsive instruction.

Despite these advances, important questions remain unanswered. Research on ethnomathematics has predominantly examined learning outcomes, including conceptual understanding and student engagement, while offering limited explanation of the pedagogical mechanisms through which culturally situated experiences become mathematical understanding. Likewise, studies on deep learning have highlighted conceptual understanding, reflection, and meaningful knowledge construction (Fauzan et al., 2024), yet have paid comparatively little attention to the contribution of cultural contexts in shaping these processes. Consequently, existing literature provides only limited explanation of how cultural contextualisation, inquiry, reflection, mathematical representation, numeracy literacy, and professional integrity interact as interconnected dimensions of learning within mathematics teacher education (Alsina & De Freitas, 2025; Batiibwe, 2025).

This limitation is particularly significant in teacher education because prospective teachers simultaneously develop mathematical understanding and pedagogical competence. Their experiences as learners influence how they later interpret mathematical concepts, select culturally meaningful learning contexts, and design mathematics instruction for elementary classrooms. Furthermore, although numeracy literacy has been widely recognised as a fundamental outcome of mathematics education (Gal et al., 2020), relatively little evidence explains how it develops through culturally responsive mathematical inquiry. Similarly, integrity has generally been examined within broader character education frameworks rather than as a professional disposition emerging through disciplinary learning. A more comprehensive understanding is therefore needed to explain how ethnomathematics-based deep learning supports the integrated development of mathematical understanding, numeracy literacy, and professional integrity among prospective teachers (Alsina & De Freitas, 2025; Batiibwe, 2025).

Although previous studies have generated valuable insights into ethnomathematics and deep learning, important questions remain regarding how these perspectives operate within mathematics teacher education. Research on ethnomathematics has largely examined learning outcomes, including conceptual understanding, engagement, and appreciation of local culture, while providing limited explanation of the pedagogical processes through which cultural experiences become mathematical understanding. Similarly, studies on deep learning have emphasised conceptual knowledge construction, reflection, and inquiry (Fauzan et al., 2024), yet have given comparatively less attention to how these processes unfold when learning is grounded in culturally meaningful experiences. As a result, the interaction between ethnomathematics and deep learning remains insufficiently explained as a coherent pedagogical process within teacher education (Alsina & De Freitas, 2025; Batiibwe, 2025).

This gap is particularly significant because prospective teachers occupy a dual position as learners of mathematics and future designers of mathematics instruction. Their experiences in teacher education shape not only how they understand mathematical concepts but also how they later interpret students' cultural backgrounds and organise culturally responsive learning. Despite the recognised importance of numeracy literacy as a key outcome of mathematics education (Gal et al., 2020), relatively little research has examined how it develops through culturally situated processes of interpretation, reflection, inquiry, and mathematical reasoning. Likewise, integrity has generally been conceptualised as a broad educational or ethical value rather than as a professional disposition emerging through disciplinary learning. Consequently, there remains limited understanding of how culturally responsive mathematical learning simultaneously supports conceptual understanding, numeracy literacy, and professional integrity during teacher preparation (Alsina & De Freitas, 2025; Batiibwe, 2025).

Preliminary observations conducted in February 2026 during an Elementary Mathematics Education course at Universitas Mandiri Subang further highlighted the relevance of these issues. The observations, consisting of non-participant classroom observations and informal conversations with the course lecturer and several prospective elementary teachers, were conducted before the present study and served solely to identify the contextual background of the research. They indicated that many prospective teachers relied primarily on procedural solutions, experienced difficulty explaining mathematical reasoning conceptually, and rarely connected mathematical ideas with meaningful everyday situations. Opportunities for reflective discussion and contextual interpretation were also limited. These observations did not constitute research findings but provided the contextual rationale for examining how culturally situated mathematics learning is enacted and experienced within teacher education.

Against this background, the present study investigates ethnomathematics-based deep learning as a culturally situated pedagogical process within an Elementary School Teacher Education Program. Rather than evaluating instructional effectiveness through predetermined learning outcomes, the study explores how cultural contexts are incorporated into mathematics learning, how prospective teachers construct mathematical understanding through culturally meaningful experiences, how reflection and inquiry develop during classroom activities, and how participants interpret the relationships among these experiences, numeracy literacy, and professional integrity. By focusing on pedagogical processes rather than outcome measures alone, this study contributes an empirically grounded explanation of how cultural contexts function as epistemic resources that support mathematical meaning construction while simultaneously fostering numeracy literacy and professional responsibility in prospective elementary teachers.

METHODS

Research Design and Context

This study employed a qualitative interpretive single-case study to investigate the pedagogical processes through which an ethnomathematics-based deep learning model supported the development of mathematical understanding, numeracy literacy, and professional integrity among prospective elementary teachers. A qualitative design was appropriate because the study sought to understand how participants interpreted culturally grounded learning experiences, constructed mathematical meaning, and reflected on their professional development within an authentic educational setting rather than to evaluate the effectiveness of an instructional intervention.

The study was informed by Stake's (1995) interpretive conception of case study, which emphasises understanding participants' perspectives within their natural context, and by Yin's (2014) approach to defining explicit case boundaries and integrating multiple sources of evidence. These complementary perspectives enabled an in-depth examination of how learning processes unfolded within a bounded educational environment while preserving the complexity of the social and cultural context in which they occurred.

The case comprised one Elementary Mathematics Education course offered in the Primary School Teacher Education (PGSD) Program at Universitas Mandiri Subang, West Java, Indonesia. The course was selected purposively because it systematically integrated ethnomathematics into mathematics instruction through cultural exploration, collaborative inquiry, contextual problem-solving, reflective dialogue, and conceptually oriented learning activities. Rather than functioning as supplementary examples, local cultural practices constituted the primary context through which mathematical ideas were explored, discussed, and interpreted.

The study was conducted during the second semester of the 2025/2026 academic year (February–May 2026). Case boundaries were defined by the institutional setting, one Elementary Mathematics Education course, participants directly involved in the learning process, and all instructional activities implemented throughout one academic semester. Establishing these boundaries enabled an intensive examination of the pedagogical mechanisms embedded within the course while maintaining the contextual integrity of the phenomenon under investigation (Stake, 1995; Yin, 2014).

Table 1. Research Design Summary

Component	Description
Research design	Qualitative interpretive single-case study
Purpose	To explore the pedagogical mechanisms through which ethnomathematics-based deep learning supports mathematical understanding, numeracy literacy, and professional integrity
Research setting	Primary School Teacher Education (PGSD), Universitas Mandiri Subang, Indonesia
Case boundary	One Elementary Mathematics Education course conducted over one academic semester
Participants	One lecturer, twelve fourth-semester prospective elementary teachers, and one Head of the PGSD Program (N = 14)
Sampling strategy	Purposive sampling
Data collection	Classroom observations, semi-structured interviews, and document analysis
Data analysis	Interactive analysis using hybrid deductive–inductive coding (Miles, Huberman, & Saldaña, 2014)
Trustworthiness	Triangulation, member checking, peer debriefing, audit trail
Ethics	Written informed consent, confidentiality, voluntary participation

Participants and Data Sources

Participants were selected through purposive sampling because they possessed direct experience of the learning processes examined in this study and were able to provide detailed accounts of their educational experiences (Patton, 1999). Selection was guided by four criteria: (1) active participation in classroom learning throughout the semester; (2) involvement in ethnomathematics-based learning activities; (3) engagement in reflective learning tasks; and (4) willingness and ability to articulate learning experiences during interviews.

The study involved fourteen participants comprising one lecturer responsible for the Elementary Mathematics Education course, twelve fourth-semester prospective elementary teachers, and one Head of the PGSD Program. Each participant group contributed complementary perspectives to understanding the phenomenon. The lecturer provided insights into instructional planning, classroom implementation, and assessment practices. Student participants described their learning experiences, conceptual development, and reflective processes, while the Head of the Program contributed an institutional perspective regarding curriculum implementation, teacher preparation, and the integration of ethnomathematics within the programme.

The twelve student participants were selected from a cohort of twenty-six students who completed the course during the study period. As fourth-semester prospective elementary teachers, they had successfully completed prerequisite mathematics education courses, providing sufficient disciplinary knowledge to engage in conceptual discussion, contextual problem-solving, and reflective inquiry. Participant selection also considered variation in classroom participation and learning experiences to capture a broad range of perspectives relevant to the research questions.

Table 2. Participant Characteristics

Participant Group	Number	Characteristics	Contribution to the Study
Lecturer	1	Responsible for planning, facilitating, and assessing the Elementary Mathematics Education course	Instructional design, pedagogical implementation, and assessment practices
Prospective elementary teachers	12	Fourth-semester PGSD students enrolled in the course	Learning experiences, mathematical meaning construction, numeracy literacy, and professional integrity
Head of the PGSD Program	1	Responsible for curriculum implementation and academic management	Institutional policy, curriculum implementation, and teacher education perspectives

The student participants represented both male and female prospective teachers and shared comparable academic backgrounds as fourth-semester students enrolled in the same programme. Their common educational preparation ensured that all participants possessed the foundational mathematical knowledge required to engage meaningfully in the learning activities, while differences in classroom participation and individual learning experiences enriched the diversity of perspectives examined in this study.

Participant selection prioritised information richness rather than statistical representation. Data collection and analysis proceeded concurrently, allowing emerging interpretations to inform subsequent data collection. Saturation was assessed through continuous comparison of observations, interview transcripts, and documentary evidence with the developing analytical categories. Data collection concluded when additional evidence consistently reinforced existing categories without generating conceptually meaningful new insights, indicating that sufficient depth had been achieved to explain the pedagogical processes under investigation (Merriam, 1998).

Finally, three complementary sources of evidence were employed to strengthen the depth and credibility of the case analysis. Classroom observations documented instructional practices and participant interactions as they occurred. Semi-structured interviews captured participants' interpretations and reflections on their learning experiences, while documentary evidence including lesson plans, instructional materials, student worksheets, reflective journals, ethnomathematics-based projects, and assessment records provided additional evidence of instructional design, learning processes, and students' developing mathematical reasoning. The integration of these data sources enabled comprehensive triangulation and supported a richer understanding of the case.

Data Collection

Data were collected through classroom observations, semi-structured interviews, and document analysis. These complementary sources of evidence enabled the investigation of instructional practices, participants' experiences, and institutional perspectives from multiple viewpoints while strengthening the credibility of the findings through methodological triangulation (Yin, 2014). Data collection was conducted throughout the second semester of the 2025/2026 academic year and proceeded alongside preliminary analysis so that emerging interpretations could inform subsequent data collection.

Classroom Observations

Classroom observations were undertaken across eight instructional sessions between February and May 2026. Each session lasted approximately 100 minutes (2 × 50 minutes), following the official course schedule. Observations focused on how ethnomathematics was enacted during classroom instruction and how learning activities supported the development of mathematical understanding, numeracy literacy, and professional integrity.

An observation protocol was developed from the study's conceptual framework to ensure consistency across observation sessions while allowing sufficient flexibility to capture naturally occurring classroom interactions. The protocol organised observations around four analytical dimensions: (1) ethnomathematical practices, referring to the use of local cultural knowledge and community practices as contexts for mathematical learning; (2) deep learning processes, including conceptual exploration, reflective inquiry, knowledge integration, and transfer of learning; (3) numeracy literacy, encompassing quantitative interpretation, contextual reasoning, and mathematical problem-solving; and (4) professional integrity, reflected in responsibility, academic honesty, independence, collaboration, and consistency during learning activities.

Field notes were recorded throughout each observation to document instructional strategies, classroom interactions, student participation, and contextual conditions that contributed to the interpretation of the learning process. Observational records also captured unexpected events and emerging patterns that informed subsequent interviews and analytical decisions.

Semi-Structured Interviews

Semi-structured interviews were conducted after participants had completed the learning activities to obtain in-depth accounts of their experiences and interpretations. Interviews involved one lecturer, twelve prospective elementary teachers, and one Head of the PGSD Program. Each interview lasted between 30 and 45 minutes and was audio-recorded with participants' consent before being transcribed verbatim for analysis.

The interview guide was developed from the same conceptual framework that informed the observation protocol, ensuring conceptual alignment across data sources while maintaining flexibility to explore issues emerging during the interviews. Questions were organised around four broad areas: participants' experiences of learning mathematics through local cultural contexts, the development of mathematical understanding, reflective learning processes, and perceptions of numeracy literacy and professional integrity.

Although a common interview structure was used, questions were adapted according to participants' roles. The lecturer was asked about instructional planning, pedagogical strategies, classroom facilitation, and assessment practices. Student interviews explored how participants interpreted cultural experiences, constructed mathematical meaning, and reflected on their learning throughout the course. The interview with the Head of the PGSD Program focused on curriculum implementation, institutional support, and the contribution of ethnomathematics to the preparation of future elementary teachers.

Representative questions included: "How did learning mathematics through local cultural contexts influence your understanding of mathematical concepts?", "Which learning experiences encouraged you to reconsider or refine your mathematical reasoning?", and "How did these learning activities influence your sense of responsibility and academic integrity?" These examples illustrate the scope of the interview guide rather than its complete content.

Document Analysis

Document analysis complemented observational and interview data by providing evidence of both instructional planning and participants' learning processes. Documents examined included the Semester Learning Plan (Rencana Pembelajaran Semester), teaching materials, student worksheets, ethnomathematics-based projects, reflective journals, and assessment records produced during the course.

The analysis focused on the alignment between instructional planning and classroom implementation, as well as evidence of conceptual development reflected in students' written work. Particular attention was given to how mathematical reasoning, reflective inquiry, numeracy literacy, and professional integrity were represented across learning tasks and assessment artefacts.

Documentary evidence was analysed alongside observations and interviews throughout the study. Comparing these sources enabled the verification of emerging interpretations, clarified inconsistencies, and strengthened the overall credibility of the findings by ensuring that conclusions were supported by multiple forms of empirical evidence.

Table 3. Data Sources and Analytical Purposes

Data Source	Evidence	Analytical Purpose
Classroom observations	Eight classroom sessions and field notes	Examine instructional practices, classroom interactions, and implementation of ethnomathematics-based deep learning
Semi-structured interviews	One lecturer, twelve prospective teachers, and one Head of Program	Explore participants' experiences, interpretations, and reflections
Documents	Semester Learning Plan, teaching materials, worksheets, projects, reflective journals, assessment records	Compare instructional planning with classroom implementation and identify evidence of conceptual development

Data Analysis

Data were analysed using the interactive model developed by Miles, Huberman, and Saldaña (2014), comprising data condensation, data display, and conclusion drawing and verification. Rather than treating these stages as a linear sequence, analysis was conducted iteratively throughout the study, allowing interpretations to develop alongside ongoing data collection and to be continuously refined through comparison across observations, interviews, and documentary evidence.

A hybrid deductive–inductive coding strategy guided the analytical process. Deductive coding was informed by the study's conceptual framework, which focused on ethnomathematical practices, deep learning processes, numeracy literacy, and professional integrity. Inductive coding complemented this framework by allowing unanticipated patterns, interactions, and meanings to emerge directly from participants' experiences and classroom practices. This combination ensured that the analysis remained theoretically informed while preserving sensitivity to the contextual characteristics of the case.

The analysis proceeded through four interconnected stages.

First, all interview transcripts, observation records, field notes, and documentary materials were read repeatedly to develop familiarity with the dataset. During this stage, attention was directed toward significant learning events, recurring interactions, participants' interpretations, and contextual features that contributed to understanding the implementation of ethnomathematics-based learning.

Second, meaningful units of data were assigned initial codes. Deductive codes reflected the four analytical dimensions underpinning the study, whereas inductive codes captured ideas that were not fully represented in the initial framework. Coding remained flexible throughout the analysis, enabling earlier interpretations to be refined as new evidence became available.

Third, related codes were systematically compared across data sources using a constant comparative approach. Similar codes were clustered into broader analytical categories, while differences among participants' perspectives and classroom events were examined to identify patterns, variations, and relationships. Categories were reviewed repeatedly until they formed coherent explanations of the pedagogical processes observed throughout the course.

Finally, categories were synthesised into overarching themes that explained how ethnomathematics-based deep learning supported the development of mathematical understanding, numeracy literacy, and professional integrity. Each theme was reviewed against the complete dataset to ensure that interpretations remained firmly grounded in empirical evidence and accurately represented participants' experiences. Emerging interpretations were continuously verified through comparison across observations, interviews, and documentary evidence, strengthening the credibility and coherence of the analytical findings.

Analytical decisions were documented throughout the study using analytical memos and coding records. Regular discussions with a qualitative researcher experienced in mathematics education were undertaken to examine coding decisions, challenge preliminary interpretations, and consider alternative explanations supported by the data. These discussions were intended to strengthen analytical rigour rather than to establish statistical intercoder agreement.

An audit trail was maintained throughout data collection and analysis. It included observation records, interview transcripts, coding logs, analytical memos, category revisions, thematic development, and methodological decisions. This documentation provided a transparent record of the analytical process, enabling the dependability and confirmability of the findings to be examined.

Table 4. Analytical Framework

Analytical Stage	Main Activities	Output
Data familiarisation	Reading observation notes, interview transcripts, and documents repeatedly	Initial understanding of the dataset
Initial coding	Hybrid deductive–inductive coding of meaningful data segments	Initial codes
Category development	Constant comparison across data sources and clustering of related codes	Analytical categories
Theme development	Synthesising categories into overarching themes and verifying interpretations across the complete dataset	Final themes explaining the pedagogical processes

Researcher Positionality

In qualitative research, the researcher serves as the primary instrument for data collection and interpretation. The researcher's academic background in mathematics education and elementary teacher education provided familiarity with ethnomathematics, numeracy literacy, and teacher professional learning, facilitating a contextually informed interpretation of the learning processes examined in this study.

Recognising that prior knowledge can also influence interpretation, reflexivity was maintained throughout the research process. Reflective memos were written following classroom observations, interviews, and analytical sessions to document emerging interpretations, methodological decisions, and potential assumptions. These records encouraged continuous critical reflection and supported the development of interpretations grounded in participants' accounts rather than the researcher's expectations.

Trustworthiness

The trustworthiness of the study was established following the criteria of credibility, transferability, dependability, and confirmability proposed by Lincoln and Guba (1985). Multiple complementary strategies were implemented throughout the research process to enhance the rigour and transparency of the findings.

Credibility was strengthened through methodological and source triangulation by comparing evidence obtained from classroom observations, semi-structured interviews, and documentary materials. Perspectives from the lecturer, prospective teachers, and the Head of the PGSD Program enabled the phenomenon to be interpreted from different viewpoints and contributed to a more comprehensive understanding of the learning processes.

Member checking was conducted after the preliminary themes had been developed. The lecturer and three student participants reviewed selected interpretations and provided feedback regarding the accuracy and completeness of the findings. Their comments were incorporated into the refinement of thematic descriptions while preserving the integrity of the original data.

Peer debriefing involved ongoing discussions with two researchers experienced in qualitative methodology and mathematics education. These discussions critically examined coding decisions, thematic development, and alternative interpretations supported by the empirical evidence, thereby strengthening the analytical rigour of the study.

Transferability was supported through detailed descriptions of the institutional context, participant characteristics, learning activities, and cultural setting, enabling readers to determine the applicability of the findings to comparable educational contexts.

Dependability and confirmability were supported through a comprehensive audit trail maintained throughout data collection and analysis. The audit trail documented research procedures, field notes, interview transcripts, coding records, analytical memos, category refinement, and interpretive decisions, providing a transparent account of how the findings were developed from the collected evidence.

Ethical Considerations

Ethical principles guided all stages of the research. Before data collection commenced, participants received written and verbal information describing the purpose of the study, research procedures, voluntary participation, confidentiality, and their right to withdraw at any stage without academic or professional consequences. Written informed consent was obtained from all participants prior to their involvement in the study.

To protect participants' privacy, personal identifiers were removed from all research materials, and role-based descriptions were used in reporting the findings. Audio recordings, interview transcripts, field notes, and documentary materials were stored securely and accessed only by the research team. All data were used exclusively for research purposes and managed in accordance with institutional requirements for ethical research involving human participants.

RESULTS AND DISCUSSION

Results

1. Enactment of Ethnomathematics-Based Deep Learning in Mathematics Learning

Analysis of classroom observations, interviews, and instructional documents showed that ethnomathematics-based deep learning was implemented through activities linking culturally situated experiences with formal mathematical representations. Learning began with familiar situations before progressing toward mathematical analysis. In a proportional reasoning activity, the lecturer introduced traditional market transactions through photographs of local markets and invited students to examine relationships among quantity, price, and expenditure. Students discussed buying and selling experiences before identifying mathematical relationships within the context.

An observation record stated, "Students initially described the market activities and compared their experiences before identifying relationships between quantity, unit price, and total cost." (Observation Note ON-01) During group discussions, students transformed contextual information into mathematical representations by constructing comparison tables, calculating unit prices, and examining relationships among quantities. This process was documented in the observation record: "After group discussion, students began arranging the transaction data into comparison tables and calculating unit prices before concluding that the relationship represented proportional reasoning." (Observation Note ON-03) The lecturer facilitated the discussion by asking students to explain their reasoning and examine alternative interpretations. One observation note recorded, "The lecturer asked students to explain the reasoning behind their conclusions before providing feedback." (Observation Note ON-05)

Evidence from instructional documents supported the observed learning sequence. The Semester Learning Plan (RPS), teaching materials, and student worksheets presented cultural situations before formal mathematical representations (Instructional Documents ID-01; ID-02). Initial worksheet responses mainly described contextual situations, whereas later responses included quantitative comparisons, proportional representations, and explanations of mathematical relationships (Student Worksheets WS-03; WS-07). Interview data reflected students' perceptions of these activities. One participant stated, "Because the examples came from places that we know, everyone had experiences to share. It was easier to discuss than when we only received numbers in textbooks." (Interview INT-S06) A reflective journal similarly noted, "I usually think of mathematics as formulas written on the board. During this lesson, I realised that situations I see in the traditional market could also become part of mathematics." (Reflective Journal RJ-04). Across the data sources, students were observed engaging with cultural contexts, quantitative analysis, mathematical representation, and explanation of solutions throughout the learning activities.

2. Learning Processes Emerging from Cultural Contextualisation, Reflection, and Inquiry

Cross-analysis of observations, interviews, reflective journals, and student artefacts identified three interconnected processes within the learning activities: cultural contextualisation, reflection, and inquiry. These processes appeared repeatedly across classroom interactions and student learning products.

Cultural Contextualisation as the Entry Point for Mathematical Reasoning

Cultural contextualisation appeared when students examined mathematical problems through situations related to their everyday experiences. During proportional reasoning activities, students compared traditional market practices from different regions and discussed how quantities and prices were determined. An observation record noted, "Students compared experiences from different traditional markets in their hometowns before discussing numerical relationships. Several students referred to buying experiences with their families." (Observation Note ON-02) Students used these experiences as references when analysing mathematical information. Instead of treating the market examples only as illustrations, they identified quantities, compared values, and discussed relationships among variables.

Interview data reflected similar experiences. One participant explained, "When the examples came from places that we know, everyone had experiences to share. It was easier to discuss than when we only received numbers in textbooks." (Interview INT-S06) Students' written reflections also described the relationship between familiar contexts and mathematical understanding: "Discussing examples from daily life helped me understand the situation before trying to solve the mathematical problem." (Reflective Journal RJ-07) Student worksheets showed a similar pattern. Initial responses mainly described buying and selling activities, while later responses organised information into tables, ratios, and mathematical explanations following classroom discussions (Student Worksheets WS-03; WS-07).

Reflection through Reconsideration and Mathematical Revision

Reflection was identified through students' reconsideration of initial interpretations, explanations, and mathematical representations during learning activities. Observation data showed that students frequently reviewed their responses after receiving questions from peers or the lecturer. One observation record documented: "Several students erased their first calculations after discussing proportional relationships with other group members and reconstructed their mathematical representations together." (Observation Note ON-04) During presentations, students compared different solution strategies and examined inconsistencies between explanations and numerical evidence, indicating that reflection emerged through discussion, comparison, and revision of mathematical work. Students described this process during interviews. One participant stated: "At the beginning I thought my answer was already correct. After listening to other groups, I realised that my explanation was incomplete, so I checked the calculations again before revising my work." (Interview INT-S04) Another participant explained: "Sometimes we arrived at different answers even though we used the same data. We discussed each step together until we understood why the results were different." (Interview INT-S09) Student worksheets and reflective journals documented similar revisions, showing that earlier responses mainly presented calculations, whereas later versions included modified representations, proportional tables, and additional explanations developed after classroom discussion (Reflective Journal RJ-05; Student Worksheets WS-04; WS-08).

Inquiry through Questioning and Verification

Inquiry was evident in students' efforts to examine mathematical relationships through questioning, comparison, and verification. Students did not simply accept initial solutions; they discussed whether mathematical relationships remained consistent under different conditions. During one activity, a group examined whether proportional relationships would remain unchanged when numerical conditions were modified. The observation record stated: "One group questioned whether the same pattern would remain if the price per kilogram changed. Students recalculated the values using different numerical examples before presenting their conclusion." (Observation Note ON-05) As discussions continued, students generated questions related to mathematical reasoning rather than only clarification of instructions. They compared alternative strategies and examined the consistency of their calculations. One participant explained: "We often had different answers at the beginning. Instead of deciding immediately, we recalculated the numbers together and compared several examples until we agreed on the solution." (Interview INT-S02) Another participant added: "The discussion made us check every calculation. We did not simply accept the first answer because other group members asked us to explain how we obtained it." (Interview INT-S07) Student worksheets contained evidence of this process through alternative calculations, annotations, and revised solution strategies rather than only final answers (Student Worksheets WS-05; WS-09). The evidence across sources indicates that students' engagement involved continuous movement between cultural situations, mathematical representations, dialogue, and revision. These processes provided the empirical basis for analysing numeracy literacy practices and integrity-related learning behaviours in the following sections.

3. Numeracy Literacy Practices in Culturally Situated Mathematics Learning

Analysis of classroom observations, interviews, student worksheets, reflective journals, and learning portfolios identified four related practices through which students engaged with mathematical information: interpreting quantitative information, constructing mathematical relationships, communicating reasoning, and applying mathematical ideas in contextual situations. These practices appeared across learning activities as students examined culturally situated problems, organised numerical information, discussed mathematical relationships, and presented their reasoning.

Interpreting Quantitative Information

At the beginning of the learning activities, students frequently approached contextual problems by searching for mathematical procedures before examining the meaning of numerical information. Classroom observations showed that some groups immediately attempted to identify formulas when analysing traditional market transactions. One observation record noted: "When students were asked to analyse price differences in traditional market transactions, several groups immediately searched for ratio formulas before discussing the characteristics of the transactions." (Observation Note ON-02) During subsequent discussions, students examined the role of each quantity within the situation by identifying unit prices, quantities, total expenditure, and relationships among these variables before selecting mathematical procedures. A later observation recorded: "Students listed the available quantitative information, organised transaction data into comparison tables, and discussed the meaning of each numerical value before performing proportional calculations." (Observation Note ON-05) Students described a similar process during interviews. One participant explained: "Previously I usually looked for the formula first. Now I try to understand the situation before deciding which mathematical concept should be used because the context tells us what the numbers actually represent." (Interview INT-S04) Written learning artefacts reflected this pattern, with early worksheets mainly containing direct calculations, whereas later worksheets included identification of relevant quantities, comparison tables, and explanations of relationships among variables (Student Worksheets WS-03; WS-07).

Constructing Mathematical Relationships

After identifying relevant quantitative information, students examined relationships among quantities through mathematical representations. Observation data showed that students used tables and comparisons to organise information before determining mathematical procedures. One observation record stated: "Before calculating the final answer, students reorganised transaction data into comparison tables showing quantity, unit price, and total expenditure. Group discussions focused on identifying whether the relationship remained constant across different purchasing quantities." (Observation Note ON-07) Students also modified their representations after comparing alternative solutions presented by other groups. Another observation noted: "After comparing the representations presented by another group, several students modified their own tables by adding unit-price calculations before reformulating the proportional relationship." (Observation Note ON-08) Interview responses indicated that students viewed representation as important for examining mathematical relationships. One participant explained:

"When the numbers were arranged in a table, it became easier to see that the relationship remained the same even though the quantities changed. Before doing that, I only looked at the total prices." (Interview INT-S08) Student worksheets showed similar evidence, with earlier responses mainly containing calculations, whereas later responses incorporated comparison tables, proportional expressions, and explanations connecting quantities and mathematical relationships (Worksheet WS-11).

Communicating Mathematical Reasoning

Students' mathematical reasoning was examined through classroom presentations, group discussions, and written explanations. Early presentations frequently focused on numerical answers without detailed descriptions of how conclusions were reached. An observation record documented: "During the initial presentations, several groups reported only the final calculations. When asked to explain how the proportional relationship had been identified, students returned to their worksheets to review the transaction data before responding." (Observation Note ON-10) Later presentations included explanations of contextual interpretation, data organisation, mathematical representation, and justification of conclusions. One observation recorded: "Each group explained the sequence of analysis before presenting the final answer. Students referred to comparison tables, unit-price calculations, and contextual evidence from the market transactions to justify their conclusions." (Observation Note ON-12) Students also described the importance of explanation during interviews. One participant stated: "Previously I only wrote the answer because I thought the calculation was enough. During this course I realised that I also needed to explain why I used that method and how the numbers were related." (Interview INT-S01) Student portfolios and worksheets contained similar evidence, with later submissions combining numerical solutions, mathematical representations, and written explanations of reasoning.

Applying Mathematics in Contextual Situations

During the final learning activities, students examined mathematical relationships in situations beyond the examples initially introduced in class. Several groups selected contexts from their own communities, including household purchasing, agricultural activities, and local trading practices. An observation record stated: "During the final learning activities, several groups referred to examples from their own communities when explaining proportional relationships. Students compared agricultural products, household purchases, and local trading practices before constructing mathematical representations." (Observation Note ON-15) Students explained that the learning activities encouraged them to examine mathematical relationships in everyday situations. One participant stated: "After these learning activities, I started paying attention to situations that I had never thought about before. When I visited the traditional market, I found myself comparing quantities and prices to see whether the relationships were proportional." (Interview INT-S10) Learning portfolios showed that students independently selected contextual examples and represented them through tables, calculations, and written explanations.

4. Integrity Practices in Collaborative and AI-Mediated Learning

Analysis of observations, interviews, reflective journals, assignments, and digital learning records identified three recurring integrity-related practices within the learning activities: transparent reasoning, verification of digital information, and accountability through revision and collaboration.

Transparent Mathematical Reasoning

Students' mathematical solutions increasingly included explanations of how conclusions were reached. Early assignments commonly presented numerical results with limited justification, whereas later submissions contained descriptions of data interpretation, calculation procedures, and supporting evidence. An observation record stated: "Several groups presented correct proportional calculations;

however, when asked to explain how the proportional relationship had been identified, some students returned to their worksheets before describing the sequence of analysis." (Observation Note ON-03) Later classroom activities showed more explicit explanation of mathematical procedures: "Before presenting the final solution, students explained how the transaction data had been organised, how unit prices had been compared, and how these comparisons supported the conclusion." (Observation Note ON-08) Students described this practice as an expectation to make their reasoning visible. One participant stated: "Previously I thought that obtaining the correct answer was sufficient. During these learning activities, we were expected to explain how each calculation was produced and why the evidence supported our conclusion." (Interview INT-S02) Assignment revisions showed greater attention to explaining procedures and linking conclusions with available evidence (Assignment Document AD-06).

Verification Practices in the Use of Generative Artificial Intelligence and Digital Resources

Students used digital resources, including generative artificial intelligence, during learning activities. Classroom observations indicated that digital information was examined through comparison with mathematical evidence rather than accepted directly. One observation record noted: "Several students consulted generative AI to obtain explanations of proportional relationships. Before accepting the responses, the lecturer asked each group to compare the AI-generated explanation with numerical evidence obtained from traditional market observations." (Observation Note ON-10) Students explained that AI was used as a reference for understanding concepts, while verification remained necessary. One participant stated: "AI helped me organise my ideas, but I still had to compare the explanation with the market data that we analysed in class. If the explanation did not match our observations, we revised it." (Interview INT-S05) Digital learning records and assignments showed that later submissions included references to consulted sources and explanations of how external information was checked against contextual evidence (Digital Learning Record DLR-01).

Revision and Accountability in Collaborative Learning

Revision occurred throughout the learning activities as students responded to lecturer questions, peer discussions, and presentation feedback. Students revised not only calculations but also explanations and mathematical representations. One observation recorded: "After each group presented its solution, students returned to their worksheets to revise calculations, reorganise comparison tables, and clarify written explanations based on questions raised during the class discussion." (Observation Note ON-13) Students described revision as part of ensuring that their reasoning could be followed by others. One participant explained: "After receiving comments from the lecturer, we checked every step again. Sometimes the calculation was already correct, but the explanation did not clearly describe how we reached the answer." (Interview INT-S04) Accountability was also visible in collaborative work, as students ensured that group members understood the reasoning behind their solutions before presentations. Another participant stated: "Before presenting our work, we made sure that everyone understood the calculations and the explanation because the lecturer could ask any group member to answer the questions." (Interview INT-S03) Assignment documents demonstrated that revisions mainly strengthened explanations, contextual justification, and connections between evidence and mathematical conclusions.

5. Empirical Derivation of the Integrated Conceptual Model

The integrated conceptual model was derived through iterative analysis of empirical data rather than imposed before data collection. The analytical process involved identifying recurring actions, comparing patterns across data sources, and developing broader categories that represented relationships among observed practices. Initial coding of observation records, interview transcripts, reflective journals, and learning artefacts generated several recurring codes:

- connecting mathematical ideas with cultural situations;
- identifying quantitative information;
- examining mathematical relationships;
- comparing solution strategies;
- explaining reasoning;
- revising mathematical representations;
- verifying information from digital sources;
- responding to peer feedback.

The codes were then compared across data sources. Similar codes were grouped into broader analytical categories.

Tabel. 1 Initial Analytical Categories and Their Empirical Basis

Initial Category	Empirical Basis
Cultural engagement	Use of local situations as contexts for mathematical activities
Mathematical inquiry	Questioning, comparison, and verification of solutions
Reflective reconstruction	Revising interpretations and mathematical representations
Mathematical communication	Explaining reasoning through evidence and representation
Responsible learning practices	Verification, revision, and accountability in learning activities

Further analysis showed relationships among these categories. Three broader themes were identified:

1) Cultural contextualisation as the starting point of mathematical exploration
2) Inquiry, reflection, and representation as processes of mathematical meaning construction
3) Revision and accountability as practices shaping responsible mathematical engagement

Based on these relationships, the integrated conceptual model was constructed.

Tabel. 2 Empirical Themes, Evidence Sources, and Functions within the Integrated Conceptual Model

Empirical Theme	Evidence Sources	Function Identified in the Case
Cultural contextualisation	Observations, interviews, instructional documents	Connected mathematical activities with familiar cultural situations
Inquiry and dialogue	Classroom interaction, presentations, interviews	Provided opportunities to examine and compare mathematical ideas
Reflection and revision	Journals, worksheets, assignments	Documented reconsideration of explanations and representations
Mathematical representation	Worksheets, portfolios	Showed how quantitative relationships were expressed mathematically
Accountability practices	Interviews, digital records, group activities	Illustrated verification and responsibility in presenting mathematical reasoning

The model represents the pattern identified within this specific teacher education context. It does not indicate a causal relationship among the components; rather, it provides an empirical representation of how ethnomathematics-based deep learning was enacted through interconnected learning practices.

Discussion

The findings demonstrate that ethnomathematics-based deep learning supported prospective elementary teachers in constructing mathematical understanding through culturally meaningful experiences rather than through procedural instruction alone. Across classroom observations, interviews, reflective journals, and learning artefacts, participants consistently began by interpreting familiar cultural situations before identifying quantitative relationships, representing them mathematically, and refining their explanations through collaborative discussion. Rather than functioning as contextual illustrations, cultural experiences served as epistemic resources through which mathematical ideas became meaningful and open to critical examination. This pattern suggests that conceptual understanding emerged from interpreting culturally situated experiences before formal mathematical abstraction, positioning learning as a process of meaning construction rather than the application of predetermined procedures.

This interpretation extends the theoretical foundations of ethnomathematics, which conceptualise mathematics as knowledge embedded within cultural practices and everyday human activity (D'Ambrosio, 2001; Rosa & Orey, 2015). While previous studies have shown that culturally grounded mathematics learning enhances engagement and conceptual understanding (Fatra et al., 2025; Mabotja, 2024), the present findings provide a more detailed explanation of the pedagogical processes through which cultural experiences become mathematical understanding. Rather than merely motivating participation, familiar cultural contexts enabled prospective teachers to identify quantitative structures, compare alternative interpretations, justify mathematical relationships, and communicate conceptual explanations. In this sense, culture functioned not only as a contextual background for learning but also as the epistemic foundation from which mathematical reasoning developed.

The findings further reinforce perspectives on culturally responsive mathematics education by showing that meaningful learning occurred through continuous interaction between cultural interpretation, collaborative inquiry, and mathematical representation. Consistent with Vygotsky's (1978) social constructivist perspective, participants refined their understanding through dialogue, comparison of alternative solution strategies, and collective evaluation of mathematical evidence. These interactions transformed informal interpretations of everyday situations into increasingly coherent mathematical explanations, illustrating that conceptual understanding was socially negotiated rather than individually transmitted. This interpretation aligns with recent studies indicating that culturally responsive mathematics instruction strengthens reasoning, conceptual understanding, and meaningful participation by positioning learners' lived experiences as legitimate resources for mathematical inquiry (Aga, 2025; Suh & Calabrese, 2025; Turner et al., 2026).

These findings are particularly significant for mathematics teacher education because prospective teachers learn not only mathematical concepts but also how mathematical knowledge can be organised for future classroom practice. By engaging in culturally situated inquiry, participants experienced how local knowledge could be transformed into opportunities for mathematical reasoning, explanation, and reflection. Such experiences may influence how they later design culturally responsive mathematics instruction for elementary classrooms, where students' everyday experiences become starting points for conceptual learning rather than supplementary examples. Accordingly, this study contributes an empirically grounded explanation that ethnomathematics-based deep learning supports mathematical meaning construction by positioning cultural contextualisation as the point of departure for inquiry, conceptual reasoning, and pedagogical reflection within teacher education.

The findings further indicate that mathematical understanding developed through recursive processes of reflection, inquiry, and conceptual reconstruction rather than through the acquisition of mathematical procedures alone. Across observations, interviews, and students' written work, participants repeatedly revisited initial interpretations, questioned assumptions, compared alternative solution strategies, and refined mathematical explanations following peer discussion and lecturer feedback. Instead of treating mathematical solutions as fixed outcomes, they continuously reconstructed their understanding by examining evidence, identifying inconsistencies, and revising representations. These patterns suggest that deep learning emerged through sustained engagement with mathematical ideas in which conceptual understanding was progressively refined through interpretation, evaluation, and revision.

This interpretation is consistent with the distinction between deep and surface approaches to learning proposed by Marton and Säljö (1976), which emphasises that meaningful learning involves seeking conceptual relationships rather than reproducing procedures. Likewise, Biggs and Tang (2011) argued that deep learning requires learners to actively construct understanding through reflection and knowledge integration, while Hattie and Donoghue (2016) highlighted the importance of evaluating and transferring knowledge across different contexts. The present findings extend these perspectives by demonstrating that reflection and inquiry were not isolated instructional activities but interconnected processes through which participants interpreted culturally meaningful situations, evaluated competing mathematical explanations, and reconstructed conceptual understanding. Rather than following a linear progression from instruction to mastery, learning evolved through iterative cycles of explanation, critique, and conceptual refinement.

Collaborative interaction played a central role in sustaining these processes. Classroom dialogue encouraged participants to articulate mathematical reasoning, compare interpretations, justify conclusions, and reconsider initial assumptions in response to alternative perspectives. Reflection therefore occurred not only as an individual cognitive activity but also as a socially mediated process in which mathematical meaning was negotiated through discussion and evidence-based argumentation. This finding supports Vygotsky's (1978) view that higher-order understanding develops through interaction with others and is consistent with recent studies reporting that culturally responsive inquiry environments strengthen conceptual reasoning by promoting collaborative dialogue, reflective thinking, and critical examination of mathematical ideas (Aga, 2025; Mabotja, 2024; Wutsqa et al., 2025).

Taken together, these findings suggest that the contribution of ethnomathematics-based deep learning extends beyond improving conceptual understanding. The integration of cultural contextualisation, inquiry, reflection, and collaborative dialogue created conditions in which prospective teachers continuously reconstructed mathematical knowledge rather than merely applying established procedures. This pedagogical process is particularly important in teacher education because future teachers are expected not only to understand mathematical concepts but also to justify instructional decisions, facilitate meaningful classroom discourse, and support students in constructing mathematical understanding through inquiry. As a result, deep learning is more appropriately understood as a recursive process of mathematical meaning making that prepares prospective teachers for reflective and conceptually oriented professional practice.

The recursive processes of cultural interpretation, reflection, and inquiry also shaped the development of numeracy literacy and professional integrity as interconnected dimensions of prospective teachers' professional learning. Rather than emerging as separate instructional outcomes, both developed through participation in authentic mathematical practices requiring participants to interpret quantitative information, justify mathematical reasoning, evaluate evidence, communicate explanations, and revise conclusions when stronger arguments or alternative evidence became available. Throughout the learning activities, students were expected not only to obtain correct solutions but also to demonstrate how conclusions were reached, explain the relationships between contextual situations and mathematical representations, and critically examine the validity of their own reasoning. These practices positioned numeracy literacy as contextual mathematical reasoning and integrity as intellectual responsibility embedded within disciplinary learning.

This interpretation is consistent with contemporary perspectives on numeracy, which define quantitative literacy as the capacity to interpret information, evaluate evidence, communicate mathematical reasoning, and make informed decisions in authentic contexts rather than merely perform computations (Gal, 2002; Tout, 2020). The findings extend these perspectives by showing that culturally meaningful situations enabled prospective teachers to develop these capabilities through sustained engagement with mathematical inquiry. Participants analysed proportional relationships, compared alternative solution strategies, defended mathematical conclusions during collaborative discussions, and refined explanations in response to peer and lecturer feedback. In this way, numeracy literacy emerged through the integration of contextual interpretation, conceptual reasoning, mathematical communication, and reflective evaluation rather than as an isolated cognitive skill.

At the same time, the learning process fostered professional integrity by requiring transparency, accountability, and critical judgement throughout mathematical inquiry. Participants were expected to justify methodological choices, acknowledge limitations in their explanations, verify information obtained from multiple sources, and revise interpretations when more convincing mathematical evidence emerged. These findings extend conventional views of integrity as a general moral attribute by demonstrating that it can also develop as an epistemic and professional disposition grounded in disciplinary practice. Consistent with Shulman's (1986) conception of professional knowledge, responsible teaching requires not only disciplinary expertise but also the capacity to exercise informed judgement, communicate reasoning coherently, and take responsibility for instructional decisions. The present findings indicate that these dispositions can begin to develop through learning environments that prioritise evidence-based reasoning and reflective mathematical practice.

The increasing use of digital resources further reinforced the importance of critical evaluation as an element of professional responsibility. Although participants consulted generative artificial intelligence and other online resources during learning activities, externally generated information was not accepted uncritically. Instead, students compared digital explanations with contextual evidence, discussed inconsistencies collaboratively, and revised their interpretations when necessary. This pattern supports recent arguments that generative AI should function as a cognitive resource that strengthens learners' critical judgement rather than replacing mathematical reasoning (Kasneci et al., 2023). Consequently, responsible engagement with digital technologies became part of the same epistemic process through which participants evaluated evidence, justified conclusions, and strengthened both numeracy literacy and professional integrity.

Taken together, these findings suggest that numeracy literacy and professional integrity should not be regarded as independent educational objectives within mathematics teacher education. Instead, both emerged through the same culturally situated processes of interpretation, inquiry, reflection, communication, and evidence-based justification that supported mathematical meaning construction. This integrated perspective extends previous research by demonstrating that authentic mathematical inquiry can simultaneously strengthen conceptual understanding, contextual quantitative reasoning, and the professional dispositions required for responsible mathematics teaching.

Taken together, the findings support an integrated conceptualisation of ethnomathematics-based deep learning as a culturally responsive pedagogical process through which mathematical understanding, numeracy literacy, and professional integrity developed simultaneously rather than independently. The analysis indicates that cultural contextualisation functioned as the starting point for mathematical exploration by enabling prospective teachers to interpret familiar situations before engaging with formal mathematical concepts. Reflection, inquiry, collaborative dialogue, and mathematical representation subsequently operated as interconnected mechanisms through which participants refined conceptual understanding, evaluated evidence, and reconstructed mathematical explanations. Within this process, numeracy literacy and professional integrity emerged not as separate educational objectives but as complementary outcomes of sustained participation in authentic mathematical inquiry.

This interpretation extends previous scholarship by integrating perspectives that have largely been examined independently within mathematics education. Ethnomathematics has primarily emphasised the relationship between mathematics and culture (D'Ambrosio, 2001; Rosa & Orey, 2015), whereas deep learning has focused on conceptual understanding through reflection and knowledge construction (Marton & Säljö, 1976; Biggs & Tang, 2011). Likewise, research on numeracy has generally highlighted contextual quantitative reasoning (Gal, 2002; Tout, 2020), while integrity has commonly been discussed within broader frameworks of professional ethics and character education (Nucci & Narvaez, 2008). The present findings suggest that these dimensions are more appropriately understood as mutually reinforcing components of a single pedagogical process in which cultural experience provides the epistemic foundation for mathematical reasoning, reflective inquiry, and responsible professional learning.

An important contribution of this study therefore lies not in proposing a universal instructional model but in providing an empirically grounded explanation of how culturally situated mathematical learning operated within teacher education. Rather than positioning culture as supplementary instructional content, the findings demonstrate that culturally meaningful experiences served as the basis from which mathematical ideas were interpreted, negotiated, represented, and critically evaluated. This perspective extends culturally responsive mathematics education by showing that cultural knowledge contributes not only to student engagement but also to conceptual development, evidence-based reasoning, and the formation of professional dispositions required for responsible mathematics teaching. Consequently, the integrated conceptual model offers a contextually grounded framework for understanding how cognitive, cultural, and professional dimensions of learning can be developed through a coherent pedagogical process.

These findings have important implications for mathematics teacher education, particularly for programmes preparing prospective elementary teachers to teach mathematics in culturally diverse contexts. The evidence suggests that meaningful mathematical learning is strengthened when cultural experiences are positioned as the starting point for conceptual inquiry rather than as supplementary illustrations introduced after formal instruction. Learning environments that encourage prospective teachers to interpret culturally situated problems, engage in collaborative dialogue, justify mathematical reasoning, and critically evaluate evidence may simultaneously strengthen conceptual understanding, numeracy literacy, and the professional judgement required for responsible teaching. Such an approach shifts the emphasis of mathematics teacher education from procedural competence towards the development of reflective practitioners capable of designing culturally responsive and intellectually rigorous learning experiences.

The findings also suggest that the integration of cultural knowledge, reflective inquiry, and evidence-based reasoning provides a productive foundation for responding to contemporary challenges in teacher education. As digital technologies, including generative artificial intelligence, become increasingly embedded in educational practice, prospective teachers require opportunities not only to access information but also to evaluate its credibility, justify mathematical interpretations, and make responsible instructional decisions. Within this perspective, professional competence extends beyond disciplinary knowledge to include critical judgement, transparency, and accountability in the use of both mathematical and digital resources.

Preparing future teachers therefore requires learning environments that cultivate these capabilities as interconnected dimensions of professional practice rather than as separate educational objectives.

Overall, this study contributes an empirically grounded perspective on how ethnomathematics-based deep learning can support the integrated development of mathematical understanding, numeracy literacy, and professional integrity within elementary teacher education. By explaining the pedagogical processes through which culturally meaningful experiences became mathematical understanding, the study advances current discussions on culturally responsive mathematics education and provides a coherent analytical framework for understanding the interaction between cultural contextualisation, conceptual learning, and professional preparation. This integrated perspective provides the foundation for the concluding discussion of the study's contributions, limitations, and directions for future research.

CONCLUSION

Preparing prospective mathematics teachers requires learning experiences that extend beyond conceptual mastery to cultivate mathematical reasoning, evidence-informed decision-making, and responsible professional practice. This study demonstrates that ethnomathematics-based deep learning functions as a pedagogical mechanism that integrates cultural contextualisation, reflection, inquiry, mathematical representation, and collaborative dialogue within the process of mathematical meaning construction. Through this interconnected mechanism, cultural experiences operate as epistemic resources that enable prospective teachers to interpret contextual situations, examine mathematical relationships, and develop deeper conceptual understanding. Simultaneously, numeracy literacy and professional integrity emerge as integral dimensions of mathematical learning rather than as separate educational outcomes.

The principal contribution of this study lies in providing an empirically grounded explanation of how cultural contextualisation mediates mathematical meaning construction through reflection, inquiry, and representation, thereby supporting the simultaneous development of mathematical competence, numeracy literacy, and professional integrity. In doing so, the study extends existing scholarship on ethnomathematics and deep learning, which has predominantly emphasised learning outcomes, by explaining the pedagogical mechanism through which cultural, cognitive, and professional dimensions interact within mathematics teacher education.

These findings suggest that mathematics teacher education should move beyond procedure-oriented instruction toward learning environments that position culturally meaningful experiences as the foundation for mathematical exploration through reflection, inquiry, collaborative dialogue, and evidence-based justification. Such an orientation has the potential to foster learning that is conceptually meaningful, culturally responsive, and professionally relevant for preparing future elementary teachers.

Because this study was conducted as a single qualitative case within one teacher education programme, the findings should be interpreted as context-specific rather than universally generalisable. Future research should examine the transferability of the pedagogical mechanism identified across diverse institutional, cultural, and educational contexts to advance understanding of how ethnomathematics-based deep learning can contribute to both the theoretical development and the pedagogical practice of culturally responsive mathematics teacher education.

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