Discovering Indigenous Science: Implications for Science Education

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ABSTRACT: Indigenous science relates to both the science knowledge of long-resident, usually oral culture peoples, as well as the science knowledge of all peoples who as participants in culture are affected by the worldview and relativist interests of their home communities. This article explores aspects of multicultural science and pedagogy and describes a rich and well-documented branch of indigenous science known to biologists and ecologists as traditional ecological knowledge (TEK). Although TEK has been generally inaccessible, educators can now use a burgeoning science-based TEK literature that documents numerous examples of time-proven, ecologically relevant, and cost effective indigenous science. Disputes regarding the universality of the standard scientific account are of critical importance for science educators because the definition of science is a *de facto* "gatekeeping" device for determining what can be included in a school science curriculum and what cannot. When Western modern science (WMS) is defined as universal it does displace revelation-based knowledge (i.e., creation science); however, it also displaces pragmatic local indigenous knowledge that does not conform with formal aspects of the "standard account." Thus, in most science classrooms around the globe, Western modern science has been taught at the expense of indigenous knowledge. However, because WMS has been implicated in many of the world's ecological disasters, and because the traditional wisdom component of TEK is particularly rich in time-tested approaches that foster sustainability and environmental integrity, it is possible that the universalist "gatekeeper" can be seen as increasingly problematic and even counter productive. This paper describes many examples from Canada and around the world of indigenous people's contributions to science, environmental understanding, and sustainability. The authors argue the view that Western or modern science is just one of many sciences that need to be addressed in the science classroom. We conclude by presenting instructional strategies that can help *all* science learners negotiate border crossings between Western modern science and indigenous science. © 2000 John Wiley & Sons, Inc. *Sci Ed* **85:**6–34, 2001.

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INTRODUCTION

One of the intense philosophical debates in education literature focuses on the inclusion of multicultural science in mainstream science education, as evidenced by the number of papers submitted to this and other science education journals. For some, multicultural science is seen as important because it can function as a pedagogical stepping stone—especially for multicultural students of science (Atwater & Riley, 1993; Hodson, 1993; Stanley & Brickhouse, 1994). Certain other science educators who champion modern Western science as the last and greatest of the sciences tend to dismiss multicultural science as faddish or heretical (Good, 1995a, 1995b; Gross & Levitt, 1994; Matthews, 1994; Slezak, 1994; Wolpert, 1993).

Suspending consideration of the intrinsic importance of multicultural science Ogawa (1995) stresses that all science students must work through both individual and indigenous science understandings in the course of constructing their knowledge of modern Western science. Ogawa proposes that every culture has its own science and refers to the science in a given culture as its "indigenous science" (Ogawa, 1995, p. 585). Westerners freely acknowledge the existence of indigenous art, music, literature, drama, and political and economic systems in indigenous cultures, but somehow fail to apprehend and appreciate indigenous science. Elkana writes: "Comparative studies of art, religion, ethics, and politics abound; however, there is no discipline called comparative science" (Elkana, 1981, p. 2). Thus, in many educational settings where Western modern science is taught, it is taught at the expense of indigenous science, which may precipitate charges of epistemological hegemony and cultural imperialism.

It would seem that the dispute over how science is to be taught in the classroom turns on how the concepts "science" and "universality" are to be defined. The debate rages over the nature of reality and knowledge, definitions of science, and the so-called universalist vs. relativist positions. Sometimes the debate appears to be at least as culture-centric as it is rational. Replying to a Stanley and Brickhouse (1994) suggestion to include examples of multicultural science in the curriculum, Good (1995a) challenged opponents to be specific with their "few well-chosen examples of sciences from other cultures":

> What are these few well-chosen examples that should be included in our school science curriculum? Additionally, it would be very nice to learn how these examples of neglected "science" should change our understanding of biology, chemistry, physics, and so on. Just what contributions will this neglected science make in modern science's understanding of nature? (p. 335)

As one example of how far the universalist vs. relativist debate can be pushed, the authors have learned that Richard Dawkins is fond of saying: "there are no relativists at 30,000 feet." No doubt that without an airplane of conventional description, a person at 30,000 feet is in serious trouble, but when universalists take off and land on vulcanized rubber tires they make use of a material and process reportedly discovered and refined by indigenous Peruvians (Weatherford, 1988, 1991). Without multicultural science contributions enabling airplanes to land and take off, there would be neither airplanes, nor for that matter, universalists at 30,000 feet.

While science educators have been fighting epistemological battles that could effectively limit or expand the scope and purview of science education, events on the ground appear to have overtaken us—working scientists have themselves been involved in wide ranging exploration and reform. Especially during the last 25 years, biologists, ecologists, botanists, geologists, climatologists, astronomers, agriculturists, pharmacologists, and related working scientists have labored to develop approaches that are improving our ability to understand and mitigate the impact of human activity upon the environment. By extending their enquiry into the timeless traditional knowledge and wisdom of long-resident, oral peoples, these scientists have in effect moved the borders of scientific inquiry and formalized a branch of biological and ecological science that has become known as the traditional ecological knowledge (TEK), which can be thought of as either the knowledge itself, or as documented ethno-science enriched with analysis and explication provided by natural science specialists. The interested reader can find numerous detailed examples of TEK (Andrews, 1988; Berkes, 1988, 1993; Berkes & Mackenzie, 1978, Inglis, 1993; Warren, 1997; Williams & Baines, 1993). Additionally, the present bibliography provides the reader with a number of specific examples of TEK in Canada and worldwide.

Thus, we face four related questions: First, is science an exclusive invention of Europeans, or have scientific ways of thinking and viable bodies of science knowledge also emerged in other cultures? Second, if WMS is taken to be universal, what is the status of the vast quantities of local knowledge that it subsumes, incorporates, and claims to legitimize? Third, what is the proper role of science educators as leaders in the process of refining and clarifying the current definitions of WMS? And fourth, when viable bodies of useful scientific knowledge emerge in other cultures, how can science educators develop programs that enable *all* students to cross cultural borders — in this instance, between the culture of Western modern science and the cultures of long-resident indigenous peoples?

Because TEK is being used by scientists to solve important biological and ecological problems and because problems of sustainability are pervasive and of very high interest to students and others, it becomes increasingly important for science educators to introduce students to the perspectives of both WMS and TEK. The availability and varied nature of TEK examples will be useful to proponents of multicultural science (Aikenhead, 1995, 1996; Atwater & Riley, 1993; Bowers, 1993a, 1993b; Hodson, 1993; Ogawa, 1989, 1995; Smith, 1982, 1995; Snively, 1990, 1995; Wright, 1992).

In this article, we argue the view that since Aboriginal cultures have made significant contributions to science, then surely there are different ways of arriving at legitimate knowledge. Without knowledge, there can be no science. Thus, the definition of “science” should be broadened, thereby including TEK as science. The intention is not to demean WMS, but instead to point out a body of scientific literature that provides great potential for enhancing our ability to develop more relevant science education programs.

TERMINOLOGY: WESTERN MODERN SCIENCE, INDIGENOUS SCIENCE, AND TEK

Since the phrases “Western modern science,” “indigenous science,” and “traditional ecological knowledge” all have multiple meanings it will be useful to linger briefly with definitions. For clarity, we shall distinguish between “Western modern science” which is the most dominant science in the world and “indigenous science” which interprets how the world works from a particular cultural perspective. This paper focuses on a subset of indigenous science referred to as “traditional ecological knowledge,” which is both the science of long-resident oral peoples and a biological sciences label for the growing literature which records and explores that knowledge.

What is Science?

As is well known, there are numerous versions of what science is, and of what counts as being scientific. The Latin root, *scientia,* means knowledge in the broadest possible sense and survives in such words as omniscience and prescience. Terms such as “modern science,” “standard science,” “Western science,” “conventional science,” and “official science” have been in use only since the beginning of the twentieth century. For some, scientific abstractions began with Sumerian astronomy and mathematics; for others, scientific theorizing began with Greek atomism; and for yet others, it began toward the end of the nineteenth century when scientists began to grapple with abstract theoretical propositions—for example, evolution, natural selection, and the kinetic-molecular theory. What confidence could one have in theoretical statements built from or based on unobservable data? Care was taken to develop logically consistent rules outlining how theoretical statements can be derived from observational statements. The intent was to create a single set of rules to guide the practice of theory justification (Duschl, 1994). Science can also refer to conceptual constructs approved by logical empiricism (positivism) which, in addition, has the capacity to carry science beyond the realms of observation and experiment. Also, we have come to refer to WMS as officially sanctioned knowledge which can be thought of as inquiry and investigation that Western governments and courts are prepared to support, acknowledge, and use. Some authors have represented “science” with the acronym WMS, which either means “Western modern science” (Ogawa, 1995) or “white male science” (Pomeroy, 1994). Striving toward comprehensive definitions, certain sociology of science scholars have described WMS as institutionalized in Western Europe and North America as a predominately white male, middle-class Western system of meaning and symbols (Rose, 1994; Simonelli, 1994).

In sharp contrast to the exclusivist definitions of science in the previous paragraph, Ogawa (1995) points science educators toward a broadly inclusive conceptualization of what science is by defining science rather simply as “a rational perceiving of reality,” where “perceiving means both the action constructing reality and the construct of reality” (p. 588). The merit of the use of the word “perceiving” gives science a “dynamic nature” and acknowledges that “science can experience a gradual change at any time” (p. 588). Another point put forward by Ogawa is that “rational” should be seen in relativistic terms, as discussed in the previous section.

The present WMS philosophical climate would require some reconfiguration if TEK, which takes a generally pragmatic approach, is to be properly received as science. Approaches to science seem to have proceeded along two fundamentally different courses—by the timeless procedure of relying on observation and experiment, and, during this century, by the theoretical examination of queries and assertions. By examining the methodology and logic of assertions, questions, and concept, logical empiricism (positivism) has come to function as a vigorous “gatekeeper” that has certainly succeeded in screening out metaphysical, pseudo-science during this century. In fact, logical empiricism (positivism) may have become so powerful a gatekeeper that even experimental science itself appears to have become diminished. Experiment cannot prove the [absolute] correctness of assertions, it can only help to rank or disconfirm theories. Hacking refers to the general difficulty in Boyd, Gaspar, and Trout (1991):

> No field in the philosophy of science is more systematically neglected than experiment. Our grade school teachers may have told us that scientific method is experimental method, but histories of science have become histories of theory. (p. 247)

Certainly, we may rejoice that logical empiricism (positivism) has been able to screen out historically destructive pseudo-science by exposing the meaninglessness of its metaphysics, but there are problems. As poet Robert Frost put it, “Before I built a wall I’d ask what I was walling in or walling out, and to whom I was like to give offense.” As an expression of Western culture (or even as a system of pure, value free, universal truth), WMS must inevitably swim in a sea of cultural assumptions about progress, self-interest, winning/losing, aggressiveness, attitude to time (the purview of meaningful history), and the benefits of immediate advantage as opposed to the importance of long-term consequences.

Until the past two or three decades, the gatekeeper's performance appears to have been generally celebrated. More recently, however, sociologists of science have been vigorous in identifying implicit values and assumptions that can be said to tacitly structure the gatekeeper's activities. At the same time, a considerable number of working scientists, no doubt mindful of both the gatekeeper's power to exclude and the real possibility of worldwide environmental collapse, have set up pragmatic TEK science shops. The fact that working scientists are increasingly acknowledging TEK suggests that there are sound reasons for changing the formal definitions of "science" so as to include such important forms of multicultural science as TEK.

Our position on "science" is closely aligned with that of Ogawa (1989), who prefers Elkana's (1981) understanding of science, which argues that "every culture has its science," . . . "something like its own way of thinking and/or its own worldview" and gives the following definition: "By science, I mean a rational (i.e., purposeful, good, directed) explanation of science of the physical world surrounding man" (p. 1437). We agree with Ogawa (1989) when he asserts that "Western science is only one form of science among the sciences of the world" (p. 248). Also, the people living in an indigenous culture itself may not recognize the existence of its own science, hence, it may be transferred from generation to generation merely by invisible or nonformal settings (Ogawa, 1989).

Indigenous Science

According to Ogawa (1995), we must distinguish between two levels of science: individual or personal science and cultural or societal science. He refers to science at the culture or society level as "indigenous science" (p. 588). He defines indigenous science as "a culture-dependent collective rational perceiving of reality," where "collective means held in sufficiently similar form by many persons to allow effective communication, but independent of any particular mind or set of minds" (p. 588).

Although we all participate in indigenous science to a greater or lesser degree, long-resident, oral culture peoples may be thought of as specialists in local indigenous science. Indigenous science, sometimes referred to as ethnoscience, has been described as "the study of systems of knowledge developed by a given culture to classify the objects, activities, and events of its given universe" (Hardesty, 1977). Indigenous science interprets how the local world works through a particular cultural perspective. Expressions of science thinking are abundant throughout indigenous agriculture, astronomy, navigation, mathematics, medical practices, engineering, military science, architecture, and ecology. In addition, processes of science that include rational observation of natural events, classification, and problem solving are woven into all aspects of indigenous cultures. It is both remembered sensory information that is usually transmitted orally in descriptive names and in stories where abstract principles are encapsulated in metaphor (Bowers, 1993a, 1993b; Cruikshank, 1981, 1991; Nelson, 1983).

We may note that indigenous science includes the knowledge of both indigenous expansionist cultures (e.g., the Aztec, Mayan, and Mongolian Empires) as well as the home-based knowledge of long-term resident oral resident peoples (i.e., the Inuit, the Aboriginal people of Africa, the Americas, Asia, Australia, Europe, Micronesia, and New Zealand).

Traditional Ecological Knowledge (TEK)

Although the term TEK came into widespread use in the 1980s, there is no universally accepted definition of traditional ecological knowledge (TEK) in literature. The term is, by necessity, ambiguous since the words *traditional* and *ecological knowledge* are themselves ambiguous. Dictionary etymology shows the Latin roots of “traditional science” to be “knowledge” *scientia* of the world that is “handed across” or “traded” (from the Latin *traduare*) across generations of long-resident oral traditional peoples. “Traditional” usually refers to a cultural continuity transmitted in the form of social attitudes, beliefs, principles, and conventions of behavior and practice derived from historical experience. However, as Berkes (1993) points out, “societies change through time, constantly adopting new practices and technologies, and making it difficult to define just how much and what kind of change would affect the labeling of a practice as traditional” (p. 3). Because of this, many scholars avoid using the term “traditional.” As well, some purists find the term unacceptable or inappropriate when referring to societies such as native northern groups whose lifestyles have changed considerably over the years. For this reason, some prefer the term “indigenous knowledge” (IK), which helps avoid the debate about tradition, and explicitly puts the emphasis on indigenous people (Berkes, 1993). The term “ecological knowledge” poses definition problems of its own. If ecology is defined narrowly as a branch of biology in the domain of Western science, then strictly speaking there can be no TEK; most traditional peoples are not modern Western scientists. If ecological knowledge is defined broadly to refer to the “knowledge, however acquired, of relationships of living beings with one another and with the environment, then the term TEK becomes tenable” (Berkes, 1993, p. 3).

TEK generally represents experience acquired over thousands of years of direct human contact with the environment. Although the term TEK only recently came into widespread use, the practice of TEK is ancient (Berkes, 1993). The science of long-resident peoples differs considerably from group to group depending on locale and is knowledge built up through generations of living in close contact with the land. Figure 1 show one way of attempting to describe TEK within an indigenous science framework and of emphasizing its importance to contemporary environmental issues. Examples of indigenous and TEK science may be accessed through living elders and specialists of various kinds or found in the literature of TEK, anthropology, ethnology, ethnobiology, ethnogeography, ethnohistory, and mythology, as well as in the archived records of traders, missionaries, and government functionaries.

TEK information is sometimes cherished as private or belonging to one family only. Also, in many traditions, oral information may only be shared under particular circumstances, for example, when it is clear that no one intends to use the knowledge for gain.

CHARACTERISTICS OF TRADITIONAL ECOLOGICAL KNOWLEDGE

A fundamental principle taught by indigenous elders is that subject matter is properly examined and interpreted contextually. For example, identification and structural examination of a particular plant and its fruits may be no less important than its uses within the context of a particular family or community and may include stories relating to its use as a food source, its ceremonial uses, its complex preparation process, the traditional accounts of its use (as in purification rituals), its kin affiliations, and so on (Christie, 1991). The context is in marked contrast with WMS where “environmental” and “social” influences are generally considered confounding, and scientists often confine their attentions to the

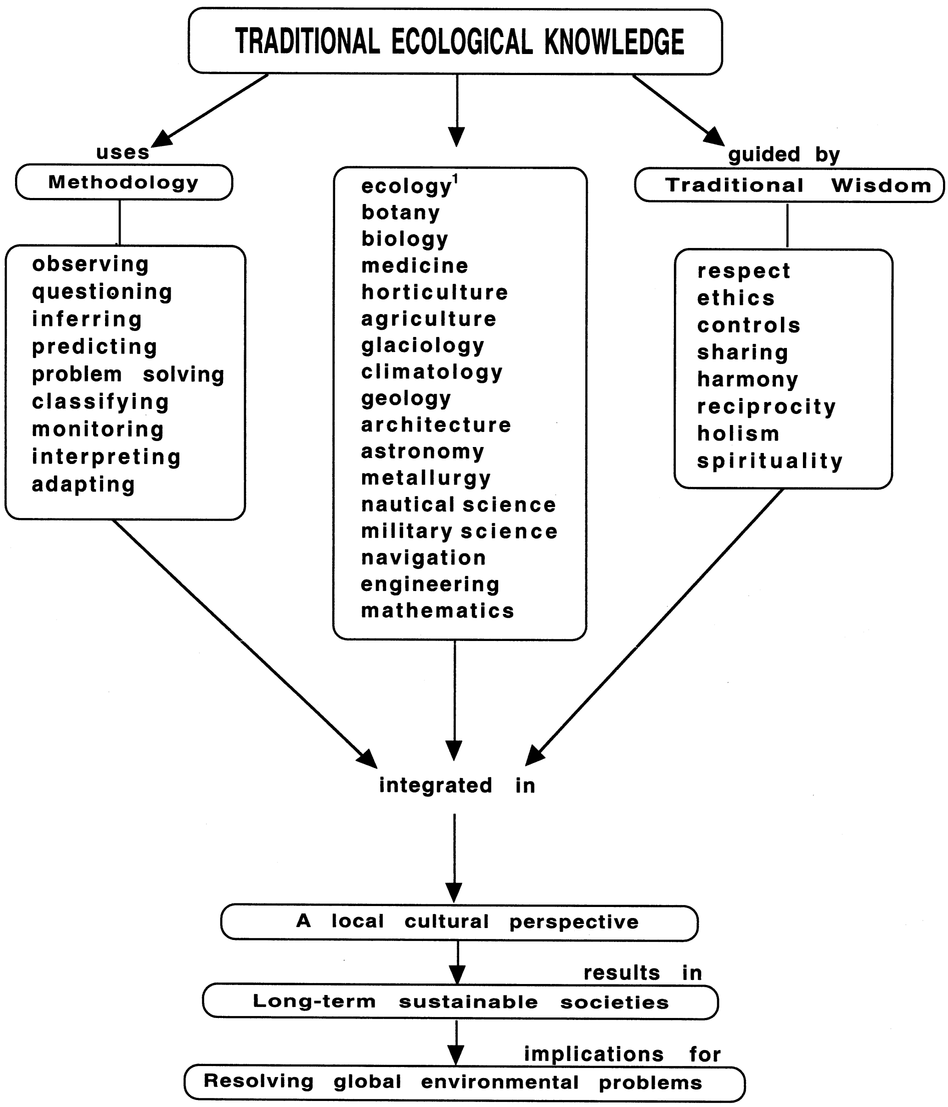

Figure 1. Traditional ecological knowledge.

controlled conditions of laboratories or the theoretician's office. Traditional ecological knowledge tends to be holistic, viewing the world as an interconnected whole. Humans are not regarded as more important than nature, thus, "traditional science is moral, as opposed to supposedly value free" (Berkes, 1993).

Metaphor and stories can be used to encapsulate and compress oral wisdom and even make it entertaining. Such stories can be decoded in relation to specific circumstances

[1] TEK knowledge corresponds variously to WMS categories. The list suggests a descending order of similarities.

upon appropriate reflection or contemplation. Oral narratives may explore historical events, such as the coming of the first outsiders, encroachment on traditional lands, or changes in animal populations due to overuse. Among the Nisga'a of Northern British Columbia stories function as deeds to land and resources (McKay, oral communication, 1979). Narratives provide information about changes in migration routes of caribou as a result of new land use activities; changes in the population of salmon or crabs; and changes in the size, vitality, longevity, and even the viscera of animal populations. Oral narratives often provide biologists with important long-term observations describing changes in plant and animal populations that can be correlated with over-fishing and pollution (Cruikshank, 1981,1991; Kuhnlein & Turner, 1991).

Because traditional people tend to spend generations learning about life in one place, traditional science often may not resemble the more mobile and dramatic Western science that was developed in close association with the rise of Western global expansionism. Experimentation and innovation may take place at a more measured pace than in WMS. In her observations of Athapaskan and Tlingit languages in the Yukon and Northwest Territories, Julie Cruikshank (1991) notes:

> Observations are made over a lifetime. Hunting peoples carefully study animal and plant life cycles, topography, seasonal changes and mineral resources. Elders speaking about landscape, climate and ecological changes are usually basing their observations on a lifetime of experience. In contrast, because much scientific research in the north is university-based, it is organized around short summer field seasons. The long-term observations included in oral accounts provide important perspectives on the questions scientists are studying. (p. 28)

Among the Nisga'a of Northern British Columbia, for example, one rarely responds to a request for information or opinion quickly—it is more respectful to consider such requests for a number of days before making a carefully considered response. Mistakes cannot be tolerated when footsteps take one where swift water rushes beneath river ice. Where a community is resident and stable, solutions to problems can be carefully preserved, refined, and re-applied. Innovation may be employed when necessary, but it is not generally taken to be a goal itself. Stories also show that when circumstances dramatically change, communities move, or people are lost or under pressure, the rate of inquiry and experimentation may be accelerated (Corsiglia & Snively, 1995).

CONTRIBUTIONS OF INDIGENOUS SCIENCE

Numerous traditional peoples' scientific and technological contributions have been incorporated in modern applied sciences such as medicine, architecture, engineering, pharmacology, agronomy, animal husbandry, fish and wildlife management, nautical design, plant breeding, and military and political science (Weatherford, 1988, 1991). In the Americas, traditional scientists developed food plants that feed some three-fifths of humanity. They also developed thousands of varieties of potatoes, grain, oilseed, squashes, and hot peppers, as well as corn, pumpkins, sunflowers, and beans. They first discovered the use of rubber, vulcanizing, and also platinum metallurgy (Weatherford, 1988, 1991). Meso-American mathematicians and astronomers used base 20 numeracy to calculate calendars more accurate than those used by Europeans at the time of contact, even after the Gregorian correction (Kidwell, 1991; Leon-Portilla, 1980). Native Americans developed highly articulated and effective approaches to grassland management (Turner, 1991) and salmon production (Pinkerton, 1989). Traditional Native American healers discovered and used quinine, Aspirin®, and ipecac (a drug still used in traumatic medicine to expel stomach contents), as well as some 500 other important drugs (Weatherford, 1988, 1991). In the Americas alone, traditional knowledge and wisdom systems sustained populations estimated at approximately 100 million (Wright, 1992), one-fifth of the world's population at the times of contact in 1492. Even today, most people do not realize that we are benefiting from the labors of Aboriginal scientists and doctors almost every time we dress, dine, travel, or visit our physicians. Suggestions that indigenous peoples cannot practice "science" turn upon narrow and restrictive definitions, old justifications of harsh expansionism, or insufficient factual data.

The Wisdom Aspect of TEK

Traditional wisdom may be thought of as an aspect of TEK that focuses on balancing human needs with environmental requirements (Bowers, 1995). In describing traditional wisdom, Corsiglia and Snively (1995) note:

> All life forms must be respected as conscious, intrinsically invaluable, and interdependent. Respecting an animal's body means honoring its spirit and using every part of an animal's body. In practical terms, traditional wisdom extends the caring relationships associated with "family" life to communities and even to the environment. We are all relations, it is wrong to exploit other life forms or take more than one's share. The deep interest our children feel in animals, plants, water, and earth should be trusted and encouraged. All creatures can be our teachers and while humans may readily affect other life forms, we need not see ourselves as superior. (p. 29)

The oral narratives of the Northwest Coast, for example, describe origins and residency in terms of Creation and the Great Flood, and they perceive a world in which humans, nature, and the supernatural are inextricably linked (Nelson, 1983). Today, as in the past, many indigenous people state that all living things—plant, animal, bird, or creatures of the sea—are endowed with a conscious spirit and therefore can present themselves in abundance or not at all (Corsiglia & Snively, 1995). Prayers were said to the spirit of the great cedar tree before felling it, that it might fall in the right direction and that its spirit would not be offended. The fisherman used many different prayers and songs to communicate with the spirit of the fish to achieve success in fishing (Emmons, 1991; Nelson, 1983; Stewart, 1977).

In *Make Prayer to the Raven*, Richard Nelson (1983) describes the Koyukon people's traditional spiritual ideology as pervaded by elements of nature. The proper role for humankind is to serve a dominant nature, in sharp contrast to the Western tradition of humankind dominating nature. The proper forms of human conduct are set forth in an elaborate code of rules and deference is shown for everything in the environment, partly through gestures of etiquette and partly through avoiding waste or excessive use. Humanity, nature, and the supernatural are not separated, but are united within a single cosmos. Hence, TEK can be thought of as the joining of detailed traditional knowledge with the values and ethics of traditional wisdom.

STRENGTHS AND LIMITATIONS ASSOCIATED WITH ORAL INFORMATION TRADITIONS

Whether attempting to conduct educational research or develop science for students, it is important to consider the strengths and limitations of oral tradition as evidence for scientific contributions and past history. Despite growing support for indigenous science, some scientists operating within Western empiricism are reluctant to accept oral information as a source of scientific knowledge for at least two reasons. First, oral cultures use information storage and retrieval systems that are substantively different from those employed in cultures that use permanent recordkeeping (Johnson, 1992); and second, indigenous oral cultural information may integrate scientific information with spiritual, mythological, and even fictional elements.

Oral tradition has been defined succinctly as "oral testimony transmitted verbally from one generation to the next or more" (Vansina, 1971). Anthropologist Cruikshank (1981) describes native oral narrative traditions in the Yukon as a distinct intellectual way of knowing (epistemology) and lists several strengths as a data source. Among those that are of interest to science educators and researchers are:

Persistence: Most aspects of indigenous cultures have changed enormously since the last century; in part, due to resource extraction (the gold rush), highways, industrialization, government programs, and schools. However, the oral traditions continue to be important to adults, particularly older people. For example, stories recorded in the Yukon in 1883 were still told by women living in the Yukon in the 1970s. The structural arrangement persists even when the details of the story vary. "This deep conservatism of Yukon oral tradition is likely to be one of its chief attractions to scientists and historians" (Cruikshank, 1981, p. 72).

Individual variation and consistency: While individual narrators may all tell different versions of one story, the women with whom Cruikshank worked were most consistent in their own versions, using similar words and phrases and insisting on the importance of "getting it right" even when retelling of stories was separated by several years.

Oral tradition as technology: Traditional narratives may contain highly technical information. Anthropologist Robin Riddington (n.d.) suggests that oral tradition is a critical adaptive strategy for hunters and gatherers, particularly in harsh environments. He argues that the conceptual ability to recreate, through language, a situation for someone who has not yet experienced it directly is a highly adaptive technology carried in the mind, rather than in the hand. Detailed descriptions of how to correctly make a caribou snare, how to make a snowshoe, how to trap specific animals, or how to find the way back home are variously embedded in stories. Accurate transmission from generation to generation becomes critical for group survival, therefore each generation is careful to get the critical aspects accurate. "This is the kind of detailed observation and technical thinking valued by scientists" (Cruikshank, 1981, p. 72).

Duration of observation: Oral traditions may provide detailed observations of natural phenomena made over a lifetime. In contrast, scientists working in laboratories, research stations, and universities are often limited to reporting on short field trips during the summer.

Absence of documentary sources: In regions where written documents date from the beginning of this century or back into the preceding century, oral tradition is a significant source of historical and ecological information. With only recently recorded observations, "scholars may dispute the validity of evidence in oral narratives, but they cannot afford to ignore it" (p. 72)

There are also limitations. Cruikshank (1991) lists some significant limitations of oral narratives as a source of evidence for those working in a Western science framework. Among those that may be of interest to science educators, Cruikshank identifies the following:

Cultural context: Traditions passed on orally begin with very different premises from Western science and cannot readily be interpreted out of context. Usually a scientist interested in a particular phenomenon will both pose a question and answer it within a Western frame of reference leading to a misinterpretation of a story.

Literary style and symbolism: Each culture has a special literary style that cannot be ignored in the analysis of narrative. Like all literature, oral narratives may seek to transform rather than accurately reflect life, and this poses problems for the scientist or historian seeking to isolate historical or scientific data. Ideally, the scientist should be skilled in all aspects of symbolic and formal narrative analysis.

Time and space perspective: A serious limitation for scientists is the extrapolation of linear time from oral narrative based on cyclical time. Most oral traditions do not contain even an internal sequence of time and would be undatable and unusable if other supporting evidence were not available. For example, events occurring over several generations may be condensed into a single generation. This limits the possibility that scientists can date scientific phenomenon on the basis of native traditions.

Quantitative data: Native resident peoples of northwest Canada do not handle quantitative data in the same manner as Western science. People may speak of "hundreds" or "thousands" of people, years, or moose when they merely mean "many." This can be most bewildering to a Western listener and limits the possibility that a scientist can date or quantify scientific phenomena on the basis of native traditions.

In summary, Cruikshank concludes that "oral tradition tends to be timeless rather than chronological, and refer to situations rather than events." Oral tradition has "a specificity of its own which puts limitations on its use." Hence, "a single tradition cannot be used by itself, but only in combination with other sources, in comparative ways."

Although cultural perspectives may make it inconvenient or difficult to incorporate traditional science examples into a Western scientific framework, science researchers and students can nonetheless learn from both the practices and the narrative stories of Native Americans. Languages, myth, and ritual generally articulate culturally and ecologically located conceptions of self in relation to others and communicate a sense of the connections which bind their communities together and to the land. Origin stories and mythologies—such as their moral stories of ancestral beings—are closely tied to place and, therefore, are not easily exportable in the same way that Western science could be exported (Bowers, 1993b; Gough & Kessen, 1992).

TRADITIONAL ECOLOGICAL KNOWLEDGE SCHOLARSHIP

As we have seen, increased appreciation for ethnoscience, ancient and contemporary, paved the way for the acceptability of the validity of traditional knowledge in a variety of fields. Fikret Berkes (Inglis, 1993) provides an overview of TEK theory and scholarship in his comprehensive article, "Traditional Ecological Knowledge in Perspective." Besides discussing the significance of TEK and comparing it with Western science, he provides the following working definition:

> TEK is a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment. Further, TEK is an attribute of societies; by and large, these are non-industrial or less technologically advanced societies, many of them indigenous or tribal. (p. 3)

Pioneering work by ecologists such as Conklin (1957) and others documented that traditional peoples such as Philippine horticulturists often possessed exceptionally detailed knowledge of local plants and animals and their natural history, recognizing in one case

1,600 plant species. Other kinds of indigenous environmental knowledge were acknowledged by scientific experts. For example, ecologist Pruitt has been using Inuit terminology for types of snow for decades, “not in any attempt to be erudite, but to aid in the precision in our speech and thoughts” because when dealing with ice phenomena and types of snow “there are no precise English words” (Pruitt, 1978).

The Yupiaq, or Eskimo people of southwest Alaska, have an extensive technology for surviving the harsh conditions of the tundra. While it is true that much of Yupiaq knowledge has been manifested most clearly in their technology, that technology, according to Kawagley and Norris-Tull (1995), did not spring out of a void. “Their inventions could not have been developed without extensive scientific study of the flow of currents in the rivers, the ebb and flow of the tides in the bays, and the feeding, sleeping, and migratory habits of fish, mammals, and birds” (Kawagley & Norris-Tull, 1995, p. 2):

> Yupiaq people have an extensive knowledge of navigation on open seas, rivers, and over snow-covered tundra. They have their own terminology for constellations and have an understanding of seasonal positioning of the constellations. They have developed a large body of knowledge about climatic and seasonal changes—knowledge about temperature changes, the behavior of ice and snow, the meanings of different cloud formations, the significance of changes in the wind direction and speed, and knowledge of air pressure. This knowledge has been crucial to survival and was essential for the development of the technological devices used in the past (and many still used today) for hunting and fishing. (p. 2)

Thus, various works showed that many indigenous groups in diverse geographical areas from the Arctic to the Amazon (e.g., Posey, 1985) have had their own systems of managing resources. Thus, the feasibility of applying TEK to contemporary resource management problems in various parts of the world was gradually recognized (Berkes, 1993; Inglis, 1993; Johannes, 1989, 1993; Johnson, 1992; Williams & Baines, 1993).

CONTRIBUTION OF TEK AND IK SCHOLARSHIP

TEK and IK scholarship is concerned with the ecological and environmental knowledge of long-resident, usually oral-culture societies. Some of the contributions of traditional ecological knowledge are[2]:

- Perceptive investigations of traditional environmental knowledge systems can provide science researchers with important biological and ecological insights (Johannes, 1993; Warren, 1997).
- Provides effective and cost effective shortcuts for researchers investigating the local resource base. Local knowledge may make it possible to survey and map in a few days what would otherwise take months, or example, soil types, plants and animal species, migration pathways, and aggregation sites (Johannes, 1993; Warren, 1991, 1997).
- Locates rare and endangered species for researchers identifying sensitive areas, such as aesthetic qualities or species diversity (Johannes, 1993).
- Helps define protected areas and can be used for natural resource management. Protected areas may be set aside to allow resident communities to continue their

[2] Adapted from the International Union of Circumpolar Nations program on Traditional Knowledge for Conservation (IUCN, 1986) and reprinted in Inglis (1992).

traditional lifestyles, with the benefits of conservation (Gadgil & Berkes, 1991; Pinkerton, 1989).

- Provides time-tested in-depth knowledge of the local area which results in more accurate environmental assessment and impact statements. People who depend on local resources for their livelihood are often able to access the true costs and benefits of development better than any evaluator from the outside. Involvement of the local peoples improves the chance of successful development (Johannes, 1993; Warren et al., 1993, 1997).

TEK and IK are of interest to the indigenous peoples from whom it originates, and is also being utilized by courts and government officials, as well as scientists. The recognition of TEK and IK globally is explicitly addressed in international agreements, including *The Convention on Biological Diversity, Agenda 21,* and *Guiding Principles on Forest.*[3] The World Resource Institute's *Global Diversity Strategy* includes as one of its ten principles for conserving biodiversity the principle that cultural diversity is closely linked to biodiversity; conversely conserving biodiversity often helps strengthen cultural integrity and values (Warren, 1997).

Convergence of Oral and Scientific Traditions in Canada

Ethnobotanists noted that there are about 550 species of plants listed in the literature as having been used in the diets of indigenous peoples of Canada (Kuhnlein & Turner, 1991). Most Aboriginal groups understood plant succession and employed fire to encourage the growth of valuable plants, foster optimum habitat conditions, and control insect pests (Ford, 1979). In British Columbia, controlled burning was practiced on southern Vancouver Island to optimize the production of edible blue camas, which grows best in an open Gary Oak meadow habitat. When controlled understory burning was practiced, the bulbs grew to the size of table potatoes. The Aboriginal management practice was outlawed by newcomer Europeans who misunderstood the practice and had very different culinary preferences and land use agendas. A century later the bulbs are the size of a small green onion and are no longer gathered (Turner, 1991). According to Turner, "the concept of genetic and ecotypic variability was obviously recognized by indigenous peoples and was a factor in food gathering" (p. 18). For example, some Pacific Coastal peoples traveled considerable distances to obtain prime cow-parsnip shoots in the spring, even though cow-parsnip could be found nearby (Kuhnlein & Turner, 1991). Most recently, yew preparations used by the Northwest Coast peoples, such as the Nisga'a, or persistent skin ulcerations have yielded taxol, which is proving effective against some forms of breast cancer.

Biologists and chemists working in field analysis acknowledge that a traditional practitioner can often detect changes in taste, water, tissues, and other substances at levels below that of contemporary testing equipment. Traditional resource harvesters near the Rattan copper-zinc mine in Northwest Manitoba have refused to eat water and eat fish and beaver from lakes which are related to the licensed discharges from the mill. These changes in taste developed over the previous 2 years. A recent field sampling program designed by the MKO and the Environmental Protection Laboratories identified sample sites and sample types on the basis of interviews with the principal resource harvesters. The field

[3] These documents, outputs of UNCED 92, or "Earth Summit" at Rio de Janeiro in June 1992 are reviewed in detail in the Scientific Panel for Sustainable Forest Practices in the Clayoquot Sound document *A Vision and Its Context: Global Context for Forest Practices in Clayoquot Sound.*

sampling techniques confirmed the significance of the 13 sampling sites suggested by an 83-year-old Cree trapper and others using the area. Work is now underway to integrate information from sources as disparate as traditional ecological monitoring with satellite imagery, modern sampling techniques, and laboratory analysis programs to manage the stewardship of the region's resources (Wavey, 1993).

The Nisga'a people of British Columbia live in the Nass Valley near Alaska. They continue to use the Nisga'a language and to preserve the culture that connects them with their river and its valley. That the Nisga'a traditional science practitioner is trained to observe nature and behave with respect is reflected in the following account, as reported by Corsiglia and Snively (1997). In 1982, a Nisga'a fisherman observed mature edible, or Dungeness crabs, marching past the dock at the mouth of the Nass River, rather than staying in the deep water of Alice Arm. Suspecting that the unusual behavior was caused by the new molybdenum mine at Alice Arm, the man conferred with others and the matter was reported to Nisga'a Tribal Council Leaders. The leaders engaged lawyers and biologists to provide official scientific knowledge and official communication about the matter. It was quickly established that the ocean floor was being affected by the heavy metal tailings with a concentration of 400 grams of suspended solids per litre, 8,000 times greater than that allowed by the Canadian government. Somehow, the company managed to get a permit that entitled them to emit an effluent that exceeded the normal toxicity standard.

We may rightly wonder at the Nisga'a fisher's ability to deduce the cause of the crab's unusual behavior. The following description of TEK as practiced among the Nisga'a is instructive:

> Among the Nisga'a, and among other aboriginal peoples, formal observation, recollection, and consideration of extraordinary natural events is taken seriously. Every spring members of some Nisga'a families still walk their salmon stream to ensure that spawning channels are clear of debris and that salmon are not obstructed in their ascent to spawning grounds. In the course of such inspection trips, Nisga'a observers traditionally use all of their senses and pay attention to important variables: what plants are in bloom, what birds are active, when specific animals are migrating and where, and so forth. In this way, traditional communities have a highly developed capacity for building up a collective data base. Any deviations from past patterns are important and noted. (p. 25)

Concerned with the multiple perils faced by their Nass River salmon, the Nisga'a have themselves implemented a salmon protection project that uses both the ancient technology and wisdom practices, as well as modern statistical methods of data analysis to provide more reliable fish counts than electronic tracking systems. The Nisga'a project, which earned a Lt. Governor's prize in British Columbia, is described and illustrated in the following account by Corsiglia and Snively (1995).

Observing that electronic fish counters can be inaccurate, the Nisga'a have instituted an ingenious fish counting system in the Nass River that combines ancient fish wheel technology with modern statistical methods. The ancient fish wheel was made of cedar wood and nettle fiber mesh, and the elongated axle of the fish wheel was fitted with three parallel vanes constructed in the form of large, flattened dip nets. The swift moving downstream current turned the wheel by exerting force against the submerged vanes, and as the companion vanes rose in turn, they gently caught and uplifted the fish as they swam upriver. As each vane rose from the horizontal, the fish slid toward wooden baffles that guided them out the side of the fish wheel and into submerged holding baskets. This technology provided the Nisga'a with an effortless fishing technique as well as a ready supply of fresh salmon.

Modern Nisga'a fishing wheels are made of aircraft aluminum and nylon mesh. Like their predecessors, these fish wheels allow fish to be captured unharmed and held in holding tanks. This enables the Nisga'a and their consulting research scientist to tag and count the fish by means of statistical analysis and projection. Returning salmon are first caught using a fishing wheel at a lower river station, held in holding tanks until tagged, measured, and released unharmed or kept for food. Fish are also tagged at an upriver fish station where the proportion of tagged fish is used to calculate returns. Reportedly, this technique provides more accurate and reliable data than that collected by electronic tracking systems (personal communication, the late Eli Gosnell, Dr. Bertram McKay, and Mr. Harry Nyce).

WORLDWIDE TRADITIONAL KNOWLEDGE AND ITS RELEVANCE TO SUSTAINABLE DEVELOPMENT

Growing worldwide acceptance among scientists and international aid agencies of indigenous knowledge is reflected in a network of 33 national and regional TEK and IK Resource Centers, so far embracing six continents, as well as the Philippines, Japan, Micronesia, and New Zealand (Healey, 1993; Warren, 1991), and a dozen more centers are in the process of becoming established (Warren, 1997).

In some of Africa's most ecologically fragile and marginalized regions, knowledge of the local ecosystem simply means survival. Famine caused by drought, deforestation, desertification, or topsoil erosion, and declining productivity are some circumstances which may have encouraged or necessitated the acceptance of innovation. Among the traditional managenent practices which encompass the individual and community wisdom and skills of African indigenous peoples, TEK scientists list the following: indigenous soil taxonomies; soil fertility; agronomic practices such as terracing, contour banding, fallowing, organic fertilizer application, crop rotation and multicropping; indigenous soil and water conservation; and anti-desertification practices (Atteh, 1989; Lalonde, 1993).

In northern Australia, it is interesting to note that white people name only two seasons—"the wet" and "the dry"—whereas Aborigines name six that are precisely defined by predictable changes in weather, tides, plant blooming and fruiting cycles, insect abundance, and the breeding cycles and migrations of fishes, mammals, and birds (Davis, 1988). According to TEK researcher Johannes (1993), the value of such information for impact assessment is obvious, but it would take years for modern researchers to assemble it using conventional means.

Although traditional pest control systems were once widely used in tropical countries, their use has been severely disturbed by the introduction of modern agro-chemicals. Dependence on expensive modern pesticides poses a potential threat to the health of traditional farmers and is often poisonous to the local ecosystem (Heeds, 1991). The earliest known mention of a poisonous plant having biopesticide properties is *Azadirachta indica*, or Indian lilac, recorded in Italian Rig Veda 2000 B.C. (Hoddy, 1991). Throughout India and Africa, traditional farmers long observed the immunity of its leaves to desert locust attack. The plant works as a repellent and antifeedant to many chewing and sucking insects in the larva or adult stages (Emsley, 1991; Heeds, 1991). Recent analysis of the neem extract determined the plant contains 20 active ingredients which makes it difficult for any insect pest to develop a resistance to them all (Hoddy, 1991). Currently, TEK researchers are working with farmers in India and Africa to develop a neem spray made from the seeds of the fruit, while over a dozen campaigns in industrialized countries are working an commercial neem products that are stable, selective, and effective as naturally occurring neem (Emsley, 1991).

Research and understanding of the nutritional vitality in the diversity of food systems developed by indigenous societies worldwide provides new knowledge and depth of understanding to contemporary dietary and medicinal patterns of indigenous cultures, as well as to our larger multicultural populations. Other areas of usefulness for information on indigenous plant foods include genetic research and development of agricultural crops. Germplasm conservation programs and databases of indigenous food are valuable resources for enhancing existing crops or for the development of new ones (Kuhnlein & Turner, 1991; Warren, 1997).

Clearly, each culture has a science, a system for adapting in an environment. The solutions are different from those of Western science, but they are by no means inferior. Although still largely untested, indigenous food plants may well have potential for nurturing an increasingly hungry and resource-starved world. Even seemingly useless plants can be rendered digestible by using Aboriginal methods of preparation. Plant identification, ways of preparation, cautions on potential toxicity, biopesticides, and the nutritional and medical benefits of specific plants are highly desired information. Clearly, the application of TEK and IK to contemporary conservation and resource management problems in various parts of the world is recognized. Teachers and students participating in wilderness programs, environmental education programs, and science education programs in general are potential beneficiaries of published knowledge on indigenous science.

TOWARDS ACKNOWLEDGING INDIGENOUS SCIENCE

There are a number of issues that make it difficult to incorporate indigenous science examples into a Western scientific framework. Chief among them is the fact that many scientists and science educators continue to view the contributions of indigenous science as "useful," but outside the realm of "real science."

At first glance, observation of the language of science, science texts, and many scientists suggest systematic racism (Aikenhead, 1993; Horseman, 1975). Analysis of the literature goes much further and gives us insights into familiar science topics such as "universalism"; science, technology, and society issues; and what it means to do in science. Of the debates which inhibit acknowledging TEK and IK as "real science," two will be articulated here: 1) the differences between a universalist and relativist position towards nature and the natural sciences; and 2) the problem among many Western scientists of recognizing traditional knowledge and wisdom as science because of its spiritual base.

UNIVERSALISM VS. CULTURAL RELATIVISM IN THE NATURAL SCIENCES

To take science seriously, according to many scientists, philosophers, and historians of science (Good, 1995a, 1995b; Gross & Levitt, 1994; Matthews, 1994; Slezak, 1994), it is necessary to assume a universal position on nature and the natural sciences. In the book *Science and Relativism,* Matthews (1994) uses the words of various scientists, including Max planck and Albert Einstein, to support the universalist position:

> The core universalist idea is that the material world ultimately judges the adequacy of our accounts of it. Scientists propose, but ultimately, after debate, negotiation and all the rest, it is the world that disposes. The character of the natural world is unrelated to human interest, culture, religion or sex. (p. 182)

Proponents of the universalists' position argue that scientists who contribute to the AAAS project (1989), *Science for All Americans,* support their views:

> Science presumes that the things and events in the universe occur in consistent patterns that are comprehensible through careful, systematic study. Scientists believe that through the use of the intellect, and with the aid of instruments that extend the senses, people can discover patterns in all of nature . . . Science also assumes that the universe is, as its name implies, a vast single system in which the basic rules are everywhere the same. (p. 25)

The National Science Education Standards (National Council, November, 1992) underline the universalist position of the natural sciences:

> Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for certainty of their proposed explanation. (p. v-166)

The world may be indifferent to Aristotle's suggestion that there is a single best answer to every question, which might be called "universally true." If proponents of universal science believe that their methodology enables them to understand the universe, they would be seeming to claim the unverifiable. In other words, all honest inquiry may make a legitimate contribution to universal science. Moreover, most proponents of indigenous and multicultural science would agree that objects and events occur in consistent patterns, but how these phenomena are interpreted is influenced by language, culture, physical conditions, and events.

A sample of statements by persons who promote a relativistic position that similarly rejects a universalist position as an underlying assumption of natural sciences follows:

> There is a need to struggle to assert the equal validity of Maori knowledge and frameworks and conversely to critically engage ideologies which reify Western knowledge (science) as being superior, more scientific, and therefore more legitimate. (Smith, 1992, p. 7)

> Traditional African science and Western science both have their positive and negative aspects. There is overlap between the two and they are not mutually exclusive. The major difficulty lies with the denial by Western science of the validity of Africa's contributions. Because every culture's way of viewing the world is different it seems probable that every culture may have developed unique strategies for doing science. Some of these may just possibly fill in the gaps in others. If the scientific knowledge of all cultures could be pooled and regarded with equal respect, the world would undoubtedly be an immeasurably richer place. (Murfin, 1994, p. 97)

> To love is not directly related to the components of Western science. Rather, it is closely related to the Japanese traditional (or indigenous) culture (Ogawa, 1986a; Okamoto & Mori, 1976) . . . We should identify what our own indigenous science is, as well as understand what Western science involves. In this context, we have investigated in recent years how we recognize and interpret "nature" in the Japanese cultural context. (Ogawa, 1989, p. 248; Ogawa & Hayashi, 1988)

Thus, discussions about the relative merit of WMS and the sciences of other cultures seem to have potential for educating students *about* science. In the words of Stanley and Brickhouse (1994), "If all students could learn how the purposes of scientific activity have varied in different cultures and historical times, and how all cultures have developed sciences to meet their needs, they can also learn that Western modern science is not universal, infallible, or unchangeable" (p. 396). This kind of critical thinking is necessary to enable students to understand how WMS is a particular way of thinking about the natural world, rooted in Western culture, and how the purposes of WMS could be changed to create future sciences that better meet the needs of diverse societies.

RECONCILING THE SPIRITUAL BASE OF TEK

A second problem of integration is that of the refusal of many scientists to recognize traditional ecological knowledge as science because of its spiritual base, which they regard as superstitious and fatalistic. What they fail to recognize is that spiritual explanations often incorporate important ecology, conservation, and sustainable development strategies (Johnson, 1992). In reference to traditional ecological knowledge, Johnson and Ruttan (1991) point out:

> Spiritual explanations often conceal functional ecological concerns and conservation strategies. Further, the spiritual aspect does not necessarily detract from the aboriginal harvester's ability to make appropriate decisions about the wise use of resources. It merely indicates that the system exists within an entirely different cultural experience and set of values, one that paints no more and no less valid a picture of reality than the one that provides its own (western) fame of reference. (Cited in Johnson, 1992, p. 13).

Johnson (1992) further asserts that "the spiritual acquisition and explanation of TEK is a fundamental component and must be promoted if the knowledge system is to survive." Essentially, criticisms of the validity and utility of indigenous science misapprehend the structure and mechanics of indigenous oral information systems. These systems do not simply assert that mythic-magical forces cause and control events. Large numbers of indigenous peoples observe, interpret, and orally report nature exhaustively. Rather than writing about their findings, they may use metaphoric stories to compress and organize important information so that it can be readily stored and accessed. In the past, when newcomers were actively marginalizing indigenous peoples, they had no inclination to access this information. However, as we have seen during recent years, the situation has changed and a very considerable number of scientists have "decoded," transcribed, and interpreted significant quantities of precise indigenous science knowledge.

The debate between Western science and advocates of indigenous science is admirably summarized in the following quote:

> Most educated people today—except for those trained in sociocultural anthropology or related disciplines—believe that traditional cultures are unscientific because they are based on magical beliefs and/or because they lack the benefit of the Western scientific method of empirical observation and experiment. Ironically, many sociocultural anthropologists also believe that the traditional cultures are unscientific. This follows from the anthropological dictum that every culture has a unique worldview. Thus, modern science, as a product of Western culture, represents but one cultural perspective, different from but no better than any other. The first group believes that Science (with a capital "S") is an invention of recent European culture. The second group professes that there can be no science (with a capital "S") because there is no Reality (with a capital "R"), only unique cultural definitions of reality. Neither perspective leaves room for TEK and modern science to join forces to the end of achieving an understanding of reality superior to both. (Hunn, cited in Williams & Baines, 1993, p. 16).

As we have seen, TEK is often revealed through stories and legends, making it difficult for non-Aboriginal people to understand. The non-Aboriginal speaker is most often unfamiliar with all of the subtleties and sophisticated terms of the Aboriginal language. Consequently, when speaking with an elder, a non-Aboriginal person may not know how to ask the proper question to obtain specialized knowledge of the ecology, medicines, and spiritual matters (Colorado, 1988; Johnson & Ruttan, 1991). When it becomes important to access TEK, local people must become directly involved in the research. This "inside" perspective is essential if the information is to be interpreted accurately (Johnson, 1992). If the goal is to integrate TEK and Western science, both First Nations peoples and Western scientists must assist in interpreting the results (Colorado, 1988; Johnson, 1992).

In the world of TEK and IK, science information may be transmitted in spiritual forms. Beyond that, for long-resident peoples, the widely held belief that all creatures are conscious may be re-stated to mean that other life forms are deserving of respect and, thus, the spiritual observation becomes a political dictum: we are simply not free to move mountains and extirpate species because of mere whims or imagined interests. At the same time, WMS appears to sympathize with certain "innovative" spiritual assumptions regarding the primacy of human interests and the legitimacy of man's dominion over nature, which trace to the beginnings of empire building in the Mediterranean Basin.

Acknowledging TEK does not mean opening doors to all and sundry. TEK is valuable precisely because it is refined over time with careful observation; it cannot arise spontaneously in modern imaginations. Thus, no itinerant creationist or messianic breatharian may arrive in a new neighborhood and spontaneously generate authentic local TEK.

Connections between respect-based wisdom and action seem to have been ubiquitous in traditional resident cultures. It is possible that traditional methodology is generalizable and that the respect-based wisdom assumptions, systems, principles, and methodologies of any one traditional culture are, in fact, very similar to the respect-based wisdom assumptions, systems, principles, and methodologies of others. The interesting possibility of the existence of such generalizability is beyond the scope of this paper.

TOWARD TAKING A CROSS-CULTURAL PERSPECTIVE TO SCIENCE EDUCATION

As discussed previously, there is a tendency in Western society to accept the evolving discoveries of WMS as our best and only possible avenue for understanding how the world functions. At the same time, Western science functions as a sub-culture of Western culture (Aikenhead, 1996, 1997; Ogawa, 1995). In this way, non-Western and minority culture students of Western science may be forced to accept Western values and assumptions about political, social, economic, and ethical priorities in the course of receiving instruction on Western science. At the same time, mainstream students can be prevented from examining important values, assumptions, and information imbedded in other cultural perspectives. Thus, students from Aboriginal cultures (as well as many mainstream students) inadvertently face a dilemma whenever they study Western science. How can science teachers enable all students to study a Western scientific way of knowing and at the same time respect and access the ideas, beliefs, and values of non-Western cultures?

In contemplating the implications of cross-cultural education, science educators have begun to explore what it means to prepare our students for life in a culturally diverse world. Should we develop a teaching approach that merely develops an appreciation for TEK and IK, or one that goes further into the implications of racism, history, and definitions, and attempts to deconstruct old prejudices. This section attempts to take into account the multidimensional cultural world of the learner and makes specific recommendations for helping students move back and forth between the science knowledge of particular cultures and the culture of WMS.

Children's Prior Beliefs and Cognitive Commitments

A growing line of investigation into children's learning in science emphasizes that children of different cultural backgrounds frequently interpret science concepts differently than the standard scientific view and that teachers need to begin instruction by determining the prior knowledge that children of Aboriginal cultures, such as the Maori in New Zealand, the Afro-Caribbean, Afro-American, Native American, and the Inuit may have about the concepts of time, life cycle, growth, death, taxonomy, food chain, energy, evolution, tidal cycle, weather, causation, and resource management (George & Glasgow, 1988, 1989; Gough & Kessen, 1992; Jegede & Okebukola, 1990, 1991; Ogawa, 1986b, 1995; Smith, 1982, 1995; Snively, 1986, 1990).

Clearly, students bring a broad range of ideas, beliefs, values, and experiences to the classroom which form a spectrum of viewpoints. Unfortunately, science educators have long assumed that only Western modern scientific knowledge was true knowledge. Smolicz and Nunan (1975) referred to this as the mythology of school science. In this context, Cobern (1996) asserts that many students will simply practice "cognitive apartheid" by walling off whatever scientific conceptual change that does take place and holding it through a form of obligation. Thus, science education as it is currently conceptualized frequently has little or no meaning for many students because "it fails to teach scientific understanding within the actual world in which people live their lives" (p. 589). In this case, Cobern (1996) is mindful of how constructivism has "elbowed aside the mythology of school science":

> Constructivism suggests that the concepts of knowledge and belief are not strictly separable (see Cobern, 1994, 1995a, 1995b), and it is through this idea that one can begin to understand how worldview directly influences conceptual development and change. The concept of worldview brings under a single umbrella the philosophical issues of epistemology and metaphysics which respectively deal with arguments that provide explanations and understandings, and the presuppositions upon which epistemological arguments are founded and delimited. (p. 591)

The argument from worldview theory is that for some students it is not that they fail to comprehend what is taught, it is simply that the concepts are either not credible or relevant. This would accomplish a break with the tacit scientific orientation of conceptual change that privileges science concepts. It would, in contrast, promote a coherence view of knowledge that recognizes the very many metaphysical orientations in which science is embedded.

We now turn our attention to a description of the relationship between culture and the subculture of science to clarify what we mean before we can examine research which suggests that a cultural perspective for science education is required for making science accessible to all students, and then conclude with a discussion of implications for practice and specific practical suggestions.

Border Crossing into the Subculture of Science

In his 1996 article, Aikenhead draws on the work of Phalen, Davidson, and Cao (1991) to provide a cultural perspective for science education that argues the need to recognize the inherent border crossings between students' lifeworld subcultures and the subcultures of science. This perspective recognizes Western science as a subculture science and conventional science teaching as an attempt at transmitting a scientific subculture to students (Cobern, 1991; Jegede, 1994, 1995; Ogawa, 1986a, 1986b, 1989; Pomeroy, 1994). Accordingly, it is important to understand that a cultural perspective for science education represents a radical shift in thinking for some educators.

Another aspect of the subculture of school science is equally important to recognize. Both Kawagley (1990) and Ogawa (1995) conclude that the culture of Western science is equally foreign to Western and non-Western students, for similar reasons. Non-Western students have acquired a traditional culture of their community that interferes with learning Western science. In the same vein, Western students have their commonsense understanding of the physical world; that is, their "traditional" science — their preconceptions — that make sense within their lifeworld subcultures. For example, Western students live in a world of sunrises and sunsets where colors are frequently adjectives rather than verbs, and where causation and gravity may not seem to exist through 6 daily hours of cartoon viewing and electronic games, such as virtual reality. Just as Western students have difficulty acquiring the culture of Western science, Aikenhead (1996) adds: "so do non-masculine students; so do humanities-oriented non-Cartesian thinking students; and so do students who are not clones of university science professors" (p. 15). Thus, within any North American or European science class, the subculture of science has borders that many students find difficult to negotiate.

An example of research undertaken with this perspective is Snively's study on children of both Native Indian background and children of Anglo-European background, and their conceptions of marine science concepts:

> Students have experienced and thought about the world, they enter learning situations with a complex cluster of ideas, beliefs, values and emotions . . . and it is the potential match between these existing cognitive commitments and the new information which determines how the student will respond to the instructional inputs. (Snively, 1986, p. 22)

Snively's study of the effects of science instruction on both native and non-native students in a small coastal community in British Columbia (1990) showed that it is possible to increase a native students' understanding of marine science concepts without altering substantially his or her preferred spiritual orientation to the seashore. This is important. "Educators need to know that it is possible to teach Western scientific concepts to native students with a preferred traditional spiritual view of the world, without changing in the sense of replacing, the students' preferred orientation. It makes sense to talk about increasing a native students' knowledge about science concepts so they can be successful in school" (p. 63). However, the focus of instruction should not be on presenting information so that children of ethnic minorities will *accept* the scientifically accepted notion of the concept, but on helping students *understand* science concepts and exploring the differences and similarities between their own beliefs and Western science concepts. At times "it makes sense to talk about changing certain alternate beliefs, but we need to be careful about changing students' culturally grounded beliefs and values. What are the ethics involved?" (p. 63).

Reforming the Science Curriculum

The fact that students bring to the classroom ideas based on prior experience and that children of different cultural backgrounds frequently interpret science concepts differently than the standard scientific view, suggested that teachers need to begin the exploration of multicultural science instruction with the prior knowledge that children bring to the classroom. Thus, teachers need to probe for and incorporate the prior beliefs of indigenous children talk about the possibility of multiple perspectives and traditions of science in a classroom that encourages mutual respect as well as appreciation for differing opinions. Cross-cultural science teachers will need a curriculum that recognizes a community's indigenous knowledge or worldview in a way that creates a need to know Western science (Cobern, 1994; Pomeroy, 1994). As such, a unit of study might include IK and TEK content along with WMS content to explore certain phenomena indepth. For example, First Nations TEK can be combined with various fields of WMS (ecology, botany, biology, medicine, and horticulture, to name a few) to give students an enriched understanding of nature in line with sustainable communities and environments (Corsiglia & Snively, 1995).

In her 1995 article, Snively outlines a five-step process for producing a TEK unit in cross-cultural science teaching. The approach Provides a general framework for exploring the two perspectives (Western science and indigenous science) while teaching about one concept or topic of interest. The process includes:

Step 1. Choose a Science Concept or Topic of Interest (e.g., 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. Research the Various Perspectives
- Research the Western modern science perspective
- Research the various indigenous perspectives and, if possible, the local TEK perspective
- Organize/process the information
- Identity similarities and differences between the two 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? (adapted from Snively, pp. 66–67)

Such an approach can begin in one large group with the teacher. Once a topic is identified, the class can be divided into small groups to research the two perspectives. At times this would lead to presenting more than one theory for explaining the phenomenon under discussion. For example, what do we know about medicinal herbs from indigenous knowledge? What do we know about medicinal herbs from modern Western science? Specifically, what do we know about the discovery of Aspirin®? We know from science textbooks that the German scientist Charles Gerhardt is credited with "discovering" in 1853 a stable form of acetylsalicylic acid, the active ingredient in Aspirin®. If ancient indigenous healers worldwide knew that white willow bark cures headaches, should science textbooks credit Hoffman with the "discovery" of Aspirin®? Who really discovered Aspirin® anyway? For the past 147 years, Gerhardt has been credited with the discovery of Aspirin®, yet only recently has WMS begun to understand "how" and "why" Aspirin® works. If Gerhardt's work was accepted as scientific, even though he couldn't answer "how" and "why" questions, how can WMS dismiss TEK and IK as "unscientific" because TEK practitioners do not address the "how" and "why" questions of WMS? What definitions do some Western scientists use to dismiss indigenous science? What reasons might some modern Western scientists and pharmaceutical companies have for denigrating indigenous knowledge? What advantages do Western scientists enjoy over indigenous healers?

Students can analyze how the Nisga'a fisherman was able to deduce the cause of the crab's unusual behaviors. What observation let the fisherman to infer the crabs were being threatened by the new molybdenum mine? As a child, how did the fisherman learn to observe? What knowledge would he have learned traveling to his family's fishing stations each year? Why did the Nisga'a Fisheries Board report the matter to lawyers and biologists to provide "official scientific knowledge and official communication?" Should the fisherman's knowledge alone have been sufficient to close the mine? Additionally, how might the 83-year-old Cree trapper have detected changes in taste, water, tissue, and other substances at levels below that of contemporary WMS testing equipment?

Students can also analyze how both Western modern science and indigenous science use observation and inquiry to obtain knowledge. For example, what can we learn from the ancient Nisga'a fish wheel? What "science principles" underpin fish wheel technology? How might the Nisga'a have invented fish wheel technology? Did they observe, infer, question, had build models? Why does combining ancient fish wheel technology with modern statistical analysis provide more accurate and reliable data than that collected by electronic tracking systems? What are the advantages of combining the two perspectives? Do science and technology interact, or did technology simply precede the advent of modern Western science in the nineteenth century? When did science begin? What is the nature of science and scientific thinking? How can Nisga'a use of the wheel be contrasted with its use by expansionists?

Although the two perspectives may interpret the world differently, students should also see that the two overlap and can reinforce one another. Discussion should stress similarities as well as differences, areas where IK helps fill the gap where knowledge in WMS is lacking, and vice versa. The study of science would be framed by questions that might include: What are the origins and consequences of our practice of viewing Western science as superior to other forms of knowing? Where did we get the ideas that Western science is the only "true" science? What are the consequences? Who were the thinkers and the historians who influenced our way of thinking? What might be the benefits of acknowledging the contributions of traditional knowledge and wisdom? The point is not to establish that one form of science is more relevant than another, but to develop scientific thinking and to ground the study of science within the actual world in which students live their lives.

Science textbooks need to provide examples of the numerous contributions of IK and TEK to prove the fact that traditional knowledge and wisdom enable indigenous people to live in environments over long periods of time. Similarly, examples from the history of WMS can be used to illustrate how the purposes, theories, and methodologies of WMS have changed and do continue to change. Current examples like the fish wheel can be used to illustrate how a synthesis of both WMS and IK can work together to solve problems associated with resource management and sustainability issues. Science textbooks and teaching materials need to provide examples of the strengths and limitations of Western science (as well as the strengths and limitations of traditional science), and opportunities for the student to examine the part of the culture under consideration in terms of futuristic considerations.

These changes in science education programs would be equally important for mainstream students. According to Snively, 1995:

> The introduction of aboriginal examples adds interest and excitement to the science classroom. All students need to identify and debate the strengths and limitations of different approaches in order to explore how others experience the world, and broaden their understanding of the nature of science. A critical approach to teaching science can be used to help confront and eliminate racism, ignorance, stereotyping, prejudice, and feelings of alienation. All students need to be encouraged to examine their own taken-for-granted assumptions and to distinguish between those that reflect perfectly natural and appropriate cultural preferences and those that are rooted in misinformation or an unwillingness to allow for the existence of alternative perspectives. (p. 68)

Discussions of differences in the ways in which societies view plants and animals and develop resources, and the reasons why they do so, establishes a suitable base for discussions of environment, appropriate technology, justice, and sustainable societies. As well, science education must emphasize the relationships between science and technology and the culture, values, and decision-making processes of the society within which we operate. As “outsiders” trying to make sense of a society continually being shaped and reshaped by science and technology, students and future practitioners need more from science instruction than an ever increasing quantity of scientific facts and concepts. Science education must help all students understand how science relates to action.

CONNECTING WITH TRADITIONAL ECOLOGICAL KNOWLEDGE AND WISDOM

Although some of us may feel unquestioned attachment to our current approaches to agriculture, industry, trade, transportation, technology, resource management, and ethics, we cannot know where these relatively new experiments may take us. TEK and IK enable us to connect with promising time-proven strategies and question cultural beliefs that appear to be associated with some of our recent problematic activities. We now know that two to three millennia of removing entire forests, and more recently mining the ocean for food and stripping away natural sod from grassland, has contributed significantly to worldwide erosion, desertification, loss of biodiversity, and famine. It becomes important to recognize the magnitude of problems caused by our incomplete appreciation of the complexity of the biosphere and the scope of indigenous knowledge. Unwillingness to recognize indigenous knowledge as “science” skews the historical record; undermines objectivity in Aboriginal, multicultural, and mainstream education; and seriously restricts approaches to some of our most vexatious and debilitating environmental, science-technology, and socio-economic problems.

In our controversies over the philosophy of science and limiting definitions of science and universalism, we have failed to take seriously the question: How is science related to ethics and wisdom? Indeed, the genius of indigenous science is its characteristic appreciation and respect for nature and all its living creatures. It is conceivable that we may begin again to value our abilities to understand and manage the problems associated with life, home places, and the planet. Who knows what circumstances lie ahead or what strategies may be required for resolving environmental, technological and societal, and resource management problems? Indigenous science proves that we are not doomed to live on the ragged edge of uncertainty—we have respectable antecedents and can make promising connections with long traditions of time-proven knowledge and wisdom—as befits a species that calls itself "wisdom man" or *homo sapiens.*

REFERENCES

AAAS. (1989). Science for all Americans. Washington, DC: American Association for the Advancement of Science.

Aikenhead, G. (1993). Forward: Multicultural issues and perspectives on science education. Science Education, 77, 659–660.

Aikenhead, G. (1995). Towards a first nations cross-cultural science and technology curriculum for economic development, environmental responsibility, and cultural survival. Paper presented at the International Organization for Science and Technology Education Conference, Edmonton, Alberta.

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

Aikenhead, G. (1997). Towards a first nations cross-cultural science and technology curriculum. Science Education, 81, 217–238.

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

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.

Berkes, F., & MacKenzie, M. (1978). Cree fish names from eastern James Bay, Quebec. Arctic, 31, 489–495.

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: Boreal Institute for Northern Studies, University of Alberta.

Berkes, F. (1993). Traditional ecological knowledge in perspective. In J. T. Inglis (Ed.), Traditional ecological knowledge: Concepts and cases (pp. 1–9). Ottawa, Ontario: International Development Research Centre.

Bowers, C. A. (1993a). Critical essays on education, modernity, and the recovery of the ecological imperative. New York: Teachers College Press.

Bowers, C. A. (1993b). Education, cultural myths, and the ecological crisis. New York: State University of New York Press.

Bowers, C. A. (1995). Educating for an Ecologically Sustainable Culture. New York: State University of New York Press.

Boyd, R., Gasper, P., & Trout, J. D. (Eds.) (1991). The philosophy of science (pp. 247–260). Cambridge: The MIT Press.

British Columbia. (1995, March). First nations perspectives relating to forest practices standards in Clayoquot Sound. Clayoquot Sound Scientific Panel, Victoria, British Columbia.

Christie, M. J. (1991). Aboriginal science for the ecologically sustainable future. Australian Science Teachers Journal, 37, 26–31.

Cobern, W. (1991). Worldview theory and science education research (NARST Monograph No. 3), Manhattan, K.S.: National Association for Research in Science Teaching.
Cobern, W. (1994). Point: Belief, understanding, and the teaching of evolution. Journal of Research in Science Teaching, 31, 583–590.
Cobern, W. (1995a). Belief and knowledge: Unnecessary conflict in the science classroom. In F. Finley (Ed.), Proceedings of the history and philosophy of science and science teaching, Vol. 1, (pp. 222–232). Minneapolis, MN: HPSST.
Cobern, W. (1995b). Science education as an exercise in foreign affairs. Science & Education, 4, 287–302.
Cobern, W. (1996). Worldview theory and conceptual change in science education. Science Education, 80, 579–610.
Colorado, P. (1988). Bridging native and western science. Convergence, 21, 49–58.
Conklin, H. C. (1957). Hanunoo agriculture. A report on an integral system of shifting cultivation in the Philippines. Forestry Development paper No. 5. FAO Rome: Food & Agricultural Organization.
Corsiglia, J., & Snively, G. (1995). Global lessons from the traditional science of long-resident peoples. In G. Snively & A. MacKinnon (Eds.), Thinking globally about mathematics and science education (pp. 25–51). Vancouver: University of British Columbia, Research and Development Group.
Corsiglia, J., & Snively, G. (1997). Knowing home: Nisga'a traditional knowledge and wisdom improve environmental decision-making. Alternatives Journal, 32, 22–27.
Cruikshank, J. (1981). Legend and landscape: Convergence of oral and scientific traditions in the Yukon Territory. Arctic Anthology, 18, 67–93.
Cruikshank, J. (1991). Reading voices: Oral and written interpretations of the Yukon's past. Vancouver, British Columbia: Douglas and McIntyre.
Davis, S. (1988). Aboriginal tenure of the sea in Northern Arnhem Land. In G. Gray & L. Zann (Eds.), Traditional knowledge of the marine environment of Northern Australia. Great Barrier Reef Marine Park Authority, Workshop Series No. 8.
Duschl, R. (1994). Research on the history and philosophy of science. In D. Gabel (Ed.), Handbook of research on science teaching and training (pp. 443–465). New York: MacMillan.
Elkana, Y. (1981). A programmatic attempt at an anthropology of knowledge. In E. Mendelshohn & Y. Elkana (Eds.), Science and culture: Anthropological and historical studies of the sciences (pp. 1–77). Dordrecht, The Netherlands: Reidel.
Emmons, G. (1991). The Tlingit Indians. Vancouver, British Columbia: Douglas & McIntyre.
Emsley, J. (1991). Piecing together a safer insecticide. New Scientist, 132, 24.
Ford, R. (1979). The science of Native Americans. In Yearbook of Science and the Future (pp. 206–223). Chicago: Encyclopedia Britannica.
Gadgil, M., & Berkes, F. (1991). Traditional resource management systems. Resource Management and Optimization, 18, 127–141.
George, J., & Glasgow, J. (1988). Street science and conventional science in the West Indies. Studies in Science Education, 15, 109–118.
George, J., & Glasgow, J. (1989). Some cultural implications of teaching towards common syllabi in science: A case study from the Caribbean. School Science Review, 71, 115–123.
Good, R. (1995a). Comments on multicultural science education. Science Education, 79, 335–336.
Good, R. (1995b). Taking science seriously. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.
Gosnell, E. (1977). Nisga'a elder (personal communication).
Gross, P., & Levitt, N. (1994). Higher superstition: The academic left and its quarrels with science. Baltimore, MD: John Hopkins University Press.
Gough, N., & Kessen, K. (1992, April). Body and narrative as cultural test. Toward a curriculum of continuity and connection. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.
Hacking, I. (1991). Experimentation and scientific realism. In R. Boyd, et al. (Eds.), The philosophy of science. Cambridge, MA: MIT Press.

Hardesty, D. L. (1977). Ecological anthropology. New York: Wiley.
Healey, C. (1993). The significance and application of TEK. In N. J. Williams & G. Baines (Eds.), Traditional Ecological Knowledge (pp. 21–26). Canberra: Center for Resource and Environmental Studies, Australia National University.
Heeds, A. (1991). Botanical pesticides. Alternatives, 18, 6–8
Hoddy, E. (1991). Nature's bitter boon: The neem tree—A substitute for pesticides. Development and Communication, 5, 29–30.
Hodson, D. (1993). In search of a rationale for multicultural science education. Science Education, 77, 685–711.
Horseman, R. (1975). Scientific racism and the American Indian in the mid-nineteenth century. American Quarterly, 27, 152–167.
Hunn, E. (1993). The ethnobiological foundation for traditional ecological knowledge. In N. J. William & G. Baines (Eds.), Traditional ecological knowledge (pp. 16–19). Canberra: Center for Resource and Environmental Studies, Australian National University.
Inglish, J. T. (Ed.). (1993). Traditional ecological knowledge: Concepts and cases. Ottawa, Ontario: International Program on Traditional Ecological Knowledge, International Development Research Centre.
IUCN. (1986). Tradition, conservation and development. Occasional Newsletter of the Commission on Ecology's Working Group on Traditional Ecological Knowledge, No. 4, Gland, Switzerland.
Jegede, O. (1994). African cultural perspective and the teaching of science. In J. Solomon & G. Aikenhead (Eds.), STS Education: International perspectives on reform (pp. 120–130). New York: Teachers College Press.
Jegede, O. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics education in Africa. Studies in Science Education, 25, 97–137.
Jegede, O., & Okebukola, P. A. (1990). The relationship between African traditional cosmology and students' acquisition of a science process skill. International Journal of Science Education, 12, 37–47.
Jegede, O. J., & Okebukola, P. A. (1991). The effect of instruction on socio-cultural beliefs hindering the learning of science. Journal of Research in Science Education, 28, 275–285.
Johannes, R. E. (Ed.). (1989). Traditional ecological knowledge: A collection of essays. Gland, Switzerland and Cambridge, UK: IUCN.
Johannes, R. E. (1993). Integrating traditional ecological knowledge and management with environmental impact assessment. In J. Inglis (Ed.), Traditional ecological knowledge: Concepts and cases (pp. 33–41). Ottawa: International Development Research Center, Canadian Museum of Nature.
Johnson, M. (Ed.). (1992). Lore: Capturing traditional environmental knowledge. Ottawa, Ontario: Dene Cultural Institute, International Development Research Center.
Johnson, M., & Ruttan, R. (1991). Dene traditional environmental knowledge: Pilot project. Hay River, NWT: Dene Cultural Institute.
Kawagley, A. (1990). Yupiaq ways of knowing. Canadian Journal of Native Education, 17, 5–17.
Kawagley, A., & Norris-Tull, D. (1995). Incorporation of the worldviews of indigenous cultures: A dilemma in the practice and teaching of western science. Paper presented to the Third International History, Philosophy, and Science Teaching Conference, Minneapolis, MN.
Kidwell, C. S. (1991). Systems of knowledge. In A. M. Josephy, Jr. (Ed.), America in 1492 (pp. 369–403). New York: Alfred A. Knops.
Kuhnlein, H., & Turner, N. (1991). Traditional plant foods of Canadian indigenous peoples. Philadelphia, PA: Gordon and Breach Science Publishers.
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, Ontario: International Development Research Center, Canadian Museum of Nature.
Leon-Portilla, M. (1980). Native Meso American spirituality (pp. 17–18). Toronto, Ontario: Paulist Press.
Matthews, M. (1994). Science teaching: The role of history and philosophy in science. New York: Routlege.

McKay, B. (1979). Nisga'a elder (personal communication).
Murfin, Brian. (1994). African science, African and African-American scientists and the school science curriculum. School Science and Mathematics, 94, 96–103.
National Committee for Science Education Standards and Assessment. (1992, October). Discussion document prepared for the AAA's forum for school science, October 30–31, 1992.
Nelson, R. K. (1983). Make prayers to the raven: A Koyukon view of the northern forest (pp. 200–237). Chicago: University of Chicago Press.
Nyce, H. (1980). Nisga's elder (personal communication).
Ogawa, M. (1986a). A preliminary study on a key concept "nature" involved in science education. Bulletin of the Faculty of Education, Ibaraki University (Educational Sciences), 35, 1–8. In Japanese with English abstract.
Ogawa, M. (1986b). Towards a new rationale of science education in a non-western society. European Journal of Science Education, 8, 113–119.
Ogawa, M. (1989). Beyond the tacit framework of "science" and "science education" among science educators. International Journal of Science Education, 11, 247–250.
Ogawa, M. (1995). Science education in a multiscience perspective. Science Education, 79, 593–593.
Ogawa, M., & Hayashi, M. (1988). Studies on the methods for extracting traditional views of nature in the context of science education. Bulletin of the Faculty of Education, Ibaraki University (Educational Sciences), 37, 41–50.
Okamoto, M., & Mori, K. (1976). The influence of Japanese traditional view of nature on science education: A study on enactment of "The Principal Point of Science Study." Kagakushi Kenkyu (Journal of History of Science Japan), Series II, Vol. 15, No. 118, pp. 98–101. In Japanese.
Phalen, P., Davidson, A., & Cao, H. (1991). Students' multiple worlds: Negotiating the boundaries of family, peer, and school cultures. Anthropology and Education Quarterly, 22, 224–250.
Pinkerton, E. (Ed.). (1989). Co-operative management of local fisheries: New directions for improved management and community development. Vancouver: University of British Columbia Press.
Pomeroy, D. (1994). Science education and cultural diversity: Mapping the field. Studies in Science Education, 24, 49–73.
Pruitt, Jr. W. O. (1978). Boreal Ecology. London: Edward Arnolt.
Posey, D. A. (1985). Indigenous management of tropical forest ecosystems: The case of the Kayapo Indians of the Brazilian Amazon. Agroforestry Systems, 3, 139–158.
Rose, H. (1994). The two-way street: Reforming science education and transforming masculine science. In J. Soloman & G. Aikenhead (Eds.), STS education: International perspectives on reform (pp. 155–166) New York: Teachers College Press.
Simonelli, R. (1994). Sustainable science: A look at science through an engineering model to a science model of experimentation. Bulletin of Science, Technology & Society, 14, 1–12.
Slezak, P. (1994). Sociology of scientific knowledge and scientific education: Part 1. Science and Education, 3, 265–294.
Smith, G. (1992). Kura Kaupapa Maori schooling: Implications for the teaching of science in New Zealand. Unpublished paper, Education Department, University of Auckland.
Smith, M. (1982). Science for the native oriented classroom. Journal of American Indian Education, 21, 13–14.
Smith, M. (1995). Scientific knowledge and cultural knowledge in the classroom. Paper presented to the Canadian Society for the Study of Science Education at Brock University, St. Catherines, Ontario.
Smolicz, J. J., & Nunan, E. E. (1975). The philosophical and sociological foundations of science education: The demythologizing of school science. Studies in Science Education, 2, 101–143.
Snively, G. (1986). Sea of Images: A study of the relationships amongst the students' orientations, beliefs, and science instruction. Unpublished Ed.D. dissertation, University of British Columbia, Vancouver.
Snively, G. (1990). Traditional Native Indian beliefs, cultural values, and science instruction. Canadian Journal of Native Education, 17, 44–59.
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 edu-

cation (pp. 53–75). Vancouver: University of British Columbia, Research and Development Group.
Stanley, W., & Brickhouse, N. (1994). Multiculturalism, universalism, and science education. Science Education, 78, 387–398.
Stewart, H. (1977). Indian fishing. North Vancouver: J. J. Douglas.
Turner N. (1991). Burning mountain sides for better crops: Aboriginal landscape burning in British Columbia. Archeology in Montana, 32, 57–74.
Vansina, J. (1971). Once upon a time: Oral traditions as history in Africa. Daedalus, 100, 442–468.
Warren, D. M. (1991). Using indigenous knowledge in agricultural development. World Bank Discussion Paper No. 127, Washington: The World Bank.
Warren, D. M., Brokensha, D., & Slikkerveer, L. J. (Eds.). (1993). Indigenous knowledge systems: The cultural dimension of development. London: Kegan Paul International.
Warren, M. (1997). Conservation of indigenous knowledge serves conservation of biodiversity. Alternatives Journal, 23, 26–27.
Wavey, R. (1993). International workshop on indigenous knowledge and community-based resource management: Keynote address. In J. T. Inglis (Ed.), Traditional ecological knowledge: Concepts and cases (pp. 11–16). Ottawa, Ontario International Development Research Centre.
Weatherford, J. (1988). Indian givers, how the Indians of the Americas transformed the world. Toronto: Random House.
Weatherford, J. (1991). Native roots, how the Indians enriched America. Toronto: Random House.
Williams, N. M., & Baines, G. (Eds.). (1993). Traditional ecological knowledge: Wisdom for sustainable development. Canberra: Center for Resource and Environmental Studies, Australian National University.
Wolpert, L. (1993). The unnatural nature of science. Cambridge, MA: Harvard University Press.
Wright, R. (1992). Stolen continents: The new world through Indian eyes since 1492. Toronto: Viking Press.