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Collaborative Integration of Indigenous Knowledge and Pedagogical Approaches in Science Education: A Systematic Review of Epistemological Perspectives (2020–2025)

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Abstract

Equipping learners to address contemporary environmental, technological, and societal challenges is a central objective of science education. However, curricula frequently prioritize Western scientific paradigms, resulting in the marginalization of indigenous knowledge systems that offer culturally meaningful and locally grounded insights. This systematic review synthesizes 11 empirical studies published between 2020 and 2025 that investigate the collaborative integration of indigenous knowledge and pedagogical approaches in science education, focusing on epistemological perspectives and educational implications. A comprehensive search was conducted across major academic databases, and relevant studies were screened using explicit inclusion and exclusion criteria to ensure rigor. The final corpus was analyzed to identify research characteristics, models of collaboration, epistemological lenses, and practical mechanisms. Findings indicate that collaborative integration strategies, including co-designed STEAM/STEM curricula and culturally responsive pedagogical approaches, enhance learner engagement, promote epistemic pluralism, and support contextually grounded learning experiences. Epistemological frameworks such as contextual constructivism, relational knowledge, and ethnoscience underpin effective integration, guiding curriculum design and instructional practice. The review concludes that embedding indigenous knowledge collaboratively with pedagogical strategies is critical for culturally responsive science education and offers actionable insights for educators, curriculum developers, and policymakers seeking pluralistic, context-sensitive, and ethically informed learning environments.

Keywords: Epistemological Perspectives, Indigenous Knowledge, Pedagogical Approaches, Science Education, Systematic Review

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INTRODUCTION | مقدمة

Science education plays a crucial role in equipping learners to understand and respond to complex environmental, technological, and societal challenges (Morris, 2025; Ng et al., 2024; Verawati & Purwoko, 2024; Vuorio et al., 2024). Research by Rustamova (2023) indicates that educational practices grounded in learners' local cultural and ecological contexts foster deeper conceptual understanding, enhance engagement, and support meaningful learning experiences. Although culturally responsive pedagogy is increasingly valued, mainstream science curricula continue to prioritize western scientific knowledge (Ajayi, 2025; Chang & Viesca, 2022; Marosi et al., 2021; Smith et al., 2022). Consequently, indigenous knowledge, which provide contextually

rich and culturally grounded insights into natural phenomena, are frequently marginalized (David, 2024; Motsumi & Nemakonde, 2024; Redvers et al., 2023; Varghese & Crawford, 2021).

Integrating indigenous knowledge into science education is therefore increasingly recognized as essential for promoting epistemic pluralism (Guibrunet et al., 2024; Yazidi & Rijal, 2024). It also supports educational practices that are socially and environmentally relevant. The epistemological lens through which indigenous knowledge is interpreted significantly shapes educational outcomes (Macfarlane et al., 2008). Approaches such as contextual constructivism, relational knowledge, and ethnoscience illustrate that knowledge is both co-constructed and ethically grounded (Gannar & Kilani, 2025). These approaches provide learners with culturally sensitive and pluralistic understandings of scientific phenomena.

Research conducted by da Silva et al. (2024) highlights that, although several studies have examined individual instances of indigenous knowledge integration in science education, a systematic synthesis of these efforts remains urgently needed. Their review primarily foregrounds structural and cultural barriers that marginalize indigenous epistemologies in formal schooling and emphasizes issues of representation, contextual relevance, and intercultural dialogue, particularly in primary education settings. Similarly, findings from Ogegbo & Ramnarain (2024) suggest that a broader synthesis could clarify how indigenous knowledge integration may enhance learning relevance and inclusivity. However, existing reviews have largely examined what forms of indigenous knowledge are included in curricula rather than how such knowledge is collaboratively integrated with pedagogical approaches in instructional practice. In contrast, earlier work by Riggs (2005) often conceptualized indigenous knowledge primarily as curri

Unlike prior systematic reviews that focus predominantly on content inclusion or structural barriers, this review explicitly emphasizes collaborative processes and epistemological alignment between indigenous knowledge holders and formal pedagogical approaches. It advances the discussion by examining how indigenous knowledge is integrated through pedagogical models such as co-designed curricula, culturally responsive teaching, and inquiry-based approaches rather than being treated as supplementary or illustrative content. Addressing this gap requires a systematic investigation of both the epistemological foundations and practical mechanisms that enable indigenous knowledge to inform pedagogy in meaningful and equitable ways. While case-specific studies provide valuable contextual insights, a comprehensive synthesis is necessary to connect pedagogical strategies with indigenous epistemologies and to examine their philosophical and educational implications. By doing so, this review offers actionable guidance for curriculum designers, educators, and policymakers seeking to advance science education that is culturally responsive, pedagogically coherent, and epistemically pluralistic.

Research Aim and Research Questions

Accordingly, this review aims to examine the collaborative integration of indigenous knowledge and pedagogical approaches in science education, with particular attention to identifying general research characteristics, models of integration, epistemological perspectives, and their implications for pluralistic and context-sensitive teaching. The research is guided by the following questions:

RQ1. What are the general research characteristics of studies addressing the collaborative integration of indigenous knowledge and pedagogical approaches in science education (2020–2025)?

RQ2. Sw do studies describe the forms and models of collaboration between indigenous knowledge and pedagogical approaches in science education?

RQ3. What epistemological perspectives are used to interpret or justify the collaborative integration of indigenous knowledge and pedagogy in science education?

RQ4. What are the philosophical implications of such epistemological perspectives for developing pluralistic and context-sensitive science education?

METHOD | منهج

Data Sources, Search Engines and Keywords

This systematic review employed a rigorous methodology to examine how indigenous knowledge (IK) has been collaboratively integrated with pedagogical approaches in science education. The review adhered to PRISMA guidelines to ensure transparency, reproducibility, and methodological rigor. Relevant studies were systematically retrieved from three major academic databases, namely Scopus, Google Scholar, and ERIC. To structure the analysis and accommodate heterogeneous evidence, the SPIDER framework (Sample, Phenomenon of Interest, Design, Evaluation, Research type) was employed.

The sample included pre-service and in-service teachers, as well as learners at early childhood, primary, secondary, and higher education levels who participated in formal educational interventions integrating indigenous knowledge. The phenomenon of interest focused on the collaborative integration of indigenous knowledge with pedagogical approaches, including culturally responsive pedagogy, project-based learning, inquiry-based learning, and STEM or STEAM frameworks. The design encompassed research and development studies, experimental and quasi-experimental interventions, classroom action research, and qualitative case studies. The evaluation emphasized outcomes related to epistemic pluralism, culturally responsive learning, scientific literacy, and recognition of indigenous knowledge systems. Quantitative, qualitative, and mixed-method studies were included to capture diverse empirical and epistemological perspectives.

A systematic search was conducted using predefined keywords combined with Boolean operators to enhance replicability. The core search string integrated three conceptual domains, namely indigenous knowledge, pedagogy, and science education. An example of the search string applied across databases was: (indigenous knowledge OR indigenous science OR local knowledge OR traditional knowledge) AND (science education OR science learning OR STEM OR STEAM) AND (pedagogy OR teaching approach OR instructional model OR culturally responsive teaching OR curriculum integration). Minor adaptations were made to align with the specific syntax of each database. It is acknowledged that restricting the search to English-language and full-text accessible publications may have resulted in the exclusion of relevant studies published in other languages, particularly from Global South contexts where indigenous knowledge is often documented in local or regional journals. This limitation represents a potential linguistic and access-related bias and should be considered when interpreting the findings.

Study Selection: Inclusion and Exclusion Criteria

To ensure methodological rigor and transparency, explicit inclusion and exclusion criteria were applied. Studies were included if they met the following conditions: (1) empirical integration of indigenous knowledge within science education contexts, (2) the implementation of pedagogical approaches that explicitly facilitated collaboration among educators, learners,

and indigenous knowledge holders, and (3) evidence-based outcomes across cognitive, socio-cultural, or epistemic dimensions. Studies were excluded if they lacked empirical data, did not involve explicit collaborative integration, or focused solely on content delivery without pedagogical or epistemological grounding. These criteria were operationalized across key dimensions, including publication year, language, subject area, document type, peer-review status, access, and education level, as summarized in Table 1.

Table 1 The Inclusion & Exclusion Criteria

Category	Inclusion Criteria	Exclusion Criteria
Publication Year	Published between 2021–2025	Published before 2021 or after 2025
Language	Available in English	Not available in English
Subject Area	Social sciences, science education, STEM/STEAM, indigenous knowledge	Not related to science education or indigenous knowledge
Document Type	Journal article	Book, conference paper, review, editorial, or other non-article types
Peer Review & Access	Peer-reviewed and full text accessible	Not peer-reviewed, full text not available, or closed access / subscription only
Education Level	Early childhood, primary, secondary, higher education, teacher professional development	Informal learning, adult learning outside formal/pre-service education, or education level not specified

Following the application of the inclusion and exclusion criteria summarized in Table 1, the initial search across multiple academic databases yielded a substantial number of records. These records represented a wide range of studies from diverse educational contexts, spanning early childhood to higher education, and covering various pedagogical approaches that integrate indigenous knowledge within science education. To ensure that only relevant and methodologically sound studies were retained, each record underwent a multi-stage screening process following the PRISMA framework. The overall study selection process, from initial retrieval to final eligibility determination, is depicted in Figure 1.

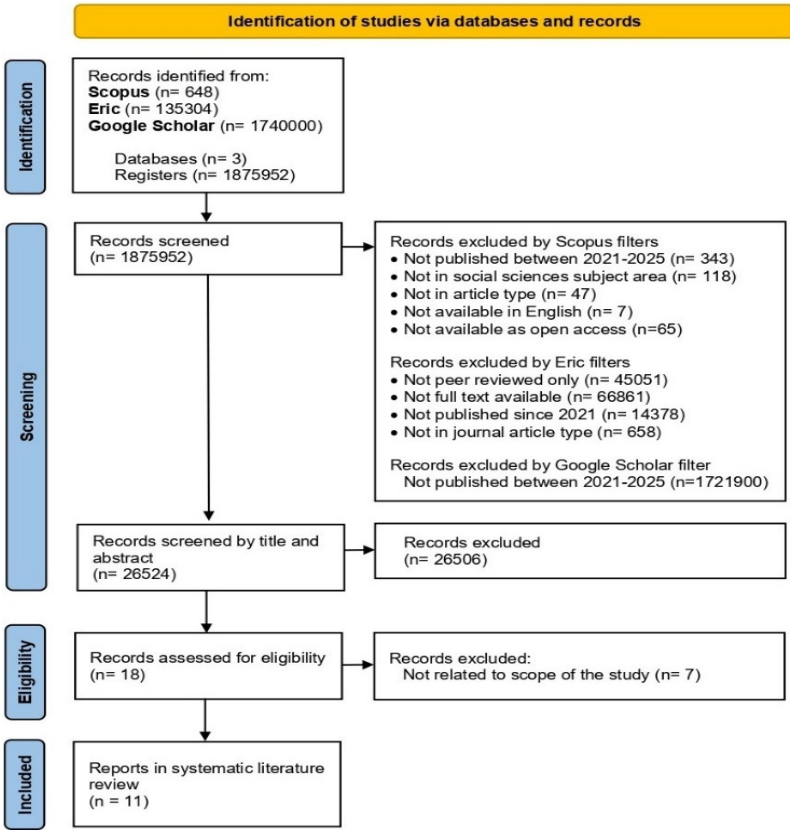

Figure 1. PRISMA Flow Diagram

As depicted in Figure 1, the multi-stage screening and eligibility assessment refined the initial pool of records to a final corpus of 11 studies. These selected studies met the inclusion criteria, providing robust evidence on collaborative practices, pedagogical approaches, and epistemological frameworks in science education. The final corpus thus forms a methodologically rigorous foundation for subsequent analysis and synthesis in addressing the research questions of this review.

RESULT | نتائج

General Research Characteristics

The selected studies reveal a diverse distribution across publication years, regions, research methodologies, and educational levels, reflecting both the global interest in culturally responsive science education and the variety of approaches employed to integrate indigenous knowledge into formal learning environments. To examine the general research characteristics of studies addressing the collaborative integration of indigenous knowledge and pedagogical approaches in science education, a structured overview was prepared. The corresponding data are presented in Table 2.

Table 2. Studies Included in the Constitution of the Corpus

Study Code	Authors	Research Focus
S1	Sukmawati et al. (2024)	Integration of Science Integrated Learning (SIL) model with Next Generation Science Standards (NGSS) to develop prospective biology teachers' ability in preserving indigenous knowledge in Indonesia.
S2	Sefoka & Chuene (2025)	Exploration of grade 10 learners' views on integrating indigenous knowledge into life sciences topics through cooperative learning in South Africa.
S3	Simpson et al. (2023)	Afterschool ARCH and STEM program integrating archaeology, indigenous knowledges, and western STEM concepts to enhance learners' intercultural understanding.
S4	Mat Noor & Roslan (2025)	Ethnographic study identifying Iban indigenous funds of knowledge and integrating them into a culturally relevant STEAM curriculum for Brunei primary education.
S5	Chen & Wu (2024)	Development of a STEM-integrated indigenous early childhood disaster preparedness curriculum grounded in Rukai traditional knowledge in Taiwan.
S6	Tra et al. (2025)	Context-based learning integrating traditional musical instruments of Central Highlands ethnic groups to teach scientific concepts of sound in Vietnam.
S7	Nyamupangedengu & Khupe (2024)	Humanizing biology teaching through integration of Karanga traditional beer brewing knowledge to connect indigenous science with formal biology concepts in South Africa.
S8	Wahyu et al. (2023)	Implementation of a STEM-based Project-Based Learning (PjBL) model incorporating Manggarai indigenous science content to improve elementary students' scientific literacy in Indonesia.
S9	O'Donoghue et al. (2024)	Collaborative design of STEAM teacher education integrating indigenous technologies and knowledge for Education for Sustainable Development (ESD) in South Africa.
S10	Chahine (2022)	Development of culturally relevant multimedia and professional development programs integrating Southeast Asian and African Indigenous Knowledge into STEM teaching in the U.S. context.
S11	Sarkingobir & Bello (2024)	Quantitative analysis of ethnoscience-integrated Problem-Based Learning (PBL) model to enhance secondary students' critical thinking in Nigerian science education.

Table 2 presents details of the studies included in the corpus, providing study codes, authors, and research focus. From this overview, it is evident that the studies span multiple educational contexts and explore diverse strategies for integrating Indigenous knowledge with formal science education, including teacher training, classroom interventions, and afterschool programs. This table serves as the foundation for analyzing trends and patterns in study objectives and contexts. To further contextualize the characteristics of the selected studies, descriptive attributes such as publication year, country, methodology, and education level were systematically compiled, as shown in Table 3.

Table 3. Characteristics of Studies Included in the Corpus

Characteristics	Variations	Studies Code	N	%
Publication Year	2022	S10	1	9.09
	2023	S3, S8	2	18.18
	2024	S1, S5, S7, S9, S11	5	45.45
	2025	S2, S4, S6	3	27.27
Region/ Country	Asia (Indonesia, Vietnam, Taiwan, Brunei)	S1, S4, S5, S6, S8	5	45.45
	Africa (South Africa, Nigeria)	S2, S7, S9, S11	4	36.36
	America (USA)	S3, S10	2	18.18
Methodology	Quantitative	S11	1	9.09
	Qualitative	S2, S3, S4, S5, S6, S7, S9	7	63.63
	Mixed Methods	S1, S10	2	18.18
	R&D	S8	1	9.09
Education Level	Preschool/ Early Childhood	S5	1	9.09
	Primary	S4, S8	2	18.18
	Secondary	S2, S6, S7, S11	4	36.36
	Higher Education	S1	1	9.09
	Teacher Education / PD	S9, S10	2	18.18

Table 3 highlights that most studies were published between 2023 and 2024, with representation from Asia and Africa. The methodological distribution is predominantly qualitative, complemented by mixed-methods, quantitative, and research and development designs. The studies also cover a range of education levels from early childhood to teacher professional development, illustrating the diversity of contexts in which collaborative integration of Indigenous knowledge occurs. Subsequently, the distribution of studies according to journal indexing and scholarly outlet was analyzed, with the summary provided in Table 4.

Table 4. Distributions of Literature with Journal Identity

Indexing	Journal Name	Studies Code	N	%
Scopus Q1	Education Sciences	S3	1	9.09
	Cultural Studies of Science Education	S4	1	9.09
	Sustainability	S5	1	9.09
Scopus Q2	Eurasia Journal of Mathematics, Science and Technology Education	S2	1	9.09
	Educational Research for Social Change (ERSC)	S7, S9	2	18.18
Scopus Q3	*Jurnal Pendidikan IPA Indonesia*	S1	1	9.09
	International Journal of Evaluation and Research in Education (IJERE)	S6	1	9.09
Google Scholar	*Jurnal Penelitian Pendidikan IPA*	S8	1	9.09
	Journal of Indigenous Research	S10	1	9.09
	International Journal of Ethnoscience and Technology in Education (IJETE)	S11	1	9.09

Table 4 shows that the studies are disseminated through a mixture of Scopus-ranked journals (Q1–Q3) and reputable Google Scholar-indexed outlets. This distribution indicates the academic recognition and credibility of the research, supporting the relevance and impact of the corpus in advancing knowledge on culturally responsive and epistemically plural science education.

Quality Appraisal of Included Studies

To ensure the credibility of the synthesized evidence, the methodological quality and potential risk of bias of the included studies were systematically appraised. Given the diversity of research designs within the final corpus, encompassing qualitative, quantitative, and mixed-method studies, a set of adapted quality appraisal criteria commonly used in education research was applied. The appraisal focused on clarity of research objectives, appropriateness of research design, transparency of data collection and analysis procedures, adequacy of sample description, and alignment between reported findings and conclusions. Each study was independently assessed by two reviewers. Any discrepancies in appraisal judgments were resolved through

discussion to reach consensus, thereby reducing subjectivity and enhancing the reliability of the quality assessment. The purpose of this appraisal was not to exclude studies solely based on quality scores, but to contextualize the interpretation of findings within the synthes

The appraisal results indicated that most included studies demonstrated moderate to high methodological quality. Studies generally provided clear descriptions of educational contexts and pedagogical interventions integrating indigenous knowledge. Qualitative studies were characterized by rich contextualization and coherent analytical interpretations, while quantitative and mixed-method studies showed reasonable alignment between research questions, instruments, and analytical approaches. Nevertheless, several recurrent limitations were identified that may introduce potential bias. These included small sample sizes, limited reporting of researcher positionality, and insufficient detail regarding the operationalization of collaboration with indigenous knowledge holders. Additionally, the absence of longitudinal designs in many studies constrained the assessment of sustained educational impacts. These limitations were considered during the thematic and epistemological synthesis, particularly when interpreting c

Overall, the quality appraisal provides a critical lens for interpreting the evidence base underpinning this review and strengthens the validity of the conclusions drawn regarding collaborative integration of indigenous knowledge and pedagogical approaches in science education.

Models and Forms of Collaborative Integration

The analysis of the selected studies highlights the various models and forms through which indigenous knowledge is collaboratively integrated with pedagogical approaches in science education. The focus is on understanding how collaboration between educators, learners, and indigenous knowledge holders is operationalized to foster culturally responsive and epistemically pluralistic learning environments. To provide a structured overview of these collaborative models, the pedagogical approaches, indigenous knowledge integration, and mechanisms of collaboration from the selected studies are summarized in Table 5, presenting the operational forms of collaboration in each study.

Table 5. Pedagogical Approaches and Indigenous Knowledge Collaboration

Study Code	Pedagogical Approach	Indigenous Knowledge Integration	Mechanism of Collaboration
S1	Science Integrated Learning (SIL) with NGSS	Indigenous ecological and cultural knowledge embedded into microteaching for prospective biology teachers	Collaborative curriculum design between teacher educators and students; NGSS content contextualized through local cultural practices and community insight
S3	Afterschool ARCH and STEM program	Integration of indigenous knowledge, archaeology, and stem inquiry	Co-facilitation by educators, scientists, and indigenous cultural experts; shared decision-making in developing inquiry activities based on Indigenous epistemologies
S4	STEAM curriculum co-design	Iban indigenous funds of knowledge integrated into primary science curriculum	Teachers and community elders co-develop curriculum materials; Indigenous knowledge guides learning goals, content selection, and assessment design
S5	STEM-based early childhood disaster preparedness program	Rukai traditional ecological knowledge applied to disaster preparedness learning	Co-creation of curriculum between Indigenous knowledge holders, teachers, and early childhood specialists; STEM concepts taught through cultural practices and storytelling
S9	Collaborative STEAM lesson design in teacher education	Indigenous technologies and local craftsmanship embedded into teacher training	Joint design of lessons by university researchers and pre-service teachers; Indigenous knowledge informs pedagogical strategies and creative lesson innovations

As shown in Table 5, the studies demonstrate diverse models of collaborative integration. Science Integrated Learning (SIL) and NGSS-aligned microteaching (S1) exemplify curriculum-level collaboration between teacher educators and prospective teachers. Afterschool programs such as the ARCH and STEM initiative (S3) emphasize co-facilitation and shared decision-making with Indigenous cultural experts. STEAM curriculum co-design (S4) and early childhood disaster preparedness programs (S5) highlight collaboration with community elders and knowledge holders to embed Indigenous practices into learning. Collaborative lesson design in teacher education (S9) illustrates joint creation of pedagogical strategies that merge local craftsmanship and Indigenous technologies with formal instruction.

Collectively, these studies indicate that collaborative integration is operationalized through structured co-creation, shared decision-making, and culturally contextualized curriculum design, providing a robust model for epistemically pluralistic and culturally responsive science education.

Epistemological Perspectives

The selected studies in this review reveal diverse epistemological perspectives used to interpret and justify the collaborative integration of Indigenous knowledge with pedagogical approaches in science education. These perspectives provide a conceptual foundation for understanding how learning practices accommodate epistemic pluralism while remaining culturally and locally grounded. The epistemological analysis aimed to identify the theoretical assumptions that informed how knowledge was positioned, negotiated, and validated within each study.

The classification of epistemological lenses presented in this review was developed through a theory-informed qualitative coding process combining deductive and inductive approaches. Initially, sensitizing concepts were drawn from established theoretical frameworks in science education and Indigenous scholarship, including constructivism, sociocultural theory, Third Space theory, situated knowledge, relational epistemology, and ethnoscience. Subsequently, each study was examined inductively to identify explicit statements or implicit assumptions regarding the nature of knowledge, learning processes, the role of culture and community, and the relationship between Indigenous and Western scientific knowledge systems.

Epistemological coding was conducted independently by two researchers to enhance analytical rigor. Each researcher assigned preliminary epistemological labels based on recurring conceptual patterns within the studies. Differences in interpretation were discussed iteratively until consensus was reached, ensuring that the final classifications reflected both theoretical coherence and empirical grounding. The resulting epistemological lenses therefore represent an integrative synthesis of prior theory and evidence emerging from the reviewed studies. A summary of the identified epistemological lenses and their interpretive meanings is presented in Table 6.

Table 6. Epistemological Lenses and Interpretive Meanings of Selected Studies

Studies Code	Epistemological Lens	Epistemological Orientation and Interpretive Meaning
S1, S5	Contextual Constructivism (Atwater, 1996; Cobern, 1996)	Knowledge is constructed through culturally contextual experiences. Scientific understanding emerges when inquiry is embedded within Indigenous worldviews and learners' lived local contexts, emphasizing context-rich and culturally responsive meaning making.
S2, S9	Sociocultural Constructivism (Vygotsky, 1978)	Learning and cognition are mediated through social interaction, cultural tools, and dialogue. Emphasizes collective participation and community-based sense making that integrates Indigenous and scientific epistemic resources.

S3, S4, S10	Third Space (Concept) (Bhabha, 1994)	Frames learning as occurring within a hybrid epistemic space where Indigenous and Western knowledge systems intersect. Challenges epistemic hierarchies and promotes intercultural negotiation of meaning.
S6, S10	Situated Knowledge (Haraway, 1988)	Knowledge is understood as socially, historically, and ecologically situated. Rejects claims of universal objectivity and affirms Indigenous standpoints as contextually valid and epistemically legitimate.
S7, S8	Relational Knowledge (Wilson, 2008)	Rooted in Indigenous epistemology, knowledge is relational, holistic, and ethically grounded. Knowing emerges through reciprocal relationships among humans, nature, and the wider cosmos.
S11	Ethnoscience (Ogunniyi, 1988; Zidny et al., 2020)	Indigenous systems of classifying and explaining natural phenomena function as an epistemic bridge connecting traditional ecological knowledge and formal scientific inquiry through dialogical pluralism.

As shown in Table 6, the epistemological lenses align closely with the collaborative models of integration identified across the studies. Curriculum-level collaborations, such as Science Integrated Learning and NGSS-aligned microteaching, reflect contextual and sociocultural constructivist orientations through co-designed learning experiences between teacher educators and prospective teachers. Afterschool programs and STEAM curriculum co-design initiatives demonstrate Third Space and relational epistemologies by emphasizing co-facilitation and shared decision making with Indigenous cultural experts and community elders. Collaborative lesson design in teacher education further illustrates how epistemological assumptions shape pedagogical practices that merge local craftsmanship and Indigenous technologies with formal science instruction.

Collectively, these findings indicate that collaborative integration of Indigenous knowledge in science education is underpinned by explicit and implicit epistemological commitments. These commitments are enacted through structured co-creation, shared epistemic authority, and culturally contextualized curriculum design, providing a robust foundation for epistemically pluralistic and culturally responsive science education.

Philosophical Implications for a Pluralistic Philosophy

The reviewed studies collectively affirm the philosophical basis for embracing pluralism in science education. The integration of indigenous knowledge into school science challenges the traditional view that science represents a single, objective way of knowing. Instead, the findings emphasize that multiple epistemologies coexist and can enrich one another (S2, S5, S8). This perspective reframes science as a human and culturally embedded enterprise that is inseparable from social, environmental, and spiritual relationships (S3, S7). Philosophically, this shift reflects a stance of epistemic humility, recognizing that knowledge is relational and partial when detached from its cultural and ecological context. Studies such as S4 and S9 show that indigenous worldviews, which connect knowledge with land, ancestry, and community, complement the analytical and empirical orientation of western science. Their coexistence enables learners to develop a balanced understanding of the natural world through both relational and evidence-based perspectives.

Several studies (S1, S5, S10) further highlight this pluralistic approach as a form of epistemic justice. When indigenous languages, ecological practices, and oral traditions are valued alongside scientific explanations, knowledge becomes both intellectually diverse and ethically grounded. This philosophical orientation positions science education not merely as the transmission of universal facts but as an act of cultural recognition and moral responsibility. Teachers also play a vital role in sustaining philosophical pluralism (S3, S6, S8). Through reflective practice, they translate philosophical principles into classroom realities by using local artefacts, lived experiences, and critical dialogue to connect scientific ideas with cultural meaning. In doing so,

educators cultivate inclusive, dialogical learning environments where students co-construct scientific understanding rather than passively receive it.

Taken together, these studies support a plural and relational philosophy of science (S2, S7, S10). Knowledge is viewed as dynamic and evolving through continuous interaction among cultures, communities, and environments. Such a philosophical framework redefines science education as a shared inquiry into meaning, relationship, and responsibility, fostering respect, cultural integrity, and intellectual openness in an interconnected world.

DISCUSSION | مناقشة

The results of this review demonstrate the substantial educational significance of the collaborative integration of Indigenous knowledge (IK) into formal science curricula. Across the selected studies, embedding local ecological and cultural knowledge within structured pedagogical models, such as the Science Integrated Learning (SIL) with NGSS framework (S1), was found to enhance students' comprehension of scientific concepts while simultaneously recognizing and validating Indigenous epistemologies. These findings are consistent with previous research by Bilican et al. (2015), which indicates that science education grounded in contextual experiences enhances conceptual understanding and learner engagement. From an educational standpoint, these results suggest that curriculum designers and educators should intentionally integrate Indigenous knowledge alongside formal science content to foster learning experiences that are both culturally meaningful and pedagogically coherent.

The integration of Indigenous knowledge also facilitates collaborative pedagogical practices that engage multiple educational stakeholders (Ogegbo & Ramnarain, 2024). Programs such as the afterschool ARCH and STEM initiative (S3) and STEAM curriculum co-design (S4) illustrate that co-facilitation involving educators, community elders, and Indigenous knowledge holders enables shared decision making that strengthens learning outcomes. This aligns with sociocultural constructivist perspectives, which emphasize that knowledge is produced through social interaction and communicative processes (Luckmann, 2008). Accordingly, collaborative mechanisms should be embedded within instructional practices, teacher education, and curriculum development to promote participatory and culturally responsive learning environments (Bottiani et al., 2018; Pasternak et al., 2023).

However, the findings also highlight the need for critical reflection on the challenges and ethical dilemmas inherent in collaborative integration. Several studies implicitly reveal tensions related to power asymmetries between formal educators and Indigenous knowledge holders, particularly in determining whose knowledge is legitimized, how it is represented, and who retains authority over its interpretation. Without careful negotiation, collaborative initiatives risk reducing Indigenous knowledge to symbolic or tokenistic inclusion, rather than recognizing it as an epistemologically equal system. Moreover, concerns regarding the commodification or instrumentalization of Indigenous knowledge emerge when such knowledge is incorporated into standardized curricula without clear agreements on ownership, consent, and benefit sharing. These challenges underscore the importance of ethical safeguards, including mutual consent, recognition of intellectual sovereignty, and transparent collaboration processes, to ensure that integration efforts do not inadvertently reproduce colonial power structures (Andreotti et al., 2011).

Culturally embedded pedagogical approaches further support epistemic pluralism while foregrounding ethical and relational dimensions of science education. Studies incorporating

traditional disaster preparedness knowledge (S5) and Indigenous craft and technological practices (S9) demonstrate that learners develop not only practical competencies but also ethical awareness grounded in local cultural values. This resonates with relational knowledge perspectives, which emphasize reciprocity, responsibility, and ethical accountability in knowledge construction (Kuhlen, 2011). Nevertheless, these approaches require sustained dialogue and reflexivity to balance educational goals with respect for cultural boundaries and community priorities. As such, Indigenous knowledge should not be positioned merely as supplementary content, but as a relational process that demands ongoing negotiation, trust building, and ethical engagement (Demssie et al., 2020).

The role of teacher professional development is therefore central to sustaining ethically grounded collaborative integration (Choi & Kang, 2019; Goodyear, 2017; Liu, 2013). Evidence from studies such as S10 suggests that professional development programs incorporating Indigenous knowledge can equip educators with the competencies needed to mediate between diverse epistemologies while remaining sensitive to cultural and ethical considerations. These findings have direct implications for educational policy, indicating that teacher education should include structured preparation in culturally responsive pedagogy, ethical collaboration, and reflexive practice. By doing so, educational systems can move beyond normative inclusion toward more equitable, context-sensitive, and ethically responsible science education capable of addressing complex environmental and societal challenges (Debasu & Yitayew, 2024; Eden et al., 2024).

CONCLUSSION | خاتمة

The present review synthesizes empirical evidence on the collaborative integration of Indigenous knowledge and formal pedagogical approaches in science education. The findings indicate that embedding Indigenous knowledge within structured teaching models, such as Science Integrated Learning, STEAM, and project-based learning, enhances students' scientific literacy while simultaneously validating local epistemologies. Collaborative mechanisms involving educators, learners, and Indigenous knowledge holders foster participatory and culturally responsive learning environments that support epistemic pluralism. Importantly, this review advances theoretical discourse in science education by reconceptualizing integration not as a mere merger of content, but as a co-epistemic practice grounded in mutual recognition, shared authority, and dialogical knowledge construction. In this sense, Indigenous knowledge functions not as an add-on, but as a constitutive epistemological dimension in the design of inclusive and context-sensitive science curricula.

The educational implications of these findings are multifaceted. First, curriculum designers and educational policymakers should institutionalize the collaborative inclusion of Indigenous knowledge within science curricula to enhance cultural relevance and epistemic inclusivity, rather than treating it as supplementary or symbolic content. Second, teacher professional development programs should systematically incorporate preparation in culturally responsive pedagogy, collaborative curriculum design, and reflexive mediation between Indigenous and scientific knowledge systems. Third, educational practice should foreground ethical, relational, and contextually embedded approaches to science learning, promoting holistic competencies such as critical thinking, problem-solving, and socio-environmental responsibility. Future research should examine the longitudinal impacts of co-epistemic integration on student learning, teacher practice, and educational equity, thereby ensuring that epistemic pluralism translates into sustained pedagogical and societal benefits.

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