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Cognitive–Cultural Balance in Designing Culture-Based HOTS Tasks: Evidence from Prospective Mathematics Teachers

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Abstract: This study aims to investigate how prospective mathematics teachers integrate cognitive and cultural dimensions in designing culture-based Higher Order Thinking Skills (HOTS) tasks. Using a qualitative descriptive approach, data were collected through task analysis, observation, and in-depth interviews. Data analysis in this study employed thematic analysis using a hybrid inductive–deductive approach. The study involved seventh-semester Mathematics Education students who had completed core pedagogical and professional courses as well as teaching practicum and were therefore considered ready as prospective teachers. Their task designs were analyzed using the Cognitive Demand and Cultural Value Framework, resulting in three classifications: cognitive dominance, cultural dominance, and cognitive–cultural balance, with one participant representing each category. Participants with cognitive dominance demonstrated strong mathematical reasoning and structured problem design but tended to disregard cultural authenticity and traditional norms. Conversely, culturally dominant participants displayed rich cultural sensitivity yet neglected mathematical coherence and contextual logic. Only participants achieving cognitive–cultural balance successfully integrated analytical rigor with cultural meaning, producing problems that were both mathematically valid and culturally grounded. These findings highlight that cognitive and cultural dimension are complementary rather than opposing forces. The study concludes that developing dual cognitive and cultural literacy is essential for prospective mathematics teachers to design transformative learning experiences that connect logical reasoning with cultural understanding, underscoring the need for teacher education institutions (LPTK) to integrate this balance explicitly into curriculum design to better prepare future teachers.

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Introduction

Fostering thinking skills represents a fundamental dimension of education in the 21st century, an era marked by increasing global complexity and diverse challenges. In this context, education is expected to cultivate learners' ability to think critically, creatively, and reflectively in responding to real-world problems (Dilekçi & Karatay, 2023; Thornhill-Miller et al., 2023). Learners are expected not only to acquire factual knowledge but also to apply it critically and reflectively in addressing various real-life situations. Therefore, improving thinking skills from a Lower Order Thinking Skills (LOTS) to a Higher Order Thinking Skills (HOTS) is a must in the learning process, especially in mathematics learning (Gradini et al., 2024; Sussex et al., 2025; Septripiyani et al., 2025; Zana et al., 2022).

Higher-order thinking skills (HOTS) in mathematics can be defined as students' ability to perform complex mathematical processes that require deep cognitive engagement (Makmuri et al., 2021; Sadijah et al., 2021; Tanudjaya & Doorman, 2020; Tanujaya et al., 2017). This ability involves making connections among concepts, engaging in logical reasoning, and solving problems across various contexts. Furthermore, HOTS in mathematics encompass critical, creative, and reflective thinking skills that enable students to explore multiple possible solutions and evaluate their own reasoning processes (Fongkanta & Buakanok, 2024; Varveris et al., 2023). Therefore, mathematics learning that emphasizes the development of HOTS not only strengthens conceptual understanding but also cultivates scientific ways of thinking and adaptability to change.

In this context, prospective mathematics teachers are required to develop competence in designing Higher-Order Thinking Skills (HOTS)–oriented tasks through the integration of strong conceptual understanding, appropriate pedagogical strategies, and reflective thinking (Lopez & Viswanathappa, 2025; Tatira, 2023). Moreover, embedding mathematical tasks in meaningful, real-world contexts deepens conceptual understanding and supports contextualized learning (Sari et al., 2024; Toheri & Muchyidin, 2025). Consequently, the ability to design HOTS-oriented tasks serves as an important indicator of prospective teachers' readiness to cultivate critical, creative, and contextually aware mathematical thinking in future learners (Alsina & Mulà, 2019; Astuti et al., 2019).

Building on this perspective, mathematics learning should not focus solely on cognitive development but must also be contextual and culturally grounded to overcome the perception that mathematics is abstract and detached from daily life. Integrating culture into mathematics enables students to connect abstract ideas with real experiences, fostering meaningful understanding (Umbara et al., 2023; Wulandari et al., 2024). Prospective mathematics teachers thus play a strategic role in promoting inclusive learning by embedding cultural values in instruction. This requires cultural competence—the ability to understand, appreciate, and engage with diverse socio-cultural backgrounds (Luzano, 2025). In this regard, developing the ability to design culture-based Higher-Order Thinking Skills (HOTS) tasks becomes essential, as it bridges cognitive depth with cultural relevance in mathematics learning (Madriaga & Cajandig, 2025; Murti, 2023; Nolan & Keazer, 2021).

Consequently, prospective teachers must cultivate a deeper understanding of both cognitive taxonomies and cultural contexts, engage in collaborative design activities, and participate in reflective practices that explore the interrelationship between cultural values and mathematical thinking (Kosasih et al., 2022; Labuem et al., 2025). Hence, analyzing prospective teachers' ability to design culture-based HOTS tasks is crucial for gaining insights into the dynamic interaction between cognitive dimensions and cultural values that shape their reasoning processes.

Although numerous studies have examined prospective mathematics teachers' competence in developing Higher-Order Thinking Skills (HOTS) tasks and the integration of ethnomathematics in mathematics education, these two lines of research have largely evolved separately. Studies focusing on the cognitive dimension reveal that prospective teachers often struggle to align learning indicators, action verbs, and assessment items with the appropriate levels of Bloom's revised taxonomy (Jailani et al., 2023; Mintohari et al., 2025; Qadar et al., 2025). Meanwhile, research on ethnomathematics emphasizes the potential of culturally embedded contexts to enhance student engagement, foster creative thinking, and make mathematics learning more meaningful (Maulina et al., 2025; Mei et al., 2025; Nursyahidah et al., 2025). However, integrating cultural elements into HOTS task design also presents critical challenges, as it may unintentionally produce culturally biased problems that are not

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equally accessible to diverse learners or reduce cognitive demand to merely contextualized story problems representing lower-order thinking rather than genuine higher-order reasoning. Despite these concerns, few studies have simultaneously explored how cognitive competence and cultural awareness interact in the process of designing culture-based HOTS tasks.

Based on this gap, the present study proposes an analytical approach that integrates cognitive and cultural value perspectives to examine prospective mathematics teachers' ability to design culture-based HOTS tasks, the depth of their thinking processes, and the representation of cultural values within the resulting problems. In line with the global movement toward Culturally Responsive Pedagogy (CRP), the novelty of this research lies in the integrated analysis of cognitive and cultural dimensions, contributing to the development of a more contextual, reflective, and culturally rooted model of mathematics teacher education grounded in local culture.

Research Method

This study employs a qualitative approach with a descriptive design that focuses on an in-depth exploration of the ability of prospective mathematics teachers to design culture-based Higher Order Thinking Skills (HOTS) tasks. The qualitative approach was chosen because it enables researchers to comprehensively understand participants' thought processes and the meanings they construct when integrating cultural values into mathematical problem design (Creswell, 2012).

Participants in this study were 7th-semester students of the Mathematics Education Study Program who had completed core pedagogical and professional courses as well as teaching practicum, and were therefore considered ready as prospective teachers. Of the 38 students who designed culture-based HOTS tasks in an ethnomathematics course, 17 met the HOTS criteria of the Revised Bloom's Taxonomy by Anderson & Krathwohl (2001), analyzing, evaluating, and creating then were subsequently classified within the Cognitive–Cultural Integration framework into cognitive–cultural balance, cognitive dominance, and cultural dominance based on the coherence between mathematical accuracy and cultural authenticity, as summarized in Table 1. One representative participant from each category was selected as the research subject and referred to as S1, S2, and S3.

Table 1. Distribution of Participants Based on Cognitive–Cultural Integration Category

Category	Identified (n=17)	Selected	Subject Code	Cognitive Demand	Cultural Value Integration	Description / Selection Criteria
Cognitive–Cultural Balance	2	1	S1	High	High	Task showing coherent integration of accurate mathematics and authentic cultural context without conceptual or cultural errors; harmonious integration of higher-order thinking and cultural meaning.
Cognitive Dominance	7	1	S2	High	Low	Task with strong mathematical rigor and procedural–analytical reasoning but limited or less accurate cultural representation.
Cultural	8	1	S3	Low	High	Task with rich cultural

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Dominance						representation and symbolic meaning but evident mathematical inaccuracies or weakened conceptual rigor.
Total	**17**	**3**	—	—	—	One representative from each category analyzed in depth.

This study utilized four complementary research instruments to collect and triangulate data on prospective mathematics teachers' cognitive abilities and cultural value awareness in designing culture-based HOTS tasks. These instruments included a HOTS analysis guideline based on the Revised Bloom's Taxonomy to examine cognitive demand, a cultural value rubric grounded in ethnomathematics and local wisdom to assess cultural integration and authenticity, a semi-structured interview protocol to explore teachers' cognitive processes, and observation sheets with reflective notes to capture verbal and non-verbal indicators such as reflection, hesitation, confidence, and cultural awareness. The instruments were applied in an integrated manner to ensure comprehensive data collection, and their validity was established through expert judgment by three experts—one specialist in educational evaluation, one in ethnomathematics, and one educational practitioner. Data source triangulation to ensure the validity, reliability, and credibility of the research findings.

Data analysis in this study employed thematic analysis using a hybrid inductive–deductive approach (Lochmiller, 2021), which provides a flexible yet rigorous framework for identifying and interpreting patterns in qualitative data. In the inductive phase, the analysis explored how prospective mathematics teachers conceptualized and implemented culture-based HOTS tasks, resulting in the emergence of three Cognitive–Cultural Integration categories. In the deductive phase, the analysis was guided by two theoretical perspectives proposed by Radmehr (2023). The cognitive perspective was examined using the principles of cognitive demand, including (1) different knowledge types, (2) different cognitive processes, (3) different representations, (4) inquiry-based tasks, (5) socio-cognitive conflict, (6) development of problem-solving and reasoning skills, and (7) the use of multiple approaches, reflection, and solution extension. In parallel, the cultural value perspective was (1) analyzed through affective–social principles encompassing the relevance of cultural context, (2) depth of cultural values and meanings, (3) authenticity and adherence to cultural norms, (4) connections to identity and social meaningfulness, and (5) Reflective Affirmation in Learning. This integrated analytical process enabled a systematic examination of the extent to which participants' tasks met high-level cognitive demands while authentically embedding cultural values.

Results and Discussion

This section presents the results of a thematic analysis guided by Radmehr's (2023) principles of cognitive demand and cultural value perspective, providing an integrated understanding of how cognitive rigor and cultural values are reflected in participants' culture-based HOTS tasks. An initial synthesis of participants' orientations is summarized in Table 1, which comparatively categorizes S1, S2, and S3 based on levels of cognitive demand and cultural value integration prior to the detailed qualitative analysis.

Subject 1 (S1)

S1 is categorized as cognitive–cultural balance since the task shows a harmonious integration of mathematical accuracy and cultural authenticity. The HOTS task created by S1 is shown in Table 2.

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Table 2. HOTS task created by S1

Original Version (Bahasa Indonesia)	Translated Version (English)
Apem dalam Tradisi Ruwahan Masyarakat Jawa Di Desa Sumbersari, masyarakat mempersiapkan tradisi Ruwahan yang dilaksanakan sekitar satu bulan sebelum Ramadan untuk mendoakan leluhur, memohon ampun kepada Tuhan, serta mengungkapkan rasa syukur dan kebersamaan melalui kegiatan slametan. Salah satu hidangan utama dalam slametan adalah apem, kue tradisional berbentuk bulat yang terbuat dari tepung beras, santan, dan gula aren. Kata *apem* berasal dari bahasa Arab *afwan* yang berarti “maaf” atau “ampunan,” melambangkan penyucian diri dan permohonan ampun. Bu Marni membuat apem untuk acara slametan dengan data berikut: biaya bahan Rp75.000 menghasilkan 100 apem; harga jual tiap apem Rp2.000; menjelang acara harga bahan naik 8%; Bu Marni tetap mempertahankan harga jual dan menargetkan keuntungan Rp180.000.	*Apem in the Javanese Ruwahan Tradition* In Sumbersari Village, the community prepares for the Ruwahan tradition held about one month before Ramadan to pray for ancestors, seek forgiveness from God, and express gratitude and togetherness through a communal feast (*slametan*). One of the main foods served in the *slametan* is apem, a traditional round cake made from rice flour, coconut milk, and palm sugar. The word *apem* derives from the Arabic *afwan*, meaning “forgiveness,” symbolizing purification and the act of seeking pardon. Mrs. Marni prepares apem for the *slametan* with the following data: the ingredient cost is Rp75,000 producing 100 apem; each apem is sold for Rp2,000; before the event, ingredient prices increase by 8%; Mrs. Marni maintains the selling price and targets a profit of Rp180,000.
Pertanyaan: Berapa jumlah minimal apem yang harus dijual agar Bu Marni mencapai target keuntungan tersebut?	Question: What is the minimum number of apem that must be sold for Mrs. Marni to achieve the targeted profit?

The findings indicate that S1 demonstrates a harmonized cognitive and cultural integration in designing Apem-based HOTS tasks, as reflected in both the cognitive demand and cultural value dimensions of Radmehr’s (2023) framework. From the cognitive perspective, S1 integrates multiple types of knowledge, factual (cost data, number of apem, material price increases), conceptual (relationships among cost, selling price, and profit), and procedural (percentage calculations and profit strategies), while exhibiting metacognitive awareness in ensuring that the cultural context remains mathematically meaningful. As stated in the interview

S1: “I want to compile a culturally based arithmetic problem so that it still has mathematical value, but also makes sense in real situations. So, I first think about the relationship between cost, selling price, and profit so that I can connect with the context of the story.”

S1 engages in higher-order processes (analysis–evaluation–creation) by designing a non-routine task that requires students to determine the minimum number of apem needed to achieve a profit target as explained in the interview.

S1: “If I immediately ask you to calculate the profit, it is too simple. But if I change it to a question about what is the minimum number of apem, students will think more deeply because they have to analyze the relationship between all the variables.”

The task employs verbal, symbolic, and numerical representations, indicating high cognitive demand and fostering analytical and reflective thinking. From the cultural value perspective, S1 selects Apem due to its authentic relevance in Javanese traditions, particularly in thanksgiving events, as expressed:

S1: “I chose apem because children must know and often see it at family events. So, they can directly relate to their own experience.”

The context is not merely symbolic; S1 embeds deeper meanings of togetherness and balance, maintains authenticity by respecting traditional forms without distortion, and intentionally positions mathematics as a medium for strengthening students’ cultural identity and pride. Overall, S1 exhibits reflective awareness that cultural context is an integral

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component of meaningful mathematics learning, successfully balancing cognitive rigor and authentic cultural integration in alignment with the Radmehr Cognitive Demand and Cultural Value Framework (2023).

Subject 2 (S2)

S2 is categorized as cognitively dominant, as the task demonstrates strong mathematical structure and logical precision but limited attention to cultural authenticity. The task designed by S2 can be seen in Table 3.

Table 3. HOTS task created by S2

<table>
<tr><th>Original Version Bahasa Indonesia</th><th>Translated in English</th></tr>
<tr><td>PAPAN CONGKLAK</td><td>CONGKLAK BOARD</td></tr>
<tr><td>Permainan tradisional Indonesia congklak menggunakan papan kayu dengan beberapa lubang dan biji sebagai alat bermain.
Seorang pengrajin congklak sedang merancang variasi papan congklak.
Berikut adalah beberapa desain:
<table>
<tr><th>Desain</th><th>Jumlah lubang per baris</th><th>Jumlah baris</th><th>Biji pada setiap lubang kecil</th></tr>
<tr><td>A</td><td>7</td><td>2</td><td>5</td></tr>
<tr><td>B</td><td>8</td><td>2</td><td>4</td></tr>
<tr><td>C</td><td>10</td><td>2</td><td>6</td></tr>
</table></td><td>The traditional Indonesian game congklak uses a wooden board with several holes and seeds as playing pieces.
A congklak craftsman is designing a variation of the Congklak board.
Here are several designs as follows:
<table>
<tr><th>Design</th><th>Number of holes per row</th><th>Number of rows</th><th>Seeds in each small hole</th></tr>
<tr><td>A</td><td>7</td><td>2</td><td>5</td></tr>
<tr><td>B</td><td>8</td><td>2</td><td>4</td></tr>
<tr><td>C</td><td>10</td><td>2</td><td>6</td></tr>
</table></td></tr>
<tr><td>Pertanyaan:</td><td>Questions:</td></tr>
<tr><td>1. Hitung jumlah total biji yang diperlukan untuk setiap desain papan (A, B, dan C).
2. Jika Rani ingin membuat papan congklak dengan jumlah lubang per baris berapa pun (n) dan s biji pada setiap lubang kecil, buatlah rumus umum untuk menentukan jumlah total biji yang diperlukan.
3. Berdasarkan rumus Anda, tentukan jumlah biji yang dibutuhkan untuk papan dengan 12 lubang per baris, 2 baris, dan 7 biji pada setiap lubang kecil.
4. Jelaskan pola hubungan antara jumlah lubang per baris dan jumlah total biji yang diperlukan.</td><td>1. Calculate the total number of seeds needed for each board design (A, B, and C).
2. If Rani wants to make a Congklak board with any number of holes per row (n) and s seeds in each small hole, derive a general formula to determine the total number of seeds needed.
3. Based on your formula, determine the number of seeds needed for a board with 12 holes per row, 2 rows, and 7 seeds in each small hole.
4. Describe the pattern or relationship between the number of holes per row and the total number of seeds required.</td></tr>
</table>

The findings indicate that S2 demonstrates strong cognitive integration but low cultural integration in designing congklak-based HOTS tasks. Based on Radmehr's (2023) Cognitive Demand Framework, S2 integrates factual knowledge (structure of the congklak board), conceptual knowledge (relationships between the number of holes and total seeds, including linear patterns), procedural knowledge (arithmetic operations and general formula construction), and metacognitive knowledge (reflection on strategies without testing each case individually). The cognitive progression moves systematically from applying to analyzing and creating, as students are guided to generalize patterns into the formula $T=2nm$, interpret variable relationships, and engage in inquiry-based reasoning. The tasks incorporate multiple representations (verbal, symbolic, and visual), promote non-routine problem solving, anticipate socio-cognitive conflict, and encourage justification and reflective verification, indicating a high level of analytical, procedural, and reflective thinking aligned with the Indicators of Cognitive Demand Framework.

However, from the perspective of Radmehr's Cultural Value Framework, S2's task reflects cognitive dominance with superficial cultural integration. Although congklak is selected due to its familiarity as stated in the interview.

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S2: "I chose congklak because it is close to the students' daily life and can be used as a context for calculating material efficiency."

The cultural context functions instrumentally as a pedagogical tool rather than as a medium for exploring deeper philosophical values such as cooperation, patience, and social harmony. Furthermore, structural modifications to the traditional board (e.g., altering the number of holes) prioritize mathematical rationality over cultural authenticity, thereby weakening adherence to traditional norms and symbolic meaning. Consequently, the task does not effectively strengthen students' cultural identity or social meaningfulness. Overall, S2 exhibits well-developed analytical and evaluative mathematical competence, yet perceives culture primarily as a supportive context rather than as an integral epistemological component in culture-based HOTS problem design.

Subject 3 (S3)

S3 is categorized as culturally dominant, as the task demonstrates rich and detailed representation of cultural practices and values, but reveals limited mathematical precision and conceptual rigor. The task developed by S3 can be seen in Table 4.

Table 4. HOTS task created by S3

Bahasa Indonesia	English
Onde-onde dan Wajik dalam Tradisi Jawa	*Onde-onde and Wajik in Javanese Tradition*
Dalam tradisi Jawa, jajanan pasar tradisional seperti onde-onde dan wajik sering disajikan pada acara selamatan (jamuan bersama), upacara tradisional, dan pertemuan keluarga sebagai simbol rasa syukur dan kebersamaan. Bentuk onde-onde melambangkan keutuhan dan harapan baik, sedangkan wajik yang terbuat dari beras ketan melambangkan kedekatan dan ikatan yang kuat dalam masyarakat. Sebuah toko tradisional menjual dua jenis kue saja: onde-onde **(O)** dan wajik **(W)**. Harga jual onde-onde adalah Rp2.000, dan wajik Rp3.000. Biaya harian bahan adalah Rp450.000. Biaya bahan untuk satu onde-onde adalah Rp1.000 dan untuk satu wajik adalah Rp1.500.	In Javanese tradition, traditional market snacks such as onde-onde and wajik are often served at selamatan (communal feasts), traditional ceremonies, and family gatherings as symbols of gratitude and togetherness. The round shape of onde-onde represents wholeness and good wishes, while wajik, made from sticky rice, symbolizes closeness and strong family bonds within the community. A traditional snack stall sells two kinds of cakes daily: onde-onde (O) and wajik (W). The selling price of onde-onde is Rp2,000, and wajik is Rp3,000. The daily capital for ingredients is Rp450,000. The cost of ingredients for one onde-onde is Rp1,000 and for one wajik is Rp1,500.
Pertanyaan	Question
1. Jika seluruh modal dihabiskan dan jumlah total kue yang diproduksi adalah 200, tentukan berapa banyak onde-onde dan wajik yang dibuat.	1. If all the capital is spent and the total number of cakes produced is 200, determine how many onde-onde and wajik are made.
2. Jika penjual ingin menggandakan keuntungan tanpa menambah modal, jelaskan perubahan jumlah masing-masing jenis kue yang harus diproduksi. Apakah hal tersebut memungkinkan? Berikan penjelasan matematis untuk jawaban Anda.	2. If the seller wants to double her profit without increasing the capital, analyze and explain the changes in the number of each type of cake that must be produced. Is it possible to do so? Provide a mathematical explanation for your answer.

Based on Radmehr's (2023) Cognitive Demand Framework, S3's HOTS task design reflects a process that moves from prior knowledge activation to reflection, with a strong dominance of cultural meaning over mathematical rigor. From a cognitive–mathematical perspective, S3 translated the cultural context of onde-onde and wajik into a system of linear equations in two variables by defining total cost and quantity as constraints. Although this demonstrates conceptual understanding, inaccuracies in formulating relationships between

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variables produced an illogical result (a negative quantity), indicating weak symbolic verification and limited logical evaluation. During coordination, strategic reasoning, and monitoring stages, S3 did not critically revise the mathematical model, showing moderate conceptual engagement but insufficient analytical reflection to ensure mathematical consistency.

From a cultural perspective, S3 demonstrated strong awareness and intentional integration of Javanese cultural values. The selection of onde-onde and wajik symbolized unity, harmony, goodwill, and familial closeness, positioning culture as the primary foundation of task construction. Throughout the design process, S3 prioritized preserving cultural authenticity and symbolic balance rather than adjusting the equations for numerical consistency. Reflection was oriented toward maintaining social and spiritual meaning rather than mathematical correction.

Overall, S3 exhibited deep cultural integration and narrative coherence, but limited cognitive adjustment and validation in the mathematical domain, resulting in an imbalance between cultural authenticity and cognitive demand in culture-based HOTS task design. S3's failure to recognize the mathematical error can be interpreted through the interplay between cognitive conflict and Cognitive Load Theory. The negative solution should have generated cognitive conflict by creating an inconsistency between the mathematical result and real-world logic. One possible explanation is that S3's strong commitment to maintaining cultural authenticity increased cognitive load, as they simultaneously managed narrative construction, symbolic meaning, and mathematical modeling. Because working memory capacity is limited, much of S3's cognitive resources may have been allocated to preserving cultural coherence, leaving insufficient capacity for analytical monitoring and error detection. As a result, the inconsistency did not trigger productive cognitive conflict, leading to weak metacognitive control and the failure to revise the mathematical model.

Furthermore, the characteristics of S1, S2, and S3 were derived through a deductive analysis guided by Radmehr's (2023) cognitive–cultural framework to systematically examine the extent to which their HOTS tasks integrated high-level cognitive demand and authentic cultural values, as presented in Table 5.

Table 5. Characterization of S1, S2, and S3 Based on Radmehr's Cognitive–Cultural Framework

Dimension	S1 (Balanced)	S2 (Cognitive Dominance)	S3 (Cultural Dominance)
Knowledge Integration & Cognitive Processes	Integrates multiple knowledge types; engages analysis–evaluation–creation	Strong conceptual–procedural rigor and generalization	Conceptual modeling present but weak evaluative control
Representation & Inquiry	Multiple representations; non-routine inquiry task	Symbolic–visual representations; pattern generalization	Narrative-rich but mathematically less investigative
Reasoning, Conflict & Reflection	Logical coherence and reflective verification	Analytical justification and validation	Inconsistency not detected; limited mathematical reflection
Cultural Relevance & Depth	Meaningful, symbolically rich, and contextually embedded	Context familiar but symbolically shallow	Deep symbolic and affective meaning
Authenticity & Identity Connection	Maintains cultural authenticity and	Cultural modification reduces authenticity	Strong preservation of norms and social

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strengthens identity	meaning

Discussion

The integration of cognitive and cultural dimensions in mathematics education represents a fundamental shift from viewing abstract reasoning and contextual understanding as separate domains toward recognizing them as interdependent components of transformative learning. In the design of culture-based HOTS tasks, cognitive rigor ensures logical precision, conceptual accuracy, and analytical depth, while cultural awareness provides contextual relevance, authenticity, and value transmission that ground learning socially and meaningfully (Umbara et al., 2023; Wulandari et al., 2024). The findings of this study empirically support this perspective by identifying three cognitive–cultural orientations, that is: cognitive dominance, cultural dominance, and cognitive–cultural balance, demonstrating that an imbalance between these dimensions compromises the integrity of mathematical learning.

Participants with cognitive dominance exhibited strong alignment with high cognitive demand through structured reasoning, procedural accuracy, and the integration of multiple knowledge types, reflecting principles of cognitively rich task design (Radmehr, 2023). However, consistent with (Madriaga & Cajandig, 2025), this emphasis often reduced culture to a superficial backdrop, neglecting symbolic meanings and cultural norms, as seen in the modification of traditional practices without epistemological consideration. The tendency of S2 toward cognitive dominance may reflect the influence of the teacher education curriculum, which has traditionally emphasized mathematical content knowledge and procedural competence over culturally responsive pedagogy. Such preparation can shape epistemic priorities, leading prospective teachers to privilege formal mathematical correctness while underutilizing cultural-symbolic depth.

Conversely, culturally dominant participants demonstrated deep sensitivity to cultural narratives and local wisdom, aligning with studies that position culture as a medium for moral and identity development (Luzano, 2025; Payadnya et al., 2025), yet their tasks frequently lacked mathematical coherence and conceptual validity, echoing concerns raised by (R. Wulandari et al., 2024) and (Daniel et al., 2025). These contrasting orientations illustrate that prioritizing one dimension at the expense of the other leads either to cultural superficiality or mathematical inconsistency.

The cognitive–cultural balance achieved by one participant exemplifies the pedagogical ideal, where high-level reasoning and multiple knowledge types coexist with cultural authenticity and symbolic integrity, supporting the view that analytical rigor and affective–social learning can be integrated through reflective practice (Radmehr, 2023). This balanced orientation may be associated not only with reflective competence but also with richer or more internalized cultural experiences that allowed S1 to navigate symbolic meaning without sacrificing mathematical precision. It is possible that S1 possessed prior engagement with local traditions, community practices, or interdisciplinary perspectives that supported dual literacy—both cognitive and cultural. This equilibrium reinforces theoretical arguments that transformative mathematics education requires dialogical interaction between cognition and culture (Alsina & Mulà, 2019; Vindigni, 2024) and highlights the need for teacher education to cultivate dual literacy that is cognitive literacy for analytical precision and cultural literacy for empathy, authenticity, and ethical sensitivity (Nolan & Keazer, 2021). Overall, the study affirms that designing culture-based HOTS tasks is a reflective act demanding both cognitive depth and cultural awareness, enabling mathematics learning to align with inclusive and transformative educational goals, including those articulated in Sustainable Development Goal 4.

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Conclusion

In conclusion, this study demonstrates that prospective mathematics teachers integrate cognitive and cultural dimensions in culture-based HOTS problem design through three orientations—cognitive dominance, cultural dominance, and cognitive–cultural balance—revealing that only a balanced integration of mathematical rigor and cultural meaning produces problems that are both mathematically valid and culturally authentic. These findings affirm that cognitive reasoning and cultural values are complementary rather than competing elements, positioning the design of culture-based HOTS problems as a reflective act of intellectual and cultural synthesis rather than a purely technical mathematical exercise. Theoretically, this study contributes novel insights by conceptualizing these three orientations as an analytical lens for understanding how prospective teachers negotiate logical rigor and cultural authenticity, thereby extending existing perspectives that often separate cognition from culture. By demonstrating that cognitive and cultural competencies function synergistically, this research advances theory in HOTS, culturally responsive pedagogy, and teacher cognition, highlighting cognitive–cultural balance as a critical construct in culturally grounded mathematics education and underscoring mathematics as a transformative medium for intellectual empowerment and cultural affirmation.

Recommendation

Future research is recommended to conduct longitudinal studies that investigate how cognitive–cultural balance develops through different stages of teacher education and classroom practice. Further studies should also design and evaluate targeted instructional interventions that explicitly support teachers in integrating cognitive demand and cultural value in HOTS problem design. In addition, future research should refine and empirically validate the proposed cognitive–cultural orientation framework and examine its impact on students' mathematical reasoning, higher-order thinking skills, and cultural understanding. Potential challenges, such as limited cultural literacy, maintaining mathematical coherence within rich cultural contexts, and aligning cultural authenticity with formal mathematical standards, should be carefully addressed to strengthen the theoretical and practical contributions of culture-based HOTS research.

Teacher education programs should move beyond teaching HOTS and ethnomathematics as separate or purely theoretical courses, and instead integrate them as interconnected design competencies embedded across the curriculum through reflective practice, collaborative lesson design, and iterative task validation. Concretely, curricula should incorporate structured opportunities for prospective teachers to (1) critically analyze culture-based mathematical tasks for both cognitive demand and cultural authenticity, (2) engage in microteaching cycles that include peer and mentor feedback on cognitive–cultural balance, (3) conduct community-based cultural inquiry to strengthen cultural literacy, and (4) practice systematic mathematical verification to ensure conceptual coherence within culturally rich contexts. Embedding these components within coursework, practicum experiences, and assessment standards would help cultivate dual literacy—analytical rigor and cultural sensitivity—necessary for sustainable and transformative mathematics education.

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