Science & Education (2020) 29:145–185
https://doi.org/10.1007/s11191-019-00100-x

ARTICLE

A Multi-Perspective Reflection on How Indigenous Knowledge and Related Ideas Can Improve Science Education for Sustainability

Robby Zidny[1,2] • **Jesper Sjöström**[3] • **Ingo Eilks**[4]

Published online: 9 January 2020

Abstract

Indigenous knowledge provides specific views of the world held by various indigenous peoples. It offers different views on nature and science that generally differ from traditional Western science. Futhermore, it introduces different perspectives on nature and the human in nature. Coming basically from a Western perspective on nature and science, the paper analyzes the literature in science education focusing on research and practices of integrating indigenous knowledge with science education. The paper suggests *Didaktik* models and frameworks for how to elaborate on and design science education for sustainability that takes indigenous knowledge and related non-Western and alternative Western ideas into consideration. To do so, indigenous knowledge is contextualized with regards to related terms (e.g., ethnoscience), and with Eastern perspectives (e.g., Buddhism), and alternative Western thinking (e.g., post-human *Bildung*). This critical review provides justification for a stronger reflection about how to include views, aspects, and practices from indigenous communities into science teaching and learning. It also suggests that indigenous knowledge offers rich and authentic contexts for science learning. At the same time, it provides chances to reflect views on nature and science in contemporary (Western) science education for contributing to the development of more balanced and holistic worldviews, intercultural understanding, and sustainability.

1 Introduction

One of the main problems in science education—is the perception of students that a lot of their secondary science lessons are neither interesting, engaging, nor relevant (Anderhag et al. 2016;

Ingo Eilks
ingo.eilks@uni-bremen.de

[1] University of Bremen, Leobener Str. NW2, 28334 Bremen, Germany

[2] Department of Chemistry Education, Faculty of Teacher Training and Education, University of Sultan Ageng Tirtayasa, 42117 Serang, Indonesia

[3] Department of Science-Mathematics-Society, Malmö University, 205 06 Malmö, Sweden

[4] Department of Biology and Chemistry, Institute for Science Education (IDN) - Chemistry Education, University of Bremen, Leobener Str. NW2, 28334 Bremen, Germany

Potvin and Hasni 2014; Stuckey et al. 2013). This is in line with Holbrook (2005) who discussed that learning of science is perceived not to be relevant in the view of students and thus becomes unpopular to them. A main factor for the missing perception of relevance is suggested in a lack of connections of the teaching of science to the everyday life of students and society (Childs et al. 2015; Hofstein et al. 2011). To raise the relevance of science education as part of relevant education, science education should accept a more thorough role in preparing students to become critical citizens (e.g., Sjöström and Eilks 2018). The role of science education is to prepare students to think responsibly, critically, and creatively in responding to societal issues caused by the impact of science and technology on life and society (e.g., Holbrook and Rannikmäe 2007; Hofstein et al. 2011; Sjöström 2013; Stuckey et al. 2013).

To improve the relevance of science education, science teaching requires new ways in the curriculum and pedagogy beyond the mere learning of science theories and facts (Eilks and Hofstein 2015). Science learning should be based on everyday life and societal situations that frame conceptual learning to enable students to appreciate the meaningfulness of science (e.g., Greeno 1998; Østergaard 2017). For acquiring more relevant science teaching and learning—as well as for innovating the curriculum—theory-driven and evidence-based curriculum development for science education and corresponding teacher education are needed (Hugerat et al. 2015). Accordingly, it is important to implement new topics and pedagogies in science teaching and to change teacher education programs. One source for such new topics is sustainability thinking and action, and a corresponding related educational paradigm is called Education for Sustainable Development (ESD) (Burmeister et al. 2012). ESD in connection with science education has been suggested to have potential to contribute to all three domains of relevant science teaching (personal, societal, and vocational relevance) (Eilks and Hofstein 2014). It is relevant for individual action, e.g., in cases involving consumption of resources, participation in societal debates about issues of sustainable development, or careers related to sustainability in science and technology (Sjöström et al. 2015).

However, it should be mentioned that the ESD movement has been criticized for a too instrumental view on the relationship between science, technology, and society. The possibilities of environmental technology for solving environmental problems are emphasized, whereas the need for other societal and behavioral changes is not so much mentioned. Such a view is called ecological modernization (e.g., Læssøe 2010; Kopnina 2014). Education for sustainability (EfS) is a more critical alternative to a narrow-focused ESD (e.g., Simonneaux and Simonneaux 2012; Birdsall 2013). According to Albe (2013), it requires the individual to take the political dimension of environmental issues and their intrinsic power relationships into consideration. The aim is to empower the individual for acting responsibly in terms of sustainability, which was also identified by Stuckey et al. (2013) as an essential justification in their model of relevant science education. Yet another related and critically oriented alternative to mainstream ESD is called ecojustice education (Mueller 2009). In this paper, we use the term *science education for sustainability* describing science education driven by critical and alternative Western views on the transformation to a sustainable world.

According to Savelyeva (2017), the dominant Western sustainability discourse is based on an anthropocentric conception, where nature needs to be managed within the three pillars of sustainability: ecological, economic, and societal sustainability. Such a view on the human-nature relationship is oriented towards producing a sustainable person. However, as will be explained more in detail below, alternative Western—and less anthropocentric—sustainability discourses have been suggested, such as self-reflective subjectivity (Straume 2015), transformative sustainability learning (Barrett et al. 2017), a virtue ethics approach (Jordan and Kristjánsson 2017), and eco-reflexive *Bildung* (Sjöström et al. 2016; Sjöström 2018).

Science is practised based on natural and environmental resources in any given cultural and socio-economic context. However, the picture of science represented in many textbooks all over the world often neglects its cultural component or restricts it to a Western view on the history of science (e.g., Forawi 2015; Khaddour et al. 2017; Ideland 2018). Indigenous views on nature and indigenous knowledge in science at different levels vary among societies and cultures across the globe. The wisdom of indigenous knowledge is often based on sacred respect of nature, due to indigenous peoples' relationships and responsibilities towards nature (Knudtson and Suzuki 1992). Thus, learning about indigenous knowledge may help students recognizing this intimate connection between humans and nature in the foreground of culture from their regional environment or beyond.

Recently, Sjöström (2018) discussed science education driven by different worldviews. Especially he discussed how science teachers' identities are related to their worldviews, cultural values, and educational philosophies, and all these are influenced by the individual's perspectives towards it. Different educational approaches in science education and corresponding eco(logy) views were commented on by Sjöström in relation to the transformation of educational practice. The focus was especially pointed on the similarities between Asian neo-Confucianism and alternative-Western North-European reflexive *Bildung* (see further below).

Indigenous cultures and the culture of (alternative) Western modern science might complement each other in students' everyday world experiences. The introduction of indigenous knowledge in the classroom will represent different cultural backgrounds and might help improve the interpretation of this knowledge (Botha 2012), so that it makes science more relevant to students in culturally diverse classrooms (de Beer and Whitlock 2009). In addition, the incorporation of indigenous knowledge into school curricula might help to enable students to gain positive experiences and develop corresponding attitudes towards science. It might help students to maintain the values of their local cultural wisdom (Kasanda et al. 2005; de Beer and Whitlock 2009; Ng'asike 2011; Perin 2011).

Some research used indigenous knowledge to contextualize science curricula by a cultural context (Chandra 2014; Hamlin 2013; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012). Indigenous knowledge offers rich contexts which have the potential to contribute understanding the relationship of environmental, sociocultural, and spiritual understandings of life and nature. This approach could be appropriate to accommodate sociocultural demand in science education curricula as well as to raise students' perception of the relevance of science learning. Aikenhead (2001) found, however, that possible conflicts may arise when students have the problem of taking information from one knowledge system and placing it into another. There is a number of barriers enabling indigenous knowledge to co-exist in the science curriculum and in the minds of learners and teachers. Barriers are related to limitations of time and corresponding learning materials, prescribed curricula, the selection of appropriate pedagogies, and teachers' doubts in conveying topics containing spiritual aspects in science (Snively and Williams 2016). Teachers have to be aware that it is especially tricky to handle indigenous spiritual views with sufficient care and respect.

Coming from a Western view on nature and science, this analysis attempts to examine the potential role of indigenous knowledge to enhance the relevance of science education with a certain view on education for sustainability. Our view is that the sciences, as well as many other subject areas, have important roles in education for sustainability (Sjöström et al. 2015; Sjöström et al. 2016). The paper suggests *Didaktik* models (in the following called "didactic models") (e.g., Jank and Meyer 1991; Blankertz 1975; Meyer 2012; Arnold 2012) and frameworks for how to elaborate on and design EfS that takes indigenous knowledge and related non-Western and alternative Western ideas into consideration. *Didaktik* can be seen as the professional science for teachers and has a long history in Germany, central Europe, and Scandinavia (e.g., Seel 1999; Schneuwly 2011; Ingerman and Wickman 2015).

A theoretical framework, which contributes multiple reference disciplines of science education (Duit 2007), is proposed for adopting indigenous knowledge in science learning. This approach encompasses the interdisciplinary nature of relevant science education to carry out science education research and development. It could provide guidance for research-based curriculum development to construct an indigenous knowledge framework for raising the relevance of science education and students' perception thereof.

2 Indigenous Knowledge and Related Concepts in the Science Education Literature

The search method in this paper used several scientific literature databases, namely Web of Science, ERIC, Science Direct, and Google Scholar. Several keywords were used to find literature related to the following three main points: (1) a conceptual framework of indigenous knowledge, which includes the definition and concept of indigenous knowledge, the perspective of indigenous knowledge and Western modern science, indigenous knowledge in science education, and the role of indigenous knowledge to promote sustainable development; (2) the relevance of science learning through indigenous knowledge, which encompasses the relevance of science learning in general and indigenous knowledge as a context that supports the relevance of science learning; and (3) research designs and pedagogical approaches to integrate indigenous knowledge in learning and education for sustainability education in science education.

The term *indigenous knowledge* is broadly defined as the local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society (Warren et al. 1993). The search for the term "indigenous knowledge" in the databases located articles pertaining to a number of different terms. Other notions of indigenous knowledge include indigenous science, traditional ecological knowledge, traditional knowledge, ethnoscience, native science, traditional wisdom, Maori science, and Yupiaq science. The search for the term "indigenous knowledge" in the Web of Science produced as much as 8436 hits (retrieved on 2018-01-29), including 577 educational research articles either combined with science education or combined with other related topics (plant sciences, environmental sciences, anthropology, environmental studies, and others). From the 577 educational articles, 446 are peer-reviewed research papers, and only a few articles discuss specific conceptual frameworks of indigenous knowledge. The search in ERIC showed 2404 results for the search term "indigenous knowledge" (retrieved on 2018-01-29). From this database, many review papers and research journal papers were found which are specifically discussing the concept of indigenous knowledge. Some research papers also focus on the relationship between indigenous knowledge and sustainable development. Similar results were also found in Science Direct and Google Scholar that mostly contain empirical and theoretical articles on indigenous knowledge. Of the many terms related to indigenous knowledge, the terminology of indigenous science, ethnoscience, and traditional ecological knowledge were the most frequently used in the literature related to science education, so the search then focused these three terms. Because of the abundance of available articles, potential articles were screened based on the relevant titles. As a result, 22 articles were selected which are directly focusing conceptual frameworks of indigenous knowledge. To complement the perspective with Western modern science and alternative Western thinking, some literature on the philosophy of science education were added by further literature searches.

The literature search for the relevance of science learning was done by using the keyword "relevant science education." It generated 5363 articles (retrieved on 2018-01-29) in ERIC (consisting of 3178 journal articles, reports articles, book chapter, and others). A more specific search was done combining "relevant science education" with "indigenous knowledge" that brought up articles relating to the sociocultural contexts of science and socio-scientific issues. Further analysis focused on raising the relevance of science learning by indigenous knowledge in terms of promoting environmental protection and sustainable development. Thirty relevant articles were identified including some of the same articles as in the previous literature search.

Further analysis of previously obtained articles was aimed to complement the literature on the topic of research designs and pedagogical approaches to integrate indigenous knowledge in science learning. The search was done with the keyword "pedagogical approach for integrating indigenous knowledge." This search generated 70 hits in ERIC and 942 results in Science Direct (retrieved on 2018-01-29). A screening for empirical research in anthropological and psychological paradigms, designing instructional approaches to introducing indigenous knowledge into science classrooms and using indigenous science to contextualize science learning by a sociocultural context, identified 14 articles. Further analysis of the articles from this search identified the need for more design research in science education for the integration of indigenous knowledge. One strategy identified in the literature is the *Model of Educational Reconstruction* (Duit et al. 2005). Search results using the keywords "Model of Educational Reconstruction" produced 88,816 hits in ERIC (retrieved on 2018-01-29). Screening related titles with science education identified seven articles. A search on the development of learning designs accommodated to the relevance of science learning for sustainable development, as well as to promote sustainable development, was added. The search for the keyword "ESD in Science Education" generated 148.499 articles on the ERIC database (retrieved on 2018-01-29). Some articles based on topics related to sustainability and referring to context- and/or socio-scientific issue–based science education were identified this way (Table 1).

3 Indigenous Knowledge, Western Modern Science, and Alternative Western Thinking

3.1 Concepts to Characterize Indigenous Knowledge

Based on an analysis of terms, there are differences in the use of terms Indigenous (with capital I) and indigenous (with lowercase i). According to Wilson (2008), Indigenous (with capital I) refers to original inhabitants or first peoples in unique cultures who have experiences of European imperialism and colonialism. Indigenous peoples have a long history of live experience with their land and the legacy from the ancestor, and their future generations (Wilson 2008; Kim 2018). Meanwhile, the term indigenous (with lowercase i) refers to "things that have developed 'home-grown' in specific places" (Wilson 2008, p. 15). In this paper, it is suggested to follow Kim's (2018) point of view to use the term "indigenous" (with lowercase i) to positioning oneself as an indigenous to one's homeland. The first author is indigenous to

Table 1 Overview of the literature search

Keywords/topic	Sources and number of hits (2018-01-29)	Identified articles and book chapter
Indigenous knowledge (focusing on conceptual frameworks of indigenous knowledge)	- Web of Science: 8436 - ERIC: 2404 - Some additional literature from Google Scholar and Science Direct	Aikenhead and Ogawa 2007; Ogawa 1995; Snively and Corsiglia 2000; Aikenhead and Michell 2011; Aikenhead 1996; Aikenhead 2001; Berkes 1993; Brayboy and Maughan 2009; Cobern 1996; Abonyi et al. 2014; Houde 2007; Kim et al. 2017; Iaccarino 2003; Kimmerer 2012; Mazzocchi 2006; McKinley 1996; McKinley and Stewart 2012; Nakashima and Roué 2002; Snively 1995; Snively and Williams 2016; Warren et al. 1993; Stephens 2000.
Relevant science education (focusing on raising the relevance of science learning by indigenous knowledge in terms of contextualizing to promote environmental protection and sustainable development)	ERIC: 5363 - Some additional literature from Google Scholar and Science Direct	Stuckey et al. 2013; Eilks and Hofstein 2015; Holbrook 2005; Atwater and Riley 1993; Hodson 1993; Stanley and Brickhouse 1994; Ramsden 1998; Childs 2006; Childs et al. 2015; Kibirige and van Rooyen 2006; Abonyi 1999; Aikenhead 1996; Aikenhead 1997; Aikenhead and Jegede 1999; Jegede 1995; Botha 2012; Costa 1995; de Beer and Whitlock 2009; De Boer 2000; De Haan 2006; Hansson 2014; Kasanda et al. 2005; Ng'asike 2011; Perin 2011; Snively and Corsiglia 2000; Snively and Williams 2016; Ogawa 1995; Mashoko 2014; Maddock 1981; Keller 1983.
Pedagogical approach for integrating indigenous knowledge	ERIC: 70	Aikenhead and Jegede 1999; Aikenhead 1996; Jegede 1995; Herbert 2008; Abonyi 1999; Aikenhead 2001; Chandra 2014; Hamlin 2013; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012; Ogunniyi and Hewson 2008; de Beer and Whitlock 2009; Fasasi 2017.
Model of Educational Reconstruction	ERIC: 88.816	Duit et al. 2005; Duit 2007; Duit 2015; Diethelm et al. 2012; Grillenberger et al. 2016; Kattmann et al. 1996; Jank and Meyer 1991.
ESD in Science Education	ERIC: 148.499	Eilks et al. 2013; Marks and Eilks 2009; Burmeister et al. 2012.

Indonesia, which is a country that has many traditional tribes and indigenous societies. These societies affect the culture of people living near indigenous environments but not living indigenous lifestyles. Even though the first author considers himself not to belong to an indigenous community, he spent his childhood in a rural environment, and he felt the experience of indigenous knowledge in his daily life as well as he was influenced by the culture of modern society. The first author is also able to speak an indigenous language (second language) used by one of the Indonesian indigenous peoples (Baduy Tribe) and interacted with them in a study focusing the Baduy's science-related knowledge (Zidny and Eilks 2018). This study is part of a project to educationally reconstruct indigenous knowledge in science education in Indonesia in order to enhance the relevance of science learning as well as to promote education for sustainability. Meanwhile, the other authors are coming from central and northern European backgrounds with experience to Eurocentric cultures. In line with Kim (2018), all authors position themselves as an "ally" to indigenous people and still maintaining their personal cultural and integrity. In this regard, Kovach (2009) encouraged non-indigenous knowledge academics to incorporate a decolonizing agenda to support indigenous scholarship. The term "decolonization" is defined as a process to acknowledge the values of indigenous knowledge and wisdom (Afonso 2013) and bring together both indigenous and non-indigenous people to learn and respect indigenous knowledge (Kim 2018).

In the last few decades, studies on the knowledge of indigenous cultures involved various disciplines both from the natural and from the social sciences. There is no universal definition available about this kind of knowledge and many terms are used to describe what indigenous people know (Berkes 1993). Some scholars define indigenous knowledge by several terms and their respective perceptions. Snively and Williams (2016) argue that this distinction describes a way to distinguish heterogeneous cultural groups' ways of knowing about nature. Many terms to describe indigenous knowledge have been used in the literature in science education (Table 2).

Ogawa (1995) proposed to understand science education in a "multiscience" perspective in order to foster "multicultural science education" contributing to the field of science education. The idea of a multiscience perspective acknowledges the existence of numerous types of science at play in science classrooms. Ogawa defined science in a multiscience perspective encompassing three categories: personal science (referring to science at the individual level), indigenous science (referring to science at the cultural or society level), and Western modern science (referring to a collective rational perceiving reality shared and authorized by the scientific community). In a more recent publication, Aikenhead and Ogawa (2007) proposed a new definition about science. They proposed a concept of science which explores three cultural ways of understanding nature. It changes the key terms to become more authentic to better represent each culture's collective, yet heterogeneous, worldview, meta-physics, epistemology, and values. They also suggested dividing the ways of understanding nature into the following three categories:

1) An indigenous way (referring to indigenous nations in North America)

Indigenous ways of living in nature are more authentic. This view is used to describe indigenous knowledge, which encompasses indigenous ways of knowing. Ways of living in

Table 2 Alternative terms to describe indigenous knowledge

Alternative terms	Literature
Indigenous science	Aikenhead and Ogawa 2007; Ogawa 1995; Snively and Corsiglia 2000
Ethnoscience	Sturtevant 1964; Hardesty 1977; Abonyi 2002
Traditional Ecological Knowledge (TEK)	Snively and Corsiglia 2000; Bermudez et al. 2017; Hamlin 2013; Kim et al. 2017; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012
Native science	Cajete 2000
Traditional wisdom	George 1999
Aboriginal science	Aikenhead 2006
Traditional (native) knowledge	ICSU 2002; Stephens 2000
Yupiaq science	Kawagley 1995
Maori science	McKinley 1996

nature are action-oriented, which must be experienced in the context of living in a particular place in nature, in the pursuit of wisdom, and in the context of multiple relationships. One example of this kind of knowledge is the Yupiaq way of understanding nature, which has the focus of surviving the extreme condition in the tundra (Kawagley et al. 1998).

2) A neo-indigenous way (bringing up distinctive ways of Asian nations of knowing nature)

A neo-indigenous way of knowing is based in far more heterogeneous indigenous cultures, which are influenced by the traditions of Islamic and Japanese cultures. The term "indigenous science" is used by Japanese literature in the context of a multiple-science perspective. Indigenous science is a collective rational perceiving reality experienced by particular culture-dependent societies (Ogawa 1995).

3) Euro-American (Western modern) scientific way

Eurocentric sciences represent a way of knowing about nature and it was modified to fit Eurocentric worldviews, meta-physics, epistemologies, and value systems. This also includes knowledge appropriated over the ages from many other cultures (e.g., Islam, India, and China).

3.2 Defining Indigenous Science and Related Terms

From the same perspective, Snively and Corsiglia (2000) defined indigenous science as science obtained from the long-resident oral community and the knowledge which has been explored and recorded by biological scientists. They interpreted indigenous science as *Traditional Ecological Knowledge* (TEK). The concept of TEK is used by various scientists in the fields of biology, botany, ecology, geology, medicine, climatology, and other fields related to human activity on the environment guided by traditional wisdom (Andrews 1988; Berkes 1988, 1993; Berkes and Mackenzie 1978, Inglis 1993; Warren 1997; Williams and Baines 1993). Even so, Snively and Corsiglia (2000) stated that the definition of TEK is not accepted universally because of the ambiguity in the meaning of *traditional* and *ecological knowledge*. Other scholars prefer the term "indigenous knowledge" to avoid the debate about tradition and give emphasis on indigenous people (Berkes 1993). In addition, Snively and Corsiglia (2000) argued that TEK does not represent the whole of indigenous knowledge because it also contributes to some aspects of Western modern science. Therefore, TEK is the product of both Western modern science and indigenous knowledge (Kim et al. 2017).

Snively and Williams (2016) distinguished the scope of indigenous knowledge, indigenous science, traditional ecological knowledge, and Western science as follows:

– *Indigenous knowledge* (*IK*): The local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society (Warren et al. 1993). IK is a broad category that includes indigenous science.
– *Indigenous science* (*IS*): IS is the science-related knowledge of indigenous cultures.
– *Traditional ecological knowledge* (*TEK*): TEK refers to the land-related, place-based knowledge of long-resident, usually oral indigenous peoples, and as noted, consider it a subset of the broader categories of IK and IS. TEK is not about ecological relationships exclusively, but about many fields of science in its general sense including agriculture, astronomy, medicine, geology, architecture, navigation, and so on.

– Western science (WS): WS represents Western or Eurocentric science in the means of modern Western science knowledge. Here, Western science knowledge is understood as mainstream Western modern science, i.e., acknowledging that also in modern Western societies' alternative worldviews and views on science and nature exist (Korver-Glenn et al. 2015). Such views are here called "alternative Western thinking."

To understand the relationship between indigenous knowledge, indigenous science, and TEK, Kim and Dionne (2014) suggest the "cup of water" analogy (Fig. 1). This analogy illustrates science as a cup or container, and knowledge as water that fills the cup. The shape of the water will adjust to the shape of the cup that holds it. Science is described as a collection of knowledge and methods that shape the perception of knowledge (Kim and Dionne 2014). Thus, knowledge will be perceived differently according to the form of science that reflects cultural traditions and the perspective of those who adhere to it. Western or European knowledge is shaped by Western modern science (WMS) who adhere to the culture and perspective of Western or European societies (Aikenhead 1996; Kim and Dionne 2014). Indigenous knowledge is formed by indigenous science which adheres to the culture and perspective of indigenous society, while TEK is part of the indigenous knowledge which is guided by indigenous science methods that are in parallel with WMS in terms of presenting solutions to ecological problems. Thus, TEK does not represent the whole indigenous knowledge system and has some similarities and differences with WMS (Kim and Dionne 2014).

The term of IK in science education is also known as "ethnoscience." Ethnoscience was first introduced by anthropologists in an ethnography approach that refers to a system of knowledge and cognition built to classify and interpret objects, activities, and events in a particular culture (Sturtevant 1964; Hardesty 1977). According to Snively and Corsiglia (2000), also IS is sometimes referred to as ethnoscience, which consists of the knowledge of indigenous expansionists (e.g., the Aztec, Mayan, or Mongolian empires) as well as the long-term residents of origin knowledge (i.e., the Inuit, the Aboriginal people of Africa, the Americas, Asia, Australia, Micronesia, and New Zealand). Abonyi (1999) emphasizes that the indigenous own thinking and relation to life is a fundamental focus of ethnoscience to realize their vision of the world. He also notes that ethnoscience may have potentially the same

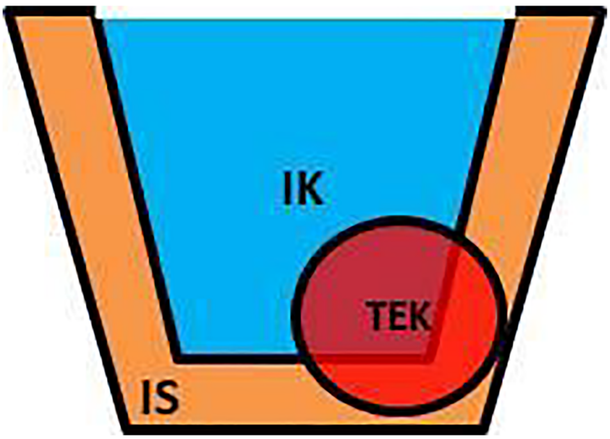

Fig. 1 Relationship between indigenous knowledge (IK), indigenous science (IS), and traditional ecological knowledge (TEK) (adapted from Kim and Dionne 2014)

branches as Western modern science because it is concerned with natural objects and events. Accordingly, the dimensions of ethnoscience would include a number of disciplines, namely ethnochemistry, ethnophysics, ethnobiology, ethnomedicine, and ethnoagriculture (Abonyi et al. 2014). Ethnoscience might have the same characteristics as TEK because it has been categorized into various disciplines of WMS-based scientific knowledge. Table 3 summarizes all the terminology, definitions, and acronyms related to indigenous knowledge in this paper.

All in all, this analysis is not intended to make contention about the different definitions of indigenous knowledge. Despite there are some different perspectives of scholars to define knowledge systems, we support the view of Snively and Williams (2016) that this distinction simply serves as a way to distinguish between highly heterogeneous groups and their ways of knowing nature.

3.3 Perspectives of Indigenous Knowledge

There is some literature in science education which has identified various characteristics and opposing views between Western modern science and indigenous knowledge. Nakashima and Roué (2002) identified that indigenous knowledge is often spiritual and does not make

Table 3 Terminology and definitions related to indigenous knowledge

No.	Terminology and acronym	Definition	References
1.	Indigenous (with capital I)	Refers to original inhabitants or first peoples in unique cultures who have experiences of European imperialism and colonialism	(Wilson 2008)
2.	indigenous (with lowercase i)	Refers to things that have developed "home-grown" in specific places	(Wilson 2008, p.15)
3.	Indigenous knowledge (IK)	The local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society	(Warren et al. 1993)
4.	Indigenous science (IS)	The science-related knowledge of indigenous cultures. This science shaped indigenous knowledge based on the culture and perspective of indigenous society.	(Snively and Williams 2016); (Kim and Dionne 2014)
5.	Traditional ecological knowledge (TEK)	TEK is part of the indigenous knowledge which is guided by indigenous science methods that are in parallel with WMS in terms of presenting solutions to ecological problems.	(Kim and Dionne 2014)
6.	Ethnoscience	Refers to a system of knowledge and cognition built to classify and interpret objects, activities, and events in a particular culture. Ethnoscience has been categorized into various disciplines of WMS-based scientific knowledge, namely ethnochemistry, ethnophysics, ethnobiology, ethnomedicine, and ethnoagriculture.	(Sturtevant 1964; Hardesty 1977); (Abonyi et al. 2014)
7.	Western science (WS)/Western modern science (WMS)/alternative Western thinking	Western science knowledge is understood as mainstream modern Western science, acknowledging that also in modern Western societies, alternative worldviews and views on science and nature exist. This we call "alternative Western thinking."	(Korver-Glenn et al. 2015)

distinctions between empirical and sacred knowledge in contrast to Western modern science, which is mainly positivist and materialist. They also emphasized that Western modern science generally tries to use controllable experimental environments on their subject of study, while on the contrary indigenous knowledge depends on its context and particular local cultural conditions. In addition, indigenous knowledge adopts a more holistic approach, whereas on the opposite, Western modern science often tries to separate observations into different disciplines (Iaccarino 2003).

The perspective of Western contemporary culture and philosophy encourages us an interesting idea about the different forms of knowledge. Feyerabend (1987) acknowledged that any form of knowledge makes sense only within its own cultural context, and doubted people's contention that the absolute truth criteria are only being determined by Western modern science. This is in line with Bateson (1979) who pointed out that the actual representation of knowledge depends on the observer's view. Therefore, every culture has its way of viewing the world so they may have developed unique strategies for doing science (Murfin 1994). The theory of multicultural education in science also proposed the same ideas which recognize science as a cultural enterprise. Aikenhead (1996, p.8) stated that "science itself is a subculture of Western or Euro-American culture, and so Western science can be thought of as 'subculture science'". It is based on the worldview presuppositions that nature and the universe are ordered, uniform, and comprehensible. However, Hansson (2014) has shown that many upper secondary students view scientific laws as only valid locally and that they differentiate between their own views and the views they associate with Western science. This indicates that also many Western people have a "personal science" (Ogawa 1995) way of thinking.

At the same time, it is widely known that there is a different perspective between Western modern science and indigenous knowledge in the context of strategies to create and transmit knowledge (Mazzocchi 2006). Eijck and Roth (2007) pointed out that both domains of knowledge are incommensurable and cannot be reduced to each other, because they are based on different processes of knowledge construction. Therefore, it is difficult to analyze one form of knowledge using the criteria of another tradition. Despite there are many distinctions on both sides, Stephens (2000) discovered the common ground between indigenous knowledge and Western modern science (Table 4), even though there are some suggestions to improve the content (e.g., Aikenhead and Ogawa 2007). Stephens (2000) emphasized that correlating one with another would be validated local knowledge as a pathway to science learning, and demonstrated that the exploration of multiple knowledge systems could enrich both perspectives to create thoughtful dialog.

3.4 Indigenous Knowledge and Alternative Western Thinking

Ideologically mainstream Western science can be described with labels such as positivism, objectivism, reductionism, rationalism, and modernism (e.g., Sjöström 2007). Many of these characteristics can be explained by the body-mind dualism that has been promulgated in Western civilization all since René Descartes (e.g., Bernstein 1983). It is called a Cartesian view and also includes the view that human beings are seen as separate from nature and with rights to exploit the Earth and its resources. In contrast to Western dualisms and modernism, most Eastern philosophies are more holistic and system-oriented (e.g., Hwang 2013). For example, Neo-Confucianism has been suggested as an alternative to the dominant Western sustainability discourse (Savelyeva 2017). Humans are positioned in harmony with cosmos and such a view can be called *cosmoanthropic*: "everything in the universe, including humans,

Table 4 Stephens's (2000) similarities and differences between indigenous knowledge and Western modern science

Themes	Indigenous knowledge	Common ground	Western modern science
Organizing principles	• Holistic • Includes physical and metaphysical worldviews linked to moral codes • Emphasis practical application of skills and knowledge	• Universe is unified • Body of knowledge is stable but subject to modification	• Part to whole • Limited to evidence and explanations within the physical world • Emphasis on understanding how
Habits of mind	• Trust for inherited wisdom • Respect for all things	• Honesty, inquisitiveness • Perseverance • Open-mindedness	• Skepticism
Skills and procedures	• Practical experimentation • Qualitative oral record • Local verification • Communication of metaphors and stories connected to life, values, and proper behavior	• Empirical observation in natural settings • Pattern recognition • Verification through repetition • Inference and prediction	• Tools expand scale of direct and indirect observation and measurement • Hypothesis falsification • Global verification • Quantitative written record • Communication of procedures, evidence and theory
Knowledge	• Integrated and applied to daily living and traditional subsistence practices	• Plant and animal behavior, cycles, habitat needs, interdependence • Properties of objects and materials • Position and motion of objects • Cycles and changes in earth and sky	• Discipline-based • Macro vs. (sub-) micro representations (e.g., cell biology, particle, and atomic theory) • Mathematical models

shares life and deserves greatest respect […] cosmos is not an object, physical reality, or a mechanical entity; cosmos is a dynamic and ever-changing interpretive reality, which reflects human understanding, sense-making and interpretation of the universe" (Savelyeva 2017, pp. 511–512).

Another more recent Korean philosophy, highly influenced by Neo-Confucianism, but also based on, e.g., Taoism and Buddhism, is called *Donghak* (=Eastern learning). Moon (2017) describes that in *Donghak* the interconnection and equal relations between God, human, nature, and cosmos go beyond the anthropocentric understanding of any human-nature relations. Similarly, Wang (2016) has discussed Taoism and Buddhism in relation to the concepts of self-realization and the ecological self-according to *ecosophy*, the eco-living philosophy developed by the Norwegian philosopher Arne Naess. It is strongly influenced by Buddhist traditions and can be explained as a lifestyle that incorporates ecological harmony and ecological wisdom.

Recently, De Angelis (2018)—in the context of sustainability—compared Buddhist/Eastern spiritual perspectives and indigenous-community learning with alternative Western thinking such as transformative learning theory (Sterling 2011) and Dewey's experience-thinking (see further below). De Angelis (2018) proposes that they all—to a higher or lower degree—share the notions of *inner experience*, *oneness of reality*, and *moral sustainable values*. Other similarities are *awareness of context* and a *holistic orientation*. She writes: "human beings are seen as strictly interconnected and co-existing with nature and their self-development is conceived in harmonious terms with it" (p. 184). Values, feelings, and emotions are seen as significantly contributing to various transformative processes. Furthermore, she emphasizes that her intention is to give "a voice to 'other' ways of perceiving the relationship between humans and the environment" (p. 189).

As indicated with the examples above, many of the ideas that are characteristic of Eastern philosophies and indigenous knowledge (according to Table 4) can also be found in some alternative Western thinking. Examples include holistic thinking, an integrated worldview, and respect for all living things. Below, we more in detail describe the following three interrelated philosophical directions of alternative Western thinking: (a) a post-human version of the European notion of *Bildung*, (b) phenomenology and embodied knowledge, and (c) network-thinking, respectively:

(a) Post-human *Bildung*: In Central and Northern Europe, there is a philosophical and educational tradition called *Bildung* (Sjöström et al. 2017). It was in its modern educational meaning coined in Germany in the late eighteenth century and then spread to Scandinavia. However, the real origins of the concept can be traced back to the Middle Age, when it had theological and spiritual connotations (Horlacher 2016; Reichenbach 2016). Meister Eckhart (1260–1328) introduced the term as early as in the late thirteenth century when he translated the Bible from Latin into German. He used it as a term for transcending "natural existence and reach real humanity" (Horlacher 2016, p. 8). Then it took roughly five hundred years until the term started to be used in educational contexts, meaning self-formation. The rooting of *Bildung* in Romanticism was later intertwined with contemporary ideas of Enlightenment (Reichenbach 2014). It became also connected to morality and virtue, or in one word to humanity (Reichenbach 2016).

Generally, the following five historical elements of *Bildung* can be identified:

- Biological-organic growth process (self-knowledge is a prerequisite for humanism)
- Religious elements (transparency for a spiritual world in contrast to only materialism)
- Connection to ancient cultures
- Enlightenment thoughts (forming informed and useful democratic citizens)
- Socio-political dimension (emancipation)

The two main elements of *Bildung* are autonomous self-formation and reflective and responsible societal (inter)actions. Most versions of *Bildung* are highly influenced by Western modernism (Sjöström 2018), although alternatives, which in a way connect to the roots of the concept, have developed during the last two decades. Rucker and Gerónimo (2017) have theoretically connected the concept to the complexity and some scholars have started to discuss it from postmodern, post-human, and sustainability perspectives, where both relations and responsibility are emphasized (e.g., Taylor 2017; Sjöström 2018; Rowson 2019). Taylor (2017) asked if a post-humanist *Bildung* is possible and she seems to think so:

> A posthuman Bildung is a lifelong task of realizing one's responsibility within an ecology of world relations, it occurs outside as well as inside formal education, in virtual as well as'real' places. [… It] is a matter of spirituality and materiality which means that it is not an 'inner process' but an educative practice oriented to making a material difference in the world. [… It is] education as an ethico-onto-epistemological quest for (better ways of) knowing-in-becoming. (pp. 432–433)

With many similarities to the Eastern thoughts of co-living, and just like "ecosophy" in a Western context, two of us have discussed what we call eco-reflexive *Bildung* (Sjöström et al. 2016). It adds an eco-dimension to critical-reflexive *Bildung* and has similarities to the cosmoanthropic view described above as well as to *Donghak*. These ideas have in common the view of life and society as interdependent and an inseparable whole.

(b) Phenomenology and embodied knowledge: The discussion about *Bildung* connects to the second alternative Western idea, which is life-world phenomenology and connected embodied experiences (Bengtsson 2013). These ideas are based on philosophical thinking originating from the philosophers Merleau-Ponty, Heidegger, and Husserl. Bengtsson (2013) describes this understanding by the view that the life of the individual and the world is interdependent and that the lived body is a subject of experiencing, acting, understanding, and being in the world. John Dewey had similar thoughts about the experience (Retter 2012) and Brickhouse (2001) has emphasized the importance of an embodied science education, which overcomes the body-mind dualism.

Related to this, some science education scholars have emphasized the role of wonder, esthetic experience, romantic understanding, and environmental awareness in science education (e.g., Dahlin et al. 2009; Hadzigeorgiou and Schulz 2014; Østergaard 2017). Hadzigeorgiou and Schulz (2014) focused on the following six ideas: (1) the emotional sensitivity towards nature, (2) the centrality of sense experience, (3) the importance of holistic experiences, (4) the importance of the notions of mystery and wonder, (5) the power of science to transform people's outlook on the natural world, and (6) the importance of the relationship between science and philosophy. These six ideas are related to "relations between self, others and nature" and to Dewey's esthetic (phenomenological existence) and reflective (pragmatic existence) experience (Quay 2013). It can also be described by "being-in-the-world" and "a total, relational whole" (p. 148).

Dahlin et al. (2009) have argued for a phenomenological perspective on science and science education and they discussed how it can foster students' rooting (see also Østergaard et al. 2008). By phenomenology, they emphasized that all human experiences are important and that "subject and object must be seen as belonging together, as two aspects of one (non-dualistic) whole" (Dahlin et al. 2009, p. 186). Furthermore, they are critical to cognitionism and technisation and instead emphasize the rich complexity of nature and lived experience. In contrast to both constructivism and sociocultural learning, they describe phenomenology to be more open to esthetic, ethical, and moral dimensions of science. These views have similarities to Eastern philosophies and indigenous knowledge.

(c) Network-thinking: The third alternative and related Western idea is network-thinking by, e.g., the French sociologist Michael Callon (born 1945) and the French philosopher Bruno Latour (born 1947). A conflict between modernism and postmodernism in science education has been identified by Blades (2008). This tension is related to the tension between views in traditional science education versus more progressive views in the area of environmental education (Dillon 2014). In an article about emancipation in science education, Zembylas (2006) discussed the philosophy of meta-reality by Roy Bhaskar. He claimed that Bhaskar's ideas offer an interesting alternative to modernist and post-modernist accounts. Bhaskar viewed everything as connected—humans, nonhumans, and "things." These thoughts are similar to some thinking of actor-network theory developed

> by, e.g., Callon and Latour. In Latour's networks, knowledge and power are not separable and he claims that it is not possible to stay outside a field of competing networks for giving an objective description of the state of affairs. Latour (2004) introduced the concept *matters of concern* to refer to the highly complex, uncertain, and risky state of affairs in which human and non-human entities are intimately entangled.

Network-oriented science education focuses on interactive relational production of knowledge. Colucci-Gray and Camino (2014) write about "science of relationships" and "epistemic and reflexive knowledge" (see also Colucci-Gray et al. 2013). More recently, the same authors suggested activities that aim at developing reflexivity about the individual's position in the global, ecological web. They related it to the thinking of Gandhi and emphasized ideas such as non-duality and interdependency, and relational ways of knowing (Colucci-Gray and Camino 2016). Except for cognitive and social development, they also emphasized emotional and spiritual development. On the question what should be the narratives of science education, they answered non-human relationships, interactions between science, values and learning, embodied experiences, and interdisciplinarity. In addition to Gandhi's philosophy they also refer to ecosophy and different Eastern traditions.

Brayboy and Maughan (2009) have pointed out that the objective for most culturally relevant science learning is not to put indigenous knowledge and Western modern science in opposition to one another, but instead to extend knowledge systems and find value and new perspectives for teaching and learning from both. This is aligned with the perspective of *two-eyed seeing* as a means to build bridges and "to help these cultures find ways to live in mutual respect of each other's strengths and ways" (Hatcher et al. 2009, p. 146): "Through two-eyed seeing students may learn to see from one eye with the strengths of indigenous ways of knowing and from the other eye with the strengths of Western ways of knowing." McKeon (2012) used the perspective of "two-eyed seeing" for weaving the knowledge from the views of non-indigenous environmental educators to enrich environmental education by indigenous understandings. The indigenous understandings are communicated through oral tradition to teach about the interconnectedness of nature and the concepts of transformation, holism, caring, and responsibility. The core ideas in environmental education (systems theory, ecological literacy, bio-philia, and place-based education) can obtain advantage from and connect to foundational values of indigenous education (Mckeon 2012).

4 Indigenous Knowledge in Science Education

4.1 Conceptual Frameworks of Indigenous Knowledge in Science Education

Studies in constructivism opened up the science educators to understand science not only as a body of knowledge but also as a way of thinking. Indigenous science is the knowledge which reflects the indigenous way of thinking about the physical world (Abonyi et al. 2014). Thus, constructivism provides the opportunity for indigenous science to adjoin with Western modern scientific views. The perspective of constructivism suggests that knowledge is not a kind of thinking that can be copied between individuals, but rather has to be reconstructed by each learner (Taber 2014). According to Taber (2013), human learning is interpretive (a sense-making process to produce a perception of the world), incremental (integrating the existing knowledge and understanding which enable learners to make sense), and iterative (reinforces the existing interpretation). Accordingly, once learners have developed a particular understanding, then they will interpret new information according to this way of thinking and tend to learn it in a way that reinforces the existing interpretation. The indigenous ways of thinking can provide corresponding learners with a broader (more holistic) view of the world to understand science and nature beyond a non-Western perspective (Kim and Dionne 2014). The integration of indigenous knowledge in science education provides a holistic learning framework of the study, which make learners with an indigenous background able to understand the role of their societal and cultural context in the production of scientific knowledge (Aikenhead and Michell 2011). It has potential to facilitate learners to make own sense of their world and reinforces their existing interpretation of natural phenomena.

Cobern (1996) suggested that learning is the active process of constructing a conceptual framework based on the interpretation of learners' prior knowledge, rather than the process of transmission which only make learners memorize knowledge. The interpretation is affected by the personal and culturally embedded background of knowledge of the learners that make learning processes meaningful. This view suggests building a conceptualization of scientific knowledge in which it is reasonable to expect culture-specific understandings of science (Cobern 1996). Accordingly, in the perspective of any learners, indigenous science can serve as a base for the construction of reality by linking culture to advance scientific knowledge (Abonyi et al. 2014). Moreover, incorporating indigenous knowledge in science education for all may help to reflect the different intellectual traditions of various cultures adjoined with scientific knowledge to solve relevant problems in the context of its ecological, societal, and economic ramifications.

McKinley and Stewart (2012) point out four major themes of research and development associated with integrating indigenous knowledge into science education. These are (a) equity of learning outcomes for students from non-Western backgrounds, (b) contributions of indigenous knowledge to the knowledge base of Western modern science, (c) environmental concerns over sustainability, and (d) inclusion of the nature, philosophy, and limits of science. For instance, Lowan-Trudeau (2012) developed a model based on *métissage* (the metis methodologies) to incorporate Western and indigenous knowledge and philosophy into ecological identities and pedagogical praxis. *Métissage* offers the diversity of views and experiences about nature which is required for the development of environmental education research for future generations. Environmental education researchers from all cultural backgrounds are encouraged to acknowledge and engage with indigenous knowledge, philosophies, and methodologies (Lowan-Trudeau 2012).

The integration of indigenous knowledge in education should recognize indigenous frameworks and methodologies to give more attention to their history, politics, cultural beliefs, and philosophical views as well as to balance the Western perspective (Smith 1999, 2002). For instance, some Maori scholars have used their frameworks and methodologies to incorporate indigenous knowledge in education. Smith (1999) suggested *Kaupapa Maori* as a research approach to reconstruct and recognize indigenous knowledge of Maori people rather than using mainstream research that is too Western paradigm-oriented. The term of *Kaupapa Maori* describes the Maori worldview that incorporates their thinking and understanding about practice and philosophy living (Smith 1997; Pihama and Cram 2002). Based on the framework and key principles of *Kaupapa Maori*, Maori's scholars developed oral traditions and narrative inquiry approaches to express their experiences. Ware, Breheny, and Forster (2018) developed a Māori approach called *Kaupapa Kōrero* to collect, introduce, and understand Māori experiences and also interrelatedness and influence of their societal expectations, indigeneity, and culture. In school education, Lee (2002) suggested the *akonga Maori* framework to view Maori secondary teachers' experiences in relation to teacher education in ways that are culturally responsive and culturally relevant to Maori students. This framework offers education providers to be more involved with Maori students in preparing them for their work in secondary schools.

In the literature, the integration of indigenous knowledge with science education has been widely distilled and packaged based on the different genres and cultures of Western modern science disciplines in the form of TEK (Afonso Nhalevilo 2013; Bermudez et al. 2017; Chandra 2014; Chinn 2009; Funk et al. 2015; Hamlin 2013; Kim and Dionne 2014; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012; Nadasdy 1999; Simpson 1999). Based on the suggested polygon framework of TEK (Houde 2007; Kim et al. 2017), it is suggested that TEK pedagogy should respect five dimensions as in the didactic model in Fig. 2.

Using the polygon framework of TEK, Kim et al. (2017) explored current pedagogical conceptualizations of knowledge systems in science education and criticized the implication of TEK (Table 5).

Reflecting on the conceptualization of the TEK polygon in science education, it is suggested that TEK should be interpreted as the product of both Western modern science and indigenous knowledge because it has distilled indigenous knowledge into Western modern science framework. The two knowledge systems should complement each other, should work together, and should be acknowledged in their respective entities. It is also suggested to take certain aspects into account when incorporating indigenous knowledge in science education:

– An educational approach to indigenous knowledge should give more attention to socioculture, history, and current politics of a place in addition to ecological and environmental aspects (Smith 2002; Ruitenberg 2005; Kim et al. 2017). This approach gives the student opportunities to learn science more authentically beyond their physical environments. From local environments, learners have a wealth of information regarding

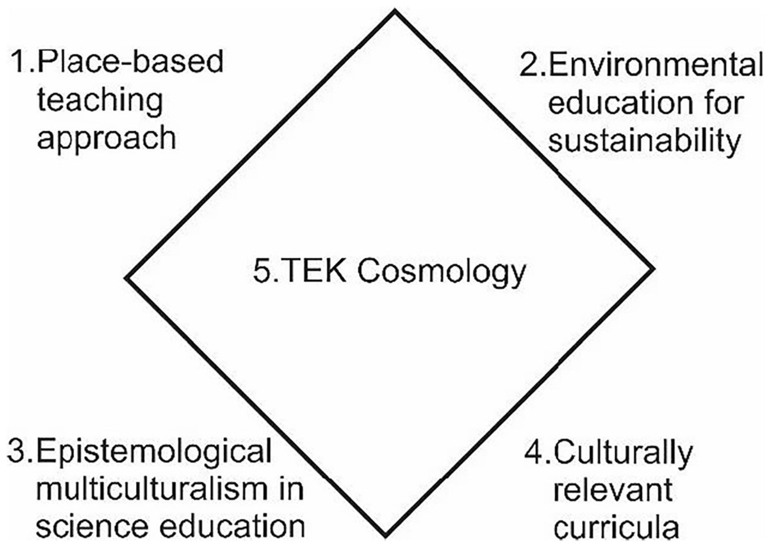

Fig. 2 TEK Polygon Framework (Kim et al. 2017)

Table 5 Conceptualization of TEK in science education

No.	TEK polygon	The current conceptualization of TEK
1	Place-based teaching approach A place-based teaching approach applies the social, cultural, economic, political, and natural aspects of local environments (Smith 2002)	- Science education sorely focuses on the advantages of learning about the natural environment through a place-based approach (Kim et al. 2017). - TEK tend to adopt a Western compartmentalized “space” conception which is not reflecting indigenous perspectives (Kim et al. 2017; Smith 2002).
2	Environmental education for sustainability In the context of science education, TEK should promote a fruitful discussion about sustainability and land care (Kimmerer 2012; McConney et al. 2011).	- TEK distilled the spiritual aspect of IK and might recognize it as a myth (Garroutte 1999; Kim et al. 2017). - The cultural appropriation in promoting TEK tend to focus on the differences between TEK and WMS and to meet the needs of Western environmental problems (Carter 2008).
3	Fostering multiculturalism in science education Science education should recognize the various ways of knowing from a cultural perspective that has contributed to modern science (Eijck and Roth 2007; Mueller and Tippins 2010).	- Science education should not view TEK and WMS as being incommensurate (Kim et al. 2017). - Some implications of TEK in science curricula highly emphasize the cultural aspect, rather than the scientific values for students (Kim et al. 2017). - Indigenous knowledge is often represented as a comparison of other cultures in science curricula and tends to assume it as primitive knowledge (Kim and Dione 2014).
4	Culturally relevant curricula for indigenous students This face of TEK focuses on revitalizing indigenous students’ cultural identities as well as facilitating their learning in science (Kim et al. 2017).	- There is a hesitation that TEK can help revitalize cultural identities for indigenous students because it is grounded in a Western framework (Kim et al. 2017).
5	TEK cosmology TEK should provide the cosmological grounding of indigenous knowledge systems that ground in the creation and rely on the interconnectedness of all things and their relations to the land (McGregor 2006; Kim et al. 2017).	- Scholars have tended to perceive TEK as a different and separate system than WMS, thus creating a divide between the knowledge systems (Houde 2007). - Spiritual aspects that concern interconnectedness of nature are missing because it is distilled in the packaging process under the empiricist philosophy of science (McGregor 2006; Kim et al. 2017).

the diverse rural sociocultural and ecological connections. Avery and Hains (2017) suggest that the diverse knowledge of rural children, which is inherited by elders’ wisdom, must be respected in order to solve the complex problems in the new age of the Anthropocene. The knowledge should be cultivated to enrich science education pedagogies and practices which can be learned from individual and unique rural contexts. Moreover, supporting and valuing students’ knowledge in urban science education is also a necessity. Science education should recognize urban students’ ways of communicating and participating in order to support the effective teaching of science to students with different cultural backgrounds in urban science classrooms (Edmin Emdin 2011).

- The pedagogy of multiculturalism of indigenous knowledge in science education must attempt to acknowledge the multiple perspective ways of knowing the differences and similarities of as well as relations of different types of knowledge systems (Ogawa 1995; Aikenhead 1996; Mueller and Tippins 2010; Kim and Dionne 2014). Kapyrka and Dockstator (2012) suggest an educational approach to encourage teachers and students to promote respective cultural understandings and collaborative solutions between indigenous and Western worldviews.
- Indigenous cosmological grounding must be involved to help revitalize cultural identities for indigenous students (McGregor 2004; Kimmerer 2012). For instance, Sutherland and Swayze (2012) used the indigenous framework of *Ininiwikisk n tamowin* (the knowledge of the people in how we understand the Earth) as a model for science and math programs in indigenous settings. This framework was applied to a culturally relevant environmental education program, as a process of lifelong learning, and to give a broad understanding of interconnected relationships with nature, living and non-living entities in the environment and beyond (Sutherland and Swayze 2012).
- Science education should recognize the significant wisdom values of indigenous knowledge that encompass spirituals, philosophical, worldviews, and stories of indigenous communities (Kawagley et al. 1998; Kawagley and Barnhardt 1998; McGregor 2004). All these aspects are necessary as a reflection on multiple perspective ways of knowing (Snively 1995) and as appreciation on the interconnected relationships of human and nature as well as to maintain the values of local cultural wisdom (Kasanda et al. 2005; de Beer and Whitlock 2009; Ng'asike 2011; Perin 2011).
- Collaborative work with indigenous experts is needed to understand nature from an indigenous perspective (Garroutte 1999; Kim and Dionne 2014). The knowledge holders and communities must be involved to avoid diminishing or misrepresenting knowledge (Kim et al. 2017).

4.2 The Potential Role of Indigenous Knowledge for Transformative Education

According to the goal of twenty-first century education, Bell (2016) suggested that conventional teaching models must shift to a transformative style of education in order for humankind to learn how to live more sustainably. This implication could accommodate student transformative experiences in which they use ideas from the science classroom to see and experience the world differently in their everyday lives (Pugh et al. 2017). The involvement of transformative education with sustainable science has the potential to play an integral role in this paradigmatic shift, which requires the wider legitimation of our ecology as a highly interconnected system of life (Williams 2013). The students can use their ideas and beliefs in another way of knowing nature, which contributes to a better understanding of social, cultural, economic, political, and natural aspects of local environments. Indigenous science could provide a potential topic in pedagogical approaches for transformative education towards a sustainable future.

There exists a general agreement on the need to reform scientific expertise by developing new ways of understanding knowledge to cope with challenging sustainability issues (Sjöström et al. 2016). Transdisciplinary aspects of sustainability became acknowledged as a transformational stream of sustainability science (Tejedor et al. 2018). Indigenous science can provide one of these transdisciplinary aspects of sustainability, which proposes a different way of knowing. It has potential to provide learners with a different view of the world to understand scientific knowledge and more holistic learning, which learners make able to understand the role of the social and cultural context in the production of scientific knowledge (Aikenhead and Michell 2011; Kim and Dionne 2014).

By integrating multiple ways of knowing into science classrooms, students can learn the value of traditional ways of knowing. They can learn to utilize a conceptual eco-reflexive perspective and to acknowledge that learning and understanding are part of a complex system that includes experience, culture, and context, as well as mainstream science that is taught in class (Mack et al. 2012). This process can facilitate transformative experiences which encompass three characteristics: (1) motivated use (application of learning in "free-choice" contexts), (2) expansion of perception (seeing objects, events, or issues through the lens of the content), and (3) experiential value (valuing content for how it enriches everyday experience) (Pugh et al. 2017). The transformation of science education for learners is not merely a set of strategies related to changing learners' behavior, changing the curriculum or pedagogy, changing definitions of science, or changing governance. Transformation of (science) education will also need to occur in the wider context to respect both indigenous and non-indigenous knowledge (Snively and Williams 2016).

4.3 The Role of Indigenous Knowledge in Science Education for Sustainability

Despite indigenous knowledge has been passed down from generation to generation over the centuries, its existence has been neglected and tended to be largely omitted from science curricula (Kibirige and van Rooyen 2006), as many other aspects of society and culture are (Hofstein et al. 2011). With the growing consideration of several problems facing the world, such as hunger, poverty, diseases, and environmental degradation, issues due to the weakness of Western modern science to overcome it has opened the insight and interest of the global community to take into account more thoroughly indigenous knowledge as a solution (Senanayake 2006; Odora Hoppers 2004). For instance, scientists have identified indigenous peoples' practices to survive their life in nature: indigenous soil taxonomies; soil fertility; agronomic practices (terracing), such as contour banding, fallowing, organic fertilizer application, crop-rotation, and multi-cropping; conservation of soil and water; and anti-desertification practices (Atteh 1989; Lalonde 1993). Practices of indigenous pest control systems gained new interest for wide use in tropical countries. An ancient known mention of a poisonous plant having bio-pesticide activities is *Azadirachta indica*. This plant contains compounds which have been established as a pivotal insecticidal ingredient (Chaudhary et al. 2017).

The acknowledgement of the knowledge and practices of indigenous people to promote sustainable development has increased around the globe. For instance, UNESCO created the *Local and Indigenous Knowledge System* (LINKS) (UNESCO 2002). This program has a goal to explore the ways that indigenous and local knowledge systems contribute to understanding, mitigating and adapting to climate change, environmental degradation, and biodiversity loss. In addition, as part of its education for a sustainable future project, UNESCO launched the *Teaching and Learning for Sustainable Future: A Multimedia Teacher Education Program* (UNESCO 2002). It provides professional development for student teachers, teachers, curriculum developers, education policymakers, and authors of educational materials. This program also encourages teachers and students to gain enhanced respect for local cultures, their wisdom and ethics, and suggests ways of teaching and learning locally relevant knowledge and skills.

The integration of an indigenous perspective in science education has been widely applied by scholars in some regions, including Africa, Australia, Asia, and America. Ogunniyi and Hewson (2008) analyzed a teacher training course in South Africa to improve the ability of teachers to integrate indigenous knowledge into their science classrooms. Ogunniyi and Ogawa (2008) addressed the challenges in the development and implementation of indigenous science curricula in Africa and Japan. In Canada, Bridging the Gap (BTG) program provides inner-city students from Winnipeg in Manitoba with culturally relevant, science-based environmental education. This program content brings together environmental education and local indigenous knowledge and pedagogies (Sutherland and Swayze 2012). Reintegration of indigenous knowledge into education has also been carried out for a long time in Alaska. This process was initiated by the AKRSI (Alaska Rural Systemic Initiative) program that reconstructs indigenous knowledge of Alaska people and develops pedagogical practices by incorporating indigenous ways of knowing into formal education (Barnhardt et al. 2000). This process aims to connect learning processes inside classroom and experience outside school so that it can broaden and deepen the students understanding as well as encouraging them to learn about traditional culture and values (Barnhardt 2007). Moreover, in Indonesia, there is a bold attempt to reconstruct ethnoscience to promote the values of nature conservation and develop critical self-reflection on own cultural backgrounds (Parmin et al. 2017; Rahmawati et al. 2017; Widiyatmoko et al. 2015). In higher education, Australian undergraduate programs implemented indigenous studies in their curricula. The results suggest that the program can promote the greater capacity for students' skills in critical reflections (Bullen & Roberts 2019).

Furthermore, the integration of indigenous knowledge is also involved in science teacher's professional development programs. Sylva et al. (2010) conducted a study to transform science teacher professional development to facilitate teachers to make the content related to the environment and agriculture science fields more relevant to Hawaiian students' lives and backgrounds. Chinn (2014) suggested that scientific inquiry learning associated with indigenous knowledge and sustainability practices supports the development of ecological attention of teachers. In addition, long-term professional development providing situated learning through cross-cultural immersion and interdisciplinary instruction also supports teachers to develop cross-cultural knowledge and literacy (Chinn 2006).

The application of indigenous knowledge to promote education for sustainability in various parts of the world is recognized. Teachers and students participating in sustainability and environmental education programs, as well as science education programs, should be considered potential beneficiaries of published research on indigenous science.

5 Raising the Relevance of Science Learning Through Indigenous Knowledge

5.1 The Relevance of Science Learning

The term relevance in science learning has many different meanings that can be viewed from different perspectives. Relevance can be defined as students' interest in learning (Ramsden 1998; Childs 2006; Holbrook 2005), usefulness or student's needs (Keller 1983; Simon and Amos 2011), or aspects of the application of science and technology to raise welfare and sustainability in social, economic, environmental, and political issues (De Haan 2006; Hofstein and Kesner 2006; Knamiller 1984). Stuckey et al. (2013) attempted to formulate a comprehensive understanding of relevance in science education and suggested a model of relevance by linking different dimensions of the relevance of science education. The model encompasses three main dimensions:

1) Individual relevance, with an emphasis on students' interests and the development of individual intellectual skills
2) Societal relevance, by facilitating the student's competence to engage responsibly in the present and future society
3) Vocational relevance, by providing vocational orientation and preparation for career development

Stuckey et al. (2013) suggested curriculum development to move dynamically to accommodate the relevance of science learning in its different dimensions and aspects (Eilks and Hofstein 2015). Current curricula in many countries are suggested to overcome a preference for learning based on scientific principles and facts that have been done in the "Golden Age" of the science curriculum in the 1950s and 1960s (Bybee 1997). At that time, the curriculum was designed using a discipline-based structured approach to provide effective learning about the concepts, theories, and facts of science (Eilks et al. 2013). The curriculum of science at that time is today considered irrelevant for most learners as it only accommodates the emphasis in the selection and preparation of a minority of students to become scientists and engineers (De Boer 2000; Stuckey et al. 2013).

Over time, science curriculum development has undergone significant changes (Eilks et al. 2013). The curriculum development in late 1990 to early 2000 was done by suggesting context-based science education and creating meaningful learning for students in many countries (e.g., King and Ritchie 2012). The contexts used were considered relevant from the perspective of Western modern science. However, in the viewpoint of global science, relevance must be concerned with the natural and environmental phenomena described by science in various contexts and cultural forms. Different views on science should be accepted by students with respect to different environments based on cultural identity, time, and society. One of the problems experienced by students in science education in developing countries is the feeling that learning science is like recognizing foreign cultures (Maddock 1981) and this is also experienced by students in industrialized countries (Aikenhead 1996; Costa 1995). The phenomenon occurs due to the fundamental differences between Western modern science and the knowledge systems of many non-Western cultures (Aikenhead 1997; Jegede 1995). The same issue is also expressed by Kibirige and van Rooyen (2006) suggesting that students with indigenous backgrounds may experience a conflict between Western modern science, that they learn in school, with their indigenous knowledge. As already described above, a similar conflict can also be expected for many students with a Western background, when their "personal science view" differ from the views of mainstream Western science (Ogawa 1995; Hansson 2014). Surely this is a challenge for researchers and educators who want to reach the goal of relevant science education for all students by bridging the difference between student's experiences in their cultural context and the world of Western science.

5.2 Indigenous Knowledge as a Socio-scientific and Cultural Context to Accommodate Relevance in Science Education

In order to realize relevant science education in a contemporary view, it is necessary to consider socio-scientific and cultural contexts in science education (Stuckey et al. 2013; Sjöström et al. 2017; Sjöström 2018). As Ogawa (1995) emphasizes, every culture has its own science called "indigenous science." Thus, every student must become aware of his individual, personal "indigenous" knowledge to constructs his knowledge of Western science. The focus of learning cannot be restricted to provide the student scientifically acceptable information, but should be to help students understand the concepts and explore the differences and similarities between their ideas, beliefs, values, and experiences with modern science concepts (Snively and Corsiglia 2000). The same view is also affirmed by Abonyi (1999) who stated that current instructional approaches in science education, which often do not take into consideration prior cultural beliefs, will lack in a contribution to students' interest in science. In consequence, it might negatively influence students' understanding and attitudes towards science learning (Alshammari et al. 2015).

The introduction of indigenous knowledge in the classroom can represent different cultural backgrounds of the learners and might improve their interpretation of knowledge (Botha 2012). It might have the potential to make science learning more relevant to students in culturally diverse classrooms (de Beer and Whitlock 2009). Related to this, Hayes et al. (2015) stated that societal culture has a major impact on the functioning of schools and the complexity of factors which affects the way schools teach science. The incorporation of indigenous knowledge into school curricula has the potential to enable students to gain further experiences and develop corresponding attitudes towards science. In the same time, it might help indigenous students to maintain the values of their local cultural wisdom (Kasanda et al. 2005; de Beer and Whitlock 2009; Ng'asike 2011; Perin 2011). Another goal of integrating indigenous knowledge in classroom learning is to reduce the notion that learning science is "strange" from the students' own point of views by providing insights that views on science and nature can be different from culture to culture (Mashoko 2014). Knowledge can be seen as a dynamic process within the context of sociocultural and ecological relations. Accordingly, knowledge is not sourced only from the teachers but can be found in the experience of the students living, which is a prominent feature of the rural experiential environment (Avery and Hains 2017). Kawagley et al. (1998) contended that although indigenous ways of knowing are different from the Western way of thinking, their knowledge is scientific and relevant to the current situation because it is obtained from the results of long-term environmental observations combined with experiments in a natural setting. Indigenous science for science learning is relevant for students because they can learn traditional knowledge and skills that are still relevant to today's life, as well as to find values and apply new insights to their practice which is essential for their survival (Kawagley et al. 1998; Barnhardt and Kawagley 2008).

Students bring ideas and beliefs based on their previous experiences in the classroom. The differences in cultural backgrounds cause them interpret the concept of science differently from a common scientific view. Accordingly, the exploration of multicultural science learning is required that brings students' prior knowledge into the classroom. In many cases, the cultural aspect of the multicultural science context is important because it plays a role in providing valuable scientific knowledge and is also a pedagogical bridge linked mainly to multicultural students of science (Atwater and Riley 1993; Hodson 1993; Stanley and Brickhouse 1994). The relevant approach to this goal is by developing culturally sensitive curricula and teaching methods that integrate indigenous knowledge—and the variety of different cultural views—into the science curriculum (Aikenhead and Jegede 1999).

Zimmerman and Weible (2017) developed science learning curricula based on the socio-cultural conceptualization of learning with specific consideration of place to understand how students' rural experiences intersect with school-based learning. They suggested that education which focuses only on scientific concepts is not enough to support young people to become representative of their community. The learners need support in methods of presenting evidence and arguments, which can be facilitated in science classroom to convince key stakeholders in their rural community. This is important to make science learning meaningful and can lead to the development of various kinds of environmental meanings as learning outcomes.

Snively and Williams (2016) suggest that science educators must strive to design new curricula that represent a balanced perspective. Furthermore, they should expose students to multiple ways of understanding science. Indigenous perspectives have the potential to give insight and guidance to the kind of environmental ethics and deep understanding that we must gain as we attempt to solve the increasingly complex problems of the twenty-first century. For instance, the empirical study of the integration of indigenous perspective in science education has become a model of science education in Canada, with sustainability at its core (Fig. 3) (Murray 2015). Sustainability sciences should provide a balanced approach to how society

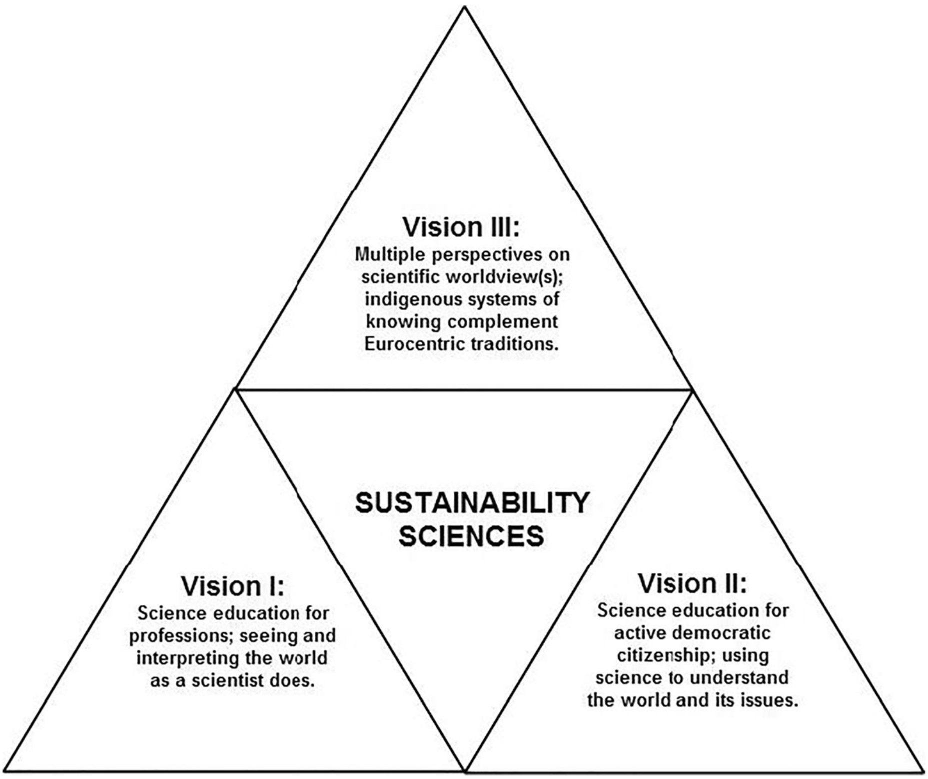

Fig. 3 Three dimensions of science education with the sustainability sciences as the foundation, as described in this didactic model by (Murray 2015)

alters the physical environment and how the state of the environment shapes society (Snively and Williams 2016).

Murray (2015) emphasized in a magazine article that the focus of sustainability sciences is not merely on environmental science. It should also recognize science outside of environmental, citizenship, and cultural contexts. Therefore, it is important to make strong connections among the pure sciences, sustainability issues, socio-scientific issues, and the relevance of the curriculum (Murray 2015; Stuckey et al. 2013). According to Fig. 3, sustainability sciences can integrate multiple perspectives on science worldviews and accommodate the three dimensions of the relevance of science education (individual, societal, and vocational relevance). In this case, indigenous science can be a source for socio-scientific and cultural issues which promote the relevance of science education. Accordingly, new pedagogical approaches should address indigenous science in order to enhance the relevance of science learning as well as to promote sustainable development.

As can be seen in Fig. 3, Murray (2015) uses the term *Vision III* for multiple perspectives on scientific worldviews and indigenous systems of knowing, complementing Western traditions. This is included in our previous use of the term, although our *Vision III* of scientific literacy and science education is even broader in scope (Sjöström and Eilks 2018). Our view is inspired by an eco-reflexive understanding of *Bildung*. It describes a socio-political-philosophical vision of science education aiming at dialogical emancipation, critical global citizenship, and socio-ecojustice. This has consequences for the science curriculum that needs to incorporate more thoroughly societal perspectives—under inclusion of indigenous perspectives—and needs to incorporate stronger socio-scientific issue–based science education of a “hot” type (Simonneaux 2014). Controversial, relevant, and authentic socio-scientific issues, e.g., from the sustainability debate, shall become the drivers for the curriculum (Simonneaux and Simonneaux 2012). Corresponding research, curriculum development, and teacher continuous professional development need to be intensified. Recently, Sjöström (2018) discussed eco-reflexive *Bildung*- and a Vision III–driven science education as an alternative to science education based on Western modernism. It integrates cognitive and affective domains and includes complex socio-scientific and environmental issues, but also philosophical-moral-political-existential and indigenous perspectives more in general.

Recent pedagogical approaches involving socio-scientific issues to teach science imply the role of science and technology for society, both present and future (Marks and Eilks 2009; Sadler 2011). Students are suggested to develop general skills facilitated by science education to achieve the goals of Education for Sustainable Development (ESD) (Eilks et al. 2013). In ESD-type curricula, learning encompasses the reflection and interaction of the application of science in its societal, economic, and ecological contexts (Burmeister et al. 2012; De Haan 2006; Wheeler 2000). ESD in connection with science education is suggested to have the potential to contribute to personal, societal, and vocational science teaching (Stuckey et al. 2013). It is relevant for individual action, e.g., in cases involving consumption of resources, participation in societal debates about issues of sustainable development, or careers related to sustainable chemistry and technology (Eilks and Hofstein 2014; Sjöström et al. 2015). Reflections on indigenous knowledge and its relatedness to Western modern science can form another focus in this selection of cases, especially if it becomes locally and regionally relevant.

Khaddoor et al. (2017) emphasized that the picture of science represented in many textbooks all over the world often neglects its societal and cultural components, and restricts it to a Western view on the history of science. Addressing indigenous knowledge in the framework of ESD, to promote relevant science education, may help students recognizing the intimate connection between humans and nature in culture. It would create science learning directly relevant to daily life and society along with regional-specific examples, but could also lead to intercultural learning. Moreover, it could facilitate authentic science experiences, which engage students with cultural-historical views (Roth et al. 2008a).

6 Research Frameworks and Didactic Models for Adopting Indigenous Science in Science Education

There are different foci of research on integrating indigenous science in science education. Some scholars suggest attention to empirical research in anthropological and psychological paradigms. This research tries to investigate the process of knowledge transition from a student's life-world into science classrooms, which forms a cross-cultural experience (Aikenhead and Jegede 1999). The research focuses on conceptualized transition as "cultural border crossing" (Aikenhead 1996) and cognitive conflicts arising from different cultural settings (Jegede 1995). They need to be addressed and resolved as "collateral learning." Research suggests investigating the nature of student's prior knowledge and beliefs about scientific phenomena when exposed to a cross-cultural topic (Herbert 2008).

Other research aims to design instructional approaches that introduce indigenous science into the science classroom. Abonyi (1999) explored the effect of ethnoscience-based instructional approaches on student's conception of scientific phenomena and attitudes towards science. The study aimed to resolve the cognitive conflicts of African students as a result of differences between their cultural background and Western science. In a similar approach, Aikenhead (2001) developed instructional strategies by involving the aboriginal community. The strategies involved the discussion about local content with elders and the aboriginal community to construct an aboriginal science education framework. Key values as a context for integration were identified. However, conflict arose when students faced the problem of taking information from one knowledge system and placing it into another. Also contextualization by indigenous science is a topic of research and development (Chandra 2014; Hamlin 2013; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012). Sometimes, indigenous science is used to contextualize curricula. This approach is suggested to be appropriate to accommodate sociocultural demands in science curricula as well as to meet students' perception of relevance. However, it is necessary to consider the students' perspectives about scientific phenomena formed by the two different knowledge systems (indigenous science and Western modern science) to avoid misconceptions and conflicts that can arise. The systemic evidence and research-based development of the curriculum is suggested to construct a reliable knowledge framework to fit indigenous science with currently operated science education curricula.

To introduce indigenous knowledge as content and contexts into science education, a multidiscipline view on science education is needed. For this, didactic models and theories might be useful. According to Duit (2015, p. 325), *Didaktik* "stands for a multifaceted view of planning and performing the instruction. It is based on the German concept of *Bildung* [… and] concerns the analytical process of transposing (and transforming) human knowledge (the cultural heritage) into knowledge for schooling that contributes to *Bildung*." It is suggested that didactic models can help teachers in their didactic choices (why? what? how? to teach). Furthermore, they can be useful in the design, action, and analysis of teaching, but also for critical meta-reflection about for instance teaching traditions. When used systematically, they can also be helpful in teacher professional development and have potential to contribute to research-informed teaching (Duit 2015).

Duit (2007) also has emphasized that multiple reference disciplines are relevant to understand and design science education. The reference disciplines are suggested to support science education research and development. These reference disciplines include the sciences, philosophy, and history of science, pedagogy, and psychology, and furthermore (Fig. 4). We suggest that local wisdom of indigenous science—where appropriate—could be named as a further reference discipline, or it could be understood implicitly as being part of science (incorporating also its non-Western body of knowledge), the history and philosophy of science (referring to the different history and maybe varying philosophy of non-Western science), and aspects of sociology, anthropology, and ethics.

A research-based model to dig into the content and context of indigenous knowledge for science education is the *Model of Educational Reconstruction* (MER) (Duit et al. 2005). This model links (1) the analysis of content structure, (2) research on teaching and learning, and (3) development and evaluation of instruction. It may also provide a framework to allow an educational reconstruction of indigenous science content in such a way that the resulting instruction meets students' perspectives, abilities, and needs. Incorporating indigenous science perspective by educational reconstruction might provide a complex representation of indigenous science for education. The complexity may result from the integrated environmental, social, and idiosyncratic contexts, in order to demonstrate their role for the life of the individual in society. The integration of indigenous science as a sociocultural context for scientific questions can also provide social demand in science learning. Diethelm et al. (2012) and Grillenberger et al. (2016) adapted social demands in educational construction to develop the innovative topic of computer science. This approach suggests identifying social demands that are relevant for students to cope with requirements that society puts on them in their everyday lives. Transferred to the aspect of indigenous knowledge in science education, a resulting didactic model might look as suggested in Fig. 5.

Based on the educational design framework, any phenomenon or process from indigenous science in question shall be analyzed both from the Western and indigenous perspectives. The analysis can provide a different view on one's own knowledge system as well as it has the potential to enrich both perspectives to create a thoughtful dialog (Stephens 2000). The context

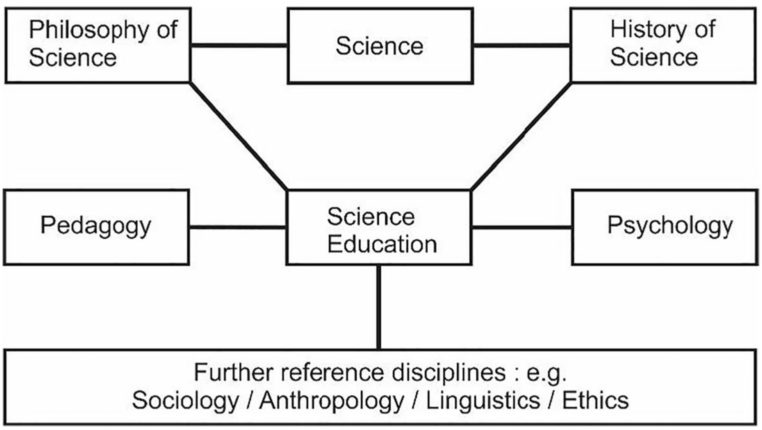

Fig. 4 A model of reference disciplines for science education (Duit 2007)

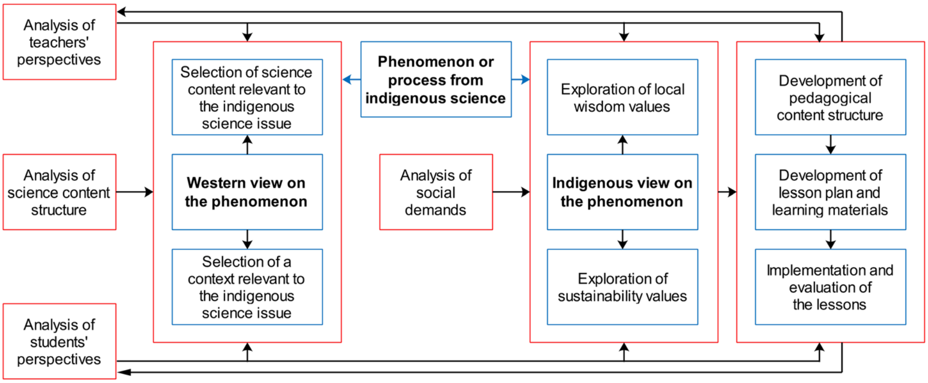

Fig. 5 Educational design framework to incorporate indigenous knowledge with science education (developed based on: Diethelm et al. 2012)

and content relevant to the indigenous science issue, which are contrasted by the Western view on the phenomenon/process, are analyzed based on the three perspectives Western modern science, students, and teachers. The analysis is suggested to facilitate the process of *elementarization* and the construction of the scientific content structure for instruction that can be enriched by putting it into contexts that are accessible for the learners (Duit 2007). The indigenous perspective on the phenomenon/process has potential to offer authentic contexts for science learning and encompasses sociocultural aspects from local wisdom values (e.g., tradition, beliefs, ethics, supernatural) (Pauka et al. 2005; Rist and Dahdouh-Guebas 2006) as well as from sustainability values (e.g., nature conservation and adapting to climate change) (Snively and Corsiglia 2000; Snively and Williams 2016). It is necessary to analyze also the social demands of educational significance of the context generated from the indigenous perspective. It offers a chance to reflect Western views on science and nature in science education for contributing to the development of more balanced and holistic worldviews as well as the development of intercultural understanding and respect (Brayboy and Maughan 2009; Hatcher et al. 2009; de Beer and Whitlock 2009). Moreover, the indigenous ways of knowing can be used as starting points and anchors for scientific knowledge (Roth et al. 2008b). Thus, the indigenous ways of knowing might also help to shape the knowledge already held in Western societies. The investigation of teachers' and students' perspective on indigenous knowledge is needed in order to identify their attitude, belief, and experiences towards the system of knowledge (Cronje et al. 2015; Fasasi 2017). The analysis also provides valuable information to avoid the conflict that could arise when the learners face different knowledge systems.

For the purpose of curriculum design, different perspectives (science, students, teachers, and society) are suggested to be analyzed to identify suitable content, contexts, and phenomena/processes for teaching about indigenous science. The structure in Fig. 5 takes into consideration that Diethelm et al. (2012) added two significant components to the original educational reconstruction model by Duit et al. (2005). One component is that contexts and phenomena are integrated, which suggest that science learning should start from a "real-world" phenomenon embedded in a context to open connections to prior experience of the student. This aims at encouraging students' interest, and to show application situations of the intended knowledge. The second improvement is the analysis of social demands, which is a very important step to consider the educational significance of intended learning content, especially when it comes to integrating indigenous knowledge as part of a society's wisdom other than Western modern science. The social demands might differ substantially in different places and cultures (countries, school, rural, or city areas). Accordingly, it is necessary to assess the educational significance of a certain topic respecting the specific circumstances, especially if it is culturally bounded. Analysis of social demands is a very important step to identify the educational significance of a certain topic (Diethelm et al. 2012). In the context of indigenous science, the analysis could be emphasized on the role of indigenous ways of knowing to promote education for sustainability. By drawing on indigenous knowledge, the issues connected to sustainability education can be included in the curriculum to provide an essential context for learning science.

The analysis of the science content structure informs how the phenomenon can be explained scientifically as well as to determine the required knowledge needed to understand the phenomenon or process (Diethelm et al. 2012). This step decides which concepts of modern science have to be dealt with in the lesson (Diethelm et al. 2012; Grillenberger et al. 2016). Meanwhile, the investigation of the students' perspectives includes their cognitive and affective perspectives (Diethelm et al. 2012; Kattmann et al. 1996). The aim is to find out more general perspectives of certain groups of learners and different conceptualizations that students have when explaining scientific phenomena, concepts, or methods. Diethelm et al. (2012) considered this perspective an "official" scientific view, even if it was correct or not. The teachers' perspective is needed as a key factor for the learning design and its implementation. This is because every teacher has different domain-specific knowledge and attitudes. In order to investigate the perspective of the student and teachers' perspective about the phenomena of indigenous science, Snively (1995) introduced a five-step approach for exploring the two perspectives (Western science and indigenous science), when teaching about one concept or topic of interest. The process includes the following: (1) choose the topic of interest, (2) identify personal knowledge, (3) research the various perspectives, (4) reflect, and (5) evaluate the process (Table 6). This approach emphasized that discussion of the two perspectives might interpret the scientific phenomena differently, but the learner should see the overlap and reinforce each other.

The selection of phenomena is the central focus of the suggested framework in Fig. 5. It emphasizes that learning science—as one out of different options—can start from a relevant indigenous context. Accordingly, certain phenomena should be perceived with senses and ideally have a surprising or mysterious element and thus triggers curiosity (Grillenberger et al. 2016). Indigenous science contains scientific phenomena embedded with spirits, magic, religion, and personal experiences (Pauka et al. 2005). Spiritual aspects of indigenous society are not used as religious instruction in the curriculum, but as an acknowledgement of the responsibility and dependence of living beings on ecosystems and respect for the mysteries of the universe (Kawagley et al. 1998). It can provide an interesting topic for the students as well as encourage them to explore local wisdom behind the scientific phenomena. Indigenous ways of knowing can become starting points and anchors for useful scientific knowledge (Roth et al. 2008b). Figure 5 suggests that indigenous science deals with scientific phenomena to be explained by science. Furthermore, the scientific phenomena are embedded in a particular cultural context that can be used to encourage students to explore the differences and similarities between their ideas, beliefs, values, and experiences between those coming from indigenous knowledge and Western science, respectively.

Design and arrangement of learning should include development and implementation as well as reflection of teacher and student experience. This process identifies ideas and concepts relevant for teaching as well as it includes developing design principles. The reflection can be

Table 6 A five-step approach for exploring the perspectives of indigenous and Western science (adapted from Snively 1995, pp. 66–67)

Step 1: Choose the topic	Choose a science concept or topic from indigenous science (medicine, cultivating plants, animal migrations, geology, sustainability)
Step 2: Identify personal knowledge	• Discuss the importance of respecting the beliefs of others • Brainstorm what we know about the concept or topic • Brainstorm questions about the concept or topic • Identify personal ideas, beliefs, opinions
Step 3: Analyze various perspectives	• Analyze the various science perspectives • Analyze the local traditional science perspective • Analyze the perspective of different indigenous peoples organize/process the information. • Identify similarities and differences between the perspectives • Ensure that authentic explanations from the perspectives are presented
Step 4: Reflect	• Consider the consequences of each perspective • Consider the concept or issues from a synthesis of perspectives consider the consequences of a synthesis • Consider the concept or issue in view of values, ethics, wisdom if appropriate • Consider the concept or issue from a historical perspective • Consider the possibility of allowing for the existence of differing viewpoints • Consider the possibility of a shared vision • Ensure that students compare their previous perspective with their present perspective build consensus
Step 5: Evaluate the process	• Evaluate the decision-making process • Evaluate the effects of personal or group actions • Evaluate possibilities in terms of future inquiries and considerations • How did this process make each person feel?

repeated in order to suit the learning environments to the particular demands of a given setting (Grillenberger et al. 2016). For the process of design and development, Diethelm et al. (2012) proposed the Berlin Model of planning processes (e.g., Zierer and Seel 2012; Duit 2015), which encompasses four different decision areas: intentions (objectives, competencies, outcomes), content (topics, knowledge), teaching methods, and media. In the development of learning design, it should be considered the pedagogical approach which accommodates the relevance of science learning for learners as well as to promote sustainability. Eilks et al. (2013) used ESD-type curricula to develop the general skills of students facilitated by science education to achieve the goals of education for sustainable development. This pedagogical approach also involved socio-scientific issues to raise relevance in science learning that implicates the role of science and technology for society both present and future (Marks and Eilks 2009). Burmeister et al. (2012) pointed out four different basic models to implement issues of sustainable development into science education:

1. Adopting principles from sustainable practices in science and technology to the science education laboratory work
2. Adding sustainable science as content in science education
3. Using controversial sustainability issues for socio-scientific issues which drive science education.
4. Science education as a part of sustainability-driven school development

Models 2 (context-based) and 3 (socio-scientific issues-based) seem suitable for the integration of indigenous science context into science education. Indigenous science can provide the contexts for science learning with a view on sustainability when learners at the same time explore the Western science perspective related to the indigenous way of knowing and behind any natural phenomena.

Moreover, students can be encouraged with socio-scientific issues (SSI) relevant to indigenous people including a discussion of differences in the ways indigenous and Western science, respectively, view natural phenomena, how modern Western and indigenous people develop solutions, and the reasons why they do so. This can establish a base for discussion about environmental and technological issues between people with (post-)modern Western and indigenous thinking for establishing sustainable societies (Snively and Williams 2016).

Accordingly, the SSI approach in the learning activity should give more attention to students' soft skill development such as argumentation (Belova et al. 2015), decision-making (Feierabend and Eilks 2011), reasoning skills (Sadler and Zeidler 2005), and using appropriate information (Belova et al. 2015). In sociocultural means, for instance, it is about using the argumentation-based course to enhance the understanding of different worldviews (nature of science and indigenous knowledge) in global awareness of the impact of scientific, technological, and industrial activities on the environment (Ogunniyi and Hewson 2008). Another example is the discussion about the controversial issue regarding Western and traditional medicine. It can be discussed in terms of reflection on the moral principles that underpin science (de Beer and Whitlock 2009) and can be useful to develop argumentation and reasoning skills.

The integration of indigenous knowledge in science education also should consider the learning objectives based on the different target of educational level (school science, higher education, and across educational levels). In school science, some studies used context-based learning about indigenous knowledge to motivate and foster interest in science learning (Abonyi 2002; Hiwatig 2008; Fasasi 2017). This approach also could lead to intercultural understanding and respect in science learning (Brayboy and Maughan 2009; Hatcher et al. 2009; de Beer and Whitlock 2009), as stated by Burford et al. (2012) as *interculturality,* which means "the inherent equality of different knowledge systems is acknowledged, with collaborative decision-making and an awareness of learning together towards share goals" (p. 33). In terms of sustainability, the learning attention should emphasize to bring together indigenous and non-indigenous students to learn about the environments, respecting their each culture, and educating future citizens to make wise decisions regarding long-term sustainable communities and environments (Snively and Williams 2016). This is, however, not limited to the inclusion of indigenous knowledge but should aim at all the different cultures present in multicultural classrooms.

In higher education, indigenous perspectives can contribute to greener science (e.g., ethnochemistry, ethnobotany, ethnomedicine). This includes learning about other substances and processes adopted from indigenous science, which are also in the focus of green chemistry (e.g., Sjöström and Talanquer 2018) and green agriculture. For instance, it can involve learning activities that involves the discussion about the development of highly effective biodegradable pesticides from neem tree oil (*Azadirachta indica*) by East Indian and North African peoples over 2000 years ago (Snively and Williams 2016). The information about biodegradable pesticide compounds from the neem tree could be used as a starting point to develop green chemistry lab activities. Across the educational levels, the focus of learning can give more emphasis on the nature of science views (more transdisciplinary and holistic), which parallels the discussion on sustainable and green science. The learning activity must shift to a transformative style by using ideas from the science classroom and multi-perspective views about sustainable science to see and experience the world differently in learner everyday lives (Murray 2015; Pugh et al. 2017). Accordingly, transformative education should be driven to reform the existing ways of knowing and understanding, to critically reflect on the values, beliefs, and worldviews that underpin them as well as to share the meanings that can contribute to sustainability (Sjöström et al. 2016; Tejedor et al. 2018; Mack et al. 2012).

7 Conclusion

Indigenous knowledge about nature and science generally differs from the traditional and dominant Western modern view of science in research and technical applications (Nakashima and Roué 2002; Iaccarino 2003; Mazzocchi 2006). It provides a different, alternative perspective on nature and the human in nature on its own right (Murfin 1994; Ogawa 1995) and therefore becomes authentic to persons having an indigenous background. It is also interesting that—more or less—similar ideas to the local wisdom of indigenous science also exist in Eastern spiritual thinking and alternative Western thinking. Such ideas are relevant to promote intercultural and intergenerational understanding and respect (Brayboy and Maughan 2009; Hatcher et al. 2009; de Beer and Whitlock 2009). From the discussion provided in this paper, it is suggested to carefully adopt views on and from indigenous knowledge into science education. Indigenous knowledge can provide further perspectives on nature and help us to reflect the nature of science. It offers rich contexts to initiate learning and connect science education with more holistic worldviews needed for promoting sustainability (e.g., Aikenhead and Michell 2011; Kim and Dionne 2014; Kim et al. 2017).

There is a lot of literature justifying a more thorough inclusion of culture into (science) education (e.g., Savelyeva 2017; Moon 2017; Wang 2016; Sjöström et al. 2017; Sjöström 2018). Justifications can be derived from different sources, like the concept of *Bildung* (Sjöström et al. 2017), as shown above. Indigenous cultures can play a role by strengthening the cultural component of science education (Hatcher et al. 2009; Murray 2015). For this, research on indigenous knowledge in science needs to be analyzed with respect to its potential for science education. It might be educationally reconstructed for integrating it into science teaching and learning. Here we have presented some frameworks and didactic models for how to elaborate on and design science education for sustainability that take indigenous knowledge and related non-Western and alternative Western ideas into consideration. Further work needs to focus on evidence-based curriculum development in science education on the integration of indigenous knowledge. This development, however, needs special care and sensitivity because it deals with different cultures, worldviews, and ethical considerations. Further discussion might also include aspects of the historical development of indigenous knowledge, the history of colonialism, and the long-term effects colonialism still has on societies and science education in many parts of the world (e.g., Boisselle 2016; Ryan 2008). Such a discussion, just like the discussion in this paper, needs respect to indigenous communities; if possible, it could be done in cooperation and exchange with persons from the corresponding communities.

Acknowledgments We are grateful for the support afforded by the Islamic Development Bank and the Indonesian Ministry of Research, Technology and Higher Education, Indonesia.

Compliance with ethical standards

Conflicts of Interest The authors declare no conflict of interest.

References

Abonyi O. S. (1999). *Effects of an ethnoscience-based instructional package on students' conception of scientific phenomena and interest in science* (thesis). University of Nigeria Nsukka.

Abonyi, O. S. (2002). Effects of ethnoscience-based instructional package on students' interest in science. *Journal of the Science Teachers Association of Nigeria, 37*(1 & 2), 60–68.

Abonyi, O. S., Njoku, L. A., & Adibe, M. I. (2014). Innovations in science and technology education: a case for ethnoscience based science classrooms. *International Journal of Scientific & Engineering Research, 5*(1), 52–56.

Afonso Nhalevilo, E. Z. D. F. (2013). Rethinking the history of inclusion of IKS in school curricula: endeavoring to legitimate the subject. *International Journal of Science and Mathematics Education, 11*(1), 23–42.

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 27*, 1–52.

Aikenhead, G. S. (1997). Toward a First Nations cross-cultural science and technology curriculum. *Science Education, 81*, 217–238.

Aikenhead, G. S. (2001). Integrating Western and aboriginal sciences: cross-cultural science teaching. *Research in Science Education, 31*, 337–355.

Aikenhead, G. S. (2006). Cross-cultural science teaching: rekindling traditions for Aboriginal students. In Y. Kanu (Ed.), *Curriculum as cultural practice* (pp. 223–248). Toronto, Canada: University of Toronto Press.

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural science education: a cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching, 36*, 269–287.

Aikenhead, G. S., & Michell, H. (2011). *Bridging cultures: Indigenous and scientific ways of knowing nature*. Toronto: Pearson.

Aikenhead, G. S., & Ogawa, M. (2007). Indigenous knowledge and science revisited. *Cultural Studies of Science Education, 2*, 539–620.

Albe, V. (2013). On the road to science education for sustainability? *Cultural Studies of Science Education, 8*, 185–192.

Alshammari, A. S., Mansour, N., & Skinner, N. (2015). The socio-cultural contexts of science curriculum reform in the state of Kuwait. In N. Mansour & S. Al-Shamrani (Eds.), *Science education in the Arab Gulf States* (pp. 49–68). Rotterdam: Sense.

Anderhag, P., Wickman, P. O., Bergqvist, K., Jakobson, B., Hamza, K. M., & Säljö, R. (2016). Why do secondary school students lose their interest in science? Or does it never emerge? A possible and overlooked explanation. *Science Education, 100*, 791–813.

Andrews, T. D. (1988). Selected bibliography of native resource management systems and native knowledge of the environment. In M. R. Freeman & L. Carbyn (Eds.), *Traditional knowledge and renewable resource management in Northern Regions*. Occasional publication number 23, (pp. 105–124). Boreal Institute for Northern Studies: University of Alberta.

Arnold, K.-H. (2012). Didactics, didactic models and learning. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 986–990). Boston: Springer.

Atteh, O. D. (1989). *Indigenous local knowledge as key to local level development: Possibilities, constraints, and planning issues in the context of Africa*. Unpublished manuscript.

Atwater, M., & Riley, J. (1993). Multicultural science education: perspectives, definitions, and research agenda. *Science Education, 77*, 661–668.

Avery, L. M., & Hains, B. J. (2017). Oral traditions: a contextual framework for complex science concepts — laying the foundation for a paradigm of promise in rural science education. *Cultural Studies of Science Education, 12*, 129–166.

Barnhardt, R. (2007). Creating a place for indigenous knowledge in education: the Alaska Native Knowledge Network. In G. Smith & D. Gruenewald (Eds.), *Place-based education in the global age: Local diversity* (pp. 113–133). Hillsdale: Lawrence Erlbaum Associates.

Barnhardt, R., & Kawagley, O. (2008). Indigenous knowledge systems and education. In G. Fenstermacher, D. Coulter, & J. Wiens (Eds.), Why do we educate? Renewing the conversation (pp. 223–241). New York, NY: NSSE.

Barnhardt, R., Kawagley, A.O., & Hill, F. (2000). Educational renewal in rural Alaska. *Proceedings of the International Conference on Rural Communities & Identities in the Global Millennium*., 140-145.

Barrett, M. J., Harmin, M., Maracle, B., Patterson, M., Thomson, C., Flowers, M., & Bors, K. (2017). Shifting relations with the more-than-human: six threshold concepts for transformative sustainability learning. *Environmental Education Research, 23*, 131–143.

Bateson, G. (1979). *Mind and nature:a necessary Unity*. New York: Dutton.
Bell, D. V. J. (2016). Twenty-first century education: transformative education for sustainability and responsible citizenship. *Journal of Teacher Education for Sustainability, 18*, 48–56.
Belova, N., Feierabend, T., & Eilks, I. (2015). The evaluation of role playing in the context of teaching climate change. *International Journal of Science and Mathematics Education, 13*, 165–190.
Bengtsson, J. (2013). Embodied experience in educational practice and research. *Studies in Philosophy and Education, 32*, 39–53.
Berkes, F. (1988). Environmental philosophy of the Chisasibi Cree people of James Bay. In M. Freeman & L. Carbyn (Eds.), *Traditional knowledge and renewable resource management in northern regions. Occasional publication number 23* (pp. 7–20). Edmonton, AL: The University of Alberta.
Berkes, F. (1993). Traditional ecological knowledge in perspective. In J. T. Inglis (Ed.), T*raditional ecological knowledge: Concepts and cases* (pp. 1-9). Ottawa, ON: International Development Research Centre (IRDC) Books.
Berkes, F., & Mackenzie, M. (1978). Cree fish names from eastern James Bay, Quebec. *Arctic, 31*, 489–495.
Bermudez, G. M. A., Battistón, L. V., García Capocasa, M. C., & De Longhi, A. L. (2017). Sociocultural variables that impact high school students' perceptions of native fauna: a study on the species component of the biodiversity concept. *Research in Science Education, 47*, 203–235.
Bernstein, R. J. (1983). *Beyond objectivism and relativism: science, hermeneutics, and praxis*. Philadelphia: University of Pennsylvania Press.
Birdsall, S. (2013). Reconstructing the relationship between science and education for sustainability: a proposed framework for learning. *International Journal of Environmental and Science Education, 8*, 451–478.
Blades, D. (2008). Positive growth: developments in the philosophy of science education. *Curriculum Inquiry, 38*, 387–399.
Blankertz, H. (1975). *Theorien und Modelle der Didaktik* (9 ed.). München: Juventa. (in German).
Boisselle, L. N. (2016). Decolonizing science and science education in a postcolonial space (Trinidad, a developing Caribbean nation, illustrates). *SAGE Open*. https://doi.org/10.1177/2158244016635257.
Botha, L. R. (2012). Using expansive learning to include indigenous knowledge. *International Journal of Inclusive Education, 16*(1), 57–70.
Brayboy, B. M. J., & Maughan, E. (2009). Indigenous knowledges and the story of the bean. *Harvard Educational Review, 79*(1), 1–20.
Brickhouse, N. W. (2001). Embodying science: a feminist perspective on learning. *Journal of Research in Science Teaching, 38*, 282–295.
Bullen, J. & Roberts, L. (2019). Driving transformative learning within Australian Indigenous studies. *The Australian Journal of Indigenous Education, 48*, 12-21.
Burford, G., Kissmann, S., Rosado-May, F. J., Alvarado Dzul, S. H., & Harder, M. K. (2012). Indigenous participation in intercultural education: learning from Mexico and Tanzania. *Ecology and Society, 17*(4), 33.
Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for sustainable development (ESD) and chemistry education. *Chemistry Education Research and Practice, 13*, 59–68.
Bybee, R. W. (1997). The sputnik era: Why is this educational reform different from all other reforms? Retrieved from www.nas.edu/sputnik/bybee1.htm.
Cajete, G. A. (2000). *Native science: natural laws of interdependence*. Santa Fe, NM: Clear Light.
Carter, L. (2008). Recovering traditional ecological knowledge (TEK): is it always what it seems? *Transnational Curriculum Inquiry, 5*, 17–25.
Chandra, D. V. (2014). Re-examining the importance of indigenous perspectives in the Western environmental education for sustainability: from tribal to mainstream education. *Journal of Teacher Education for Sustainability, 16*, 117–127.
Chaudhary, S., Kanwar, R. K., Sehgal, A., Cahill, D. M., Barrow, C. J., Sehgal, R., & Kanwar, J. R. (2017). Progress on Azadirachta indica based biopesticides in replacing synthetic toxic pesticides. *Frontiers in Plant Science, 8*(610), 1–13.
Childs, P. E. (2006). Relevance, relevance, relevance. *Physical Sciences Magazine., 2006/5, 14*.
Childs, P. E., Hayes, S., & Dwyer, A. (2015). Chemistry and everyday life: relating secondary school chemistry to the current and future lives of students. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education - from theory to practice* (pp. 33–54). Rotterdam: Sense.
Chinn, P. W. U. (2006). Preparing science teachers for culturally diverse students: developing cultural literacy through cultural immersion, cultural translators and communities of practice. *Cultural Studies of Science Education, 1*, 367–402.
Chinn, P. W. U. (2009). Authentic science experiences as a vehicle for assessing orientation towards science and science careers relative to identity and agency: a response to 'learning from the path followed by Brad'. *Cultural Studies of Science Education, 4*, 639–647.

Chinn, P. W. U. (2014). Place and culture-based professional development: cross-hybrid learning and the construction of ecological mindfulness. *Cultural Studies of Science Education, 10*, 121–134.
Cobern, W. W. (1996). Constructivism and non-western science education research. *International Journal of Science Education, 18*, 295–310.
Colucci-Gray, L., & Camino, E. (2014). From knowledge to action? Re-embedding science learning within the planet's web. In L. Bencze & S. Alsop (Eds.), *Activist science and technology education* (pp. 149–164). Dordrecht: Springer.
Colucci-Gray, L., & Camino, E. (2016). Looking back and moving sideways: following the Gandhian approach as the underlying thread for a sustainable science and education. *Visions for Sustainability, 6*, 23–44.
Colucci-Gray, L., Perazzone, A., Dodman, M., & Camino, E. (2013). Science education for sustainability, epistemological reflections and educational practices: from natural sciences to trans-disciplinarity. *Cultural Studies of Science Education, 8*, 127–183.
Costa, V. B. (1995). When science is 'another world': relationships between worlds of family, friends, school, and science. *Science Education, 79*, 313–333.
Cronje, A., de Beer, J., & Ankiewicz, P. (2015). The development and use of an instrument to investigate science teachers' views on indigenous knowledge. *African Journal of Research in Mathematics, Science and Technology Education, 19*, 319–332.
Dahlin, B., Østergaard, E., & Hugo, A. (2009). An argument for reversing the bases of science education – a phenomenological alternative to cognitionism. *Nordic Studies in Science Education, 5*, 185–199.
De Angelis, R. (2018). Entwining a conceptual framework: transformative, Buddhist and indigenous-community learning. *Journal of Transformative Education, 16*, 179–196.
De Beer, J., & Whitlock, E. (2009). Indigenous knowledge in the life sciences classroom: put on your de bono hats! *The American Biology Teacher, 71*, 209–216.
De Boer, G. (2000). Scientific literacy: another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*, 582–601.
De Haan, G. (2006). The BLK'21' programme in Germany: a 'Gestaltungskompetenz'- based model for education for sustainable development. *Environmental Education Research, 12*, 19–32.
Diethelm, I., Hubwieser, P., Klaus, R., München, T. U. & Klaus, R. (2012). Students , teachers and phenomena: educational reconstruction for computer science education. Proceedings of the Koli Calling International Conference on Computing Education Research, 164–173.
Dillon, J. (2014). Environmental education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (2nd ed., pp. 497–514). New York: Routledge.
Duit, R. (2007). Science education research internationally: conceptions, research methods, domains of research. *Eurasia Journal of Mathematics, Science and Technology Education, 3*, 3–15.
Duit, R. (2015). Didaktik. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 325–327). Dordrecht: Springer.
Duit, R., Gropengießer, H., & Kattmann, U. (2005). Towards science education that is relevant for improving practice: the model of educational reconstruction. In H. Fischer (Ed.), *Developing standards in research on science education* (pp. 1–9). Leiden: Taylor & Francis.
Eijck, M. V., & 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.
Eilks, I., & Hofstein, A. (2014). Combining the question of the relevance of science education with the idea of education for sustainable development. In I. Eilks, S. Markic, & B. Ralle (Eds.), *Science education research and education for sustainable development* (pp. 3–14). Aachen: Shaker.
Eilks, I., & Hofstein, A. (2015). *Relevant chemistry education*. Rotterdam: Sense.
Eilks, I., Rauch, F., Ralle, B., & Hofstein, A. (2013). How to balance the chemistry curriculum between science and society. In I. Eilks & A. Hofstein (Eds.), *Teaching chemistry* (pp. 1–36). Rotterdam: Sense.
Emdin, C. (2011). Dimensions of communication in urban science education : interactions and transactions. *Science Education, 95*, 1–20.
Fasasi, R. A. (2017). Effects of ethnoscience instruction, school location, and parental educational status on learners' attitude towards science. *International Journal of Science Education, 39*, 548–564.
Feierabend, T., & Eilks, I. (2011). Teaching the societal dimension of chemistry using a socio-critical and problem-oriented lesson plan based on bioethanol usage. *Journal of Chemical Education, 88*, 1250–1256.
Feyerabend, P. (1987). *Farewell to reason*. London: Verso.
Forawi, S. A. (2015). Science teacher professional development need in the United Arab Emirates. In N. Mansour & S. Al-Shamrani (Eds.), *Science Education in the Arab Gulf States* (pp. 49–68). Rotterdam: Sense.
Funk, J., Guthadjaka, K., & Kong, G. (2015). Posting traditional ecological knowledge on open access biodiversity platforms: implications for learning design. *Australian Journal of Indigenous Education, 44*(2), 150–162.

Garroutte, E. M. (1999). American Indian science education: the second step. *American Indian Culture and Research Journal, 23*(4), 91–114.
George, J. M. (1999). World view analysis of knowledge in a rural village: implications for science education. *Science Education, 83*, 77–95.
Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53*, 5–26.
Grillenberger, A., Przybylla, M., & Romeike, R. (2016). Bringing CS innovations to the classroom using the model of educational reconstruction. *Proceedings of ISSEP, 2016*, 31–39.
Hadzigeorgiou, Y., & Schulz, R. (2014). Romanticism and romantic science: their contribution to science education. *Science & Education, 23*, 1963–2006.
Hamlin, M. L. (2013). 'Yo soy indígena': identifying and using traditional ecological knowledge (TEK) to make the teaching of science culturally responsive for Maya girls. *Cultural Studies of Science Education, 8*, 759–776.
Hansson, L. (2014). Students' views concerning worldview presuppositions underpinning science: is the world really ordered, uniform, and comprehensible? *Science Education, 98*, 743–765.
Hardesty, D. L. (1977). *Ecological anthropology*. New York: Wiley.
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.
Hayes, A., Mansour, N., & Fisher, R. (2015). Adopting western models of learning to teaching science as a means of offering a better start at University? In N. Mansour & S. Al-Shamrani (Eds.), *Science Education in the Arab Gulf States* (pp. 49–68). Rotterdam: Sense.
Herbert, S. (2008). Collateral learning in science: students' reponses to a cross-cultural unit of work. *International Journal of Science Education, 30*, 979–994.
Hiwatig, A. D. F. (2008). Education ethno-scientific teaching approach, student proficiency, and attitude toward science and ethnic culture. *Education Quarterly, 66*(1), 3–21.
Hodson, D. (1993). In search of a rationale for multicultural science education. *Science Education, 77*, 685–711.
Hofstein, A., & Kesner, M. (2006). Industrial chemistry and school chemistry: making chemistry studies more relevant. *International Journal of Science Education, 28*, 1017–1039.
Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal issues and their importance for contemporary science education: a pedagogical justification and the state of the art in Israel, Germany and the USA. *International Journal of Science and Mathematics Education, 9*, 1459–1483.
Holbrook, J. (2005). Making chemistry teaching relevant. *Chemical Education International, 6*(1), 1–12.
Holbrook, J., & Rannikmäe, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*, 1347–1362.
Horlacher, R. (2016). *The educated subject and the German concept of Bildung - a comparative cultural history*. London: Routledge.
Houde, N. (2007). The six faces of traditional ecological knowledge: challenges and opportunities for Canadian co-management arrangements. *Ecology and Society, 12*(2), 34.
Hugerat, M., Mamlok-Naaman, R., Eilks, I., & Hofstein, A. (2015). Professional development of chemistry teachers for relevant chemistry education. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education* (pp. 369–386). Rotterdam: Sense.
Hwang, K. (2013). Educational modes of thinking in Neo-Confucianism: a traditional lens for rethinking modern education. *Asia Pacific Education Review, 14*, 243–253.
Iaccarino, M. (2003). Science and culture. *EMBO Reports (European Molecular Biology Organization), 4*, 220–223.
ICSU (International Council for Science). (2002). *Science and traditional knowledge: Report from the ICSU study group on science and traditional knowledge*. Paris, France: Author.
Ideland, M. (2018). Science, coloniality, and "the great rationality divide". *Science & Education, 27*, 783–803.
Ingerman, Å., & Wickman, P.-O. (2015). Towards a teachers' professional discipline: Shared responsibility for didactic models in research and practice. In P. Burnard, B.-M. Apelgren, & N. Cabaroglu (Eds.), *Transformative teacher research: theory and practice for the C21st* (pp. 167–179). Rotterdam: Sense.
Inglis, J. T. (Ed.). (1993). *Traditional ecological knowledge: concepts and cases*. Ottawa, ON: International Program on Traditional Ecological Knowledge, International Development Research Centre.
Jank, W., & Meyer, H. (1991). *Didaktische Modelle [Didaktik models]*. Berlin: Cornelsen Verlag (in German).
Jegede, O. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics education in Africa. *Studies in Science Education, 25*, 97–137.
Jordan, K., & Kristjánsson, K. (2017). Sustainability, virtue ethics, and the virtue of harmony with nature. *Environmental Education Research, 23*, 1205–1229.
Kapyrka, J., & Dockstator, M. (2012). Indigenous Knowledges and Western Knowledges in environmental education : Acknowledging the tensions for the benefits of a " two-worlds " approach. *Canadian Journal of Environmental Education, 17*, 97–112.

Kasanda, C., Lubben, F., Gaoseb, N., Kandjeo-Marenga, U., Hileni Kapenda, H., & Campbell, B. (2005). The role of everyday contexts in learner-centred teaching: the practice in Namibian secondary schools. *International Journal of Science Education, 27*, 1805–1823.
Kattmann, U., Duit, R., Gropengiesser, H., & Komorek, M. (1996). Educational reconstruction - bringing together issues of scientific clarification and students' conceptions. Paper presented at the annual meeting of the National Association of Research in Science Teaching, St. Louis, MO.
Kawagley, A. O. (1995). *A Yupiaq worldview: a pathway to ecology and spirit*. Prospect Heights: Waveland Press.
Kawagley, A. O., & Barnhardt, R. (1998). Education indigenous to place: Western science meets native reality. *Alaska Native Knowledge Network*, 2–17 Retrieved from http://search.ebscohost.com.cyber.usask.ca/login.aspx?direct=true&db=a9h&AN=44047668&site=ehost-live.
Kawagley, A. O., Norris-Tull, D., & Norris-Tull, R. A. (1998). The indigenous worldview of Yupiaq culture: its scientific nature and relevance to the practice and teaching of science. *Journal of Research in Science Teaching, 35*, 133–144.
Keller, J. M. (1983). Motivational design of instruction. In C. M. Reigeluth (Ed.), *Instructional design theories: An overview of their current status* (pp. 386–434). Hillsdale: Lawrence Erlbaum.
Khaddour, R., Al-Amoush, S., & Eilks, I. (2017). The curriculum emphasis in grade-10 chemistry textbooks from seven cross regional Arab countries. *Chemistry Education Research and Practice, 18*, 375–385.
Kibirige, I., & van Rooyen, H. (2006). Enriching science teaching through the inclusion of indigenous knowledge. Indigenous knowledge in the science classroom. In J. De Beer & H. van Rooyen (Eds.), *Teaching science in the OBE classroom* (pp. 235–247). Johannesburg: Macmillan.
Kim, E.-J. A. (2018). *The relationships at play in integrating indigenous knowledges-sciences (IK-S) in science curriculum: a case study of Saskatchewan K-12 science curriculum*. Doctoral thesis: McGill University.
Kim, E. J. A., & Dionne, L. (2014). Traditional ecological knowledge in science education and its integration in grades 7 and 8 Canadian science curriculum documents. *Canadian Journal of Science, Mathematics and Technology Education, 14*, 311–329.
Kim, E.-J. A., Asghar, A., & Jordan, S. (2017). A critical review of traditional ecological knowledge (TEK) in science education. *Canadian Journal of Science, Mathematics and Technology Education, 17*, 258–270.
Kimmerer, R. W. (2012). Searching for synergy: Integrating traditional and scientific ecological knowledge in environmental science education. *Journal of Environmental Studies and Sciences, 2*, 317–323.
King, D., & Ritchie, S. M. (2012). Learning science through real world contexts. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 69–80). Dordrecht: Springer.
Knamiller, G. (1984). The struggle for relevance of science education in developing countries. *Studies in Science Education, 11*, 60–78.
Knudtson, P., & Suzuki, D. (1992). *Wisdom of the elders*. Toronto, ON: Stoddart.
Kopnina, H. (2014). Future scenarios and environmental education. *The Journal of Environmental Education, 45*, 217–231.
Korver-Glenn, E., Chan, E., & Howard Ecklund, E. (2015). Perceptions of science education among African American and white evangelicals: a Texas case study. *Review of Religious Research, 57*, 131–148.
Kovach, M. (2009). *Indigenous methodologies: Characteristics, conversations and contexts*. Toronto, ON: University of Toronto Press.
Læssøe, J. (2010). Education for sustainable development, participation and socio-cultural change. *Environmental Education Research, 16*, 39–57.
Lalonde, A. (1993). African indigenous knowledge and its relevance to sustainable development. In J. Inglis (Ed.), *Traditional ecological knowledge: Concepts and cases* (pp. 55–62). Ottawa, ON: International Development Research Center, Canadian Museum of Nature.
Latour, B. (2004). Why has critique run out of steam? From matters of fact to matters of concern. *Critical Inquiry, 30*, 225–248.
Lee, J. B. J. (2002). Akonga Mäori: a framework of study of Mäori secondary school teachers and teacher education. *Action in Teacher Education, 24*(2), 64–74.
Lowan-trudeau, G. (2012). Methodological Métissage : an interpretive indigenous approach to environmental education research. *Canadian Journal of Environmental Education, 17*, 113–130.
Mack, E., Augare, H., Cloud-Jones, L. D., Davíd, D., Gaddie, H. Q., Honey, R. E., et al. (2012). Effective practices for creating transformative informal science education programs grounded in native ways of knowing. *Cultural Studies of Science Education, 7*, 49–70.
Maddock, M. N. (1981). Science education: an anthropological viewpoint. *Studies in Science Education, 8*, 1–26.

Marks, R., & Eilks, I. (2009). Promoting scientific literacy using a socio-critical and problem-oriented approach to chemistry teaching: concept, examples, experiences. *International Journal of Environmental and Science Education, 4*, 231–245.
Mashoko, D. (2014). Indigenous knowledge for plant medicine: inclusion into school science teaching and learning in Zimbabwe. *International Journal of English and Education*, *33*, 2278–4012.
Mazzocchi, F. (2006). Western science and traditional knowledge. *EMBO Reports (European Molecular Biology Organization), 7*, 463–466.
McConney, A., Oliver, M., Woods-McConney, A., & Schibeci, R. (2011). Bridging the gap? A comparative, retrospective analysis of science literacy and interests in science for indigenous and non-indigenous Australian students. *International Journal of Science Education, 33*, 2017–2035.
McGregor, D. (2004). Coming full circle: Indigenous knowledge, environment and our future. *American Indian Quarterly, 28*, 385–410.
McGregor, D. (2006). Traditional ecological knowledge. Ideas: the arts and science review, 3.Retrieved from http://www.silvafor.org/assets/silva/PDF/DebMcGregor.pdf
Mckeon, M. (2012). Two-eyed seeing into environmental education : revealing its "natural" readiness to indigenize. *Canadian Journal of Environmental Education, 17*, 131–147.
McKinley, E. (1996). Towards an indigenous science curriculum. *Research in Science Education, 26*, 155–167.
McKinley, E., & Stewart, G. M. (2012). Out of place: Indigenous knowledge (IK) in the science curriculum. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second international handbook of science education* (pp. 541–554). New York: Springer.
Meyer, M. (2012). Keyword: didactics in Europe. *Zeitschrift für Erziehungswissenschaft, 15*, 449–482.
Moon, S. (2017). Donghak (eastern learning), self-cultivation, and social transformation: towards diverse curriculum discourses on equity and justice. *Educational Philosophy and Theory, 49*, 1146–1160.
Mueller, M. P. (2009). Educational reflections on the 'ecological crisis': ecojustice, environmentalism, and sustainability. *Science & Education, 18*, 1031–1056.
Mueller, M., & Tippins, D. (2010). Van Eijck and Roth's utilitarian science education: why the recalibration of science and traditional ecological knowledge invokesmultiple perspectives to protect science education frombeing exclusive. *Cultural Studies in Science Education, 5*, 993–1007.
Murfin, B. (1994). African science, African and African-American scientists and the school science curriculum. *School Science and Mathematics, 94*, 96–103.
Murray, J. J. (2015). Re-visioning science education in Canada: a new polar identity and purpose. *Education Canada*, 55(4). Retrieved from http://www.cea-ace.ca/education-canada/article/ re-visioning-science-education-Canada.
Nadasdy, P. (1999). The politics of TEK: power and the 'integration' of knowledge. *Artic Anthropology, 36*(1–2), 1–18.
Nakashima, D.J., & Roué, M. (2002) Indigenous knowledge, peoples and sustainable practice. In Timmerman P (ed.) *Encyclopedia of global environmental change. 5: Social and economic dimensions of global environmental change* (pp 314–324). Chichester, UK: Wiley.
Ng'asike, J. T. (2011). Turkana children ' s rights to education and indigenous knowledge in science teaching in Kenya. *New Zealand Journal of Teachers' Work, 8*(1), 55–67.
Odora Hoppers, C.A. (2004). Culture, indigenous knowledge and development. Paper presented at Conference on Development Priorities and the Role of Tertiary Education, Wilton Park, UK.
Ogawa, M. (1995). Science education in a multiscience perspective. *Science Education, 79*, 583–593.
Ogunniyi, M. B., & Hewson, M. G. (2008). Effect of an argumentation-based course on teachers' disposition towards a science-indigenous knowledge curriculum. *International Journal of Environmental & Science Education, 3*, 159–177.
Ogunniyi, M. B., & Ogawa, M. (2008). The prospects and challenges of training South African and Japanese educators to enact an indigenized science curriculum. *South African Journal of Higher Education, 22*, 175–590.
Østergaard, E. (2017). Earth at rest – aesthetic experience and students' grounding in science education. *Science & Education, 26*, 557–582.
Østergaard, E., Dahlin, B., & Hugo, A. (2008). Doing phenomenology in science education: a research review. *Studies in Science Education, 44*, 93–121.
Parmin, S., Ashadi, S., & Fibriana, F. (2017). Science integrated learning model to enhance the scientific work independence of student teacher in indigenous knowledge transformation. *Jurnal Pendidikan IPA Indonesia, 6*, 365–372.
Pauka, S., Treagust, D. F., & Waldrip, B. (2005). Village elders' and secondary school students' explanations of natural phenomena in Papua New Guinea. *International Journal of Science and Mathematics Education, 3*, 213–237.
Perin, D. (2011). Facilitating student learning through contextualization: a review of evidence. *Community College Review, 39*, 268–295.

Pihama, L., & Cram, F. (2002). Creating methodological space: a literature review of Kaupapa Maori research. *Canadian Journal of Native Education, 26*, 30–43.
Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research. *Studies in Science Education, 50*, 85–129.
Pugh, K. J., Bergstrom, C. M., & Spencer, B. (2017). Profiles of transformative engagement: identification, description, and relation to learning and instruction. *Science Education, 101*, 369–398.
Quay, J. (2013). More than relations between self, others and nature: outdoor education and aesthetic experience. *Journal of Adventure Education & Outdoor Learning,13*, 142–157.
Rahmawati, Y., Ridwan, A. & Nurbaity (2017). Should we learn culture in chemistry classroom? Integration ethnochemistry in culturally responsive teaching. *AIP Conference Proceedings*, 1868.
Ramsden, J. M. (1998). Mission impossible? Can anything be done about attitudes to science. *International Journal of Science Education, 20*, 125–137.
Reichenbach, R. (2014). *Humanistic Bildung*: regulative idea or empty concept? *Asia Pacific Education Review, 15*, 65–70.
Reichenbach, R. (2016). The source of learning is thought' reading the *Chin-ssu lu* (近思錄) with a 'Western Eye. *Educational Philosophy and Theory, 48*, 36–51.
Retter, H. (2012). Dewey's progressive education, experience and instrumental pragmatism with particular reference to the concept of *Bildung*. In P. Siljander, A. Kivelä, & A. Sutinen (Eds.), *Theories of Bildung and growth* (pp. 281–302). Rotterdam: Sense.
Rist, S., & Dahdouh-Guebas, F. (2006). Ethnosciences - a step towards the integration of scientific and indigenous forms of knowledge in the management of natural resources for the future. *Environment, Development and Sustainability, 8*(4), 467–493.
Roth, W.M., Eijck, M. V, Reis, G. & Hsu, P.L. (2008a). Authentic science experience as vehicle to change students' orientation towards science and scientific career chouces. In W. M. Roth, M. V. Eijck, G. Reis & P. L. Hsu, *Authentic science revisited* (p. 175–200). Rotterdam: Sense.
Roth, W. M., Eicjk, M. V., Reis, G., & Hsu, P. L. (2008b). Learning science in/for the community. In *Authentic science revisited* (pp. 201–217). Rotterdam: Sense.
Rowson, J. (2019). *Bildung in the 21st Century – why sustainability prosperity depends upon reimagining education*. CUSP essay in series on the Morality of Sustainable Prosperity, No 9. Retrieved from the World Wide Web at https://www.cusp.ac.uk/essay/m1-9.
Rucker, T., & Gerónimo, E. D. (2017). The problem of *Bildung* and the basic structure of *Bildungstheorie*. *Studies in Philosophy and Education, 36*, 569–584.
Ruitenberg, C. (2005). Deconstructing the experience of the local: toward a radical pedagogy of place. In K. Howe (Ed.), *Philosophy of education 2005* (pp. 212–220). Urbana: Philosophy of Education Society.
Ryan, A. (2008). Indigenous knowledge in the science curriculum: avoiding neo-colonialism. *Cultural Studies in Science Education, 3*, 663–702.
Sadler, T. D. (2011). *Socio-scientific issues in the classroom*. Dordrecht: Springer.
Sadler, T. D., & Zeidler, D. L. (2005). The significance of content knowledge for informal reasoning regarding socioscientific issues: applying genetics knowledge to genetic engineering issues. *Science Education, 89*, 71–93.
Savelyeva, T. (2017). Vernadsky meets Yulgok: a non-Western dialog on sustainability. *Educational Philosophy and Theory, 49*, 501–520.
Schneuwly, B. (2011). Subject didactics – an academic field related to the teacher profession and teacher education. In B. Hudson & M. A. Meyer (Eds.), *Beyond fragmentation: Didactics, learning and teaching in Europe* (pp. 275–286). Leverkusen: Budrich.
Seel, H. (1999). *Didaktik* as the professional science of teachers. In B. Hudson, F. Buchberger, P. Kansanen, & H. Seel (Eds.), *Didaktik/Fachdidaktik as science(−s) of the teaching profession?* (Vol. 2, pp. 85–94). Umeå: Thematic Network of Teacher Education in Europe.
Senanayake, S. (2006). Indigenous knowledge as a key to sustainable development. *The Journal of Agricultural Sciences, 2*, 87–94.
Simon, S., & Amos, R. (2011). Decision making and use of evidence in a socio-scientific problem on air quality. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 167–192). Dordrecht: Springer.
Simonneaux, L. (2014). *Questions socialement vives* and socio-scientific issues: new trends of research to meet the training needs of postmodern society. In C. Bruguère, A. Tiberghien, & P. Clement (Eds.), *Topics and trends in current science education* (pp. 37–54). Dordrecht: Springer.
Simonneaux, J., & Simonneaux, L. (2012). Educational configurations for teaching environmental socioscientific issues within the perspective of sustainability. *Research in Science Education, 42*, 75–94.
Simpson, L. R. (1999). *The construction of TEK: Issues, implications and insights (doctoral dissertation)*. Fort Gerry, WPG: University of Manitoba.

Sjöström, J. (2007). The discourse of chemistry (and beyond). *HYLE: International Journal for Philosophy of Chemistry, 13*, 83–97.
Sjöström, J. (2013). Towards *Bildung*-oriented chemistry education. *Science & Education, 22*, 1873–1890.
Sjöström, J. (2018). Science teacher identity and eco-transformation of science education: comparing Western modernism with Confucianism and reflexive *Bildung*. *Cultural Studies of Science Education, 13*, 147–161.
Sjöström, J., & Eilks, I. (2018). Reconsidering different visions of scientific literacy and science education based on the concept of *Bildung*. In Y. Dori, Z. Mevarech, & D. Baker (Eds.), *Cognition, metacognition, and culture in STEM education* (pp. 65–88). Dordrecht: Springer.
Sjöström, J., & Talanquer, V. (2018). Eco-reflexive chemical thinking and action. *Current Opinion in Green and Sustainable Chemistry, 13*, 16–20.
Sjöström, J., Rauch, F., & Eilks, I. (2015). Chemistry education for sustainability. In I. Eilks & A. Hofstein (Eds.), *Relevant chemistry education - from theory to practice* (pp. 163–184). Rotterdam: Sense.
Sjöström, J., Eilks, I., & Zuin, V. G. (2016). Towards eco-reflexive science education: a critical reflection about educational implications of green chemistry. *Science & Education, 25*, 321–341.
Sjöström, J., Frerichs, N., Zuin, V. G., & Eilks, I. (2017). Use of the concept of *Bildung* in the international science education literature, its potential, and implications for teaching and learning. *Studies in Science Education, 53*, 165–192.
Smith, L. T. (1997). *Nga Aho o te kakahu matauranga: The multiple layers of struggle by Maori in education*. The University of Auckland: Unpublished PhD.
Smith, L. T. (1999). *Decolonizing methodologies: Research and indigenous peoples*. London: Zed Books.
Smith, G. A. (2002). Place-based education: learning to be where we are. *Phi Delta Kappan, 83*(8), 584–594.
Snively, G. (1995). Bridging traditional science and western science in the multicultural classroom. In G. Snively & A. MacKinnon (Eds.), *Thinking globally about mathematics and science education* (pp. 53–75). Vancouver, BC: University of British Columbia.
Snively, G., & Corsiglia, J. (2000). Dicovering indigenous science: implications for science education. *Science Education, 85*, 6–34.
Snively, G., & Williams, W. L. (2016). *Knowing home: Braiding Indigenous Science with Western Science, book 1*. Oak Bay, BC: University of Victoria.
Stanley, W., & Brickhouse, N. (1994). Multiculturalism, universalism, and science education. *Science Education, 78*, 387–398.
Stephens, S. (2000). *Handbook for culturally responsive science curriculum*. Fairbanks, Alaska: Alaska Native Knowledge Network.
Sterling, S. (2011). Transformative learning and sustainability: sketching the conceptual ground. *Learning and Teaching in Higher Education, 5*, 17–33.
Straume, I. S. (2015). The subject and the world: educational challenges. *Educational Philosophy and Theory, 47*, 1465–1476.
Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education, 49*, 1–34.
Sturtevant, W. C. (1964). Studies in ethnoscience. American Anthropologist, 66(3), 99-131.
Sumida Huaman, E. (2016). Tuki Ayllpanchik (our beautiful land): indigenous ecology and farming in the Peruvian highlands. *Cultural Studies of Science Education, 11*, 1135–1153.
Sutherland, D., & Swayze, N. (2012). Including indigenous knowledges and pedagogies in science-based environmental education programs. *Canadian Journal of Environmental Education, 17*, 80–96.
Sylva, T., Chinn, P., & Kinoshita, C. (2010). A culturally relevant agricultural and environmental course for K–12 teachers in Hawaii. *Journal of Natural Resources and Life Sciences Education, 39*, 10-14.
Taber, K. S. (2013). *Modeling learners and learning in science education*. Dordrecht: Springer.
Taber, K. S. (2014). Constructing active learning in chemistry: concepts, cognition and conceptions. In I. Devetak & S. A. Glažar (Eds.), *Learning with understanding in the chemistry classroom* (pp. 5–23). Dordrecht: Springer.
Taylor, C. A. (2017). Is a posthumanist *Bildung* possible? Reclaiming the promise of *Bildung* for contemporary higher education. *Higher Education, 74*, 419–435.
Tejedor, G., Segalàs, J., & Rosas-Casals, M. (2018). Transdisciplinarity in higher education for sustainability: how discourses are approached in engineering education. *Journal of Cleaner Production, 175*, 29–37.
UNESCO (2002). Teaching and learning for a sustainable future. Retrieved from http://unesdoc.unesco.org/images/0012/001252/125238e.pdf.
van Lopik, W. (2012). Traditional ecological knowledge in the tribal college classroom. *Journal of Environmental Studies and Sciences, 2*, 341–345.
Wang, C.-L. (2016). Towards self-realisation: exploring the ecological self for education. *Educational Philosophy and Theory, 48*, 1256–1265.

Ware, F., Breheny, M., & Forster, M. (2018). Kaupapa Kōrero: a Māori cultural approach to narrative inquiry. AlterNative, 14, 45–53.

Warren, M. (1997). Conservation of indigenous knowledge serves conservation of biodiversity. *Alternatives Journal, 23*(3), 26–27.

Warren, D. M., Brokensha, D., & Slikkerveer, L. J. (Eds.). (1993). *Indigenous knowledge systems: The cultural dimension of development*. London: Kegan Paul.

Wheeler, K. (2000). Sustainability from five perspectives. In K. A. Wheeler & A. P Bijur (Eds.), *Education for a sustainable future* (p. 2–6). New York: Kluwer.

Widiyatmoko, A., Sudarmin & Miranita Khusniati. (2015). Reconstruct ethnoscience based-science in karimunjawa islands as a mode to build nature care student character. *International Conference on Mathematics, Science, and Education 2015 (ICMSE 2015)*, SE 65–70.

Williams, L. (2013). Deepening ecological relationality through critical onto-epistemological inquiry: where transformative learning meets sustainable science. *Journal of Transformative Education, 11*, 95–113.

Williams, N. M., & Baines, G. (1993). *Traditional ecological knowledge: wisdom for sustainable development*. Canberra: Center for Resource and Environmental Studies, Australian National University.

Wilson, S. (2008). *Research is ceremony: indigenous research methods*. Halifax, NS: Fernwood.

Zembylas, M. (2006). Science education as emancipatory: the case of Roy Bhaskar's philosophy of meta-reality. *Educational Philosophy and Theory, 38*, 665–676.

Zidny, R., & Eilks, I. (2018). Indigenous knowledge as a socio-cultural context of science to promote transformative education for sustainable development: a case study on the Baduy Community (Indonesia). In: I. Eilks, S. Markic & B. Ralle (eds.), *Building bridges across disciplines for transformative education and a sustainable future,*(P. 249-256). Aachen: Shaker.

Zierer, K., & Seel, N. M. (2012). General didactics and instructional design: eyes like twins: a transatlantic dialogue about similarities and differences, about the past and the future of two sciences of learning and teaching. *SpringerPlus, 1*, 15.

Zimmerman, H. T., & Weible, J. L. (2017). Learning in and about rural places : connections and tensions between students ' everyday experiences and environmental quality issues in their community. *Cultural Studies of Science Education, 12*, 7–31.