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Equitable Integration of Indigenous Knowledge System in STEM Education Professional Development: A systematic review

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Abstract: The integration of Indigenous Knowledge Systems (IKS) into STEM education is critical for addressing longstanding inequities and fostering a culturally responsive educational framework. This systematic literature review examines professional development initiatives aimed at incorporating IKS into K-12 STEM education, with a focus on teacher preparation, equity, and science education between 2009 and 2024. Through thematic and quantitative analyses of 30 peer-reviewed studies, the review highlights challenges, such as the dominance of Western epistemologies and the marginalization of Indigenous perspectives in professional development programs. It identifies effective strategies, including place-based learning, storytelling, and reciprocal partnerships with Indigenous communities, as essential for bridging epistemological gaps and promoting cultural sustainability. The findings emphasize the need for professional development models that prioritize Indigenous methodologies, foster critical consciousness, and challenge colonial biases embedded in STEM curricula. This study underscores the transformative potential of integrating IKS to create equitable and inclusive educational practices that honor diverse ways of knowing.

Keywords: STEM Education, Indigenous Knowledge Systems, Professional Development, Equity.
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Introduction

The Sociopolitical Context of Science Education

A persistent issue in STEM education is the traditional focus on content knowledge and scientific methodologies, which often disregards the sociopolitical contexts within which science operates. This framing perpetuates the view of science as objective, neutral, and apolitical—sometimes even dangerously absolute. However, science is inherently shaped by specific historical and cultural contexts, influencing its development, dissemination, and application (Tolbert & Bazzul, 2016). For instance, institutions like the National Science Foundation (NSF), National Institutes of Health (NIH), and Department of Energy determine what scientific knowledge is produced by funding research aligned with their agendas, demonstrating how sociopolitical forces control science through the approval of grant proposals.

Hegemonic Structures in STEM and Education

Apple (2019) highlighted how subjects like science are positioned in education to serve economic roles within hegemonic structures. The curriculum prioritizes technical skills and knowledge which align with the demands of the capitalist labor market, fulfilling Gramsci's (2020) concept of hegemony, wherein ideological constructs are presented as neutral and natural (Apple, 2019). Consequently, science education often emphasizes economic utility over cultivating critical and reflective citizens, reinforcing existing social and economic hierarchies instead of challenging them.

Colonial Legacies and Epistemic Inequality

Western science, long regarded as the definitive framework for understanding nature, perpetuates hegemonic structures by upholding colonial and racist ideologies. These biases manifest in study designs, research questions, methodologies, and data interpretations (Held, 2023). During colonial times, Western scientific practices marginalized Indigenous knowledge systems, labeling them as primitive or unscientific. This epistemological dominance persists in science education, supported by standardized curricula, high stakes testing, and policies framing science as a tool for economic preparation (Rezende & Ostermann, 2020). Such practices disconnect science from its social, cultural, and political dimensions, reinforcing systemic power imbalances and marginalizing alternative ways of knowing.

The Marginalization of Indigenous Knowledge Systems

Climate change discourse exemplifies the dismissal of Indigenous knowledge systems. For instance, polar bears are often used as symbols of climate change impacts, while the lived experiences and ecological insights of Indigenous Arctic communities are overlooked (Tam et al., 2021). Indigenous peoples have a deep understanding of their environment developed over millennia, yet their knowledge is excluded due to Western epistemic dominance (Tam et al., 2021; Held, 2023). In global discourse, climate change in the Arctic is framed so that it serves the interests of capitalist nations and corporations as opposed to the lived realities of the Indigenous communities in the Arctic. Polar bears are vulnerable to climate change due to their use of the sea ice as a place of rest, walking, and seal hunting, labeling them and other marine mammals as “ecosystem sentinels”. Of the 19 polar bear populations, some of them are experiencing starvation and reproductive issues (Moore and Reeves, 2018 as cited by Tam et al., 2021). However, the Inuit state the overall health of polar bears in Canada is overall well, however hunting restrictions have caused mismanagement of the populations, leading to an increase in fatal bear and human encounters (Tam et al., 2021). Western bias in climate science specifically has been reproduced: 45% of all countries from the developing world have not had contributions from authors to the processes of the Intergovernmental Panel on Climate Change (IPCC) (Biermann and Moller, 2019 as cited by Tam et al., 2021). Thus, the scientific and civic viewpoints of climate change, its impacts, and possible solutions as well as the victims are designed from a Western (Global North) perspective, whereas Indigenous, poor, developing (Global South) peoples experiences are explicitly ignored in the design of solutions. This ‘sacred ecology’ (Berkes, 2012) is pointedly ignored, as is Indigenous people's deep relationship with their land, plants and animals alike. They have developed place-specific knowledge which provides guidance for resource management, spiritual connections to their environment and relationships with their land, and thus both a reverence for animals and practicality of use for their mixed subsistence economy (Tyrrell and Clark, 2014). As opposed to natural resource exploitation that focuses on short-term gains, Indigenous ways emphasize long-term sustainability, such as rotational hunting, controlled burns, and selective harvesting (Tam et al., 2021). The focus on Western knowledge represses the cultural and social aspects of Indigenous communities: their rituals, ceremonies, and traditions often rely on the relationship between the people and their environment. These cultural practices remind them of their ethical obligations to be stewards for their lands, pass down ecological knowledge through stories, art, and communal practice (Tam et al., 2021). Unfortunately, with issues such as

environmental degradation, climate change, and resource extraction, the solutions which are developed without the input of those where this is their lived realities, the ones most affected by these issues (Tolbert and Bazzul, 2016). Nwokocha and Legg-Jack (2024) argue that accelerated biodiversity loss, environmental degradation, and loss of cultural practice and heritage makes the study of Indigenous Knowledge Systems (IKS) a crucial focus. Al-Mansoori and Hamdan (2023) discuss that the place-based knowledge Indigenous communities have for the fauna and flora which is not obvious to outsiders, there are relationships and interactions in these environments that are not considered by Western science, which can be used to make predictions about the changes seen in species behavior or population shifts which can be potentially utilized to mitigate biodiversity loss. IKS, also sometimes referred to as native or local knowledge that is made up of local, indigenous, or traditional forms of knowledge or skill within a specific community and are formed through continuous experiences over time in their environments and challenges these peoples face and provide transferable knowledge or application outside of their original geographical context (Bruchac, 2014). As an example, Amazon rainforest Indigenous communities have observed and know of a symbiotic relationship between specific tree species and insects which are pivotal for pest control in the area and improve the general health of the ecosystem, promoting a balance between the human needs and conservation of the environment and ecosystem (Ramadoss and Poyya Moli, 2011).

Literature Review

Challenges in Integrating Diverse Epistemologies

Coloniality in science and in STEM education recreates the power imbalances seen in society: Western, capitalist, technologically driven forms of knowledge are institutional, while lording over local, relational, and ecological knowledge, as well as place-specific knowledge (Takeuchi and Marin, 2022). Any other view, such as sacred ecology, challenges the Western notion that nature is simply a resource to be controlled, commodified, and dominated (Tam et al., 2021). This cognitive injustice, systemic devaluation of non-Western knowledge systems (de Sousa Santos, 2015), has stemmed from the historical imposition of the Western scientific paradigms, used to perpetuate oppression of Indigenous and other marginalized groups. Colonizers dismissed Indigenous knowledge as primitive or unworthy of inclusion in scientific discourse during the colonial era, which has led to loss of valuable knowledge and furthering ongoing social and epistemic inequality (Haverkort, 2021). This epistemological dominance, described by de Sousa Santos (2015) as “epistemicide,” dismisses Indigenous ways of knowing as unscientific, despite their long-standing contributions to environmental understanding and resource management.

The Role of Education in Addressing Inequities

Integrating Indigenous Knowledge Systems (IKS) into STEM education offers a holistic approach, blending Indigenous and Western scientific views. Constructivism supports this integration, emphasizing knowledge construction through experience (Taber, 2014). It broadens learners’ understanding of science within societal and cultural contexts (Aikenhead & Michell, 2011), enhancing their interpretation of natural phenomena (Zidny et al.,

2020). Research also shows that incorporating IKS improves students' comprehension and achievement in subjects like chemistry (Ugwu & Diovu, 2016).

As it stands, many educators lack the skills to integrate Indigenous perspectives into their teaching. Addressing this requires professional development to equip teachers with the tools to incorporate Indigenous Knowledge Systems (IKS). Providing culturally accurate resources, such as textbooks and multimedia, developed in collaboration with Indigenous communities, is vital. Partnerships with Indigenous organizations and experts can further support educators with resources and guidance (Al-Mansoori and Hamdan, 2023). One of the gaps we see in professional development portion for integration of IKS with science or STEM education is simply resource availability, such as textbooks and curriculum, as well as training specific for effective incorporation of IKS (Hennessy et al., 2022). Another and much bigger issue is the epistemological conflict with Western-centric educational frameworks for which most if not all teachers are trained under (Al-Mansoori and Hamdan, 2023). Mainstream institutions often question the validity of Indigenous perspectives, dismissing them as anecdotal or unscientific (Godard and Smith, 2004). Addressing epistemological conflicts within Western-centric educational frameworks requires educators to unlearn inequitable assumptions and embrace critical pedagogies which empower students through culturally relevant teaching methods (Ladson-Billings, 1998).

Research Question

The purpose of this systematic literature review was to see what was currently in the literature regarding what professional development is either being developed, theorized, or has been implemented for equitable integration of Indigenous Knowledge Systems in science education. It is important to take the temperature of the literature and academia to know what directions have been done and where there is still more room to grow, especially taking note of which countries seem to be focusing more on integration with their native populations.

This SLR sought to answer the following research questions:

1. What are the characteristics of sampled studies on K-12 S-T-E-M/STEM teacher professional development in Indigenous Knowledge Systems, science education, and equity published in peer-reviewed journal articles between the years 2009 and 2024 (Table 1)?
2. What patterns exist in the Indigenous Knowledge Systems (Table 2), science education (Table 3), and equity (Table 4)?

Methods

A systematic literature review (SLR) was conducted on 30 articles as listed in the Appendix. A SLR is a method for synthesizing evidence to address a specific research question in a transparent and reproducible manner, while introducing gaps and areas in need of further research. They aim to incorporate all published evidence on the topic while critically assessing the quality of that evidence (Lame, 2019). The primary goal of the SLR is to minimize bias and enhance transparency throughout the review process (Nightingale, 2009; Lame, 2019). This is achieved by

employing explicit, systematic methods to reduce bias in study selection and inclusion, evaluate the quality of the included studies, and objectively summarize their findings. Clinical sciences and healthcare were some of the first fields to employ this method, but have since spread to other fields, such as education research (Nightingale, 2009). SLRs have been used previously to investigate pedagogical practices used for incorporation of IKS in science education (Ogegbo and Ramnarain, 2024), analysis and synthesis of the global conceptualization of IK from a variety of cultural perspectives of Indigenous peoples (Madonsela and Machete, 2023), implementation of cross-cultural research in regard to indigenous science education (Ruddell et al., 2021), review of reported programs from 2011-2020 that supported Indigenous students in science and STEM education (Jin, 2021), and the incorporation of Indigenous and local knowledge into sustainability and environmental education (Druker-Ibanez and Caceres-Jensen, 2022) A collection of databases was used to search for articles such as: ERIC, Scopus, and Google Scholar.

In the first phase, the search focused on pre-service teachers (PSTs) only, the keywords used were: "science education", "PD", "indigenous knowledge systems", and "pre-service". In the second phase, the search focused on in-service teachers (ISTs), the keywords used were: "science education", "PD", "indigenous knowledge systems", and "in-service". The final phase, the focus was equity, and the keywords used were: "equity", "science education", "PD", and "indigenous knowledge systems ".–Articles were selected for this SLR based on the following criteria: publication from 2009-2024, focus was K-12, must be an empirical journal article, and general reliability that had all the proper components of an empirical study (population of study, research methodology, and instruments of data collection). Studies within and outside the United States were considered and included. This study was confined to only 30 articles per the scope of the class. An exception was made for A Metasynthesis of the Complementarity of Culturally Response and Inquiry-Based Science Education in K-12 Settings: Implications for Advancing Equitable Science Teaching and Learning by Brown (2017). It was crucial to include as it brings in the conflict between CRP and Western science-based education, as well as the idea inquiry-based sciences create issues for linguistically and culturally diverse students, which leads to further marginalization, therefore a reason to look further at inquiry as a practice and ensure that they are not only Western in approach and implementation. A checklist was created based on the criteria, screened abstracts regardless of inclusion and exclusion were stored and documented in Zotero. Data was extracted from the 30 studies using Garrard's (2004) Matrix Method, as recommended when conducting SLR by Cho and Egan (2009). The characteristics of the selected studies shown in Table 1 as a quantitative presentation of the articles were developed through tabulation of frequency counts and taking the percentage from total studies for basic characteristics of the study such as target focus (PST or IST), location, methods, research methodology used, and instruments used in data collection.

For the qualitative analysis as shown in Tables 2, 3, and 4, thematic analysis was employed to describe patterns across the data, which was collected through coding of patterns and relationships seen across the 30 articles in regard to IKS, science education, professional development, and equity (Braun and Clark, 2006). The coding process was conducted in multiple iterative stages. Initially, an open coding approach was used to generate preliminary codes, capturing key concepts emerging from the articles. This was followed by axial coding, wherein codes were refined, merged, or split

based on their conceptual relationships (Strauss and Corbin, 1998). Themes were developed through an inductive and deductive sorting of codes, grouping them into overarching themes and subthemes based on their connections and shared meanings (Braun and Clark, 2006).

Results

It is worth noting that the majority of the papers included in this analysis were from South Africa (n= 12, 38.7%), with only (n= 5) 16.1% coming from the United States. Most papers were qualitative (n=22, 70.9%) and the research methodologies were mainly on case studies (n=8, 25.8%) with a wide spread of different methodologies used (see Table 1). Primary instruments for data collection were interviews (n=20, 64.5%) and observations of the participants (n=10, 32.2%). While there were articles which utilized IKS or local Indigenous culture as part of their methods and instruments, unfortunately only 6.4% (n=2) of the studies found. These two papers, along with others made strong arguments for integration of IKS into Western hegemonic STEM education, but the other 28 articles did not make an effort in their design to begin that integration in the very methodologies themselves. Many of the papers focused on ISTs (n=19, 61.3%) and 38.7% (n=12) addressed PSTs, but it must be noted many studies focused on ISTs, very few focused on PST only, many articles studied both populations.

Table 1

Study characteristics

		Number of Studies	Percentage (%)
Focus	Pre-service Teachers (PST)	12	38.7%
	In-service Teachers (IST)	19	61.3%
Location	USA	5	16.1%
	Ghana	2	6.4%
	South Africa	12	38.7%
	Australia	5	16.1%
	Zimbabwe	2	6.4%
	Jordan	1	3.2%
	New Zealand	2	6.4%
	Philippines	1	3.2%
	Morocco	1	3.2%
Method	Quantitative	1	3.2%
	Qualitative	22	70.9%
	Theoretical	2	6.4%
	Quant + Qual (no mixing)	6	19.3%
Research Methodology	Descriptive survey	2	6.4%
	Thematic analysis	3	9.7%
	Case Study	8	25.8%
	Phenomenology	1	3.2%
	Qualitative analysis (using IK method)	2	6.4%
	Text analysis	1	3.2%
	Document analysis	2	6.4%
	Participatory Action	4	12.9%
	Community Based	1	3.2%

	Design Based	3	9.7%
	Field survey	1	3.2%
	Dialogic/Argumentative	2	6.4%
	Discourse analysis	1	3.2%
	Metasynthesis	1	3.2%
	Ethnography	1	3.2%
	Conceptual Framework	1	3.2%
	Theoretical argumentation	1	3.2%
Instruments	Close-ended questionnaire	1	3.2%
	Open-ended questionnaire	4	12.9%
	Reflections	6	19.3%
	Observations	10	32.2%
	Semi-structured interviews	20	64.5%
	Document analysis	5	16.1%
	Focus group	4	12.9%
	Systemic Literature Review	1	3.2%
	Pre and Post Teaching Efficacy Belief (TEBI)	1	3.2%
	Artifact analysis	3	9.7%
	View on nature of IK (VNOIK)	1	3.2%
	Portfolios	1	3.2%
	Task Based Dialogues (TBD)	1	3.2%

Themes for Indigenous Knowledge Systems

Relationship with Place and Community

The codes for this theme were place-based, community-based, and reciprocity, as shown in Table 2. Indigenous knowledge is deeply rooted in their environments and communities and is passed along within their communities (Naah and Osei-Himah, 2024; Marin and Bang, 2015). A strong sense of reciprocity with their land and community exists as a result, with a focus on mutual respect and responsibility (Conrad and Harison-Stevens, 2024).

Holistic and Spiritual Integration

Spirituality, holistic approaches, and suitability as subthemes and as phrases are seen frequently described throughout many of the articles, referring to knowledge construction having a spiritual and holistic aspect in its construction (Vongai and Elaosi, 2017; De Beer, 2016). This supports an interconnectedness between the social, spiritual, and ecological aspects of life within a single knowledge system. The respect of the natural cycling of matter and ecosystems aligns to the spiritual reverence for the world, leading to sustainability and balance.

Knowledge Validated by Experience and Storytelling

Indigenous knowledge is experiential, community- based, and grounded in the realities of their daily lives, passed down through stories which reinforce scientific, historical, and moral lessons. This knowledge has been tested over generations and remains relevant, practical, and adaptable. The idea that utilization of storytelling in a science lesson connects to sociocultural history and social contexts, honoring the experiences of the Indigenous peoples and how their knowledge is passed through their communities through methods such as storytelling (Marin and Bang, 2015).

Integration with Western Science and Cultural Responsiveness

Indigenous STEM education often finds ways to selectively integrate Western science while maintaining cultural integrity. An asset-based approach that respects both knowledge systems, advocating for culturally responsive practices which support diverse learners is likely to be most effective for widespread integration when developing teachers who have been trained to adhere to Western science throughout their own educations (Mandikonza, 2019).

Challenges and Resilience within Knowledge Systems

IKS faces many challenges, such as external biases that lead to undervaluing or misrepresentations. Despite these challenges, Indigenous knowledge systems are resilient and continue to offer valuable insights, often seen as "asset-based" approaches in STEM, especially in the face of climate change (Mkhwebane, 2024) and ecosystem sustainability (Anor, 2024; Mhakure and Mushaikwa, 2014; De Beer, 2016).

Table 2

Thematic Analysis for Indigenous Knowledge Systems (IKS)

Themes for Indigenous Knowledge Systems (IKS)	Subthemes
Relationship with Place and Community	Place-Based, Community-Based, Reciprocity
Holistic and Spiritual Integration	Spirituality, Holistic, Sustainability
Knowledge Validated by Experience and Storytelling	Experiential, Storytelling, Grounding in real world contexts
Integration with Western Science and Cultural Responsiveness	Western Science Adherence, Integration, Culturally Responsive Teaching, Use of Indigenous Knowledge in Teaching Practices

Note. "Reciprocity" refers to mutual respect and responsibility within Indigenous knowledge systems.

Themes for STEM Education

Human-Centered and Culturally Rooted STEM Knowledge

STEM is not a purely objective field but one shaped by human intentions, cultural contexts, and embodied experiences. It reflects how scientific knowledge creation and interpretation are influenced by diverse social, cultural, political, and economic factors.

A common thread throughout the articles was that (Western) science is collectively not seen as a human activity or reflection society, but as an amoral, objective approach to processing the world and its phenomena (Riley et al., 2024).

Integration of Prior Knowledge, Lived Experiences, and Cultural Contexts

It is important to recognize the practice of building on students' pre-existing knowledge, cultural backgrounds, and environmental understanding, as is described through culturally relevant pedagogy (Ladson-Billings, 1996). STEM learning is enriched and made more meaningful when connected to the learner's personal and community experiences, creating a relevant and situated approach to education, as is seen in IKS in practice (Paige et al., 2024).

Coexistence and Co-Creation of Diverse Knowledge Systems

Mandikonza (2019) emphasized a collaborative, pluralistic approach to STEM, where Indigenous and Western knowledge systems can coexist and complement each other. It promotes a model of shared practice within communities, fostering a collective and integrated approach to knowledge creation and learning, which was seen in a PD where community members were partners in bringing community knowledge to the teachers and their classrooms (Hunter and Hunter, 2024).

Challenges in STEM Education: Exposure, Bias, and Misunderstandings

Barriers within STEM education as a field arise from limited exposure to non-Western knowledge systems, fear of misrepresentation of Indigenous peoples and their ways of knowing, and biases equating science exclusively with Western frameworks. This underscores the need for greater openness, understanding, and inclusivity in teaching practices, as mentioned in the theme prior.

STEM as a Catalyst for Socioeconomic Growth and Environmental Awareness

STEM has a dual role in promoting economic and social growth (Rezende & Ostermann, 2020) while also recognizing the importance of environmental stewardship and local knowledge. Approaching it as a catalyst allows consideration to the potential for STEM to drive positive socioeconomic change which aligns with sustainable practices, especially when integrated with IKS and Indigenous stewardship (Chinn, 2015).

Table 3

Thematic Analysis for STEM Education

Themes for STEM Ed (in IKS)	Subthemes
Human-Centered and Culturally Rooted Nature of STEM Knowledge	Design and Research as Human Activities, Nature of Science as Human Society, Interpretation as Sociocultural/Political/Economic, Embodied Ways of Knowing
Integration of Prior Knowledge, Lived Experiences, and Cultural Contexts	Prior Knowledge, Lived and Cultural Experiences, Local Cultural Practices, Environmental Knowledge
Coexistence and Co-Creation of Diverse Knowledge Systems	Knowledge System Co-Existence, Co-creation of STEM Knowledge, Individual Effort vs Shared Practices, Communities of Practice
Challenges in STEM Education: Exposure, Bias, and Misunderstanding	Lack of educator exposure to Non-Western Science, Fear of Teaching Pseudoscience, Lack of Understanding Nature of Science as Non-Equivalent to Western Science
STEM as a Catalyst for Socioeconomic Growth and Environmental Awareness	STEM advances Economic Growth, Integrated STEM promotes socioeconomic growth, Local Cultural Practices and Environmental Knowledge

Themes for Equity

Recognition and Rights of Indigenous Communities

Chinn, 2015 emphasizes the need to acknowledge and protect the rights of Indigenous communities in STEM contexts, including their autonomy and their role in stewarding the land for ecological health. Equity in STEM requires respecting Indigenous sovereignty and self-determination as a foundation for meaningful participation (Burgress et al., 2020). Having a place at the metaphorical tabling, through mentoring teachers during professional development for example, begins the cultural journey to integration.

Addressing Cultural Injustice and Shifting Deficit Perspectives in STEM

By addressing cultural injustices and biases within STEM that often marginalize Indigenous perspective, it is a shift away from deficit-based views which frame Indigenous knowledge as lacking (Brown, 2017), instead recognizing the active role Indigenous communities play in bridging cultural gaps and enriching STEM fields (Botha, 2012).

Inclusive, Inquiry-Based Education for Diverse Learners

The importance of inclusive, inquiry-based educational approaches which cater to diverse linguistic and cultural backgrounds means there is need for equitable access to resources, enabling all students especially those from Indigenous backgrounds, to actively participate and make informed decisions regarding STEM societal issues (Brown, 2017; Sheehan, 2011; Yazidi and Rijal, 2024). Indigenous Knowledge in inclusive education allows development of a more compassionate, respectful, and inclusive outlook, which is critical for fostering a more sustainable and equitable global society (Yazidi and Rijal, 2024).

Valuing Indigenous Knowledge as Beneficial for All Humanity

The recognition of Indigenous knowledge as a valid knowledge system, can result in deeper insights that can benefit global challenges, from environmental conservation to ethical science practices. Recognizing and integrating these values can enrich STEM for everyone, fostering a more holistic and inclusive knowledge base (Botha, 2009; Sheehan, 2011; Hunter and Hunter, 2024).

Empowerment Through Reciprocity and Political Engagement

IKS in its heart emphasizes the power of reciprocity—mutual respect and exchange—and so, when utilized can empower Indigenous communities politically within STEM (Sheehan, 2011). By valuing Indigenous contributions to biodiversity and resource management, STEM education can become a tool for political empowerment and sustainable collaboration (Burgress et al., 2020; Yazidi and Rijal, 2024; Conrad and Harison-Stevens, 2024).

Table 4

Thematic Analysis of Equity in IKS and STEM Education.

Themes for Equity in IKS and STEM Education	Subthemes
Recognition and Rights of Indigenous Communities	Rights to Indigenous Community, Self-determination, Land Stewardship for Biodiversity
Addressing Cultural Injustice and Shifting Deficit Perspectives in STEM	Cultural injustice in STEM, Counter Deficits View, Indigenous Folks Doing the Cultural Work to Integrate
Inclusive, Inquiry-Based Education for Diverse Learners	Inquiry-Based Education Discourse with Culturally/Linguistically Diverse Students, Equitable Access to Information to Make Informed Actions
Valuing Indigenous Knowledge as Beneficial for All Humanity	Reflection on IK values in Western Science and their own community, IK benefits all humanity
Empowerment Through Reciprocity and Political Engagement	Political Empowerment through Reciprocity, Land Stewardship for Biodiversity

Discussion

This SLR found that the gaps raised earlier are reaffirmed as the same issues continuously seen throughout the literature. It is still clear through this SLR that educators still overall lack the appropriate skills, training, and knowledge to integrate Indigenous perspectives and ways of knowing into their teaching. As illustrated in Table 1, the number of papers regarding studies in the United States (n=5; 16.1%), while the methodologies utilized were primarily of Western epistemology, approaches which were community based or ethnographic were low (n=1; 3.2%), which would align with Indigenous peoples placed-based, community-based relationships to knowledge construction. This continues the struggle seen in the literature regarding IKS integration still being pursued but maintaining Western perspectives and methods. The dominance of Western epistemologies in U.S.-based studies reflects a systemic undervaluing of Indigenous, place-based knowledge. This imbalance perpetuates colonial perspectives in STEM education, creating barriers to meaningful integration of IKS.

Challenges in Integrating Indigenous Knowledge Systems

Most current efforts to incorporate Indigenous knowledge tends to rely on epistemic and pragmatic models that are based outside of Indigenous ways of knowing (Botha, 2009). This means it falls primarily to the Indigenous people to make the ‘cultural’ journey or bridge the gap, instead of serving as the mediator (Jegede and Aikenhead, 1999 as cited by Botha, 2009). For Indigenous pre-service teachers in the Hart et al. (2012) study, the teaching practicum was both a learning opportunity and a site of tension. As they entered classrooms, they navigated a system where IK was often sidelined, struggling for legitimacy within a Eurocentric curriculum. While national policies promoted embedding Indigenous perspectives, the reality remained Western Many pre-service teachers faced high expectations from supervisors, often assumed to be experts on "all things Indigenous" simply due to their identity. Some found support in schools that valued Indigenous knowledge, while others encountered resistance, isolation, or even discouragement

from integrating it into their lessons. The lack of explicit pedagogical models in their university coursework left them uncertain about how to embed Indigenous perspectives effectively. Despite these barriers, pre-service teachers persisted, drawing on their cultural knowledge and seeking ways to connect curriculum content with Indigenous perspectives. Their experiences highlighted the ongoing struggle for Indigenous knowledge to gain equal standing in Australian education, emphasizing the need for stronger institutional support, clearer pedagogical strategies, and a shift towards genuinely inclusive teaching practices not only for science teachers, but also the teacher educators.

Given the experiential and holistic nature of IKS, it remains in seeming epistemic opposition to Western science, making it difficult for both PSTs and ISTs to be able to actively integrate within their current curriculum frameworks (Mandikonza, 2019; Table 2). Western science has actively erased Indigenous peoples and their ways of knowing through settler colonial logic in both historical and contemporary times, aiming for human-nature separation (Conrad and Harison-Stevens, 2024). This makes it difficult to have professional development be the solution when the issue is an epistemic conflict. This makes it important for teachers to develop the capacity for identification of colonial logic in their practice and classrooms and recognize their obligation to honor the Native nations and communities and their knowledge well. Conrad and Harison-Stevens (2024) discussed that point and gave an anecdotal piece of evidence where a science teacher participant in their PD was able to position an Indigenous student's understanding of a concept, showing IK can be compatible with a concept like evolutionary theory. This would require PD which can aid in developing critical consciousness in both PSTs and ISTs in the classroom. One teacher's journey in integrating IK presented by Mavuru (2022) began with recognizing the wealth of knowledge students brought from home—stories of traditional healing, farming, and weather prediction. However, bridging this knowledge with the structures of Western science curriculum was difficult, especially when some colleagues would dismiss IK as folklore. Breakthroughs with IK and science came when students connected fermentation to brewing umqombothi or linked traditional remedies to immunity lessons. Yet, language barriers and curriculum constraints often still limited deeper exploration. Some students hesitated to share their beliefs, while others held onto misconceptions, such as attributing lightning to ancestral spirits. By embracing the Ubuntu philosophy of shared knowledge, the teacher was able to transform the classroom into a space for dialogue. They invited elders to share wisdom, encouraged students to explore their cultural knowledge, and used IK to make science more relevant. This journey was not just about teaching but about co-constructing knowledge, fostering inclusivity, and redefining what it means to truly learn science.

The idea of inquiry-based science as another potential solution has its merits but does create potential marginalization of students' science identities if diverse voices, cultures, and languages are not considered (Brown, 2017). It is understood that inquiry-based science instruction can support the general academic success of students of color, culturally responsive approaches are essential for validating their backgrounds, challenging oppressive systems, and countering deficit views of their abilities (O. Lee & Buxton, 2010, as cited by Brown, 2017). Having established the systemic challenges to integrating Indigenous Knowledge Systems, the following section explores professional development strategies designed to address these barriers and foster equity in STEM education.

Strategies for Professional Development

Chinn (2015) studied the incorporation of place-based and culture-based elements in a professional development model that aimed to address disparities in science education, particularly for students from marginalized communities who may feel disconnected from conventional science curricula. This PD encouraged teachers to integrate local cultural practices and environmental knowledge, fostering students' understanding of ecological relationships and environmental stewardship (Table 3). Through cross-hybrid learning, educators were equipped to integrate ecological knowledge that resonates with the students' cultural backgrounds, helping to make science more accessible, inclusive, and relevant. Botha (2019) discussed how expansive learning allowed for a dialogical approach where Indigenous knowledge is not sidelined or merely "added on" but is integrated through activities which respect their cultural contexts (Table 4). It promoted a collaborative and reflexive approach to knowledge creation that placed value on Indigenous and (Western) scientific perspectives. By doing so, expansive learning promotes equity by breaking down the hierarchical structure often seen in traditional science education, where Western scientific knowledge is prioritized.

Equity and Inclusion in Professional Development

Another approach considered was through a PD program described by Marin and Bang (2015) that utilized PoC ISTs where they collaborated with local Indigenous leaders as a teacher planning group, when one of the community members brought up switching to storytelling as an opener to a science lesson, from typical hooks used in lesson design, the teachers decided to try storytelling, which suggested this teachers' understanding is rooted in sociocultural historical and social contexts. Honor of everyday experiences of Indigenous folks is essential to the decolonizing processes. This approach resonates with Ladson-Billings' (1995) theory of Culturally Relevant Pedagogy, which emphasizes leveraging students' cultural knowledge and lived experiences to make learning meaningful and engaging. By incorporating storytelling—a deeply embedded practice in Indigenous traditions—teachers were not only honoring Indigenous ways of knowing but also aligning with the CRP principle of valuing cultural diversity as an asset rather than a barrier. This integration fosters deeper student engagement and validates the epistemic significance of Indigenous practices within STEM education.

Further, Freire's (1974) concept of conscientization (critical consciousness) provides a theoretical framework for addressing the systemic barriers which prevent Indigenous Knowledge Systems (IKS) from being fully integrated into science education. Critical consciousness involves recognizing and dismantling colonial assumptions in STEM curricula while actively validating and integrating Indigenous Knowledge Systems as legitimate and rigorous frameworks. PD programs grounded in Freirean principles would create spaces for dialogical reflection, where teachers critically examine colonial assumptions embedded in traditional STEM curricula. For example, teachers might engage in reflective sessions with Indigenous community members, challenging hierarchical views of knowledge and learning to see IKS as rigorous and essential for environmental stewardship. The teachers in the groups worked through the stories had them critique and work through Western forms of science and Indigenous ways of knowing, created contradictory spaces, intersections of cultural protocol, knowledge generation, relationships, and

aspects of science content, and literacy. This illuminated that typical teacher education programming for POC are sites of struggle and conflict between the systems of knowledge in which they reside: they do not have this opportunity in their programs to develop pedagogy practices which can capitalize on their own experiences and the experiences and knowledge of other students of color. By adopting culturally relevant and critically conscious professional development practices, educators can create equitable learning environments that honor Indigenous ways of knowing while challenging systemic barriers in STEM education.

Limitations and Future Directions

There was a 30-article boundary set by the rubric for a doctoral course this paper was intitally written was for sake of scale and time constraints. Being able to include more than 10 articles for each phase of the study; PST only, IST (PST if included), and equity, would have likely given a more robust idea of the literature available for IKS in STEM education in terms of professional development. Another limitation was the exclusion of book chapters, while not appropriate for an SLR, there were many that appeared in the search that did include professional development programs and outcomes of implementation, as well as more studies done within the United States.

Future Directions

Professional development should consider integrating the place-based and community-centered aspects, as is reflected in IKS itself. The literature has shown a significant gap in community-based and ethnographic approaches (Table 1, n=1; 3.2%). Future research should focus on design and evaluation of place-based PD models that prioritize Indigenous community collaboration. This should include incorporation of Indigenous practices such as storytelling, traditional ecological practices, and reciprocal partnerships with Indigenous knowledge holders.

Teacher education and PD should address epistemic conflicts directly through critical pedagogy. PSTs and ISTs need training that empowers them to critically examine, and challenge embedded colonial logic in STEM curricula and instruction. Freire's critical consciousness (1974) can also be a guide in the development of educators in recognition and dismantling of epistemic hierarchies. This would move educators past just the adding of inclusion but position Indigenous and Western knowledge as coequal and complementary.

The dominance of Western-centric methodologies in STEM education research (Table 1, n=5; 16.1%) indicates a need for more studies grounded in Indigenous epistemologies. Future research should prioritize methodologies that respect and reflect Indigenous knowledge systems, such as participatory action research or community-based ethnography. Expanding the epistemological framework of STEM research would enrich the field by valuing diverse ways of knowing, fostering greater equity in both research and practice.

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