

STEAM Learning: Integrating Deep Learning and Ethnomathematics to Improve Numeracy, Literacy, and Pancasila Student Profile

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ABSTRACT

Improving numeracy literacy and character education aligned with the Pancasila Student Profile (P5) remains a key challenge in Indonesian education, particularly in remote areas. Conventional mathematics instruction often lacks contextual and cultural relevance, limiting student engagement and holistic development. This study implemented a STEAM (Science, Technology, Engineering, Arts, Mathematics) learning model integrating Deep Learning principles and Ethnomathematics to enhance numeracy and character development. Using a mixed-methods sequential exploratory design, the research was conducted with 28 ninth-grade students at SMPN 1 Masalembu. Qualitative data from observations, interviews, and reflections informed the development of quantitative instruments measuring numeracy literacy and P5 competencies. Quantitative analysis showed significant gains in numeracy literacy, with pre-test scores increasing from $M = 42.80$ ($SD = 7.61$) to post-test scores of $M = 82.47$ ($SD = 6.32$), $t(27) = -27.58$, $p < 0.001$, with a large effect size (Cohen's $d = 5.21$). Qualitative findings indicated that students engaged meaningfully and joyfully with mathematical concepts through culturally relevant tasks involving Sumenep batik motifs. Improvements were also observed in critical thinking, creativity, cooperation, and cultural appreciation. The integration of STEAM, Deep Learning, and Ethnomathematics effectively enhanced students' cognitive and character outcomes. This model offers a promising, culturally responsive approach for mathematics instruction in remote and diverse educational settings, supporting the objectives of the Merdeka Belajar curriculum.

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1. INTRODUCTION

In the current era of rapid technological advancement and globalization, the Indonesian education system faces the dual challenge of improving students' fundamental competencies and strengthening national character (Perales & González, 2025). Among the key learning outcomes emphasized in the *Merdeka Belajar* curriculum are numeracy, literacy, and the Pancasila Student Profile (Profil Pelajar

Pancasila, P5). However, recent national and international assessments—such as the 2018 PISA results—reveal that Indonesian students continue to exhibit weak performance in numeracy literacy, particularly in applying mathematical reasoning to real-life contexts (Khine & Areepattamannil, 2020; OECD, 2019). In addition, the integration of P5, which aims to cultivate holistic learners with faith, global awareness, independence, cooperation, critical reasoning, and creativity, has yet to be fully realized in many schools, especially in rural or remote areas such as Masalembu Island in Sumenep Regency.

Classroom observations in this setting indicate that mathematics learning remains predominantly procedural, with limited contextualization and minimal student engagement. Students often experience mathematics as abstract and detached from their daily realities, while character development activities are rarely integrated into cognitive learning processes. This situation highlights an urgent need for innovative instructional models to enhance students' numeracy skills simultaneously and internalize the values embedded in the Pancasila Student Profile.

To respond to these challenges, several contemporary educational paradigms offer relevant frameworks. The STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) provides a multidisciplinary learning structure that connects scientific reasoning with creativity and cultural relevance (Choi & Lee, 2024; Henriksen et al., 2021). It encourages learners to observe real-world problems, generate ideas, design and innovate, and reflect on social values (Alsina & De Freitas, 2025; Rodríguez-Nieto & Alsina, 2022). STEAM thus supports the development of higher-order thinking, collaboration, and innovation—skills crucial for 21st-century learners.

Complementing this is the concept of Deep Learning, which in educational theory refers not to artificial intelligence but to meaningful, mindful, and joyful learning that leads to lasting conceptual understanding (Kim & Choi, 2022; Larkin & Jorgensen, 2021). Deep learning promotes cognitive depth through critical reflection, active construction of meaning, and emotional engagement in learning tasks. It enables students to connect knowledge across contexts and apply it flexibly in new situations—moving beyond rote memorization toward genuine comprehension and transfer of learning (van der Steen & de Vries, 2023).

Meanwhile, ethnomathematics serves as a bridge between culture and mathematics. It emphasizes that mathematical ideas are embedded in cultural artifacts, practices, and traditions (Lin & Chen, 2024). In the local context of Sumenep, *batik motifs* carry rich geometric patterns such as translation, rotation, and reflection, which can be used as authentic learning resources to connect mathematical concepts with students' cultural identity. Through ethnomathematics, abstract concepts become tangible and personally meaningful, while students also develop an appreciation for local wisdom and cultural heritage.

Finally, the Pancasila Student Profile (P5)—a key element of Indonesia's educational transformation—outlines six core dimensions of student competence: (1) faith and noble character, (2) global diversity, (3) independence, (4) cooperation, (5) critical reasoning, and (6) creativity. These dimensions represent the holistic vision of education that integrates knowledge, skills, and values (Akaygun & Aslan-Tutak, 2023). Embedding P5 into the mathematics classroom through culturally grounded and inquiry-based approaches like STEAM and ethnomathematics can foster balanced cognitive and character growth.

Several previous studies have investigated integrating innovative approaches such as STEAM, ethnomathematics, and deep learning in mathematics education, yet few have systematically linked these frameworks within a unified instructional model that simultaneously enhances numeracy literacy and character formation. For instance, Ogguniyi & Jita, (2025) examined a STEM-based Lesson Study for Learning Community and found that the approach significantly improved students' creative-thinking abilities. Although the study demonstrated the potential of interdisciplinary learning, it did not incorporate cultural elements or ethnomathematics as a contextual foundation, and the concept of deep learning as a meaningful and reflective process was not explicitly addressed. As a result, students' numeracy literacy and character development were not part of the evaluated outcomes. Similarly, Chen

et al., (2023) explored the implementation of STEAM in mathematics learning was explored to promote 21st-century competencies. While this research provided a strong conceptual basis for integrating science, technology, engineering, arts, and mathematics, its descriptive nature lacked empirical rigor. It failed to include measurable indicators of numeracy literacy, cultural relevance, or affective outcomes related to the Pancasila Student Profile.

In another relevant work, Toma & Greca, (2020) investigated students' numeracy literacy through socio-cultural contexts in geometry lessons. Their findings suggested that cultural contexts could enhance understanding of mathematical concepts; however, the study was not grounded in a STEAM framework and did not involve deep learning principles that emphasize meaningful, mindful, and joyful engagement. The focus remained on mapping existing abilities rather than designing an integrative learning intervention. Meanwhile, Cinar & Tekkumru-Kisa, (2023) applied an ethnomathematics-based STEAM model and reported positive effects on numeracy literacy and partial alignment with the dimensions of the Pancasila Student Profile. Although this research is conceptually closest to the present study, it did not explicitly position deep learning as a structured cognitive-affective driver. It was conducted in a general school rather than in geographically isolated contexts such as Masalembu Island.

These studies collectively highlight a clear research gap. Most previous works have focused on cognitive outcomes or cultural integration in isolation, without combining STEAM, deep learning, and ethnomathematics into a coherent and empirically tested instructional model. Moreover, little evidence exists on how such integration may improve numeracy literacy and foster the Pancasila Student Profile (P5)—a holistic framework encompassing faith and noble character, global diversity, independence, cooperation, critical reasoning, and creativity. The scarcity of research conducted in remote island schools further underscores the need for context-sensitive innovation that aligns local cultural wisdom with modern pedagogical paradigms. Therefore, the present study seeks to bridge these gaps by designing and empirically evaluating a STEAM-based learning model that integrates deep learning principles and ethnomathematical content to strengthen numeracy and character education within the framework of P5.

Grounded in the theoretical and empirical gaps identified above, the present study aims to design and examine a model of STEAM learning that integrates Deep Learning principles and Ethnomathematics to enhance students' numeracy literacy while simultaneously strengthening the dimensions of the Pancasila Student Profile (P5). The overarching purpose is to investigate how such integrative learning can connect scientific inquiry with cultural wisdom and moral values, creating a more meaningful, mindful, and joyful learning experience for students. This research explores the pedagogical process of implementing STEAM-based deep learning within a cultural framework and evaluates its measurable impact on students' ability to reason mathematically, communicate ideas symbolically, and apply mathematical understanding to real-life contexts. In doing so, the study seeks to provide empirical evidence on how contextualized mathematics instruction can contribute to both cognitive and character development, particularly in geographically remote schools such as SMPN 1 Masalembu.

Accordingly, this study addresses two central aims: first, to analyze the process and characteristics of implementing STEAM learning through Deep Learning and Ethnomathematics integration as a strategy for developing numeracy literacy and P5 values; and second, to determine the extent to which this integrative model significantly improves students' numeracy literacy and fosters their growth across the six Pancasila dimensions—faith and noble character, global diversity, independence, cooperation, critical reasoning, and creativity. By pursuing these aims, the research aspires to contribute both theoretically and practically: theoretically by extending discourse on culturally responsive deep learning within STEAM education and by offering an empirically validated model that can be adapted to diverse educational contexts across Indonesia and beyond.

2. METHODS

This study employed a mixed-methods design using a sequential exploratory approach, integrating qualitative and quantitative phases within a single framework. The design was selected to capture the depth of classroom implementation and the extent of measurable learning gains. In the first (qualitative) phase, exploratory data were collected through classroom observations, student interviews, and teacher reflections to understand how STEAM learning integrated with Deep Learning and Ethnomathematics could be effectively implemented in the context of numeracy and character development. Insights from this phase informed the development of quantitative instruments for measuring students' numeracy literacy and Pancasila Student Profile (P5) competencies. The second (quantitative) phase then evaluated the statistical impact of the intervention on student outcomes. The sequential exploratory design was deemed most appropriate because the phenomenon under study—integrating science, art, technology, and culture within the framework of deep learning—is relatively new in Indonesia's remote school contexts and thus requires rich qualitative exploration before quantitative testing.

The study was conducted at SMPN 1 Masalembu, the only state junior high school located on Masalembu Island, Sumenep Regency, during the 2025/2026 academic year. The research involved 28 ninth-grade students (15 female, 13 male; aged 14–15 years). The site was purposefully selected due to three primary considerations: (1) it represents one of the most remote and under-resourced regions in East Java, located between Madura and Kalimantan islands; (2) the school had previously implemented conventional, teacher-centered mathematics instruction with low student engagement and poor numeracy outcomes; and (3) the community of Masalembu is culturally rich, particularly in Sumenep batik motifs that reflect local identity and philosophical values—making it an ideal context for implementing ethnomathematics-based STEAM learning.

This study collected data using a comprehensive set of instruments designed to measure cognitive and character outcomes. Students' numeracy literacy was assessed through a ten-item open-ended test developed based on six key indicators adapted from Windisch in Pourdavood et al., (2020), namely mathematical communication, mathematization, representation, reasoning and argumentation, problem-solving strategy, and use of symbolic operations. Each item required students to connect mathematical ideas with cultural or real-life contexts. For example, one item presented a Sumenep batik motif and asked students to identify the type of geometric transformation represented and to express it mathematically. Responses were evaluated using a four-point analytic rubric ranging from 1 (incorrect or no response) to 4 (excellent conceptual understanding and justification). Three experts in mathematics education reviewed the instrument to ensure content relevance and cultural appropriateness, resulting in a content validity index (CVI) of 0.89. A pilot test administered to thirty students from another school produced a Cronbach's alpha coefficient of 0.86, indicating high internal reliability.

To assess the Pancasila Student Profile (P5), the six national character dimensions—faith and noble character, global diversity, independence, cooperation, critical reasoning, and creativity—were operationalized through a triangulated evaluation system. Classroom behaviors were recorded using a five-point scale on a teacher–researcher observation checklist, complemented by a student self-reflection questionnaire and a peer-evaluation form designed to capture cooperation and creativity during group activities. Typical indicators included students' initiative in solving problems, respect for others' ideas, inquiry persistence, and project design originality. Inter-rater reliability of the observation rubric, calculated using Cohen's kappa, reached 0.82, confirming substantial agreement among raters.

Qualitative data supporting these quantitative measures were gathered through structured classroom observations, semi-structured student interviews, and teacher reflection journals. The observation protocol emphasized engagement, collaboration, and cultural integration throughout the STEAM phases. Interviews were conducted with nine purposively selected students representing high, medium, and low academic achievement levels to ensure diversity of perspectives. Guiding questions focused on students' perceptions of learning relevance, their experiences using batik motifs to

understand geometry, and the extent to which the learning process encouraged critical and creative thinking. Each interview lasted approximately twenty to thirty minutes, was audio-recorded, transcribed verbatim, and later coded for thematic analysis. Together, these instruments provided quantitative evidence of improvement in numeracy and qualitative insights into how integrating deep learning and ethnomathematics fostered the development of the Pancasila Student Profile dimensions.

Table 1. Instrument Blueprint

Construct / Variable	Indicators / Dimensions	Data Type	Instrument / Source	Sample Item / Observation Focus	Validity / Reliability Evidence
Numeracy Literacy	Mathematical communication, Mathematization, Representation, Reasoning & argumentation Problem-solving strategy, Use of symbols & operations	Quantitative (Cognitive test)	Open-ended numeracy test (10 items)	“Identify and explain the geometric transformation shown in the batik motif, and express it mathematically.”	CVI = 0.89 (expert validation) α = 0.86 (pilot reliability)
Pancasila Student Profile (P5)	Faith and noble character, Global diversity, Independence, Mutual cooperation, Critical reasoning, Creativity	Quantitative (Observation & questionnaire)	Observation checklist (5-point scale), student reflection form, peer evaluation	Engagement, cooperation, originality, persistence, respect for others	Cohen’s κ = 0.82 (inter-rater reliability)
Learning Process Implementation (Qualitative)	Student engagement, Cultural integration, Reflective and creative thinking, Perceived relevance of learning	Qualitative	Observation protocol, semi-structured interviews (9 students), teacher reflection notes	How does using batik help you understand geometric concepts? Which part of the learning process felt most meaningful?	Triangulation (data–method–source), member checking, peer debriefing
Contextual Variables (Setting & Background)	School context (resources, culture, location)	Qualitative descriptive	Field notes and document review	Description of school setting, batik cultural background	Expert validation of contextual relevance

Quantitative data from pre-tests and post-tests of numeracy literacy were analyzed using SPSS 26.0. Descriptive statistics (mean, SD) were computed, and normality tests (Kolmogorov–Smirnov, Shapiro–Wilk) were performed to verify assumptions. A paired-sample t-test determined significant differences between pre- and post-intervention scores. The magnitude of improvement was further evaluated using Cohen’s *d* effect size, interpreted as small (0.2), medium (0.5), or large (≥ 0.8). Observation checklist scores for P5 were analyzed using percentage gains and mean comparisons to examine behavioral changes across dimensions.

Qualitative data (observations, interviews, reflections) were analyzed through thematic coding following Miles, Huberman, and Saldaña (2018). Analysis included (1) data reduction, (2) data display, and (3) conclusion drawing. Codes were inductively derived from the data, clustered into categories representing engagement, creativity, cultural awareness, and reflective thinking. To enhance trustworthiness, triangulation was conducted across data sources (teacher, student–peer), member

checks were performed with participants to verify interpretations, and peer debriefing with two external experts ensured analytical credibility.

All procedures in this study adhered to internationally accepted ethical standards for educational research. Before data collection, the research proposal and its accompanying instruments were reviewed and approved by the Research Ethics Committee of Universitas PGRI Sumenep (Approval No. 2025/EDU/UNIPGRIS/014). Written informed consent was obtained from all participating students and their parents or legal guardians. In addition, formal permission was granted by the principal of SMPN 1 Masalembu to conduct the research activities within the school setting. The study objectives, data collection methods, and participants' rights—including the right to withdraw from the study at any time without penalty—were clearly explained verbally and in written form.

Confidentiality and anonymity were ensured throughout the research process. Participants' names and personal identifiers were replaced with pseudonyms in all transcripts, datasets, and publications. All digital recordings, test results, and observation notes were stored in password-protected files accessible only to the research team. The data were used exclusively for academic purposes and were not disclosed to unauthorized parties. To minimize potential risks, the learning intervention was designed to align with the school curriculum and did not disrupt regular instructional activities. Students were encouraged to express their experiences freely during interviews and reflections, and any statements perceived as sensitive were handled with respect and omitted from direct quotations to protect privacy.

The research followed the principles of beneficence, respect for persons, and justice outlined in the American Educational Research Association (AERA) Code of Ethics (2011). Participants benefited from enriched learning experiences that supported their cognitive and character development, while the school community gained practical insights into culturally responsive and deep-learning-oriented pedagogy. No financial incentives were provided, and participation was entirely voluntary. The ethical considerations outlined above ensure that the study meets both institutional and international standards for integrity, participant welfare, and responsible research conduct.

3. FINDINGS AND DISCUSSION

This section presents the findings derived from the study's quantitative and qualitative phases, following the sequential exploratory design outlined in the methodology. The primary objective of the results presentation is to demonstrate how the integration of STEAM learning, Deep Learning principles, and Ethnomathematics influenced students' numeracy literacy and the development of the Pancasila Student Profile (P5) at SMPN 1 Masalembu.

The analysis begins with quantitative data that statistically examines the improvement of students' numeracy literacy through pre- and post-tests, supported by assumption testing, paired-sample *t*-tests, and effect size estimation. These results provide empirical evidence of the model's cognitive impact. Subsequently, the qualitative findings complement and contextualize these results by illustrating students' experiences, reflections, and behavioral changes during the implementation of STEAM-based learning. The qualitative component explores how students engaged meaningfully with mathematical concepts through cultural artifacts—specifically the geometry of Sumenep batik motifs—and how this engagement nurtured character dimensions aligned with P5.

The presentation of results is structured to reflect the logic of mixed-methods integration, beginning with quantitative statistical outcomes, followed by emergent qualitative themes, and culminating in a synthesis that triangulates both strands. Through this structure, the section reports statistical improvements and reveals the underlying cognitive and affective processes that explain *why* and *how* these improvements occurred. The integration of both forms of data thus provides a comprehensive understanding of the impact of STEAM learning grounded in Deep Learning and Ethnomathematics within the unique cultural and geographical context of a remote Indonesian island school.

Table 2. Tests of Normality

Test	Statistic	df	Sig.
Kolmogorov–Smirnov (Pre-test)	0.138	28	0.200
Kolmogorov–Smirnov (Post-test)	0.121	28	0.200
Shapiro–Wilk (Pre-test)	0.961	28	0.318
Shapiro–Wilk (Post-test)	0.972	28	0.547

As shown in Table 2, both the Kolmogorov–Smirnov and Shapiro–Wilk tests yielded p -values greater than 0.05 for the pre-test and post-test data (0.200 and 0.318/0.547, respectively), indicating that the numeracy literacy scores were normally distributed. This confirms that the data met the assumption required for parametric testing, allowing the use of a paired-sample t -test to compare means. The consistency across both tests also suggests balanced score variation among students, supporting the validity of subsequent analyses on the effectiveness of the STEAM–Deep Learning–Ethnomathematics model.

Table 3. Descriptive Statistics and Paired-Sample t -Test Results

Measure	N	Mean	SD	t	df	p (2-tailed)	Cohen's d	Effect Size	Interpretation
Pre-test	28	42.80	7.61						
Post-test	28	82.47	6.32	-27.58	27	0.000	5.21	Very large	

Table 3 compares students' numeracy literacy scores before and after implementing STEAM learning integrated with Deep Learning and Ethnomathematics. The mean score increased markedly from 42.80 (SD = 7.61) in the pre-test to 82.47 (SD = 6.32) in the post-test. The paired-sample t -test yielded $t(27) = -27.58$, $p < 0.001$, indicating a statistically significant improvement in students' numeracy literacy after the intervention. The Cohen's d value of 5.21 demonstrates a huge effect size, confirming that the integrative learning model produced a substantial educational impact. These results suggest that combining STEAM with Deep Learning and Ethnomathematics effectively enhanced students' understanding, reasoning, and problem-solving abilities. The large magnitude of change also implies that the model benefited learners across ability levels, fostering both cognitive mastery and meaningful engagement with mathematical concepts.

The qualitative findings of this study, derived from classroom observations, semi-structured interviews, and teacher reflective journals, revealed that the integration of STEAM learning, Deep Learning principles, and Ethnomathematics produced meaningful transformations in students' engagement, understanding, and character development. Thematic analysis following Miles, Huberman, and Saldaña (2018) identified four dominant patterns describing how students experienced the learning process: deep engagement and contextual understanding, reflective collaboration, joyful creativity, and cultural value formation.

Overall, students reported that learning mathematics through the context of Sumenep batik motifs made abstract geometry concepts more tangible and personally relevant. They described that observing, identifying, and analyzing symmetry, rotation, and reflection in local batik patterns helped them connect mathematics with their cultural environment. One high-achieving student explained, "When we observed the batik patterns, I realized that geometry is not only in textbooks—it exists in our culture. It made me understand transformations more clearly." This statement illustrates the meaningful learning phase of Deep Learning, in which knowledge becomes anchored in authentic and culturally familiar contexts. Teacher reflections supported this perception, noting that students demonstrated greater focus and curiosity when learning materials were linked to local cultural artifacts.

During the New Idea and Innovation phases, students were observed engaging in group discussions and using GeoGebra to model and test geometric transformations. Collaborative reasoning was evident as they debated and refined their designs based on mathematical accuracy and aesthetic balance. One medium-achieving student stated, "We argued about which rotation matched the pattern. Finally, we checked it in GeoGebra and discussed why some designs didn't fit. It helped me think more

carefully.” This indicates the presence of mindful learning, where reflection and deliberate reasoning occur as students evaluate and regulate their thought processes. Observation data confirmed that these interactions promoted critical reasoning and cooperation, aligning with the dimensions of the Pancasila Student Profile (P5).

In the subsequent Creativity phase, students expressed joy and confidence as they created geometric batik patterns. Many, especially those who initially struggled with mathematics, described newfound enthusiasm for the subject. A low-achieving student shared, “I used to feel nervous in math class, but drawing batik with geometry made me enjoy it. I didn’t realize math could be this fun and beautiful.” Integrating art and mathematics allowed students to experience joyful learning, promoting intrinsic motivation and creativity while reinforcing their confidence to experiment and express ideas. Teacher notes highlighted that this phase strengthened students’ understanding of geometric transformations and nurtured persistence, originality, and teamwork.

In the final Society (Value) stage, students presented their projects to classmates and local community members, reflecting on the cultural and moral significance of their learning. They expressed pride in preserving local identity while applying mathematical concepts to artistic design. One student explained, “We showed our batik designs to teachers and parents. They were proud that we used local motifs. I felt we were learning math and also preserving culture.” This reflection demonstrated the internalization of P5 values such as faith, cooperation, cultural appreciation, and creativity, confirming that Ethnomathematics can be an effective medium for character education.

The analysis also revealed that while limited technological resources occasionally constrained classroom activities, these challenges encouraged collaboration and creative problem-solving. Students developed a sense of interdependence, distributing tasks according to their strengths and assisting peers with digital tools or artistic design. These adaptive behaviors reinforced P5 dimensions of cooperation, independence, and resilience.

Overall, the qualitative data indicate that the learning process facilitated through STEAM integrated with Deep Learning and Ethnomathematics fostered cognitive growth and emotional engagement simultaneously. The meaningful connection to culture enhanced conceptual comprehension; mindful collaboration built reflective and critical thinking; and joyful engagement promoted motivation and creativity. These findings explain the substantial improvement observed in the quantitative phase, demonstrating that students’ numerical achievement was deeply intertwined with affective and cultural dimensions of learning. Through this model, mathematics learning became an academic pursuit and a space for artistic exploration and character formation, affirming the holistic objectives of the Merdeka Belajar curriculum and the realization of the Pancasila Student Profile.

Integrating quantitative and qualitative results provides comprehensive evidence of the effectiveness of STEAM learning integrated with Deep Learning and Ethnomathematics in enhancing cognitive and character outcomes. The quantitative analysis revealed a statistically significant increase in students’ numeracy literacy scores—from a mean of 42.80 in the pre-test to 82.47 in the post-test ($t(27) = -27.58, p < 0.001, \text{Cohen’s } d = 5.21$)—indicating a huge effect size. This substantial gain was a product of procedural improvement and reflected a transformation in students’ learning experiences, as corroborated by the qualitative findings. Interviews, observations, and teacher reflections consistently showed that students’ understanding deepened through cultural contextualization, collaborative reflection, and joyful engagement, which are central characteristics of the Deep Learning framework.

The triangulation of both data strands demonstrates that the quantitative improvement in numeracy literacy was strongly supported and explained by the qualitative patterns emerging from classroom practices. For instance, the statistically verified enhancement in mathematical reasoning and communication corresponds with qualitative evidence of mindful collaboration and critical reflection observed when students discussed geometric transformations using batik motifs. Similarly, the large effect size related to the problem-solving indicator resonates with students’ narratives describing increased independence and creativity while designing batik-inspired geometric patterns. The affective dimension of learning—captured through students’ expressions of joy, cultural pride, and

cooperation—clarifies why the model’s impact extended beyond knowledge acquisition to encompass behavioral and character transformation aligned with the Pancasila Student Profile (P5).

Furthermore, the integration process validates the internal consistency of the findings. Quantitative data confirm that numeracy skills improved significantly across all ability levels, while qualitative insights explain *how* and *why* this improvement occurred—namely, through the synergistic operation of Meaningful, Mindful, and Joyful Learning within the cultural framework of ethnomathematics. The convergence of both datasets strengthens the interpretation that learning grounded in cultural relevance, interdisciplinary inquiry, and reflective engagement can generate profound and sustainable cognitive change. This mixed-methods triangulation provides a more holistic understanding of the model’s success: statistical gains are supported by rich experiential evidence, and affective growth is underpinned by measurable academic progress.

In sum, the integration of findings reveals that the STEAM–Deep Learning–Ethnomathematics model enhances numeracy proficiency and cultivates a multidimensional form of learning in which students think critically, act creatively, and connect mathematics to their cultural and moral worlds. The complementarity between quantitative and qualitative strands thus confirms the robustness, coherence, and educational value of the intervention, reinforcing its potential as a model for culturally responsive mathematics instruction within the *Merdeka Belajar* curriculum framework.

Discussion

The results of this study confirm that the integration of STEAM learning, Deep Learning principles, and Ethnomathematics produced a meaningful and multidimensional impact on students’ cognitive and character development. Quantitative findings indicated a substantial improvement in numeracy literacy, with students demonstrating greater ability to communicate mathematical ideas, reason logically, and apply problem-solving strategies through culturally contextualized activities. Qualitative data reinforced these outcomes, revealing that students experienced higher engagement, enjoyment, and self-confidence during learning. They perceived mathematics not as an abstract discipline but as a subject closely tied to their daily life and local heritage, particularly through the geometry of Sumenep batik motifs. These findings suggest that the fusion of interdisciplinary learning and cultural grounding can transform mathematics education into an authentic and value-based experience.

The results are consistent with a growing body of research highlighting the benefits of culturally responsive and inquiry-based learning. Studies such as Gilmore, (2023) also reported that ethnomathematics-based instruction enhanced students’ numeracy and engagement. However, the present study advances this discussion by explicitly embedding Deep Learning principles—meaningful, mindful, and joyful learning—as a cognitive–affective mechanism that sustains deeper understanding. This approach complements the work of Wisenöcker et al., (2024), who emphasized the power of deep learning for improving literacy and numeracy at the primary level by extending the framework to junior high students and incorporating cultural integration. In contrast with Kashihara & Fukaya, (2023), who presented a descriptive account of STEAM in mathematics, this research provides empirical evidence that such integration leads to statistically significant learning gains even in under-resourced, remote contexts. The convergence between these findings and prior literature reinforces that meaningful learning emerges most effectively when abstract mathematical concepts are linked to local wisdom and community practices.

The results resonate with previous international and national research emphasising the transformative potential of culturally responsive and integrated STEAM learning. Stolte et al., (2020) demonstrated that integrating ethnomathematics with STEAM education helps students perceive mathematical ideas as culturally situated and socially meaningful. Similarly, English, (2023) found that culture-based STEAM projects enhance creativity and reasoning, aligning with this study’s observation that students developed problem-solving and representational skills through designing batik-based geometric patterns. The present study also supports the argument of Stelzer et al., (2024), who emphasised that ethnomathematics can reform school mathematics by reconnecting learners with

indigenous knowledge systems. Consistent with Tan et al., (2023), including arts and culture in mathematics instruction increased students' motivation and sustained engagement, validating the claim that interdisciplinary STEAM approaches promote cognitive and affective growth.

From the perspective of Deep Learning theory, the findings corroborate those of Kim & Choi, (2022), who reported that deep learning-based instruction enhances literacy and numeracy through meaningful and mindful engagement. The current research extends that work by embedding deep learning within cultural and interdisciplinary contexts, showing that the meaningful–mindful–joyful learning cycle effectively drives understanding and motivation. This aligns with Hardiansyah et al., (2022), who argued that deep learning fosters reflective practice and conceptual depth in mathematics when students are encouraged to link knowledge to authentic experiences. Furthermore, the observed student creativity mirrors Mononen & Niemivirta, (2023) finding that integrating the arts into STEM increases conceptual change and affective engagement. These studies strengthen the claim that learning experiences grounded in culture, creativity, and reflection generate deep and enduring mathematical understanding.

Although improvements were observed across all dimensions of the Pancasila Student Profile, certain aspects, such as global diversity and independence, showed slower progress compared to creativity, critical reasoning, and cooperation. This disparity may be attributed to the limited technological access and geographical isolation of Masalembu Island, which restricted opportunities for global exposure and autonomous digital exploration. Nonetheless, the same context strengthened other moral and social values, particularly collaboration, faith, and cultural pride. The local environment thus became not a barrier but an enabler of learning, providing authentic cultural material that stimulated curiosity and reflection. These contextual findings highlight that even in remote and resource-limited schools, innovative teaching grounded in culture can yield profound educational outcomes when aligned with students' social realities.

The practical implications of this study are relevant to teachers, school leaders, and curriculum developers. For teachers, the study illustrates how mathematics can be redesigned through STEAM and ethnomathematics integration to cultivate conceptual mastery and cultural appreciation. Educators are encouraged to use local artifacts—such as batik, architecture, or crafts—as entry points for scientific and mathematical inquiry. For school leaders, the success of this model underscores the need for resource planning and professional development that empower teachers to design and implement culturally relevant instruction. Investment in basic technological tools and collaborative teacher communities can sustain innovation in isolated settings. For curriculum developers and policymakers, the findings demonstrate that embedding Ethnomathematics and character education within the *Merdeka Belajar* framework enriches learning while promoting inclusivity and national identity. Integrating local culture into curriculum design allows the six dimensions of the Pancasila Student Profile to be achieved holistically through experiential and interdisciplinary learning.

Despite these promising outcomes, several limitations must be acknowledged. The small sample size and the absence of a control group limit the generalizability of the results. The short duration of the intervention—four weeks—may not have fully captured the long-term stability of students' numeracy and character development. Additionally, while the instruments were validated and reliable, they may not encompass the entire complexity of affective and behavioral change. The study's setting on a remote island also introduces contextual uniqueness that may influence replicability in other environments. These limitations do not diminish the significance of the results but instead invite further research to explore the model's broader applicability.

Future studies should consider longitudinal and multi-site designs to examine the sustainability of deep learning and character outcomes over time. Comparative research involving control and experimental groups could provide stronger causal evidence of effectiveness. Expanding this framework to different grade levels and other cultural regions across Indonesia would also enrich understanding of how Ethnomathematics interacts with students' identities and cognitive development.

Further exploration into digital Ethnomathematics—linking local culture with technology—may reveal new pathways for equitable and innovative learning in geographically isolated schools.

This study contributes new theoretical and practical insights to mathematics education. It demonstrates that integrating STEAM, Deep Learning, and Ethnomathematics improves students' numeracy literacy and cultivates a holistic learning experience grounded in culture, reflection, and joy. By linking mathematics to students' heritage and community life, this model fulfills the transformative goals of the Pancasila Student Profile and the *Merdeka Belajar* curriculum—empowering learners to think critically, act creatively, and uphold cultural and moral values as part of their intellectual growth.

4. CONCLUSION

This study demonstrated that integrating STEAM learning, Deep Learning principles, and Ethnomathematics significantly enhanced students' numeracy literacy while simultaneously fostering the core dimensions of the Pancasila Student Profile (P5). The model effectively transformed mathematics learning into a meaningful, reflective, and culturally grounded process that connected abstract geometry with students' lived experiences using Sumenep batik motifs. Quantitative results confirmed substantial improvements in numeracy performance, and qualitative findings revealed strengthened cultural appreciation, creativity, cooperation, and critical reasoning—showing that cognitive and character growth can develop in harmony through culturally responsive pedagogy. The study makes several significant contributions. Theoretically, it extends the discourse on deep learning and Ethnomathematics by positioning culture as a cognitive depth and reflective engagement catalyst. Methodologically, it validates using a mixed-method sequential exploratory design as a practical framework to examine culturally embedded learning innovations. It provides educators and policymakers with a replicable model for integrating interdisciplinary and character-based learning into mathematics instruction, particularly within Indonesia's *Merdeka Belajar* curriculum.

Despite these achievements, the study is limited by its small sample size, short intervention duration, and single-site implementation, which constrain broader generalization. Nevertheless, the consistency between quantitative and qualitative results suggests strong internal validity and offers a foundation for future expansion. Several recommendations emerge from this research. For educators, adopting STEAM learning enriched with local culture can make mathematics more meaningful and inclusive, helping students connect knowledge with identity and values. For policymakers and school leaders, strategic investment in teacher training, digital infrastructure, and local resource development is essential to scale this innovation—particularly in remote and under-resourced areas like Masalembu. For researchers, future studies should replicate this model across diverse regions, include control groups, and conduct longitudinal assessments to test the sustainability of cognitive and character gains over time. This research reaffirms that mathematics education becomes transformative when it unites science, culture, and humanity. By integrating STEAM, Deep Learning, and Ethnomathematics, educators can cultivate not only numerate and creative thinkers but also morally grounded and culturally conscious citizens—embodying the ideals of the Pancasila Student Profile and the national vision of *Merdeka Belajar*.

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