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Contextualising IPAS learning through local wisdom: A culturally rooted PJbL model for primary education

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Abstract

The present study analyses the needs and readiness for implementing Science and Social Studies (IPAS) learning based on Project-Based Learning (PjBL) integrated with local wisdom values, particularly the Toba Nauli cultural philosophy, at the elementary school level. Motivated by the low science literacy of Indonesian students as revealed in the 2022 PISA results and the lack of contextual relevance in IPAS content, the research adopts a mixed-methods design combining qualitative and quantitative approaches. Data were collected through interviews, classroom observations, document analysis, and Likert-scale questionnaires involving 20 teachers and 40 students across four elementary schools in Medan. The research results show that teachers have a positive perception of the importance of PjBL and science literacy, as well as a high belief in the relevance of Toba Nauli values in IPAS learning (M = 4.20; SD = 0.68). However, the limitations of teaching modules, lack of training, and low use of local media have made cultural integration in learning not optimally implemented. On the other hand, students show high enthusiasm for project-based learning. However, their actual experience with learning incorporating local culture is minimal (only 15% of students reported having experienced it). These findings indicate a significant potential yet to be realised within the current IPAS learning system. Therefore, this research recommends developing a PjBL-based IPAS learning model that incorporates the Toba Nauli philosophy as a foundation for the local context to enhance students' science literacy in a meaningful, contextual, and culturally rooted manner. These findings are expected to serve as a conceptual and empirical foundation in designing transformative learning innovations in elementary schools.

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1. Introduction

The ability of science literacy is the primary foundation in preparing the 21st-century generation to think critically, solve data-based problems, and make responsible decisions for the environment and society. Science literacy includes understanding scientific concepts and the skills to apply them in real-life contexts reflectively and ethically. However, the reality of primary education in Indonesia shows that students' science literacy achievements are still concerning. Based on the results of the Programme for International Student Assessment (PISA) 2022, the average science literacy score of Indonesian students only reached 398, far below the OECD average of 500, with only 1% of students able to achieve the highest level of scientific thinking and apply scientific knowledge complexly in real-world contexts (*PISA 2022 Results (Volume I)*, 2023). Most students are only able to answer questions at a basic level and face significant difficulties when confronted with contextual scientific phenomena. This finding is reinforced by the study of Luh et al., 2025, which revealed that the science literacy of elementary school students falls into the low to very low category, particularly in the areas of conceptual understanding and scientific reasoning ability. Ironically, IPAS learning, which should serve as a vehicle for early science literacy development, is still dominated by a one-way approach, minimal exploration, and a lack of engagement with students' real-life dimensions.

This issue is not unrelated to the IPAS learning approach, which has yet to provide meaning through contexts relevant to the students' environment and culture. In the teaching at many elementary schools, the use of learning resources based on local experiences, surrounding ecosystems, and traditional cultural values is minimal, even almost neglected. However, a contextual approach that links science with local culture and environment has proven to enhance students' science literacy, as demonstrated in a systematic review by Muyassaroh et al., 2024, which concluded that the integration of local wisdom in science education can improve eco-literacy, science process skills, and student engagement in scientific inquiry activities. Local contexts such as the Lake Toba ecosystem and the Batak philosophy of life, 'Toba Nauli,' which emphasises balance and harmony between humans and nature, have great potential as meaningful learning environments for IPAS, but have not yet been integrated into the design of elementary school curricula. This creates a critical gap in our education system: science is taught as something abstract and distant from students' lives, rather than as a tool for understanding and preserving the world they inhabit.

Among the various local philosophies across Indonesia, Toba Nauli—a cultural worldview rooted in the Batak Toba community of North Sumatra—holds significant educational potential yet remains underutilised. Toba Nauli emphasises harmony between humans, nature, and the spiritual realm, advocating sustainability, communal responsibility, and environmental respect. These values align closely with science literacy and project-based learning objectives, particularly protecting ecologically aware, reflective, and community-oriented learners. However, despite this alignment, there is a scarcity of studies that explore how the Toba Nauli philosophy can be integrated into primary science education. Most culturally responsive science models have been developed in other regions, such as Java, Bali, or Lombok, while North Sumatra's rich local wisdom remains pedagogically unexplored.

These gaps indicate the existence of three main research gaps that underlie the urgency of this study. First, no study explicitly examines the relationship between low student science literacy and the absence of a local culture-based learning approach at the elementary school level. Second, there is a scarcity of needs research exploring how teachers, students, and the school context perceive the importance of integrating local values into IPAS learning. Third, although the validity of local culture-based science literacy instruments has been empirically proven (Ningsetyo & Sunarti, 2024; Suryanti, 2024) , there has been no study examining the readiness and needs of elementary

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schools in regions like North Sumatra to develop a contextual IPAS learning model rooted in local culture. Therefore, this research aims to analyse the factual needs for integrating local wisdom in IPAS learning to enhance elementary school students' science literacy. By elevating local living values as a conceptual framework and the local ecosystem as a learning laboratory, this study is expected to provide a foundation for formulating learning innovations and expand the paradigm of science education to be more inclusive, relevant, and rooted in local identity. The research novelty lies in the development of an empirical needs map within the local context that has not yet been explored, as well as the emphasis on the urgency of making culture the heart of science learning, rather than merely an ornament of multicultural education (Delimanugari & Yogyakarta, 2024).

2. Literature Review

2.1 Science literacy

Science literacy is the ability to understand scientific concepts and processes and apply them in daily life reflectively and responsibly towards the environment. In the context of primary education, science literacy becomes an essential foundation for shaping students who are critical, adaptive, and ecologically aware from an early age. Science literacy is vital in cultivating students' critical thinking, ecological awareness, and problem-solving abilities from an early age. It equips learners to make informed decisions based on evidence and ethical considerations in real-life situations. However, several studies indicate that the science literacy achievements of elementary school students in Indonesia are still in the low category. Based on the PISA 2022 results, Indonesian students' average science literacy score reached only 398, with only 1% of students achieving level 5 or 6, namely the highest scientific proficiency category (*PISA 2022 Results (Volume I)*, 2023). This is reinforced by the findings of Annafi & Agustina, (2018), which state that most elementary school students show significant weaknesses in scientific reasoning, data interpretation, and connecting scientific concepts to real-life phenomena. In another study, Yulianti et al. (2023) emphasised that low science literacy is closely related to the lack of contextual, interactive, and curiosity-stimulating learning media. This means that the problem of science literacy is not only caused by students' cognitive factors but also by the learning design that has yet to connect science with the local realities of the students. Therefore, a learning approach is needed that can ground science in contexts close to students' daily life experiences.

2.2 Local wisdom

Local wisdom is a form of collective knowledge that grows and develops from the cultural values of society, encompassing principles of sustainability, ecosystem balance, and social harmony that essentially intersect with scientific values (Febrian et al., 2024). Integrating local wisdom in learning enriches students' learning context and fosters a sense of ownership over the knowledge they acquire. Muyassaroh et al., (2024) their systematic literature review states that integrating local wisdom in science can enhance ecological literacy, science process skills, and students' critical thinking abilities. The study by Verawati & Wahyudi, (2024) also, science material contextualised with local cultural values significantly improves students' learning outcomes and conceptual understanding. A similar point was made by (Ramdani, 2023), who found that a culture-based science approach could encourage active student engagement, as they felt connected to the delivered content. On the other hand, research by Ningsetyo & Sunarti, (2024) developed a locally based science literacy assessment instrument that proved valid and reliable, reinforcing that the dimension of local wisdom is not merely a cultural narrative, but can be transformed into a legitimate scientific tool. However, these studies generally still focus on the regions of Bali, Yogyakarta, or Lombok, and very few explore the potential of local culture in North Sumatra, such as the 'Toba

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Nauli' philosophy as a learning framework. This indicates a geographical and conceptual gap in the literature on culturally-based science education, which demands further exploration of local Batak values as a learning resource for IPAS.

2.3 IPAS learning in elementary schools

The IPAS (Natural and Social Sciences) subject in the Merdeka Curriculum aims to integrate the understanding of science and social studies through a contextual and student-centred thematic approach. However, in practice, IPAS learning in elementary schools is still primarily conducted traditionally, with a dominance of lectures, rote memorisation of concepts, and minimal student involvement in the exploration process. Shofiyah et al., (2020) study mentions that teachers use textbooks as the sole learning source, without involving the surrounding environment as a contextual laboratory. The excellent opportunity to connect IPAS learning with local wisdom or ecosystems, such as Lake Toba, is often overlooked. However, research by Fauziah et al. (2023) shows that PISA questions formulated based on the local context of North Sumatra are valid in measuring students' scientific literacy, emphasising that the regional context is vital for learning and assessment. On the other hand, Lara Wanggi et al. (2023) study emphasises that learning media that combine local cultural elements with digitalisation can significantly enhance student participation and learning outcomes. Unfortunately, few IPAS learning models fully integrate contextual approaches and cultural values, especially in regions rich in culture and nature like North Sumatra. Therefore, it is crucial to map the needs and readiness of elementary schools in integrating local values into IPAS learning to enhance students' relevance, significance, and scientific literacy.

3. Method

This research uses a qualitative approach with an exploratory study design, aiming to deeply explore the needs, potential, and perceptions regarding the integration of local wisdom in IPAS learning as an effort to enhance the science literacy of elementary school students. The research was conducted in four elementary schools in Medan, selected through purposive sampling: SD Katolik Budi Murni 2, SD 066050 Medan Denai, SD Antonius 5 Medan Menteng, and SD PKMI 1 Medan. These four schools were selected based on two primary considerations. First, these schools have a learning environment relevant to the 'Toba Nauli' philosophy, a Batak Toba culture principle emphasising harmony between humans, nature, and spirituality. These values align with the essence of contextual and life-based IPAS learning and support a project-based learning (PjBL) approach with a local flavour. Secondly, the teachers at these schools demonstrate willingness and readiness to engage in learning innovations, particularly in implementing a PjBL approach integrated with local culture.

The research subjects consist of IPAS teachers, the school principal, and fourth and fifth-grade students who were purposively selected to provide rich and relevant data regarding the learning context and culture. Data collection techniques include semi-structured interviews, direct observation of learning activities, and document studies such as school curricula, lesson plans, and the teaching media. Interviews focus on the perceptions, experiences, and readiness of teachers and students in integrating local values into IPAS, while observations are directed at learning activities, classroom interactions, and the potential for contextualization that emerges (Prayuda et al., 2024). All data were analysed using a thematic analysis approach following the six stages of the Braun and Clarke model, namely: (1) data familiarisation, (2) initial coding, (3) theme searching, (4) theme reviewing, (5) theme naming and defining, and (6) narrative result compilation. This study applied methodological triangulation to enhance the validity and credibility of the findings. This

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involved cross-checking data from interviews, observations, questionnaires, and document analysis. Source triangulation was also applied by comparing perspectives from teachers, students, and principals to identify consistent themes and discrepancies.

4. Results

4.1 Teachers' perceptions of science literacy and the application of PjBL

The results of in-depth interviews and Likert scale questionnaires distributed to 20 IPAS teachers in four elementary schools in Medan show a positive tendency in their perceptions of the importance of science literacy and the potential of the Project-Based Learning (PjBL) approach in enhancing students' understanding. Most teachers stated that they generally understand the basic principles of PjBL and recognise the relevance of this approach to IPAS achievements, which emphasise problem-solving, collaboration, and the interconnection of concepts across disciplines. Teachers frequently cited practical constraints for the disconnect between their beliefs and practices. Interview data revealed that while most teachers had attended training sessions on PjBL, the sessions were generic and lacked technical guidance on designing culturally contextualised projects. Additionally, time limitations and the absence of localised teaching resources were recurrent barriers. Teachers expressed the need for ready-to-use, culturally relevant modules that align with the national curriculum and facilitate easier project design and evaluation. This is reflected in the high average scores on the item "I understand the basic concept of Project-Based Learning (PjBL)" (M = 4.05; SD = 0.76), as well as the item "I feel ready to implement PjBL in IPAS learning" (M = 3.85; SD = 0.74). These findings are consistent with the observation results, where two out of four schools have implemented simple project activities. However, they have not yet been fully integrated into the thematic IPAS learning system.

Table 1. Teachers' perceptions of project-based learning (pjbl) in ipas instruction

Questionnaire Item	Mean (M)	Standard Deviation (SD)	Percentage of Responses (%)
I understand the basic concept of Project-Based Learning (PjBL)	4.05	0.76	82
I feel ready to implement PjBL in IPAS learning	3.85	0.74	75
PjBL supports the achievement of IPAS objectives	4.1	0.68	88
I am confident in designing project-based learning activities	3.7	0.82	70
I have received training in PjBL methods	2.75	0.9	35

Nevertheless, there is a gap between conceptual knowledge and ideal implementation practices. Teachers stated that their training is generally generic and does not provide technical skills in designing contextual and measurable PjBL units. As many as 7 out of 8 teachers mention that the available teaching modules do not fully support the PjBL format, especially in integrating local cultural values. The teachers also stated that there is a time limitation in designing project activities that align with the IPAS curriculum, let alone those based on local culture. This condition shows that although the perception of science literacy and PjBL is relatively high, teachers still need concrete support in teaching modules, project examples, and systematic technical training. This is in line with the study by PUTRI et al., (2024) which states that teachers have a positive perception of the contextual approach but face technical limitations in its implementation. Therefore, enhancing

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teachers' capacity becomes a strategic aspect in promoting the implementation of PjBL to improve science literacy at the elementary school level.

4.2 Integration of local wisdom in IPAS learning

Integrating local wisdom in IPAS learning is still a limited and unstructured practice in Medan's primary education. The interviews with eight IPAS teachers revealed that 6 out of 8 teachers had never explicitly linked IPAS material with local culture, such as the Batak Toba philosophy 'Toba Nauli'. They stated that the main factors are the limited learning resources, the absence of locally-based teaching modules, and the lack of training. This is in line with the findings from the document study, which show that the IPAS teaching modules still rely on national theme books without adjustments to the students' local context. In the eight teaching modules reviewed, no learning activities linked the IPAS theme with aspects of culture, folklore, customary environments, or local ecosystems such as Lake Toba.

The results of the questionnaire also reinforce these findings. The statement "I have knowledge about local wisdom values (for example: Toba Nauli philosophy)" only received an average score of 3.25 (SD = 1.02), with only 45% of teachers giving a score of 4 or 5. This indicates that although teachers understand the importance of local culture, their mastery is still partial and not yet operational in teaching. Similarly, in the statement "I find it difficult to find ways to connect local culture with the IPAS topic," the average score reached 3.95 (SD = 1.08), indicating that most teachers acknowledge the conceptual and technical challenges in integrating these two domains. On the other hand, a high score was found on the item "I believe the Toba Nauli philosophy is relevant to be used as the context for IPAS learning" (M = 4.20; SD = 0.68; 80% of respondents gave a score of ≥4), indicating potential and openness to a locally-based cultural approach.

Table 2. Teachers' perceptions of local wisdom integration in IPAS learning

Questionnaire Item	Mean (M)	Standard Deviation (SD)	Percentage of Responses (%)
I know local wisdom values (e.g., Toba Nauli philosophy)	3.25	1.02	45
I believe the Toba Nauli philosophy is relevant to be used as the context for IPAS learning	4.2	0.68	80
I find it challenging to find ways to connect local culture with the IPAS topic	3.95	1.08	65
The IPAS modules I use are adapted to the local context	2.6	0.85	25
I have received training on integrating local culture into science or IPAS learning	2.4	0.94	20

Furthermore, classroom observations reveal that those activities that can potentially explore local values, such as discussing the surrounding environment or cleanliness customs, have not been explicitly implemented. The regional context only appears in the form of general geographical location mentions, without the development of cultural values. Meanwhile, students also state that they rarely or seldom learn IPAS related to Batak culture or local folklore. Only 15% of students report ever hearing the teacher explain IPAS material with references to local culture. These results indicate that integrating local wisdom in IPAS has potential but is not yet actual. There is a gap between teachers' positive perceptions and the reality of classroom learning practices. This reinforces the findings of Muyassaroh et al., (2024) and Verawati & Wahyudi, (2024), which emphasises the importance of culture-based science education in enhancing student relevance and literacy while confirming the need to develop contextual teaching models and modules that support local values'

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systemic and applicative integration. Although teachers demonstrate high awareness and favourable perceptions of both Project-Based Learning (PjBL) and the relevance of local wisdom, these beliefs are only partially translated into classroom practice. Observational data reveal a few instances where elements of PjBL are adopted, such as student group work, poster presentations, or simple hands-on projects related to environmental themes. For example, in one school, students collaborate to create visual reports on waste management around their school environment. This activity reflects some aspects of PjBL, such as collaboration and real-world relevance. Still, it lacks structured phases like sustained inquiry, critique, and revision, or public presentation, which are central to full PjBL implementation.

4.3 Student readiness and learning environment

Students' readiness to participate in project-based and culturally contextualised IPAS learning shows high potential, although it is currently not fully supported by a conducive learning environment. The results of the questionnaire given to 40 fourth and fifth-grade students in four elementary schools in Medan show that 75% of the students liked the IPAS subject, especially when the learning involved hands-on practice or simple experiments. This is reflected in the high positive response to questions about experiences with projects such as planting, recycling, or making simple reports about the environment (60%). Meanwhile, 82% of students prefer IPAS learning linked to stories, shows, and real projects, indicating a strong preference for experience-based and contextual approaches.

Table 3. Students' perceptions of IPAS learning and cultural integration

Questionnaire Item	Mean (M)	Standard Deviation (SD)	Percentage of Positive Responses (%)	Percentage of Responses ≥4 (%)
I like learning the IPAS subject	4.15	0.72	75	75
I enjoy doing hands-on projects in IPAS (e.g., planting, recycling)	3.85	0.78	60	65
I prefer IPAS learning that includes stories, videos, or real-life projects	4.35	0.68	82	82
I have learned that IPAS is linked to local culture (e.g., Batak stories, Lake Toba)	2.5	0.95	15	18
I find IPAS learning more interesting when related to my daily life or environment	4	0.74	68	70

However, only 15% of students report studying IPAS referencing local culture, such as Batak folktales or discussions about Lake Toba. This indicates that although there is potential interest and high enthusiasm, students' experience with IPAS learning incorporating local culture is minimal. These limitations are confirmed through classroom observations, where learning activities are dominated by lecture and question-and-answer methods, with slight variation in the use of teaching media or locally-based learning resources. In two schools that have previously implemented thematic projects, the activities are general, such as creating environmental posters or weather reports, without any connection to the students' cultural values or local context. The learning environment also does not fully support project-based learning approaches or cultural integration. The visual media used are still limited to images in textbooks, and there has been no use of learning aids that incorporate local cultural symbols. Teachers' teaching modules follow national theme

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books without local adaptation. Meanwhile, the principal states that there is currently no school policy encouraging the use of local culture in teaching, although they welcome the idea positively.

5. Discussion

The triangulated findings from interviews, classroom observations, module reviews, and Likert-based questionnaires collectively indicate an urgent yet promising opportunity to innovate IPAS (Science and Social Studies) learning in Indonesian primary schools. Specifically, implementing a culturally grounded Project-Based Learning (PjBL) model holds significant potential, particularly when anchored in the philosophical tenets of Toba Nauli. However, this potential remains underutilised due to systemic and pedagogical fragmentation across the three primary domains: teacher perception, student readiness, and environmental support.

Teachers show encouraging awareness of both science literacy and the conceptual utility of PjBL, as demonstrated by the high mean scores for items measuring confidence and understanding (M = 4.05 for PjBL understanding). Yet, this awareness has not translated into consistent pedagogical action. Despite openness to the idea of integrating local wisdom, reflected in 80% agreement on the relevance of Toba Nauli, practical constraints such as the lack of localised teaching modules, inadequate training, and time limitations impede implementation. These gaps corroborate Perdana et al., (2024), who emphasise that technical and media support is critical for transforming teachers' positive perceptions into practice. The results reinforce the assertion of Muyassaroh et al., (2024; Verawati & Wahyudi, (2024) that cultural integration in science education strengthens student identity and cognitive engagement, an assertion yet unrealised in the Medan primary context.

Based on the student perspective, the findings revealed a pronounced affective readiness toward culturally contextualised and experience-based learning. More than 80% of the students surveyed preferred IPAS instruction that incorporates stories, visual media, and real-life project elements that align with constructivist principles of learning, which posit that knowledge is best constructed when learners engage with meaningful, authentic experiences. This preference suggests that students are not merely passive recipients of information but are intrinsically motivated to engage with content that resonates with their lived realities and cultural narratives. Motivation is critical in primary education, where curiosity and emotional engagement are foundational to scientific literacy and long-term academic interest.

However, this motivational potential is sharply undercut by the scarcity of exposure to culturally grounded content within current IPAS practices. Despite living in a region rich with contextual learning opportunities, only 15% of students reported having learned IPAS topics connected to their local heritage, such as Batak folktales, traditional ecological practices, or themes related to Lake Toba. This mismatch between preference and practice is reinforced by classroom observation data, which revealed that most lessons rely heavily on didactic teaching methods, workbook completion, and textbook-driven questioning, with limited integration of multimedia resources or exploratory tasks.

This disconnect reflects what Rahmadani et al., (2025) identify as a pedagogical paradox: learner enthusiasm without corresponding instructional responsiveness. In such cases, student motivation becomes a missed asset rather than a catalyst for learning. When learners' cultural backgrounds are ignored in the design of science instruction, the result is diminished engagement and a failure to build on the cognitive scaffolds that local knowledge naturally provides. Without contextual anchors, abstract scientific concepts remain disconnected from students' daily lives, hindering conceptual understanding and relevance. The findings thus underscore a critical implication: motivation alone is insufficient in the absence of a learning environment that activates

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and channels that motivation through context-sensitive design. The underutilisation of student affective readiness represents a structural inefficiency within current pedagogical practice, one that this research seeks to address through developing a model that bridges motivation with implementation, and cultural identity with scientific reasoning.

The juxtaposition of internal motivation (both among teachers and students) with external limitations (lack of infrastructure, media, and curricular guidance) constitutes a critical educational tension. This tension supports the broader findings of the PISA 2022 report, which diagnosed Indonesia's low science literacy due to disembodied science education, one detached from students' lived experiences (*PISA 2022 Results (Volume I)*, 2023). Furthermore, the lack of geographical coverage in existing literature, especially regarding the Toba cultural framework, underscores the originality and necessity of this research. Previous studies examining the integration of local wisdom in primary science education have predominantly centred on regions with well-documented cultural pedagogies, such as Yogyakarta, Lombok, and parts of Java. For instance, Ningsetyo & Sunarti (2024) developed instruments for science literacy rooted in the cultural context of Probolinggo, emphasising how local traditions can be embedded into environmental education. Similarly, research by Azizah & Wulandari, (2024) in Lombok explored the Sasak community's ecological wisdom in designing thematic learning media, focusing on applying Sundanese culture in constructing contextual science modules. These works illustrate the growing recognition of local wisdom as a pedagogical asset. However, they also share a standard limitation: a concentration of case studies within Java-centric or island-specific educational ecosystems.

In contrast, North Sumatra, particularly its Toba Batak cultural landscape, remains significantly underrepresented in the discourse surrounding culturally responsive science education. The philosophy of Toba Nauli, which promotes harmony between humans, nature, and spirituality, offers profound alignment with the objectives of IPAS learning, particularly in fostering ecological literacy and holistic reasoning. This cultural foundation has yet to be meaningfully translated into instructional models, teaching modules, or curriculum design despite its richness. A review of national and regional science education journals reveals minimal scholarly engagement with the Batak culture as a pedagogical resource, let alone within the framework of Project-Based Learning.

This underrepresentation constitutes a critical research gap. It suggests both a theoretical blind spot and a missed opportunity to diversify the national landscape of contextualised science pedagogy. The present study addresses this regional imbalance by focusing on integrating Toba Nauli into IPAS learning. It contributes to a more inclusive vision of science education that validates Indonesian cultures' diversity as meaningful epistemological resources in formal learning. As such, this study offers novelty in its empirical context and its potential to expand the conceptual boundaries of culturally grounded science education beyond previously explored dominant regions. The Merdeka Curriculum emphasises contextual, student-centred, and flexible learning, making it highly compatible with implementing a Project-Based Learning (PjBL) model that integrates local wisdom. However, turning this theoretical alignment into school-level practice requires deliberate planning, institutional support, and culturally relevant resources.

Therefore, this study substantiates a pressing need to develop a culturally contextualised PjBL model for IPAS learning. Such a model should provide systematic guidance, localised modules, and training interventions to transform philosophical resonance into educational praxis. The model can act as a pedagogical bridge by aligning local culture with scientific inquiry, rooting abstract concepts in familiar realities, and enhancing students' scientific reasoning and ecological sensitivity. Implementing such a model also aligns with curriculum mandates under *Merdeka Belajar*, where contextualisation and student agency are prioritised. These findings map the readiness and gaps in the current system and contribute to the theoretical advancement of culturally responsive science

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pedagogy in Indonesia. The empirical insights generated here establish a strong foundation for model development that is both locally grounded and globally relevant.

6. Conclusion and Implications

This study has revealed a clear and actionable gap in the current implementation of IPAS learning in Indonesian primary education, specifically in how the potential of Project-Based Learning (PjBL) and local wisdom, such as the Toba Nauli philosophy, remains untapped, mainly despite positive dispositions from both teachers and students. The triangulation of interview, observation, document analysis, and questionnaire data presents a consistent pattern: while teachers demonstrate strong conceptual awareness of science literacy and express high regard for the relevance of PjBL, they lack the pedagogical tools, technical training, and contextual resources to translate these ideals into practice. Meanwhile, students exhibit high levels of affective readiness and a clear preference for experiential and culturally relevant learning. Yet, their classroom experiences remain disconnected from their cultural environments and local knowledge systems.

These findings affirm earlier research suggesting that meaningful learning occurs when scientific instruction is rooted in the cultural, ecological, and social realities of students (*PISA 2022 Results (Volume I)*, 2023). Moreover, the evidence highlights a geographical gap in current literature: unlike regions such as Java or Lombok, North Sumatra, particularly the Batak cultural ecosystem, has not been the focus of pedagogical innovation in science education. This study, therefore, contributes a novel empirical foundation for developing a contextually grounded, culturally responsive PjBL model tailored to the Toba Nauli worldview.

The implications of this research are twofold. First, at the pedagogical level, there is an urgent need to design and pilot IPAS learning models that add cultural elements as supplementary content and embed them structurally within the curriculum through project-based activities. These models should be supported by localised teaching modules, flexible learning media, and structured guidance that enable teachers to bridge scientific concepts with cultural narratives and real-world phenomena. Second, the results call for targeted capacity-building initiatives at the policy and teacher development level, particularly in regions where cultural heritage is rich but underutilised. Training programs must move beyond abstract curriculum interpretation and offer hands-on, community-based approaches to integrate local wisdom meaningfully into science education. This study lays the groundwork for an academically rigorous, socially and culturally inclusive pedagogical transformation. Future research should focus on testing culturally rooted PjBL models across different regions of Indonesia, such as Papua, Kalimantan, and Sulawesi, to evaluate their adaptability and effectiveness in diverse cultural and ecological contexts. Such cross-regional studies will help determine the generalisability and scalability of localised pedagogical models. Additionally, longitudinal research is needed to assess the sustained impact of integrating local wisdom on students' science literacy, environmental awareness, and cultural identity development. Another important avenue is the co-development and testing localised IPAS modules, in collaboration with teachers, cultural experts, and community members, to create scalable and context-sensitive instructional frameworks. Furthermore, future studies should explore the role of digital technology in enhancing culturally relevant PjBL, particularly how multimedia tools, virtual platforms, or locally developed digital content can facilitate the integration of indigenous knowledge in science education, especially in remote or underserved schools.

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