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Field-Based Education and Indigenous Knowledge: Essential Components of Geoscience Education for Native American Communities

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ABSTRACT: The purpose of this study is to propose a framework drawing on theoretical and empirical science education research that explains the common prominent field-based components of the handful of persistent and successful Earth science education programs designed for indigenous communities in North America. These programs are primarily designed for adult learners, either in a postsecondary or in a technical education setting and all include active collaboration between local indigenous communities and geoscientists from nearby universities. Successful Earth science curricula for indigenous learners share in common an explicit emphasis on outdoor education, a place and problem-based structure, and the explicit inclusion of traditional indigenous knowledge in the instruction. Programs sharing this basic design have proven successful and popular for a wide range of indigenous cultures across North America. We present an analysis of common field-based elements to yield insight into indigenous Earth science education. We provide an explanation for the success of this design based in research on field-based learning, Native American learning styles research, and theoretical and empirical research into the nature and structure of

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indigenous knowledge. We also provide future research directions that can test and further refine our understanding of best practices in indigenous Earth science education. *Sci Ed*, 1–18, 2004

RESERVATION REALITIES AND EARTH SCIENCE: CLEAR NEEDS, FEW RESOURCES

In recent years, the Earth sciences community worldwide has come to understand the need to increase gender, racial, and ethnic diversity in academic ranks and to simultaneously find ways for diverse public communities to gain a better understanding of basic geoscience in order to increase the quality of public policy decisions that are made relating to the Earth and environmental sciences (American Geophysical Union [AGU], 2003; Karsten, 2003; Marcus, 2002; Semken & Morgan, 1997). This has been accompanied in the United States by support for these efforts by funding agencies that traditionally support geoscience research and graduate training, notably the National Science Foundation. This welcome attention to diversity issues from research scientists and funding agencies has led to increased support for geoscience education research into the nature and structure of cultural barriers to entry for traditionally underrepresented groups.

Many ethnic and cultural groups are persistently underrepresented in Earth science, with the situation being only marginally better in environmental and agricultural sciences(NSF, 1999, 2000; Zappo, 1998). In the North American context, Native Americans and First Nations peoples are of particular concern for Earth and environmental science educators as an underrepresented group because of the large land base managed by tribal authorities, coupled with the simultaneous lack of professional scientific expertise within reservation communities themselves (Bevier et al., 1997; Riggs & Marsh, 1998; Riggs & Semken, 2001). Despite the great richness of native empirical knowledge related to environmental stewardship and the Earth (e.g. Kawagley, Norris-Tull, & Norris-Tull, 1998; Martinez, 1996; Suzuki & Knudtson, 1992), the lack of on-reservation, geoscientific expertise often results in tribal communities being forced to rely on outside expertise when dealing with the technical issues relating to the Earth sciences discussed in geotechnical reports, environmental impact statements, etc.

The values and priorities of land use, resource management, and environmental stewardship of the dominant culture often do not mesh well with the indigenous knowledge and values of a native community. While non-native geoscience professionals hired by tribes are usually thorough in their work and sincere in their desire to help tribes make good resource decisions, the lack of a shared cultural perspective places both the external consultants and tribes at a disadvantage in achieving clear and open communication. Practical issues also commonly arise regarding the sensitive and proprietary nature of the data collected by non-native consultants and scientists on tribal land because of the clear historical link between the work done by these professionals, the reporting of collected data to either the scientific community or to corporate and governmental entities, and to the ultimate dispossession of native people of these natural resources (Churchill & LaDuke, 1992; Deloria, 1995; Guerrero, 1992; Karr, 2000). Sometimes this history complicates the building of cooperative relationships between scientists, educators, and tribes.

GENERAL ISSUES IN CROSS-CULTURAL SCIENCE EDUCATION FOR INDIGENOUS PEOPLES

Compounding the existing difficulties discussed earlier, science education in native communities is made harder still by the fact that teaching and research styles common to much of science are not automatically compatible with much of the paradigms and institutions of indigenous cultures. This is one of the key reasons cited for the underrepresentation of Native Americans in the sciences in general (Nelson-Barber & Estrin, 1995). There is often a specific conflict with the perception of the role of the scientist as a controller, manipulator, or exploiter of the natural world (Murray, 1997; Riggs, 1998). All of these reasons can set up internal conflicts for indigenous people (and other minority cultural groups as well) in science classrooms and with scientific work in general as they struggle with "cultural border crossings" (Aikenhead, 1996, 1997), which are the transitions between the daily worldview and lifeways of indigenous peoples and the culture and norms of science. The nature and severity of these border crossings are a function of both the learners themselves (Aikenhead, 2001b; Costa, 1995) and the curricula and teachers they encounter. The wide range of cognitive and behavioral strategies employed by indigenous and other minority students to negotiate and mitigate the relative level of assimilation or acculturation they experience in learning science has been studied in detail by Aikenhead and Jegede (1999).

These differences in ways of knowing among Native American and other indigenous students can lead to both significant problems and opportunities in the approach to community and classroom science education, especially in the context of Earth systems science where the situation is frequently complicated by history and politics. However, the opportunities for combining traditional ways of knowing and scientific knowledge into a continuous pedagogical approach for students are numerous in the Earth sciences, and we maintain that these opportunities and potential benefits are sufficient to outweigh the problems. Warren and coauthors (2001) show that successful linkages can be made between science and the everyday world of minority students provided that science is carefully presented in the classroom as just another portion of students' everyday lives rather than some foreign body of thought and knowledge that is fundamentally separate. They argue that the key is that science must be shown to be congruent with common ways of logical thinking that students recognize from within their own cultures, using everyday experience to illuminate and provide context for scientific instruction.

This paper illustrates that Earth system science provides many opportunities for providing linkages between the everyday lives of students and the world of science, and that the key to finding the right connections between the daily lives and preferred learning styles of indigenous people and science is in identifying and understanding the indigenous Earth science knowledge that still lives on within tribal communities. We proceed to adapt a theoretical and empirical model for successful field-based geoscience education in order to explain the consistent success of the field-based components of indigenous geoscience education, drawing on elements present in most indigenous cultures that lead to a possible predisposition for field-based learning environments. The final section of this paper deals with the complexities of knowledge within indigenous cultures, and how understanding the nature and structure of indigenous knowledge along with the history and current political and economic situation of a tribal population leads to more informed educational decisions. The goal is to build an understanding of the elements of the local environment that can provide the best connections to the geosciences for indigenous communities, and to find content areas and pedagogical approaches that will spark the most interest and be of the most utility to the communities with whom we work.

EARTH SCIENCE EDUCATION AND THE EXPLORATION OF ETHNOGEOSCIENCE

There have been a number of positive developments in North America in bridging the gaps between indigenous groups, scientists, and educators in the Earth and environmental sciences from the dominant culture. A significant number of geoscience education research and outreach projects in recent years have worked at the interface of indigenous and scientific knowledge to find common ground in empirical knowledge and to find ways for indigenous communities to most effectively manage the merging of indigenous and scientific knowledge. This has resulted in a wide variety of regionally adapted Earth and environmental science classroom curricula and field courses for Native Americans and First Nations people. Semken and Morgan (1997), for example, working in the Navajo nation have successfully developed an integrated Earth science curriculum for Diné College, the tribal college of the Navajo nation, and for professional development of K-12 teachers on the Navajo reservation (Dubiel, Hasiotis, & Semken, 1997) that incorporates a Navajo framework for understanding nature and Navajo language into a learning structure where the major themes of Earth science are related directly to the natural processes embodied in a traditional Navajo understanding of the Earth. The curriculum also incorporates traditional pedagogy and indigenous empirical Earth science knowledge where possible, all with the goal of reducing the magnitude of the border crossings required by students. The work at Diné College is particularly advanced relative to other indigenous Earth science curriculum development projects, largely because the mission of the college explicitly instructs faculty to build in Navajo indigenous knowledge wherever possible and to strive to maintain the cultural integrity of the Navajo nation. Because of the large size of the Navajo nation and intact native culture and language on the reservation, there is also little doubt as to what is and is not indigenous knowledge, giving science faculty a distinct advantage in identifying empirical knowledge that can be successfully built into science courses. Similar projects at various stages of maturity and with differing goals and audiences now exist scattered throughout the United States and Canada (e.g. Bevier et al., 1997; Murray, 1997; Riggs & Riggs, 2003). The hallmark of such efforts is a focus on the particular needs, environment, experiences, and learning styles of local tribal groups.

THE INDIGENOUS EARTH SCIENCES PROJECT: A SOUTHERN CALIFORNIA EXAMPLE

Southern California Native Americans have not historically benefited from much Earth science curriculum adaptation work, largely because of the relatively geographically and culturally fragmented nature of the surviving native population. Despite the fact that California has the largest native population of any state in the United States, the individual tribal groups are relatively small (usually under 2000 residents, frequently under 200) and were historically located in relatively remote areas, although today recent suburban development has expanded outwards to near tribal lands. The small and scattered structure of tribal bands today is partially due to the consequences of colonization and the removal of tribes from arable land and the lack of firmly established reservation boundaries or ratified treaties when California gained statehood (Shipek, 1988). Much of this current distribution of peoples is also due to the fact that California natives tended traditionally to settle in extended family groups, often within geographically bounded regions, such as watersheds, valleys, desert basins, or mountainous areas (Bean, 1972). As a result, the indigenous Earth and environmental science knowledge contained within the traditions of separated but culturally related tribal groups is potentially extensive, as California natives were not generally nomadic, but lived in geographically bounded and distinct areas and developed a deep familiarity with geologic, surficial, and environmental processes and features. The current indigenous cultural landscape of southern California includes diverse reservation-based communities, multiple mixed-ethnicity urban groups, and some indigenous communities that do not currently have reservations. The native landscape of southern California, northern Mexico, and western

Arizona is amazingly diverse, with many language groups and native cultural heritages represented.

The modern challenges for the 32 federally recognized, reservation-based communities in the southern third of California today are related to the extensive population and development pressures in the region, specifically those related to water rights, environmental degradation, landfills, and mineral resource development (e.g. Karr, 2000). Adding to the problems, most tribal communities do not have their own full-size schools because of their small size. They therefore generally rely on the mainstream public school system, supplemented by small tribal learning centers that offer limited culturally specific programs. Tribes in this region are also interested in increasing their geoscientific literacy and education within their communities at all educational levels, allowing fruitful and ongoing collaborations with outside educators and scientists.

The Indigenous Earth Sciences Project (Riggs & Marsh, 1998) was founded in response to these needs, and with the explicit recognition of the role of the potential of indigenous knowledge among southern California Native American groups concerning the Earth and the natural world. Furthermore, because of the active inquiry and field-based components that are common to Earth and environmental science education, the IESP was founded to explore the proposition that the geosciences should offer a more culturally compatible entry into science for Native American students. The project continues today through activities at a variety of educational levels in cooperation with the learning centers and tribal environmental offices on a few partnering reservations in the San Diego region. We are actively working to determine what of the potential indigenous knowledge remains intact and how it can be incorporated to help raise the scientific expertise on reservations. To simplify the cultural environment in which we attempt to apply the framework described above for identifying indigenous knowledge, and to maximize the effect of the programs we do develop, most of our work has recently been concentrated within the Luiseño, Cahuilla, and Cupeño communities of the San Luis Rey river watershed in northern San Diego county. We have to date uncovered a few key elements of successful Earth and environmental science education in the local indigenous context, and have also begun to identify the working elements of surviving indigenous knowledge. These emerging discoveries and their educational potential are discussed later.

THE CENTRAL IMPORTANCE OF FIELD-BASED (OUTDOOR) EDUCATION IN NATIVE AMERICAN EARTH SCIENCE EDUCATION

The history of the programs operated by the author's research group with local Native American communities and other programs operating across North America underscore the importance of the outdoor, field-based teaching and learning environment as central to the success of these programs. While Earth science education for the majority population often has a significant classroom and laboratory component that is only lightly supplemented by field work, programs offered within Native American and First Nations communities typically rely on the field environment to a significantly greater degree with correspondingly less emphasis on classroom and laboratory work. The predominance of this instructional design in these programs, and the simultaneous success and endurance of these programs, especially in attracting and retaining community members into the programs, is of note and can be understood in terms of research on field-based learning in the Earth sciences.

A review of the published geoscience education literature on Earth science curricula for indigenous students (Aikenhead, 2001a; Bevier et al., 1997; Murray, 1997; Riggs &

Semken, 2001; Semken & Morgan, 1997) shows that each of these programs share three common qualities and features:

1. Major emphasis on place-based curricula, emphasizing experiential, outdoor learning in familiar environments within the traditional homelands of the indigenous groups
2. Inclusion of relevant indigenous scientific knowledge wherever possible and appropriate
3. Explicit involvement and cooperation of indigenous community members, elders, and educators in the design of the content, location, and delivery of curricula and programs

A session involving many of these authors and others at the international Geoscience Education IV meeting in 2003 in Calgary, Canada, shows that the same curricular elements presented in the published reports referenced earlier still persist years later in ongoing work that successfully serves indigenous communities. These three items are central and enduring themes in indigenous Earth science education that deserve further examination in the context of science education and indigenous education.

Much attention has been paid to the last factor on the preceding list, mainly because without complete community involvement, in-community science education programs stand little chance of community acceptance or success. Indeed without total community involvement any educational program or researcher will not even typically gain access to native communities. To some extent this guarantees and ensures the involvement and inclusion of the second factor on this list, indigenous knowledge, but as will be discussed later, this is not always a simple thing to identify and incorporate especially in communities that have suffered a loss of native language and cultural continuity due to colonization. This issue is addressed in the last sections of this paper.

However, little attention to date has been paid to the recurring appearance of field-based education as central to Earth and environmental science education in an indigenous context. We propose that the persistent recurrence and success of this teaching environment in these programs can be explained by applying the empirical and theoretical work of Orion and coworkers (Kempa & Orion, 1996; Orion, 1993, 2003; Orion & Hofstein, 1994) to Native American and First nations learners.

NOVELTY SPACE IN AN INDIGENOUS EDUCATIONAL CONTEXT

The framework developed and tested by Orion and coworkers shows that for the outdoor learning environment to be a truly effective educational environment and for field trips to succeed at being more than a social experience for students or a day free of regular classroom work, teachers and curriculum designers must deliberately reduce Novelty Space, or the combined effects of geographic, psychological, and cognitive novelty presented by the field learning environment. Figure 1 shows a graphical portrayal of this concept. None of the three factors identified by Orion and coworkers are fully independent of the others, nor are the boundaries between them well defined. The Novelty Space construct merely serves to identify continuously interacting elements of a system that, when properly managed by educators, serves to enhance learning in a field-based setting. Only by minimizing the total space encompassed by all three elements of novelty space can students reach a point of optimum preparation, personal comfort, and maximum learning in the field. Orion and Hofstein (1994) systematically tested groups of Israeli high school students who were following the Earth science "major" or track and found that those who learned most effectively in the field environment had been given what they called the "Optimum Concrete

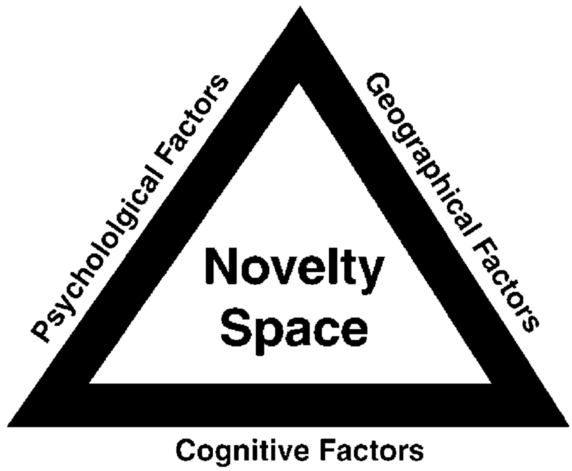

Figure 1. Graphical representation of Novelty Space; after those presented by Orion (1993, 2003).

Preparation" in their curriculum. This included in-class sessions prior to the field trip that provided the students with

1. thorough knowledge of the physical location of the field trip relative to more familiar landmarks from their daily life and all other geographic factors and features related to the field area and stops to be made (geographic preparation),
2. a briefing of the physical conditions they could expect, including weather, temperature, duration, time of arrival and departure, provisions for personal comfort (food, drink, etc.), and other personal factors so that they could minimize the separation between their personal expectations and the reality of the field environment as it actually occurred (psychological preparation),
3. a full suite of transferable, relevant, and necessary skills and prior knowledge from the content area in question that they could draw on to conduct meaningful investigations in the field environment, akin to scaffolding any other set of classroom exercises (cognitive preparation).

When all of these conditions were met, the students showed measurable learning gains and improved attitudes toward the field trip and ultimately received the optimal educational experience from the investment of time and resources involved in setting up and running an educational field trip.

As the Novelty Space construct was developed not in the context of indigenous education, but within the context of the Israeli educational system and therefore also local culture and values, it is worth devoting some discussion to the appropriateness of applying this framework to understanding the educational challenges facing students from indigenous cultures with often radically different worldviews. Reports from science education research in indigenous communities show that students and community members alike in many indigenous communities view all knowledge as an interconnected system, and that "science" as a field of inquiry is not separated from other bodies of knowledge and ways of understanding nature to the extent that is typical in Euro-American, Judeo-Christian culture (Kawagley et al., 1998; Nadasdy, 1999). This is reflected in indigenous conceptions of all areas of content knowledge being related in a holistic manner, and an understanding that natural phenomena arise from the operation of cyclical, interconnected systems through time (Allen & Crawley, 1998). As is examined later in this paper, indigenous knowledge systems have a significant component of empirical knowledge, and therefore cannot be incommensurate with Western science. It stands to reason therefore that despite cultural differences, there must also be much of Western science *education* that is applicable in an indigenous context. Kawagley et al. (1998) illustrate this point by describing Yupiaq indigenous education concerning scientific topics as employing "modeling and guided practice, and that cooperative learning, peer tutoring, and hands-on learning are essential strategies." We argue then that frameworks constructed outside of indigenous culture may still be applicable within indigenous cultures provided they are holistic, systems based, and place based, and allow for the influence of culture and experience on learning. The framework constructed by Orion and coworkers meets these requirements, and is therefore a viable candidate as an explanatory framework for aspects of field-based indigenous education. It is very possible that there are other active elements in the system described by this framework that remain undiscovered at this time because the Novelty Space idea was not developed in the context of indigenous education.

We argue that this framework is directly relevant in the context of indigenous Earth science education, and that indigenous learners in the Earth and environmental science education programs referenced earlier should automatically be at or near the state of Optimal Concrete preparation even *without* special prior preparation of the learners on the part of the program organizers. If this assertion holds true, then field-based education should be advanced as the ideal model and the norm for Earth science education for indigenous students.

GEOGRAPHICAL PREPARATION

As noted earlier in this study, Native American people in southern California have a great geographic familiarity with their traditional homelands. This is a product of millennia of collective lived experience in the landscape, and the deep knowledge of place present in these communities is seen in the geographically specific and bounded nature of the physical landscape, which is expressed in indigenous knowledge. This is also observed (and perhaps even more clearly seen) in the other referenced geoscience education activities with indigenous peoples from the Colorado plateau or the northern United States and Canada. The issues of cultural coherence and completeness with regard to indigenous knowledge will be addressed in more detail later in this paper.

Cajete (2000) makes an eloquent case from a cultural and educational perspective how Native American people and indeed indigenous people worldwide perceive a strong sense of place, and how the lived sense of geography for most indigenous peoples greatly exceeds a Euro-American notion of geography. He builds a case that native cultures perceive geography at a far deeper level than the symbolic and representational maps used in Western culture. Geography is not only a matter of location, distance, and elevation, but is additionally permeated with meaning and cultural significance. Indeed the worldview and cosmology of many indigenous cultures is indistinguishable and inseparable from the physical geography. As a result, in terms of field-based science education, students raised within an indigenous culture have a distinct advantage over their counterparts from within the settler or colonizing culture. Cajete argues that native students' sense of place and geography permeates their every thought and action, so locating oneself in a field study area is not only trivial especially in the context of reservations or traditional homelands, it is an automatic element of conscious perception, permeated with culture.

For non-native students to master the geography of a field area, they have to learn the symbolic language and representation of maps without the benefit of deep cultural and personal familiarity. Even if one does not admit the cultural arguments, one can clearly see that Native American students raised on a reservation would have an advantage working in home territory. An open question remains whether students raised in rural environments in general learn the physical geography commonly experienced in geoscientific field work as a matter of daily life as well, or whether there is a special cultural predisposition for indigenous learners. This is a fruitful direction for further empirical research, but naturalistic observations by the author and collaborators suggest that Native American learners do have a greater initial facility with maps than do their non-native counterparts, perhaps as a result of their deeper initial familiarity with the landscape derived from culturally based elements related to worldview and cosmology.

PSYCHOLOGICAL PREPARATION

Because most indigenous cultures existed as an integral part of the ecology, geology, and physical geography of landscapes, Cajete (2000) further argues that an indigenous person in a natural landscape perceives no meaningful distinction between themselves and the landscape—they are coevolutionary entities. Most indigenous cultures make claim to having always existed in a landscape for the entirety of their cultural memory, and claim kinship with all other natural parts of that landscape, living or not as defined in a Western worldview. If culture is strong and historically continuous for indigenous learners, then from the point of view of psychological preparation these learners have another automatic advantage over nonindigenous learners in a field environment, and they approach field studies in any scientific field at a more advanced level of psychological preparation because of their cultural background.

Certainly in the context of reservation-based Earth and environmental science education in the field, issues of weather, field trip duration, and other physical conditions are already in the personal experience of Native American learners relative to those encountering similar field conditions without additional prior experience. If psychological preparation for field-based learning is intended to minimize the slippage between a student's expectations of the field environment and actual experience, a lifetime of personal exposure to all the variability in a landscape must aid in field-based learning. Based on this argument, however, it would seem that all students from any cultural background should enjoy similar benefits of studies in their local region. However, in local field work with local students from the majority culture (i.e. non-indigenous), we do not observe the same automatic psychological familiarity as is seen with Native American learners. This does suggest that there is some psychological ease afforded to native learners in the outdoor environment relative to their non-native counterparts, at least those of their non-native counterparts without substantial prior experience in outdoor learning environments.

COGNITIVE PREPARATION

If cognitive preparation for field studies not only includes just strictly factual content knowledge, but also a conceptual framework appropriate to studying the geosciences in the field, then once again many indigenous students will have an automatic advantage in this learning environment. Because many indigenous cultures perceive time to be cyclical instead of linear and processes in a landscape to be fundamentally long-lived, dynamic, and ever-changing, and because this relationship with the natural world is often also built into the structure of indigenous languages (Bean, 1972; Cajete, 2000; Suzuki & Knudtson, 1992; Thomson, Scott, & Whipple, 2002), many indigenous peoples again enjoy a culturally derived inroad to the modern scientific understanding of Earth system science. While ultimately this connection is more speculative in nature, it is possible that having prior knowledge based in culture may be a distinct advantage in coming to understand the modern

Earth sciences, in the sense that it may lead to ease of transfer from the concrete domain of the field environment to the abstract realm of long time scales, large spatial scales, and complex interactions in nature. This deliberate progression from concrete to abstract is a suggested element of field-trip planning and subsequent integration into classroom curricula (Orion, 2003), and may help in retention of knowledge by participants, although at this point this remains a theoretical suggestion. In general though, this element related to cognitive preparation does relate clearly to the indigenous knowledge within a community, and may serve as a bridge over which to integrate indigenous empirical knowledge of natural systems with mainstream science, a point addressed in detail later.

Beyond issues of preparation alone, there are other aspects of field work and field-based instruction in the Earth sciences that help to explain the success of field-based programs for Native American and First Nations communities. Field instruction in the Earth and environmental sciences is most often cooperative in nature, and this has been true of our outdoor instruction as well as of other Earth science programs for indigenous peoples of which we are aware. Field work is also generally teacher structured, but has major components of student-structured instruction, as the details of that data are collected and how they are recorded and interpreted are usually left to the students. All of these factors are completely consistent with recent findings in learning styles and student motivation research with Native American students (Aragon, 2002), and suggest as a recommendation for practice that most Earth science education with indigenous peoples should be conducted in the outdoor teaching environment. The learning gains in this setting are likely to be much greater than if restricted to the classroom, as a result of increased cultural coherence and better alignment with preferred learning styles, resulting in greater engagement and motivation among learners. At this point this is supported by our observations and those of colleagues operating similar programs, and through future work is testable and potentially quantifiable.

THE INCORPORATION OF INDIGENOUS KNOWLEDGE: AN ESSENTIAL BUT OFTEN COMPLEX TASK

In addition to a field-based learning environment, the other powerful common aspect of all of the Earth and environmental programs under study here is the incorporation of indigenous knowledge (sometimes more narrowly referred to as *traditional ecological knowledge* in this context) as curricular elements. The inclusion of indigenous knowledge as an equal source of valuable information helps ensure cultural equity and also increases the student motivation and community ownership of a particular educational program. This point is made especially well in the research of Aikenhead (2001a) working with Cree communities in Canada and Semken and Morgan (1997) experimenting with an entire introductory college geology course in a Navajo framework.

Aikenhead (2001a) makes the point that having local indigenous knowledge included as a central piece of the instruction is critical to the success of the resulting program or curriculum, regardless of the educational level of the audience. He reports that teachers have not been successful in trying to use curricula developed in using the context of different indigenous populations. There is potentially much value in melding Western geoscientific knowledge with indigenous geoscientific knowledge, but the indigenous knowledge must be locally relevant and coherent with local culture. There is also intrinsic value in the preservation of this diversity of thought and thinking skills, and there is often economic value in indigenous knowledge, as has been shown by the success of pharmaceutical advances rooted in indigenous ethnobotanical knowledge. Nadasdy (1999) points out that there are many instances when the recording and attempted integration of indigenous knowledge with scientific knowledge have been counterproductive for indigenous communities as indigenous knowledge capture and misuse have become a tool of political leverage in certain situations. However, in the absence of this type of political forcing, any sincere attempts to combine indigenous and scientific knowledge can result in new educational programs and curricula that will readily be contextually relevant in providing new scientific content knowledge for an indigenous community. However, to achieve this integration, the curriculum developer must be able to identify and draw on the indigenous knowledge of the community. In developing these curricula and programs, the non-native academics working consistently with tribes also have the advantage of having easy access to readily identifiable indigenous knowledge, still embedded in an actively spoken language situated in a relatively intact local culture.

In southern California Native American communities, the potentially straightforward process of identifying indigenous knowledge is rather complex. This is due to the extensive and repeated colonization of this region, first by Spanish missionaries, then Mexican settlers and landowners, and finally by the United States with accompanying extensive settlement of the area, wholesale reduction of the land base under tribal control, and direct efforts to eliminate native language and culture. This colonization and dispossession has almost completely destroyed the language of the Luiseño and Cahuilla peoples in this region, reducing the number of native speakers to only a few individuals. The language of the Kumayaay peoples in southernmost California and northern Mexico has survived better, but there are still few individuals who speak the language. There are tribally driven efforts to recover and promote these languages, but the reality is that most indigenous people in this region speak English or Spanish as a first language, not their native languages.

Much of the survival (and ready identification and protection) of indigenous knowledge depends on being communicated and understood in the language in that it was originally constructed (Hunn, 1999; Thomson et al., 2002). The Navajo language, for example, has a grammatical structure that conveys meaning and movement through verbs in more complex and subtle way than English (Locke, 1992). Ethnogeological work in a Navajo context (Semken & Morgan, 1997) shows that this linguistic structure may provide Navajo students with a culturally derived advantage in understanding Earth systems, as the interactions and processes are more central than the objects acted upon in the systems. Similar differences in mathematical and geometrical thinking related to this cultural and linguistic difference have also been documented (Giamati & Weiland, 1997). Unfortunately, languages are very fragile under the influences of colonization or globalization, largely because they are fundamentally local in nature and scope (Hunn, 1999). As a result, the languages and indigenous knowledge intertwined with them are rapidly disappearing (Lord, 1996; Thomson et al., 2002) or are already extinct. This increases the need for a framework that enables recognition and recovery of indigenous knowledge systems even when native languages have fallen into disuse.

Furthermore, the recent work of Welsh (2003) in the Jamul community of Kumayaay people in the eastern portions of the San Diego region shows that most children and young adults in this indigenous community no longer perceive their culture as having indigenous knowledge that contains any relevant scientific information or value. Welsh shows through interviews with community members that this perception is relatively new, taking place at an accelerated rate over the last two to three generations, and that most of the damage to the indigenous knowledge of this community has paralleled American colonization efforts and the associated direct efforts to remove native language and native culture from American Indian people in this region. This result means that the recovery of indigenous knowledge for incorporation into culturally based Earth and environmental science programs is not likely to be simple or automatic. However, many people in communities we have worked with in the region still report a rich variety of indigenous culture, custom, and knowledge that has been passed to them by their grandparents, despite the lack of native language. This is encouraging, as it is likely that the indigenous knowledge of these peoples still survives, but is likely intertwined with local knowledge derived at least in part from the settler community. In the absence of a clear means of distinguishing indigenous knowledge from subsequent colonial influence, we need a framework which native and non-native curriculum developers both can use to discover that collective information surviving within a culture is truly indigenous in origin.

THE CENTRAL PROBLEM: WHAT *IS* INDIGENOUS KNOWLEDGE?

Despite the rather extensive literature that addresses the collection, preservation, appropriate treatment, and legal protection of indigenous knowledge, there are few instances in this body of work where authors have defined what this knowledge is, and how it differs from other forms of place-based, geographically situated scientific and social knowledge. From a science education standpoint, it is essential to sharpen this definition in order to better identify which knowledge within a community is the most culturally supportive of science learning in a field-based, traditional land-based Earth science curriculum.

At a minimum, indigenous knowledge is defined as knowledge that emerges from and resides within precolonial (i.e. indigenous) peoples, to the best extent that that status may be determined, and which is almost always concerned with the balance of humans and human activities within the interwoven functions of the natural environment and natural surroundings. As such, most indigenous knowledge is very practical in nature, and most of the day-to-day work in the collection and integration of indigenous knowledge worldwide is associated with the establishment of sustainable agriculture and environmental management in settings where precolonial peoples still retain land stewardship and usually where Western scientific approaches to environmental resource management have failed or are less desirable.

Because of its intrinsic value and its characteristics of being interwoven with the culture and values of indigenous peoples, indigenous knowledge needs to be identified as such and distinguished from other knowledge systems that have been overlain or imposed on indigenous communities, or that have origins in surrounding settler communities. The reasoning for the establishment of this distinction is that nonindigenous knowledge originates from colonial cultures and nations, which rarely have initial intentions of sustainable or environmentally benign extraction of resources from a given colonized region. One then cannot automatically expect locally viable solutions to problems of sustainability from non-indigenous knowledge, although it may be true in some cases that long-settled colonists have gained local knowledge that does result in sustainable practices. Hunn (1999) further points out that other key features of indigenous knowledge are an interrelationship with cultural, religious, social, and other value systems that guide the application of knowledge in management practices. This interrelationship will be discussed in detail later, and proves to be central to the identification of indigenous knowledge for the inclusion in culturally relevant science education.

Indigenous knowledge is not only a collection of scientific observations. This knowledge is linked epistemologically and socially to the community structure that gives rise to it. Kalland (2000) provides a useful theoretical framework for deconstructing indigenous knowledge, that we will adopt for the following discussion of the distinctions in the types of knowledge mentioned earlier. He proposes that indigenous knowledge is actually composed of three separate and independent types of knowledge, namely *empirical* knowledge, *paradigmatic* knowledge, and *institutional* knowledge. Empirical knowledge is defined as the observation and experience-based knowledge that results from long and direct experience working with natural systems. It is via empirical knowledge that the clearest connections and collaborations can be built between indigenous societies and scientists, and it is because of this that the preservation of indigenous knowledge is very important to scientific researchers. Put in other words, this is the "data set" of basic observations that a population holds and transmits.

Paradigmatic knowledge is, as the name suggests, the knowledge related to the interpretation and cultural construction of causal relationships, interrelations, and the meaning of these relationships within the empirical knowledge held within an indigenous knowledge system. These interpretations are embedded in and arise from culture and are shaped by the cosmology or worldview. From a functional standpoint, indigenous paradigmatic knowledge can come into conflict with more typical "Western" scientific worldviews. For example, such a conflict might arise from analysis based on an underlying assumption of linear chains of causes and causation as opposed to those that are cyclical or interwoven. Similar conflicts might arise regarding other existing interpretive frameworks or standards for evidence. However, sometimes the norms of practice within certain scientific disciplines offer valuable commonalities between the often more holistic viewpoint contained within the worldviews of many indigenous people and a scientific framework. A paradigmatic framework can be based in religion or spirituality, and while it itself is not scientific per se, one cannot ignore the influence of culture, values, and tradition on the arrangement and acquisition of empirical knowledge. This issue has been discussed in the geological literature (Huckleberry, 1999; Riggs & Marsh, 1998; Semken, 1999), as it is a point of great importance and controversy among scientists who may attempt to dismiss the importance of indigenous knowledge or conversely worry that paradigmatic knowledge may be mistaken for empirical knowledge as scientists explore indigenous Earth science knowledge.

The Earth system science "worldview," which seeks to teach science organized around the interactions and interconnections between empirically recognized subsystems, is potentially quite coherent with many holistic indigenous cultural paradigms. Where in many cases a cultural barrier might be present because of the misfit between the worldview of reductionist science and a student from a holistic indigenous culture, the scientific approach common to the Earth sciences may provide a very useful bridge for facilitating the cultural border crossings of Aikenhead and Jegede (1999) and in recognizing the overlapping similarities in the bodies of knowledge commonly framed as "scientific" and "indigenous," as described in Agrawal (1995). Value systems and issues of appropriate relationships with nature and with scientific inquiry of natural systems are also embedded in paradigmatic knowledge, so connections to other aspects of cultural knowledge also come into play here. These might include religion, philosophy, and traditional relationships with authority and social structure, and potentially also cognitive issues related to temporal and spatial scales. In geoscience education this is manifested in learners' conceptualizations of what constitutes a "long time" or a "large system."

Finally, institutional knowledge is described by Kalland (2000) as the characteristic way in which empirical and paradigmatic knowledge are operationalized in the daily existence and behavior of a population. These are habits and norms of management of access to natural resources or empirical knowledge of the natural world, along with social structures related to the acquisition, interpretation, and application of both empirical and paradigmatic knowledge. Institutional knowledge can also potentially cause conflicts with externally mandated management practices or with externally introduced science education, especially if local practices and policies have not first been explored and checked for coherence with the externally developed practices and approaches (Nadasdy, 1999).

Grenier (1998) makes the point that indigenous knowledge is usually distributed widely and unevenly throughout indigenous cultures. Different subsets of empirical, paradigmatic, and institutional knowledge are often gender or age specific, or could be distributed by social status, role, or profession. Additionally, there is much knowledge that is distributed by individual factors such as skill, interest, or curiosity. To assess the entirety of indigenous knowledge in a population and to tap into that store of knowledge to enhance science education or any other activity, one must first build trust within a community and learn to listen carefully to community concerns. It was our experience in southern California that once key members of our partnering native communities understood that the intention of our work was to improve tribally controlled education and resource management, then we were put in touch with the appropriate people within the community. Through these connections we have also slowly come to understand something of the distribution and structure of the indigenous knowledge held by the community, as well as the social structure through which one can propose educational innovations.

In all cases, great effort must be made to make sure that local cultures are empowered and respected by the sharing of their indigenous knowledge, and to a large measure this involves no more advanced skills on the part of the outsider than the ability to listen patiently and well, without imposing any judgment or demands on what is shared. International guidelines have been established that provide protocols for recording and transmitting indigenous knowledge, procedures through which local communities can become equal partners in any educational or other research venture, and means by that the intellectual property rights of indigenous peoples can be ensured (e.g. Grenier, 1998; Nakashima, Prott, & Bridgewater, 2000; Nuffic, 2002). It is very important that all attempts and explorations of the bridges between indigenous knowledge and Earth systems education be governed by these guidelines and work in concert with international initiatives.

INDIGENOUS KNOWLEDGE OR JUST LOCAL FAMILIARITY?

While many authors on indigenous knowledge have drawn no distinction between indigenous knowledge and local knowledge, we propose that there is a useful difference in these knowledge sets if the goal is to bridge cultural barriers in science education by including specifically indigenous knowledge. Often in colonized regions it is not always immediately obvious what fraction of indigenous knowledge still exists among the original inhabitants, and what of that knowledge is common with much of the settler population and is the product of a few generations of life experience in the same geographical region, which is to say, *local* or *situated* knowledge. In a long-colonized region, such as southern California and elsewhere in the southwestern quadrant of the current United States, it is also valid to question if the indigenous knowledge surviving in native populations is substantially different from the local knowledge since acquired by settlers who have now lived on the land for perhaps ten or more generations, as in the case of the ecological knowledge of Spanish-Mexican populations in the upper Rio Grande region of New Mexico described by Peña (1999).

If we interpret indigenous knowledge as containing the three distinct subtypes of empirical, paradigmatic, and institutional knowledge, one can distinguish how indigenous knowledge is distinct from and related to local knowledge and how they are related to one another. Indigenous and local knowledge may share much the same content with respect to empirical knowledge, the major difference being that the recorded memory contained with indigenous cultures can extend over a much greater time span due to the length of time spent living in a given location. This allows for the observation of much lower frequency natural phenomena and usually leads to a cultural sense of cyclicity in natural events and a greatly expanded sense of long time scales relative to the settler culture (e.g. Riggs & Riggs, 2003).

To distinguish local knowledge from indigenous knowledge, identification of the type and source of the paradigmatic knowledge is key. While both contain empirical knowledge, the paradigmatic knowledge should be distinct. The paradigms evident in indigenous knowledge should be associated strongly with the local indigenous culture, and should be intertwined with worldview, religion, language, and other noncolonial aspects of indigenous life. Colonial paradigms and institutions are commonly imported along with settlers, and are usually quite distinct from the cultural perspectives of indigenous peoples. If knowledge is fundamentally intertwined with culture, then empirical knowledge of a region held by people with transplanted paradigmatic knowledge will result in a different institutional knowledge set, or some hybrid of indigenous and settler culture.

It is important to acknowledge at this juncture that much of the framework presented earlier remains largely untested in the field in southern California and elsewhere. While significant progress has been made in the identification of indigenous knowledge relevant to Earth science education in Native North American populations, especially with the Cree (Murray, 1997) and the Navajo (Semken & Morgan, 1997), the framework presented earlier has not been tested in these settings or used as a discriminant for sorting out knowledge systems currently in use in southern California tribal communities. This framework is serving as the basis for further empirical research in this direction, and needs further testing in a field setting in cooperation with partner communities.

Early test cases for this framework are presented in more detail in Riggs (2003), but will be summarized briefly here to illustrate how this framework may be employed to identify indigenous knowledge. Our work to date has shown that the indigenous knowledge surviving and operating still in tribal management decisions is most distinct from local knowledge in the following ways:

1. *Time scales and a culturally based understanding of the long-range effects of actions*. For example, one reservation community was assured by a non-native water agency that its plans for injection of relatively high-salinity imported water into a neighboring aquifer would not affect the water quality of the tribe's aquifer for a "long time," estimated at 200 years. The tribe rejected this argument, and opposed the injection of the imported water because in their opinion 200 years was merely an instant of time, and not a long time at all. From the perspective of tribes who have lived in this natural landscape for at least 8,000 years and potentially tens of thousands of years, a few thousand years may have been viewed as a "long time," but not 200. This is a clear example of the culturally based paradigmatic differences in the knowledge held by both groups. In this case the paradigmatic portion of indigenous knowledge came to bear on a management decision, related fundamentally to an indigenous worldview and perhaps also to empirical knowledge of longer term, lower frequency events in the natural landscape.
2. *Interconnection of Earth systems*. Tribal environmental managers frequently express an understanding that all aspects of watershed management and water use effect all other aspects of the environment. An explicit understanding exists (with no prior formal education in environmental science) that water withdrawals stress riparian systems, which in turn can jeopardize environmental health and potentially tribal water quality. This is evidence of a culturally based paradigm, which is distinct from most of the settler culture.
3. *Gendered aspects of indigenous knowledge*. We have observed that much of the traditional institutional knowledge structure is still intact despite colonial influences. The gendered distribution of ecological and solid-earth knowledge is consistent with anthropological work in the region (e.g. Cuero, 1968), and suggests that indigenous

empirical knowledge, while perhaps hard to find or identify, probably does still survive and has relevance for modern geoscience education efforts.

All of these factors lead to a cautious optimism that much indigenous knowledge is available for incorporation into tribal environmental education programs, and already provides much of the framework for our existing efforts, and has strongly influenced decisions related to course content and choices of learning environments.

INCORPORATING INDIGENOUS EARTH SYSTEMS KNOWLEDGE AND LEARNING STYLES INTO EARTH SCIENCE EDUCATION

By way of recommendations and conclusions, we reiterate that indigenous knowledge can be located only with the full cooperation of native people and can be differentiated from local knowledge by the framework presented here. It can be effectively combined with instructional innovations to make curricula that are relevant and useful to indigenous learners. One the most powerful teaching strategies in an indigenous context is the use of the local field environment, especially on lands that have been occupied and managed by indigenous people for generations. In all the projects in North America to date, this has been a common theme, and elsewhere in the world with other indigenous populations, this is also the case. The field is one of the easiest teaching environments in which to make connections between scientific and indigenous knowledge, and it is also one of the best places to explore the interaction of Earth systems. While the effectiveness of a Earth systems science approach is not yet fully understood in an indigenous context, fieldwork and other experience-based teaching styles are likely to hold the greatest potential for the enhancement of diversity in the geosciences as well as the greatest potential for bringing Earth and environmental science expertise to indigenous populations worldwide.

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