

RESEARCH

Open Access



Two-Ways thinking and Two-Eyed Seeing as ways of implementing Indigenous perspectives in the science education curriculum

Michael Michie^{1*} , Michelle Hogue^{1,2} and Joël Rioux^{1,3}

Abstract

A groundswell to include Indigenous Knowledge in the school science curriculum has led to the inclusion of Aboriginal and Torres Strait Islander Histories and Cultures (generally known as Indigenous perspectives) in the overall Australian Curriculum (AC) and the Australian Curriculum: Science (ACS). However, the experiences in other countries, their states and provinces are quite different and diverse, particularly when it comes to incorporating Indigenous Knowledge in resistant disciplines such as science. The AC and ACS are examined and compared with similar curriculum from elsewhere. The causes of resistance to the inclusion of Indigenous perspectives are identified, as well as other structural impediments. Strategies such as the Two-Ways or Two-Eyed Seeing approaches with epistemic insight are seen as a functional way of bridging Indigenous and Western cultures for policy makers, curriculum developers, educators and teachers, and ultimately students.

Keywords Science curriculum, Indigenous perspectives, Two-Ways approach, Two-Eyed Seeing, Epistemic insight, Indigenising the curriculum

Introduction

One of the common new features of the science curriculum of some countries or their member states, provinces and territories, has been the inclusion of Indigenous perspectives as interdisciplinary features with the more-widespread Western science. These countries include settler states such as Australia, Canada, Aotearoa New Zealand and the United States of America. In this paper

we look at aspects of science education policy and curriculum (Theme 1).

Theme 1: How have officially prescribed science policy, curriculum standards, and teaching materials been interpreted and translated by policy makers, researchers, and practitioners into local policies and classroom practice in K-12 science education?

The theme is from the special issue on “Science Education Policy, Standards, and Teaching Materials”, for which this paper was prepared. Using theme 1 as a guide, we consider that there are two interrelated research questions (RQ) which we investigate in this paper:

RQ1: *Can Indigenous Knowledge be incorporated in the school science curriculum?*

RQ2: *How can this done in a way that bridges cultures (Aikenhead & Michell, 2011)?*

*Correspondence:

Michael Michie
michael.michie@batchelor.edu.au

¹ Present Address: Batchelor Institute of Indigenous Tertiary Education, Casuarina, NT, Australia

² Present Address: University of Lethbridge, Lethbridge, Canada

³ Present Address: Montessori Noosa Australia, Sunshine Coast, QLD, Australia

We start by looking at how Indigenous Ways of Knowing and Learning (IWKL) can be included in the science curriculum, making use of some of our previous papers (Michie et al., 2018, 2021). We then consider the use of the Australian Two-Ways and the Canadian Two-Eyed Seeing approaches as models for enabling students to understand Indigenous Knowledge’s place in science. We use the exemplar of the Australian Curriculum (AC), and in particular the Australian Curriculum: Science (ACS), to see how the inclusion of IWKL can be justified (through policy and the *Declarations*) and included as a cross-curriculum priority in the AC. As part of this analysis we illustrate ways in which inclusion has been or not been achieved successfully in Australia, Canada and other parts of the world, primarily in the settler states at the national, state or provincial levels. Finally, we show how inclusion of IWKL can be brought together with a specific focus on the Two-Ways of Australia and Two-Eyed Seeing of Canada.

In a previous article (Michie et al., 2018), the authors of this present paper compare several characteristics of Western and Indigenous worldviews (Table 1) and make the point that each characteristic could seemingly be interpreted in two different ways depending on which lens, Western or Indigenous, is being used.

Firstly, each of the endpoints could be considered as a binary pair, where each member of the pair is in opposition or conflict with the other. Alternatively, according to the authors, the pairs can be considered as endpoints so that the space between represents a continuum of interpretation that varies with an individual’s worldview. This means that the endpoints are no longer in conflict but are complements and act as anchors for each idea. As an exemplar, Michie et al. (2021) illustrate how two

complementary interpretations of time—linear and cyclical—can be presented as a Two-Ways or Two-Eyed Seeing topic in both Western and Indigenous science, how time is considered in the Australian Curriculum (primarily in the science and mathematics learning areas), and ways in which the inclusion of Indigenous knowledge can be achieved. Here in this paper, the same authors are suggesting a complementary approach between Western universal knowledge and Indigenous local knowing when developing a school science curriculum that is inclusive of IWKL.

Inclusion of Indigenous knowledge in science

As McKinley and Stewart (2012) describe in their paper, *Out of place, Indigenous knowledge in the science curriculum*, there has been a long historical and fierce debate about whether Indigenous knowledge (IK) should even be included in the science curriculum let alone give it equal merit to Euro-Western science as we know and practice it. With a global focus on enabling Indigenous academic success and retention at all levels, and with an eye to building capacity in the science, technology, engineering and mathematics (STEM) fields in this time of global environmental crisis, many are asking, “How do we create an inclusive science curriculum?” One way, and arguably the easier way, is to just incorporate Indigenous perspectives into the curriculum while the other more inclusive way is to additionally attend to the pedagogy of IWKL; take a Two-Ways or Both-Ways (Ober, 2009; Ober & Bat, 2007) or Two-Eyed Seeing (Bartlett et al., 2012) approach that creates bridges between both Indigenous and Western perspectives as well as ways of learning and coming to know.

Indigenous perspectives in this context are the collection of general Indigenous knowledges that relate to topics taught in school science. The original rationale for the inclusion of Indigenous perspectives was to increase the awareness and knowledge of the Indigenous world for non-Indigenous students and teachers (Michie, 2002), and importantly illustrate that science is an integral part of the Indigenous paradigm. However, its incorporation is often seen as fragmentary, tokenistic, stereotyped and a caricature of Indigenous knowledge (McKinley & Stewart, 2012), particularly as it appears in textbooks (Ninnes, 2000). In Canada, there are examples of Indigenous perspectives being incorporated into the K-12 science curriculum and education more broadly (Aikenhead & Michell, 2011; Aikenhead et al., 2014; Azam & Goodnough, 2018; Snively & Williams, 2016, 2018) but with limited success, and similarly the same is true in Aotearoa New Zealand (Moeed & Rofe, 2019). Indigenous perspectives differ from culturally relevant and culturally responsive pedagogies as they are situated predominately

Table 1 Generalised comparison of characteristics associated with Western and Indigenous worldviews (after Michie et al., 2018; NTDE, 1999)

Western worldview	Indigenous worldview
materialistic	spiritual
reductionist	holistic
rational	intuitive
decontextualised	contextualised
individual	communal
competitive	cooperative
explain mystery	celebrates mystery
time is linear	time is cyclical
universal knowledge	local knowing
seeks power over nature and people	seeks to coexist with nature and people
knowledge production for the sake of it, to progress society	knowledge production for specific cultural outcomes, to maintain society

within the Western school science curriculum as content or ‘what’, rather than pedagogy, which focuses on the practice or the ‘how’ of teaching. We need to understand that pedagogy and teaching can be addressed and implemented through strategies such as Two-Ways Learning (Deslandes et al., 2019; Michie et al., 2018, 2021; Skamp, *in press*) and Two-Eyed Seeing (Bartlett & Marshall, 2009; Bartlett et al., 2012).

Two-Ways Learning and Two-Eyed Seeing

Two-Ways (sometimes referred to as Both-Ways) originates through a story which McConvell (1982) recollects hearing as early as 1975, in which Pincher Nyurmiyarri, a Gurindji man from the Northern Territory of Australia (NT), advocated for ‘two-way school’ rather than ‘one-way school’ or ‘only *kartiya* (European) way’. This Two-Ways approach to education “brings together Indigenous Australian traditions of knowledge and Western academic disciplinary positions and cultural contexts” (Batchelor Institute, 2007, p. 8). It has been used and continues to be used at all three levels of education in Australia (Deslandes et al., 2019; Michie et al., 2018, 2021; Skamp, *in press*).

One (Western) way of comparing Western and Indigenous knowledge is to illustrate them using a Venn diagram, with Western knowledge and Indigenous knowledge each in their own field and the intersection of the two fields representing common or shared knowledge, the space of bridging cultures or the liminal space of possibility (Hogue in Michie et al., 2018). Figure 1 is an example indicating some of the common knowledge

that exists between Indigenous and Western knowledges about the estuarine crocodile, *Crocodylus porosus* (Michie et al., 2018; NTDE, 1999).

Two-Ways learning can be achieved by making use of an integrated approach in the classroom. Given the Australian Curriculum was developed as a “discipline-based curriculum [it] should allow for cross-disciplinary learning that broadens and enriches each student’s learning” (ACARA, 2012, p. 22). It is also accompanied by cross-curriculum priorities—in this case Aboriginal and Torres Strait Islanders Histories and Cultures (ATSIH&C)—that are reinforced in the learning areas. An integrated approach, identified as the transdisciplinary approach (Moss et al., 2019), is described as: “Planning begins with an issue, problem or topic and a framework is established around concepts and a central idea or question. The fluidity of subject curricular frameworks is emphasised.” (p. 26). Time, which Michie et al. (2021) use as an example, can be considered as an appropriate topic to be integrated with inputs primarily from the science and mathematics learning areas, and as a particular site for integrating Indigenous knowledge as a cross-curriculum priority.

Comparatively to the Two-Ways concept of Australia, is the guiding principle of *Etuaptmunk*, the M’ikmaq word for *Two-Eyed Seeing* (TES) in Canada, first brought forward by Mi’kmaq Elders Albert and the late Murdena Marshall and Dr. Cheryl Bartlett in 2004 for the Integrated Science Program at Cape Breton University (Nova Scotia, Canada; Marshall & Bartlett, 2004). TES refers to seeing from one eye with the strengths of Indigenous ways

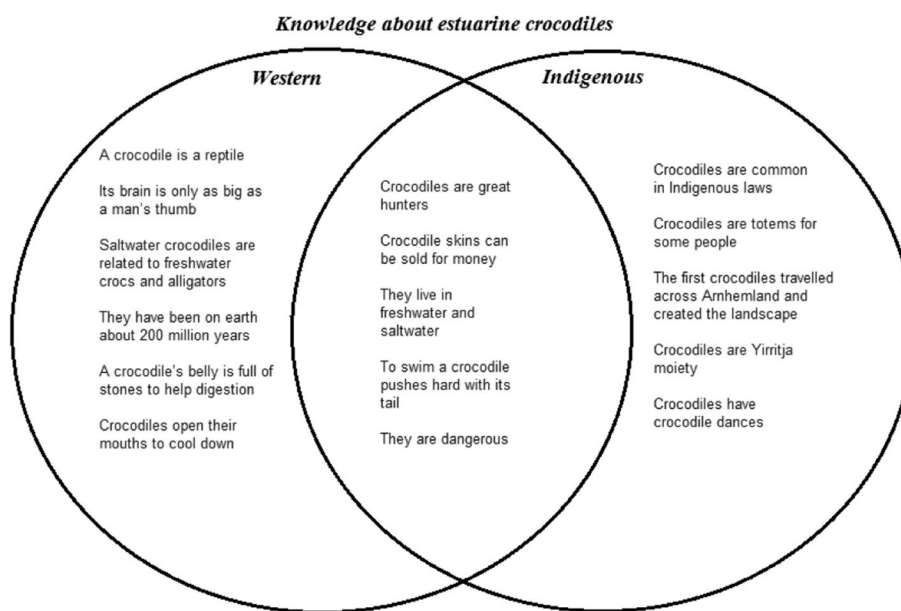


Fig. 1 Comparing Western and Indigenous knowledges about estuarine crocodiles (Michie et al., 2018; NTDE, 1999)

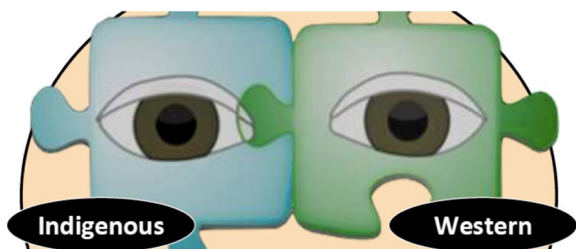


Fig. 2 Two-Eyed Seeing. The connection represents an informed vision using both eyes. (Bartlett & Marshall, 2009; Bartlett et al., 2012)

of knowing and from the other eye with the strengths of Western ways of knowing and using both eyes together for a holistic and truly informed (depth) perspective (Bartlett et al, 2012; Hatcher et al. 2009; Marshall & Bartlett, 2004). These Canadian pioneers of the TES model use the image of two connected puzzle pieces (Fig. 2), each containing an eye, to portray their concept. If one looks closely, the puzzle pieces don't fit exactly, a metaphor for the challenges we experience in truly connecting Indigenous and Western knowledge (Bartlett, personal communication).

In light of Canada's recent Truth and Reconciliation Commission Report (TRC, 2015) and its 94 Calls to Action (CTA), the guiding principle of Two-Eyed Seeing has gained renewed recognition and momentum across the nation as a way to work together to address the TRC-CTAs. Like the Two-Ways approach, TES enables the bridging of Indigenous and Western cultures and ways of knowing and learning for educators, students, curriculum developers and policy makers alike.

Method

Methodology

We make use of three qualitative methodologies in this work: case study, environmental scanning and re-reading. Our treatment of the Australian Curriculum as a *case study* (Harland, 2014) looks at the history of the implementation of the Aboriginal and Torres Strait Islander Histories and Cultures cross-curriculum priority in the overall Australian Curriculum and more specifically the Australian Curriculum: Science.¹

In focusing on this priority, we carried out *environmental scanning* (Gordon & Glenn, 2009) of the literature, policies and programs that particularly focused on Indigenising science curriculum. In our environmental scan of the literatures, we looked primarily at the other settler nations mentioned earlier for any information or analysis regarding the incorporation of Indigenous perspectives

into their overall curriculum and particularly into their science curriculum. We included peer-reviewed literature produced by other researchers, as well as grey literature (Benzie et al., 2006; Pappas & Williams, 2004) such as newspapers and magazines.

Another methodology we used is *re-reading* (Dampier, 2008; Stanley & Temple, 2008; Michie, in prep.), in which data regarding the researchers' story are found incidentally in a text on some related topic. This is more likely to occur in a qualitative text or narrative and is similar to environmental scanning. For example, in our previous paper (Michie et al., 2019), we discussed the notion of a frog life cycle as showing that the concept of an event being cyclical is not exclusively Indigenous. Re-reading of this idea shows that a life *cycle* is really a life *spiral*, and for most living organisms, the gametes do not clone into their parents which then reproduce to produce themselves (which is implied in a life cycle model, if taken literally).

Data analysis

Unlike most quantitative methodologies, the data collected using qualitative methodologies tend to be mostly copious verbal tracts and documents from many sources. In many of the qualitative methodologies, analysis and discussion are merged together (Webster & Mertova, 2007), and in this paper we have done this because we use many sources, both academic peer-reviewed and grey literatures. Firstly, there are the AC and ACS documents themselves, which we have condensed and contextualised to relate to our research topics, i.e., Aboriginal and Torres Strait Islanders Histories and Cultures (ATSIH&C) as a cross-curriculum priority. Then, we made the links between the AC/ACS and other curriculums both in and outside Australia. Thirdly, we show how the Two-Ways and Two-Eyed Seeing approaches give us a way of considering the ATSIH&C at three levels, from Indigenous perspective to epistemic insight.

The school science curriculum: a quasi-international perspective

In this section we undertake a quasi-international comparative study² in which the Australian Curriculum is a case study of the integration of Indigenous perspectives in the overall curriculum (AC) and more specifically the science curriculum (ACS). Then, we look at a number of examples from the science education literature from Australia and other countries which could modify in some way the process of Indigenisation explained earlier.

¹ To learn more about either AC or ACS, visit the ACARA website at www.acara.edu.au/curriculum.

² It ended up that all of the documents which were used in the study were written in English. MM has published in Bahasa Indonesia and JR has fluent French, but most other documents from other countries showed limited concern for potential Indigenous perspectives.

In Australian practice, the curriculum is usually thought of as what is required to be taught, its scope and sequence (Michie, 2015), and also can include curriculum standards and student work sample portfolios for the guidance of teachers. These are usually in the form of documents prepared by an educational authority to be used in schools and colleges under its auspices. In recent times some of this work has been done at a national level by agreement with state, provincial, and local educational authorities (where they exist) which may then modify and enact the curriculum within their domains. These days, the curriculum can be online, with active links between components and the world beyond the classroom (as in Australia [ACARA, 2022] and the USA [NGSS, 2021]). The curriculum differs from individual teacher's or school-based programs which are interpretations of the curriculum for individual school or classroom contexts.

Another interpretation of curriculum refers to curriculum resources, a classroom resource which may have been developed by the educational authority, by an interested organisation, or often by groups of teachers to interpret and implement the curriculum. Curriculum resources are usually considered to be a link between the curriculum (content) and the classroom pedagogy (practice); however, resources may be developed which are not completely based on the curriculum or reflect a particular interpretation of its meaning. Textbooks are considered as curriculum resources and they should reflect the curriculum.

The Australian curriculum

In Australia over the past thirty-five years there has been a groundswell in school education to produce a world class Australian Curriculum over eight learning areas,³ which includes science. This led to the publication of Statements and Profiles for each subject area by the then Curriculum Corporation (Australian Education Council, 1994a, b). These documents were basically a definition of the subject area over the 10 or so years of compulsory schooling, and a profile of eight levels relating to student knowledge at each level. They were used by curriculum writers in each state or territory for the preparation of curriculum and resource materials.

This led the establishment in 2008 of the Australian Curriculum, Assessment and Reporting Authority (ACARA), a federal statutory authority responsible to the education ministers of the federal, state and territory governments. However, education is still the responsibility of

state and territory governments and the interpretation of the curriculum resides with them.

The Australian Curriculum exists in many forms; these can be crafted online to serve the purposes of the user. Its home page is located at www.acara.edu.au/curriculum. Material regarding all learning areas and cross-cultural priorities is found under the heading Foundation–Year 10 Curriculum, and the same formatting is used throughout.

Indigenous perspectives: policy and the Australian curriculum

There is no specific document called 'Policy' in the Australian Curriculum.⁴ However, there have been a series of four *Declarations* which contain the national goals for education for Australian schools released by the Ministerial Council of Education Ministers (now called the Education Council). According to Smith and Michie (2019), the idea of a formal Indigenous (or Aboriginal or First Nations) perspective in the Australian science curriculum can be traced back formally to the initial *Hobart Declaration* (MCEECDYA, 1989). This statement listed the Common and Agreed National Goals for Schooling in Australia, including: "To provide students with an understanding and respect for our cultural heritage including the particular cultural background of Aboriginal and ethnic groups" (p. 1). Committees and positions were set up by the Education authorities in the states and territories to implement this goal, which was known informally as the Indigenous Perspectives, across the curriculum (Smith & Michie, 2019). Since then, the *Hobart Declaration* has been rewritten and renamed three times (as the *Adelaide Declaration* in 1999, followed by the *Melbourne Declaration* in 2008, then the *Alice Springs (Mparntwe) Declaration* in 2019) and in each case the emphasis on Indigenous knowledge has been reinforced (Table 2).

The participation of Indigenous students and parents in the education process is also considered among the goals and was included for the first time in the *Adelaide Declaration*.

According to Sambono (2021), the *Mparntwe Education Declaration* of 2019 ensures all Australian education ministers commit to supporting Aboriginal and Torres Strait Islander learners to reach their potential. The *Mparntwe Education Declaration* states that:

Australia's education system must embrace Aboriginal and Torres Strait Islander cultural identities and provide Aboriginal and Torres Strait Islander peoples with safe learning environments. (Education

³ The eight learning areas are English, Mathematics, Science, Humanities and Social Education (under a variety of titles), Technology, Health and Physical Education, The Arts and Languages other than English. Work Studies was added subsequently.

⁴ There were shaping documents for various purposes which also refer back to the *Declarations* (ACARA, 2012).

Table 2 The evolution through the *Declarations* of the role of Indigenous perspectives

Declaration, (Place, year)	Statement
Hobart, 1989	To provide students with an understanding and respect for our cultural heritage including the particular cultural background of Aboriginal and ethnic groups
Adelaide, 1999	All students understand and acknowledge the value of Aboriginal and Torres Strait Islander cultures to Australian society and possess the knowledge, skills and understanding to contribute to, and benefit from, reconciliation between Indigenous and non-Indigenous Australians
Melbourne, 2008	Understand and acknowledge the value of Indigenous cultures and possess the knowledge, skills and understanding to contribute to, and benefit from, reconciliation between Indigenous and non-Indigenous Australians (p. 9)
Alice Springs (Mparntwe), 2019	Students learn about Australia's rich Aboriginal and Torres Strait Islander histories and cultures. This cross-curriculum priority provides Aboriginal and Torres Strait Islander students with the ability to see themselves, their identities and cultures reflected in the curriculum and allows all students to engage in reconciliation, respect and recognition of the world's oldest continuous living cultures. (p. 15)

Council, 2019, p.16)

Delivering a world class curriculum remains a key commitment of the *Mparntwe Education Declaration*. The Australian Curriculum continues to work towards addressing the two distinct needs identified in the earlier *Melbourne Declaration*):

1. Aboriginal and Torres Strait Islander students are able to see themselves, their identities and their cultures reflected in the curriculum of each of the learning areas, can fully participate in the curriculum and can build their self-esteem
2. Ensure all students learn about Australia's rich Aboriginal and Torres Strait Islander histories and cultures to allow all students to engage in reconciliation, respect and recognition of the world's oldest continuous living cultures.

As noted above, the theme of reconciliation between Westerners and Indigenous Australians has been identified through the goals, as had been suggested earlier by Michie (2002).

The cross-curriculum priority and the Australian curriculum
 Known formally as Aboriginal and Torres Strait Islander Histories and Cultures (ATSIH&C), this is one of the three cross-curriculum priorities⁵ in the Australian Curriculum (ACARA, 2011). The priorities are intended to provide students with the tools and language to engage with, and better understand, their world at a range of levels. These priorities provide dimensions that will enrich the curriculum through development of considered and focused content that fits naturally within learning areas (ACARA, 2022).

This curriculum also included a category to encompass knowledge, skills, behaviours and dispositions called General Capabilities, of which one was Intercultural understanding. This and the ATSIH&C are often combined and are known informally, and continue to be referred to in schools, as Indigenous perspectives (Smith & Michie, 2019). Indigenous perspectives in this context have morphed into a collection of general Indigenous knowledges that relate to topics which can be taught in school science.

The cross-curriculum priority and the Australian curriculum: science

In the ACS, the Aboriginal and Torres Strait Islander Histories and Cultures cross-curriculum priority is working towards addressing the two distinct needs identified in the *Melbourne Declaration* (see above) through the publication of comprehensive resource materials for primary and junior secondary years (ACARA, 2019; Sambono, 2021). These materials are linked directly to particular content descriptions in the curriculum and expanded as elaborations in a manner similar to the Western science content.

According to Sambono (2021), some non-Indigenous educators continue to resist the mandate from the ministerial Declarations to include this cross-curriculum perspective. He refers to hearing educators commenting that: (a) the Aboriginal and Torres Strait Islander Histories and Cultures cross-curriculum priority is only for First Nations Australian students and is non-essential in schools with low inclusion of identified First Nations students; and (b) that the priority is not relevant at all in classes that have no First Nations students. However, in the recent review of the Australian Curriculum, it was observed that:

The explicit inclusion of First Nations perspectives into the content descriptions and elaborations was positively received by jurisdictions. However, some noted that

⁵ The other two priorities are Asia and Australia's Engagement with Asia, and Sustainability.

professional development and practical implementation support (e.g., resources) will be needed (ISSR, 2021a, p.55).

It was noted earlier that there are two other cross-curriculum priorities, Asia and Australia's Engagement with Asia, and Sustainability. These are implemented in the curriculum as elaborations in the same way as the content, general capabilities and Indigenous perspectives are included.

Resistance to incorporation of Indigenous perspectives

There are a number of ways in which resistance to the incorporation of Indigenous perspectives in the curriculum has been displayed. In some cases, this could be across all subject areas, whereas some only apply in the science learning area.

Playing politics

At the time that the AC was being devised, Australia and the other settler nations mentioned earlier and many other countries worldwide were being influenced by neoliberalism, a philosophy of small government with a market ideology driven by profits. According to Giroux and Giroux (2008), the function of education from the neoliberal perspective is to train workers for service sector jobs and produce lifelong consumers" (p. 181). They see neoliberalism as "one of the most pervasive and dangerous ideologies of the twenty-first century". This creates a quandary: Are the powers-that-be only including IK in the curriculum to exploit it for monetary gain?

Each of the countries examined would consider themselves democracies, and over the past thirty years they have had swings in government from the conservative right-wing to a more radical left, and back to the right, and back. The development of Indigenous perspectives (in Australia at least, if not some or all other countries) has taken place in times associated with left-wing governments, followed by reactionary right-wing government which favours a less intrusive, or even no, Indigenous perspective.

In Australia, this can be seen in the demise of the Statements and Profiles around 1999 coinciding with the election of the Howard Liberal Government (conservative); the establishment of ACARA by the Rudd and Gillard Labor Governments (left wing); a review of the curriculum for the newly-elected Abbott Liberal Government (Donnelly & Wiltshire, 2014); followed by the more recent 2020–21 Australian Curriculum Review for the Morrison Liberal Government of that time.

In post-apartheid South Africa, development of a new curriculum seemed to promise the inclusion of Indigenous knowledge systems (IKS):

The White Paper ... indicates that the government considers IKS as a body of knowledge that can be used in teaching school Science and the incorporation of IKS into the school curriculum has been the focus of South African Educational Policy... The inclusion of IKS in Science curriculum is further discussed in the National Curriculum Statements... Such consideration of IKS in Science curriculum has to be complemented by efforts of assisting Science educators to derive meaningful components of IKS for use in Science classrooms. (Keane & Moyo, 2010, p. 94)

But it was not to be: in 2009 the appointment of new Ministers of Education led to changes in government policy and this initiative was dropped.

The situation in Ontario (Canada) in 2022 again demonstrates the fragility of integrating Indigenous perspectives into the curriculum, particularly where conservative politics are involved:

The Ontario government removed parts of an overarching theme in its elementary science curriculum that would have taught students the connections between Indigenous and Western science.

Just three weeks before the release of the science and technology curriculum in early March, [the Conservative] Education Minister's office directed Ministry of Education staff to delete the language that also included examining the "scientific and technological knowledge systems and perspectives of various cultures. (Alphonso, 2022)

Not 'real' science

There have been a number of scientists and science educators (Dawkins, 2006; Matthews, 2009; Plimer, 1994) worldwide who have been quite outspoken about, and dismissive of, Indigenous knowledge, because they consider it is not 'real' science; primarily, this means it is not like Western science (and technology); and secondly, because it is often considered to be somewhat like creation science. So, it falls under other forms of science (except 'real' Western science) that need to be avoided (Matthews, 2009).

Australia has not been immune to this type of thinking in the past; a one-time director of ACARA, a science teacher by experience, said that because the science curriculum contained references to the Dreamtime which he considered to be the spiritual aspect of creation for Aboriginal Australians, these references would be removed from the draft document (Ferrari, 2010). At present in Aotearoa New Zealand there is an animated discussion going on between Māori and Western scientists about

the inclusion of *Mātauranga Māori* (Māori knowledge) with Western science (Matthews, 2022; Stewart, 2019), which may have consequences for curriculum content.

This is a difficult problem to work through, although the interactions between Western Science and Indigenous Knowledge in some areas (ecology, environmental science, and land management come to mind) does resonate with some Indigenous and non-Indigenous peoples especially in our current global environmental crisis. The relationship of science and religion and the use of *epistemic insight* were factors we considered in writing the first of this series of papers (Michie et al, 2018). Epistemic insight has been described as 'knowledge about knowledge' (Epistemic insight, 2017), going beyond facts and exploring their contexts (Billingsley et al., 2013; Michie et al., 2018).

Michie (2011, 2014) uses the model of identity learning of Geijssel and Meijers (2005) to distinguish between border crossers (Aikenhead & Michell, 2011), those people in our case here who are happy to adapt and include IK in their teaching, and those who are not. Geijssel and Meijers (2005) propose a model of identity learning with both cognitive and affective inputs regarding a new professional situation. These can result in an individual either having a positive response leading to identity learning, or a negative response which reinforces previously-held beliefs. Michie uses this identity learning model to examine border crossing as a professional learning experience for people teaching in Indigenous communities. He uses this to hypothesise that those people who have a positive response to First Nations people and their cultures can become border crossers whereas those who have a negative response are not border crossers. He extends this to teachers in mainstream situations and suggests that effective teachers are also border crossers. Thus, Geijssel and Meijers (2005) and Michie (2011, 2014) are telling us that to change people's opinion takes time and good experiences, and that, in some cases, there will be no change at all.

Teachers' attitudes

Firstly, many science teachers share the notion that IK is not 'real' science with the group above. As well, there are non-Indigenous teachers who see IK as only for Indigenous students or irrelevant for classes with few or no First Nations students (Sambono, 2021). Other reasons for not teaching Indigenous perspectives have been lack of training in their use; lack of resources; and lack of professional development. In their review, ISSR (2021a, p.55) also suggests that professional development and practical resources are needed.

Concerns of Indigenous people: whose knowledge is it?

There is a long historical and fierce debate about whether Indigenous knowledge (IK) should even be included in science curriculum let alone give it equal merit to Euro-Western science as we know and practice it (McKinley & Stewart, 2012). They use terms such as stereotype and caricature to describe attempts to incorporate Indigenous perspectives. On top of this, there needs to be concern regarding the kind of IK used, whether it is sacred, men's business or women's business. The concept of 'Whose knowledge is it?' is alien to most Westerners who view knowledge as accessible to everybody, yet its context is quite important to many Indigenous people.

Other structural impediments

There are factors which impede the potential success of the Australian Curriculum (AC, and ACS as its science component) which we consider to be structural, i.e. built-in as part of the agreements to develop the curriculum. Some of these factors are examined here.

A National project

To develop the Australian Curriculum and resources, the Australian Curriculum, Assessment and Reporting Authority (ACARA) drew on the best national talent and expertise and consulted widely.

Our commitment to develop a national curriculum always reflects a willingness to work together, across geographical and school-sector boundaries, to provide a world-class education for all young Australians. Working nationally makes it possible to harness collective expertise and effort in the pursuit of this common goal. (ACARA, 2022).

In comparison, in some of the other curriculum we were able to examine, there was no similar cohesiveness. Aotearoa New Zealand was the first country to prepare a curriculum in their Indigenous language (*Te reo Māori*), but only with slight reorganisation of the content of the Western science curriculum (McKinley, 1996). In Canada during the 1990s, there were attempts to prepare a pan-Canadian curriculum, but lacking leadership from the top (no federal ministry) or funding, these efforts seem to have been in vain. Over time, several researchers have produced Aboriginal science resources but these most often don't articulate with the Western Science curriculum including Aboriginal perspectives into the science curriculum through Traditional Ecological Knowledge (TEK) (Kim & Dionne, 2014) and curriculum and pedagogical resources associated with Aboriginal perspectives (Aikenhead et al., 2014; Lewthwaite & Renaud, 2009;

Manitoba Education & Youth, 2003; Snively & Williams, 2016, 2018) are first steps and are often directed towards Indigenous rather than Western students. However, we found that there is a concerted effort to engage Indigenous students at all levels of education with STEM in ways that attend to IWKL and enable success (Deslandes et al., 2019; Hogue & Provost, 2023; Rioux, *in prep.*; Songoro, 2019). With concern over our current global environmental crisis and the decline in numbers of students entering into STEM and attention to the Canadian Truth and Reconciliation Commission (TRC) Calls to Action, some Canadian provinces, such as Saskatchewan (Kim, 2022), are leading the way in terms of integrating Indigenous and Western knowledges into their science curriculum. However, there do not appear to be any policies or frameworks in place either at the provincial or federal level.

A similar situation exists in the USA where the Next Generation Science Standards (NGSS, 2021) have been prepared at the behest of a bipartisan group of governors and business leaders led by a nonprofit organisation, Achieve (2021), but only for science. There are implications regarding ownership of the curriculum (which should be explored further elsewhere), comparing what has been achieved in Australia as ‘our curriculum’, rather than the ‘their curriculum’ elsewhere because the curriculum is written and implemented without consulting those who are to use it (Ryan, 2008). Examination of the standards, particularly the science content standards, reveal an orthodox Western science worldview. Some jurisdictions, particularly those with high First Nations populations, have supported development of curriculum resource materials for use primarily by First Nations students rather than by non-Indigenous students. For example, the Alaskan Native Knowledge Network has developed resource materials in science based on the work of Elder, Oscar Kawagley (1995).

In 1999 in the state of Montana, the state legislature passed the *Indian Education for All Act*, encouraging educators to: (a) increase cultural sensitivity and reduce bias; (b) enrich education for all students by expanding relevance and accuracy; and (c) revitalise pride and cultural identity for and with members of Indigenous communities. Key to this is that all educators, regardless of subject or grade, will teach about Indigenous experiences to all students (Stanton et al., 2019)—cross-curricular in the context of this paper. There has been an attempt to develop resource materials in various subject areas including science, but not to the extent done by the ACS (ACARA, 2019).

In 2023, the Minnesota House of Representatives passed a K-12 education bill which calls for policy

changes in regards to three measures long sought by American Indian educational advocates (Abrams, 2023):

- prohibiting schools from using Native American symbols or names as mascots, unless all 11 of the state’s tribal nations sign off on an exemption request;
- replacing Columbus Day with Indigenous Peoples’ Day on the school calendar; and
- adding Indigenous education to the state’s academic standards during the next 10-year review.

Whether the understanding exists of which of (1), (2) or (3) in Appendix 1 below is inclusive of science is a moot point; only time may tell. Also, nowhere is there given clearly a timeline or budget to complete Native American education for all students. However, in preparation for the start of the initiative, there has been some analysis undertaken of Native American resources currently used in schools in Minnesota (Wood-Krueger, 2022).

In Canada, the 94 Calls to Action—an outcome of the TRC—has at least 10 of the CTAs focused on education equity, but none specifically on science education. On 30th September 2021, Canada implemented Orange Shirt Day as the National Day for Truth and Reconciliation in response to #80 of the 94 CTA of the TRC. This day is to mark the day when many Indigenous children were annually taken from their families into residential schools.

Using the latest research, pedagogies and expertise from and beyond the nation

The experience of preparing the previous Australian curriculum (e.g., AEC, 1994a, b) began with the involvement of world-renowned academics; for example, Professor Peter Fensham, at that time considered the doyen of science education in Australia, co-wrote one of the major position papers in science education (Fensham et al., 1989). As noted above, there was involvement of subject specialists in universities, schools and the ministries or departments of education. As documents were produced, they were incorporated into the curriculum of education faculties in the universities. ACARA itself sought major evaluation of its programs in developing the curriculum and NAPLAN testing,⁶ in particular the one undertaken by the Institute of Social Science Research, University of Queensland, in 2020–21. (ACARA, 2022; ISSR, 2021a; ISSR, b). These together ensured that the work of ACARA was considered by many people in

⁶ NAPLAN testing: National Assessment Program—Literacy and Numeracy testing takes place for each student every two years in Literacy and numeracy. Science is being considered as well.

society and its schools, and that there was confidence in the future work of ACARA.

Using the latest information technologies

The use of information technology was embraced from the origins of ACARA in 2008. The structure of the Australian Curriculum is consistent within and between subjects and learning areas, and this means that there is more potential for multidisciplinary between learning areas, general capabilities and cross-curriculum priorities (Moss et al., 2019). This is in contrast to IT-formatted curriculum such as the Next Generation Science Standards (NGSS, 2021) from the USA, which seems to only be for the science learning area.

A reasonably stable political environment

As noted above, the Australian Curriculum has withstood the fickleness of swings between the conservative right wing and the left wing because (i) there is seen to be lots of kudos in staying in the AC project, rather than going alone; and (ii) the two sides are not that radically different.

From curriculum to classroom

How is space created in the curriculum for both Indigenous and Western perspectives of the scientific concepts (e.g., seasons) being taught? The majority of educators struggle with ‘Indigenising’ and don’t know where or how to begin (Statistics Canada, 2018; ISSR, 2021a, b). We

suggest beginning where you are most comfortable and move from there. It is suggested that the following three pedagogical approaches—Indigenous perspectives, Two-Ways/Two-Eyed Seeing (TES) approach, and Two-Ways/ TES approach with epistemic insight—promote increasingly the inclusion of Indigenous knowledge and localised ways of knowing (Table 3).

1. The **Indigenous perspective** is considered to be the simplest form of inclusion, where Indigenous knowledge is included with limited regard for its context. It is often criticised as being stereotypic or tokenistic and a caricature of the reality (McKinley & Stewart, 2012). It represents a superficial and fragmentary understanding of Indigenous knowledge.
2. In the **Two-Ways/ TES approach**, Indigenous knowledge is compared with the Western science interpretation, so that there are two ways of knowing which may be in conflict. Often Indigenous knowledge is localised and compared with the universal Western scientific explanation. The Two-Ways/ TES approach is a more bridging of cultures approach than the tokenistic Indigenous perspective described above but it runs the risk of being comparative and polarizing rather than creating a true understanding of the ways each knowledge system understands a particular topic.
3. This can be avoided by taking the **Two-Ways/ TES approach with epistemic insight**, where the two ways

Table 3 The three pedagogical approaches to including Indigenous perspectives, using seasons as an exemplar (Michie et al., 2020)

Way of inclusion	Features	Explanation	Suitable activities relating to seasons: Students...
Indigenous perspectives	Stereotypic or tokenistic knowledge, or a caricature	Superficial understanding of Indigenous knowledge	<ul style="list-style-type: none"> • discuss local seasonal variations and relate them to the Western seasonal calendar • search for Indigenous seasonal calendars on the internet and other sources
Two-Ways/ Two Eyed Seeing approach	Knowledges may be in conflict	Two ways of knowing: Indigenous (local) science compared with Western (universal) science	<ul style="list-style-type: none"> • compare variations in their Western seasonal calendar with those in their local Indigenous seasonal calendar • discuss observable seasonal features, including bird migration and plant flowering and fruiting
Two-Ways/ Two Eyed Seeing with epistemic insight (<i>epistemic insight = knowledge about knowledge</i>)	Knowledges are complementary	Two ways of knowing: making use of both Indigenous (local) and Western (universal) science	<ul style="list-style-type: none"> • discuss the benefits of organising their local Indigenous calendar as a cycle • investigate why Indigenous seasonal calendars vary from place to place, including languages which are in close proximity • discuss how Indigenous seasonal knowledge has been used to inform Western science, particularly botany, zoology, ecology and meteorology • analyse how both knowledge traditions complement each other

of knowing are considered to be complementary. Epistemic insight is often referred to as “knowledge about knowledge” (Epistemic Insight, 2017), and refers to the inclusion of the context of the knowledge and the ways of understanding that knowledge. Again, it is often an Indigenous localised explanation that is being compared with the universal Western science one, and what is being explored is how the two worldviews can complement each other. Importantly this approach requires a deep cultural, as well as Western knowledge which builds on relationships – the sharing of knowledge and coming to understand one another. It is a collaborative process. Canadians Hogue and Provost (2023) describe this as requiring their C⁴-R⁴ philosophy where C⁴ is Co-learning, Co-designing, Co-creating and Co-sharing which cannot happen ethically when working with Indigenous peoples and communities without the R⁴ of good Relationships built on Respect that attend to Responsibility and ensure Reciprocity (Hogue & Provost, 2023).

Discussion

In sum, it is evident that Indigenising science is a challenge. Who should be doing it and how should it be done are the next questions to be asked and answered. Many teachers feel that Indigenous peoples should be doing the Indigenising, at the very least in concert with non-Indigenous educators and curriculum developers (Bull, 2008; Hogue & Provost, 2023; Sambono, 2021). Importantly, this requires educated Indigenous peoples with the scientific expertise as well as the cultural knowledge, to be in positions to create those bridges and effect that. While that is the goal, and there are exemplar pockets of success, locally and internationally we are not there yet. However, as educators and curriculum developers, we can indigenise our practice – how we teach – in ways that attend to IWKL (Hogue & Forrest, 2019; Hogue, 2018, 2019a, 2019b). This is critically important if we are to, not only engage Indigenous learners in the sciences, but also retain them to completion such that they are able to enter into STEM-related academic paths and subsequent professions.

So how do we do this? True indigenisation of the curriculum requires a shift away from the ‘one-size-fits-all’ traditional Western or ‘real’ science model to one that is inclusive of local and place-based Indigenous culture (Hogue, 2018; van Eijck & Roth, 2007). It requires the expertise of both educated Indigenous and non-Indigenous peoples and a C⁴-R⁴ philosophical approach (Hogue & Provost, 2023) for Two-Eyed Seeing and for Two-Ways [Both-Ways] Knowing (Hogue & Forrest, 2019)—a tall

order—and it must be community and place-based. These caveats seem to be more like roadblocks than pathways forward. It will take time and certainly we don’t want to take the path again of a ‘quick fix’. It is however, possible in the meantime to Indigenise our teaching practice—take an approach that attends to IWKL.

Policy

None of the countries examined seem to have had specific policies regarding inclusion of Indigenous perspectives. In the case of the Australian Curriculum, the four *Declarations* mentioned earlier are the basis for development of the national curriculum and interpretation of the cross-curriculum priorities. Such policies are the responsibility of the states and territories where decisions would be made as to the implementation of Indigenous perspectives, maybe reflecting the politics of the day. In Canada there is no equivalent federal agency—there is the Council of Ministers of Education Canada (CMEC)—and the relevant Calls to Action of the Truth and Reconciliation Commission are coming from stakeholder organisations with different priorities to ministries of education. Aotearoa New Zealand has only the one level of government and it will be interesting to see the impact that the *Mātauranga Māori* initiative has on the pending development of the science curriculum.

Curriculum standards

In the ACS, curriculum standards are included with the description of content, for every grade level. Elaborations which relate to specific cross-cultural priorities or general capabilities are identified with an icon. There are also portfolios of work samples available. A question which often arises (and is often used as an excuse for not teaching them) in a discussion of Indigenous perspectives is “*How do you assess them?*” We suggest that teachers take into account the 3rd approach above, Two-Ways / Two-Eyed Seeing with epistemic insight approach, and assessments should be hands-on and assignment-based rather than assessment by examination or testing.

Teaching materials

We consider that teaching materials, including textbooks, should be aligned with the Two-Ways or Two-Eyed Seeing with epistemic insight approach when including Indigenous Knowledge. Table 3 gives an exemplar using the seasons as to the types of activities that students can be exposed to, at all three levels. It may be the case that appropriate Indigenous knowledge, particularly local knowledge, cannot be sourced from secondary sources and will have to (and should) involve working together with local Indigenous people.

Conclusion

The application of Indigenous perspectives in the Australian Curriculum as a cross-curriculum priority, entitled Aboriginal and Torres Strait Islander Histories and Cultures, is unique internationally, as it is applied across all subject areas in a similar fashion. This is particularly the case in the Australian Curriculum: Science, where there has been substantial discussion regarding the nexus between ‘real’ Western science and Indigenous Ways of Knowing and Learning (IWKL). We consider the Australian Curriculum and its components (including the Australian Curriculum: Science) to be one of the best overall curriculum available at this time and the reason for this is that it was developed as a single unit and structures are consistent throughout.

This examination of the inclusion of Indigenous perspectives in international science curriculum proved that it is essentially a missing element and in most cases of its inclusion, somewhat haphazard. It is suggested using the Two-Ways / Two-Eyed Seeing with epistemic insight approach as the way of developing teaching materials and attending to Indigenous Ways of Learning and Knowing (IWLK). With epistemic insight, these are seen as a functional way of bridging Indigenous and Western cultures for policy makers, curriculum developers, educators and teachers, and ultimately students.

Appendix 1

The amendments made to Sect. 5 of the Minnesota Statutes, 2022 to incorporate Indigenous Education for All Students (Minnesota Statutes, 2023, pp.60–61)

“Sec. 5. Minnesota Statutes, 2022, Sect. 120B.021, is amended by adding a subdivision to read: Subd. 5. Indigenous education for all students. To support implementation of Indigenous education for all students, the commissioner must (1) provide historically accurate, Tribally endorsed, culturally relevant, community-based, contemporary, and developmentally appropriate resources. Resources to implement standards must include professional development and must demonstrate an awareness and understanding of the importance of accurate, high-quality materials about the histories, languages, cultures, and governments of local Tribes; (2) provide resources to support all students learning about the histories, languages, cultures, governments, and experiences of their American Indian peers and neighbors. Resources to implement standards across content areas must be developed to authentically engage all students and support successful learning; and (3) conduct a needs assessment by December 31, 2023. The needs assessment must fully inform the

development of future resources for Indigenous education for all students by using information from Minnesota’s American Indian Tribes and communities, including urban Indigenous communities, Minnesota’s Tribal Nations Education Committee, schools and districts, students, and educational organizations. The commissioner must submit a report on the findings and recommendations from the needs assessment to the chairs and ranking minority members of legislative committees with jurisdiction over education; to the American Indian Tribes and communities in Minnesota, including urban Indigenous communities; and to all schools and districts in the state by February 1, 2024. EFFECTIVE DATE. This section is effective the day following final enactment.”

Abbreviations

AC	Australian Curriculum
ACARA	Australian Curriculum, Assessment and Reporting Agency
ACS	Australian Curriculum: Science
AEC	Australian Education Council
ATSIH&C	Aboriginal and Torres Strait Islanders Histories and Cultures
CMEC	Council of Ministers of Education Canada
CTA	Calls to Action
IK	Indigenous Knowledge
IKS	Indigenous Knowledge Systems
IWKL	Indigenous Ways of Knowing and Learning
NGSS	Next Generation Science Standards
NTDE	Northern Territory Department of Education
RQ	Research Question
STEM	Science, Technology, Engineering and Mathematics
TEK	Traditional Environmental Knowledge
TES	Two-Eyed Seeing
TRC	Truth and Reconciliation Commission
TRC-CTA	Truth and Reconciliation Commission – Calls to Action

Acknowledgements

Not applicable.

Authors’ contributions

MM was the main writer and investigator. He carried out the case study on the Australian Curriculum. MH provided critical and editorial input, particularly regarding Canada and Indigenous knowing. JR provided critical and editorial input. All authors read and approved the final manuscript.

Authors’ information

Dr Michael Michie is an adjunct research fellow at the Batchelor Institute of Indigenous Tertiary Education, Australia. He has extensive interest in Indigenous perspectives in the science curriculum, particularly using a two-way approach.

Dr Michelle Hogue is an associate professor at the University of Lethbridge, Canada. Her teaching and research focus on building bridges between Indigenous and Western ways of knowing and learning using culturally relevant and innovative methodological approaches.

Dr Joël Rioux has been a science and mathematics education lecturer with Indigenous preservice teachers at the Batchelor Institute of Indigenous Tertiary Education, Australia. He now works with Montessori Noosa in Queensland.

Funding

Not applicable.

Availability of data and materials

Qualitative data only, please ask.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 1 February 2023 Accepted: 2 November 2023

Published online: 21 December 2023

References

- Abrams, S. (2023, 16 May). House passes K-12 education bill that features \$2.2 billion funding boost, contentious policy changes. Minnesota House of Representatives. Retrieved from <https://www.house.mn.gov/SessionDaily/Story/18099>.
- ACARA. (2011). *Australian Curriculum*.
- ACARA. (2012). Shape of the Australian Curriculum (Version 4.0). Australian Curriculum, Assessment and Reporting Authority. https://acaraweb.blob.core.windows.net/resources/The_Shape_of_the_Australian_Curriculum_v4.pdf Accessed 24 June 2020.
- ACARA. (2019). Australian Curriculum: Science Aboriginal and Torres Strait Islander Histories and Cultures cross-curriculum priority. Australian Curriculum, Assessment and Reporting Authority. <https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/aboriginal-and-torres-strait-islander-histories-and-cultures/>.
- ACARA. (2022). *Australian Curriculum: Science (version 8.4)*. Australian Curriculum, Assessment and Reporting Authority. Science - Foundation to Year 12 (acara.edu.au).
- Achieve. (2021). www.achieve.org Accessed 24 June 2022.
- Aikenhead, G., Brokofsky, J., Bodnar, T., Clark, C., Foley, C., Hingley, J., Isbister, D., Johanson, T., Lauze, C., Myers, S., Roadhouse, T., Rioux, T., Speidel, D., Speidel, W. D., & Strange, G. (2014). *Enhancing school science with Indigenous knowledge: What we know from teachers and research*. Saskatoon Public School Division.
- Aikenhead, G., & Michell, H. (2011). *Bridging cultures: Indigenous and scientific ways of knowing nature*. Pearson Canada.
- Alphonso, C. (2022). *Indigenous science framework removed from Ontario elementary school curriculum*. *The Globe and Mail*. Retrieved from Indigenous science framework removed from Ontario elementary school curriculum - The Globe and Mail.
- Australian Education Council. (1994a). *A statement on science for Australian schools*. Curriculum Corporation.
- Australian Education Council. (1994b). *Science—a curriculum profile for Australian schools*. Curriculum Corporation.
- Azam, S., & Goodnough, K. (2018). Learning together about culturally relevant science teacher education: Indigenizing a science methods course. *International Journal of Innovation in Science and Mathematics Education*, 26(2), 74–88.
- Bartlett, C., & Marshall, A. (2009). *Integrative science and Two-Eyed Seeing*. *Life Long Learning – from Youth to Elder*; conference on Aboriginal education, organized by the Atlantic Aboriginal Economic Development Integrated Research Program (AAEDIRP) of the Atlantic Policy Congress of First Nation Chiefs Secretariat. Fredericton, NB, 23–25, March 2009.
- Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. *Journal of Environmental Studies in Science*, 2, 331–340.
- Benzies, K., Premji, S., Hayden, A., & Serrett, K. (2006). State-of-the-evidence reviews: Advantages and challenges of including grey literature. *Worldviews on Evidence-Based Nursing*, 3(2), 55–61.
- Billingsley, B., Taber, K., Riga, F., & Newdick, H. (2013). Secondary school students' epistemic insight into the relationships between science and religion—a preliminary enquiry. *Research in Science Education*, 43, 1715–1732. <https://doi.org/10.1007/s11165-012-9317-y>
- Bull, R. (2008). *Small study – big success story. Primary Connections incorporating indigenous perspectives pilot study report*. Australian Academy of Science.
- Dampier, H. (2008). Re-reading as a methodology: The case of Boer women's testimonies. *Qualitative Research*, 8(3), 367–377.
- Dawkins, R. (2006). *The God delusion*. Melbourne: Allen & Unwin.
- Deslandes, C., Deslandes, S., Broun, D., Hugh, C., Walsh, F., Bradshaw, F., & Griffith, J. (2019). *Two-Way science: An integrated learning program for Aboriginal desert schools*. CSIRO Publishing.
- Donnelly, K., & Wiltshire, K. (2014). *Review of the Australian curriculum – Final report*. Australian Government.
- Education Council. (2019). *Alice Springs (Mparntwe) Education Declaration*. Australian Education Council.
- Fensham, P. J., Corrigan, J., & Malcolm, C. (1989). *Science for everybody? A summary of research findings*. Curriculum Development Centre.
- Ferrari, J. (2010, 04 March). Dreamtime 'spiritual', so off science courses. The Australian. Accessed 14 Dec 2014 at <http://www.theaustralian.com.au/news/nation/dreamtime-spiritual-so-off-science-courses/story-e6frg6nf-1225836724718?nk=47021c3a76c8eb627105a39241e3465b>
- Geijsel, F., & Meijers, F. (2005). Identity learning: The core process of educational change. *Educational Studies*, 31(4), 419–430.
- Giroux, H.A., & Giroux, S.S. (2008). Challenging neoliberalism in the world order: The promise of critical pedagogy. In Denzin, N.K., Lincoln, Y.S., & Smith, L. Tuhiwai. (2000). *Handbook of critical and Indigenous methodologies*, pp. 181–189. Los Angeles: Sage.
- Gordon, T. J., & Glenn, J. C. (2009). *Environmental scanning. Futures Research Methodology—V3.0. Millenium Project*. Environmental Scanning (researchgate.net).
- Harland, T. (2014). Learning about case study methodology to research higher education. *Higher Education Research & Development*, 33(6), 1113–1122.
- Hatcher, A., Bartlett, C., Marshall, A., & Marshall, M. (2009). Two-Eyed Seeing in the classroom environment: Concepts, approaches, and challenges. *Canadian Journal of Science, Mathematics and Technology Education*, 9(3), 141–153.
- Hogue, M. (2019a). Approaches to Indigenous education in Canada: The journey. In M. Peters (Ed.), *Encyclopedia of educational philosophy and theory*. Springer Publishers.
- Hogue, M. (2019b). Indigenous science and mathematics in the 21st Century. *Encyclopedia of educational philosophy and theory*. M. Peters (ed). Springer Publishers: Singapore. https://doi.org/10.1007/978-981-287-532-7_644-1
- Hogue, M.M. & Forrest, J. (2019c). Bridging cultures over-under: A unique collaboration between two Indigenous academic enabling programs in Canada and Australia in *Transitioning students in higher education: Philosophy, pedagogy and practice*. A. Jones, A. Olds, & J. Lisciandro (eds). New York: Routledge. https://doi.org/10.1007/978-981-287-532-7_652-1 <https://www.jcharltonpublishing.com/product/dropping-the-t-from-cant-enabling-aboriginal-post-secondary-academic-success-in-science-and-mathematics/>
- Hogue, M. (2018). *Dropping the "T" from CAN'T: Enabling Aboriginal post-secondary success in science & mathematics*. JCharlton Press.
- Hogue, M., & Provost, I. (2023). *C4–R4 in the development of co-management practice of crown lands (aka Indigenous traditional territories) (In review)*. Epistemic Insight. (2017). www.epistemicinsight.com/. Accessed 27 Dec 2017.
- Batchelor Institute. (2007). Strategic plan. Batchelor: Batchelor Institute of Indigenous Tertiary Education. https://www.batchelor.edu.au/file_documents/Strategic_plan_2007V1.3.pdf. Accessed 22 April 2012.
- ISSR. (2021b). *Final report – Science*. Institute of Social Science Research, University of Queensland.
- ISSR. (2021a). *Final report – Cross-curriculum priorities*. Institute of Social Science Research, University of Queensland.
- Kawagley, A. O. (1995). *A Yupiaq worldview: A pathway to ecology and spirit*. Waveland Press.
- Keane, M., & Moyo, D. (2010). *Science educators' ideas of the 'science' in IKS and their willingness to include IKS in the school science curriculum* (pp. 92–98). Proceedings of the 18th Annual Meeting of the Southern African Association for Research in Mathematics, Science and Technology Education.
- Kim, E.-J.A. (2022). *Integrating Indigenous and Western Education in science curricula: Relationships at play*. Palgrave Macmillan.

- Kim, E.-J.A., & Dionne, L. (2014). Traditional Ecological Knowledge in science education and its integration into Grades 7 and 8 Canadian science curriculum documents. *Canadian Journal of Science, Mathematics and Technology Education*, 14(4), 311–329. <https://doi.org/10.1080/14926156.2014.970906>
- Lewthwaite, B., & Renaud, R. (2009). *Pilimmaksarniq: Working together for the common good in science curriculum delivery in Nunavut*. *Canadian Journal of Science, Mathematics and Technology Education*, 9(3), 154–172. Manitoba Education and Youth. (2003). *Integrating Aboriginal perspectives into curricula: A resource for curriculum developers, teachers, and administrators*. Manitoba Education and Youth, School Projects Division, Winnipeg, MB.
- Marshall, A., & Bartlett, C. (2004). *Two-eyed seeing*. Integrative Science.
- Matthews, M.R. (2022). Indigenous science and the science curriculum: The New Zealand Debate. *History and Philosophy of Science and Science Teaching Newsletter*, March 2022, 17p.
- Matthews, M. R. (2009). Introduction. In M. R. Matthews (Ed.), *Science, world-views and education* (pp. 1–26). Springer.
- McConvell, P. (1982). Supporting the two-way school. In J. Bell (Ed.), *Language planning for Australian Aboriginal languages* (pp. 60–76). Institute for Aboriginal Development/Aboriginal Languages Association.
- MCEECDYA. (1989). The Hobart Declaration on Schooling. Ministerial Council for Education, Early Childhood Development and Youth Affairs. Retrieved from http://www.mceecdya.edu.au/mceecdya/hobart_declaration,11577.html.
- McKinley, E. (1996). Towards an indigenous science curriculum. *Research in Science Education*, 26(2), 155–169.
- McKinley, E., & Stewart, G., et al. (2012). Out of place: Indigenous knowledge in the science classroom. In B. J. Fraser (Ed.), *Second international handbook of science education* (pp. 541–554). Springer.
- Michie, M. (2015). Science curricula and indigenous knowledge. In R. Gunstone (Ed.), *Encyclopedia of Science Education*, pp.871–877. Dordrecht: Springer Publishers, doi https://doi.org/10.1007/978-94-007-6165-0_312-2.
- Michie, M., Rioux, J., & Hogue, M. (2020). *Incorporating Both-Ways Thinking about Time into the Science Curriculum: Aboriginal and Torres Strait Islander histories and cultures cross-curriculum priority in the Australian Curriculum: Science*. A poster presented at the 51st annual conference of the Australasian Science Education Research Association in June 2020.
- Michie, M. (2002). Why Indigenous science should be included in the school science curriculum. *Australian Science Teachers' Journal*, 48(2), 36–40.
- Michie, M. (2011). *Working across cultures in indigenous science education*. Unpublished doctoral dissertation, University of Waikato, Hamilton, New Zealand.
- Michie, M. (2014). *Working cross-culturally: Identity, border crossing and culture brokerage*. Sense Publishers.
- Michie, M., Hogue, M., & Rioux, J. (2018). The application of Both-Ways and Two-Eyed Seeing pedagogy: Reflections on engaging and teaching science to post-secondary Indigenous students. *Research in Science Education*, 48(6), 1205–1220.
- Michie, M., Rioux, J., & Hogue, M. (2021). Incorporating Two-Ways thinking about time into the science curriculum. *Teaching Science*, 67(1), 36–43.
- Michie, M. (in prep.). Cross-culturalists or expatriates? Western workers, including teachers, in Indigenous communities.
- Minnesota Statutes. (2022). Article 1. General Education, Section 120B.021, HF2497.
- Minnesota Statutes. (2023). The amendments made to Sect. 5 of the Minnesota Statutes, 2022 to incorporate Indigenous Education for All Students, pp. 60-61 (See Appendix 1, herein).
- Moeed, A., & Rofe, C. (2019). *Learning through school science investigation in an Indigenous school: research into practice*. Springer Briefs in Education.
- Moss, J., Godinho, S., & Chao, E. (2019). Enacting the Australian curriculum: Primary and secondary teachers' approaches to integrating the curriculum. *Australian Journal of Teacher Education*, 44(3), 24–41.
- NGSS. (2021). Next Generation Science Standards: For states by states. Retrieved from www.nextgenscience.org.
- Ninnes, P. (2000). Representations of Indigenous knowledges in science textbooks in Canada and Australia. *International Journal of Science Education*, 22(6), 603–617.
- NTDE. (1999). *Intercultural understandings in teaching science: A handbook for teachers*. Darwin: Northern Territory Department of Education. <http://members.ozemail.com.au/~mMichie/intercultural.pdf>. Accessed 27 Sep 2018.
- Ober, R. (2009). Both-ways: Learning from yesterday, celebrating today, strengthening tomorrow. *The Australian Journal of Indigenous Education*, 28, 232–265.
- Ober, R., & Bat, M. (2007). Paper 1: Both-ways: The philosophy. *Ngoonjook*, 31, 64.
- Pappas, C., & Williams, I. (2004). Grey literature: Its emerging importance. *Journal of Hospital Librarianship*, 11(3), 228–234.
- Plimer, I. (1994). *Telling lies for God: Reason vs creationism*. Sydney: Random House Australia.
- Rioux, J. (in prep.). *Building and sustaining successful STEM learners at an urban NT primary school*.
- Ryan, A. (2008). Indigenous knowledge in the science curriculum: Avoiding neo-colonialism. *Cultural Studies of Science Education*, 3(3), 663–683.
- Sambono, J. (2021). The Aboriginal and Torres Strait Islander Histories and Cultures Cross-curriculum Priority: Cultural responsiveness in science education. *SASTA Journal*, 2021(1), 4–13.
- Skamp, K. (in press). *Teaching primary science constructively* (8th edition). Cengage.
- Smith, G., & Michie, M. (2019). Towards an understanding of Indigenous perspectives through the eyes of pre-service science education students. *Learning Communities: International Journal of Learning in Social Contexts*, 24, 22–39. <https://doi.org/10.18793/lcj2019.24.03>
- Snively, G., & Williams, W. L. (Eds.). (2016). *Knowing home: Braiding Indigenous science with western science Book 1*. University of Victoria.
- Snively, G., & Williams, W. L. (Eds.). (2018). *Knowing home: Braiding Indigenous science with western science Book 2*. University of Victoria.
- Songoro, R. (2019). Prioritise Indigenous knowledges and embed a western science perspective, <https://indigenous.com.au/prioritise-indigenous-knowledges-and-embed-a-western-science-perspective/>.
- Stanley, L., & Temple, B. (2008). Narrative methodologies: Subjects, silences, re-readings and analyses. *Qualitative Research*, 8(3), 275–281.
- Stanton, C. R., Carjuzaa, J., & Hall, B. (2019). The promises, purposes, and possibilities of Montana's *Indian Education for All*. *Journal of American Indian Education*, 58(3), 78–104.
- Statistics Canada (2018). 'Aboriginal peoples survey'. www150.statcan.gc.ca/n1/en/catalogue/89-653-X, Accessed 15 Jan 2023.
- Stewart, G. T. (2019). Mātauranga and Pūtaiao: The question of 'Māori science'. *New Zealand Science Review*, 75(4), 64–68.
- Truth and Reconciliation Commission of Canada. (2015). *Final report of the Truth and Reconciliation Commission of Canada Volume one: Summary: Honouring the Truth, Reconciling for the future*. James Lorimer & Company Ltd., Publishers.
- van Eijck, M., & Roth, W.-M. (2007). Keeping the local local: Recalibrating the status of science and traditional ecological knowledge (TEK) in education. *Science Education*, 91, 926–947.
- Webster, L., & Mertova, P. (2007). *Using narrative inquiry as a research method. An introduction to using critical event narrative analysis in research on teaching and learning*. Routledge.
- Wood-Krueger, O. (2022). *Restoring our place: An analysis of Native American resources used in Minnesota's classrooms*. Shakopee Mdewakanton Sioux Community.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.