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Nanotechnology and Traditional Knowledge Systems

abstract

Several artifacts and practices important to traditional knowledge systems make use of phenomena described in nanotechnology research. These include nanotubes in ancient “Damascus” steel, surface nanostructure in Mayan blue pigment, the piezoelectric effect in Lakota quartz rattles, and the use of surface tension in African animist ritual. These artifacts and practices are presented in popular media as either fortuitous accidents or historical curiosities, but a more careful examination of their epistemological status and social history can provide a more accurate portrait and improve their application to minority student education and indigenous intellectual property rights.

Traditional knowledge systems, such as those of the indigenous societies of India, Africa and South America, have made a surprising impact on many disciplines surrounding science and technology. The pharmaceutical industry, for example, has long used "ethnobotany" – the study of indigenous utilization of plants—to help discover biologically active molecules. The use of curare in surgery, quinine in malaria prophylaxis, and other traditional medical applications of these indigenous discoveries now pale in comparison to the massive efforts in "bioprospecting" — so much so that the American Association for the Advancement of Science has instituted a project on indigenous knowledge and intellectual property rights, and the concerns have spread to other ethnoscience disciplines (Hansen and VanFleet 2003, Nicholas and Bannister 2004). Thus the epistemological status of traditional knowledge is critical to preventing appropriations of indigenous heritage. Another important area of application has been in under-represented minority student education. Many K-12 teachers in science, technology and math have turned to cultural connections, which often includes traditional knowledge from ancient state societies (Egyptian, Mayan, Hindu, etc.) as well as those of smaller scale tribal or band societies. Again this application hinges on the epistemology of these practices; unless they have the status of knowledge they cannot be used to contest primitivist or ethnocentric portraits of non-western culture. This essay will describe some connections between traditional knowledge and nanotechnology, and show how a more careful examination of the social histories of these artifacts and practices can shift our understanding of their epistemological status, and open new possibilities for their application regarding education and the protection of indigenous heritage.

Epistemological Status, Root Metaphors, and Intentionality

As Watson-Verran and Turnbull (1995) note, "indigenous peoples have been frequently portrayed as closed, pragmatic, utilitarian, value laden, indexical, context dependent, and so on, implying that they cannot have the same authority and credibility as science." A key challenge to this dismissal of traditional knowledge has been the acknowledgement that western science is also local and value laden. Scott (1996) for example notes that all knowledge systems make use of "root metaphors" to provide a cohesive framework (e.g. the title of Haraway's 1976 book, "Crystals, Fabrics, and Fields," describes three competing root metaphors of embryologists). Scott shows that the root metaphor of personhood in native conceptions of particular species allows the construction of (what we could translate as) ecologically sustainable natural resource management.

Species personhood as a native root metaphor leading to sustainable practices has been proposed by other researchers as well, perhaps most spectacularly by Langdon (2007) who uses archaeological data to show the change in Tlingit salmon harvesting methods, which accompanied both the invention of the personhood root metaphor and a substantial increase in salmon abundance (despite a simultaneous rise in human population). Langdon concludes: "it is possible that the patterns of human engagement in the last thousand years before Euro-American penetration may have enhanced and/or optimized salmon abundance through conscious intervention" (p. 269). The extent to which we can draw parallels between an indigenous root metaphor and analogous phenomena in technoscience (Kuhn's paradigm, Lakatos' research programme, Fujimura's standardized packages, Knorr-Cetina's reconfigurations, and Turnbull's assemblage, to name but a few) is a question that needs to be asked on a case-by-case basis, but the essential point is that indigenous knowledge systems cannot be automatically dismissed as merely non-theoretical, unintentional, and unconscious; just as they cannot be automatically valorized as transparent equivalents to western science.

The choice of species personhood as a root metaphor is perhaps easy to understand since both people and non-human species have similar needs for reproduction and sustenance. For example, respect for human maternity can easily be extended to respect for non-human maternity, which would result in prohibitions against hunting breeding females. But indigenous knowledge can also encompass areas such as physics and mathematics. For example, the Inuit igloo is not a dome but rather takes the shape of a catenary curve, which is the optimal for reducing sheer stress in an arch. That does not mean we can assume the Inuit invented trigonometry. But to assume the opposite extreme—that since there was no explicit attempt to calculate the shape, the igloo structure does not count as knowledge at all—is also an error. Long-term daily practice—the evolution from trial and error over centuries—can build up remarkable bodies of knowledge; a kind of "collective intentionality" that contrasts with the individual intent we assume to be the basis for innovation in the west.[i] For example, a 1970 study of igloos by a civil engineer found that they deviated from the optimum catenary height to base diameter ratio by a small amount; quantitative measures of the snow block sheer strength showed that this compensated for compressive creep as the snow blocks age, resulting in a design that has better optimization than the mathematical abstraction alone provides (Handy 1973). Moreover the architectural construction of catenary arches in Europe also took place using trial and error, physical models and rules of thumb, even long after Leibniz, Christiaan Huygens, and Johann Bernoulli derived the catenary equation in 1691. Indeed the most famous use of the catenary arch in Europe is Antonio Gaudi's 20th century application of physical modeling, especially in his crypt for the Chapel of the Colònia Güell (1905–15) (Huerta 2006). Gaudi hung weights on cords in proportion to the weight the arches would hold, recorded the resulting shape, and then turned it upside-down to get the arch structures. Even if he had wanted to use the catenary equation, a numerical solution would have required computers unavailable in his day. Gaudi's methodical approach was also supported by his strong Catholic beliefs: when asked about the many years it was taking him simply to create the design, he replied "my client is in no hurry." Western science and technology also occurs in a cultural context.

Skeptical questions and falsifiable hypothesis testing are crucial to the documentation of traditional knowledge, as both deliberate charlatanism as well as well-meaning efforts leaning on pseudoscience or misinformation can destroy its scholarly value (Oritz 1993, Martel 1994, Restivo 1985). The best approach is not to claim wholesale equivalences (e.g. that the Inuit "know" the mathematics of the catenary arch) but rather to show the various connections between the body of knowledge in its original and historical context and their parallels (and differences) in contemporary science and technology; illuminating both in the process.[ii]

Connections to Nanotechnology in the Traditional Knowledge of Ancient State Societies

One of the most spectacular nano/culture connections has been the discovery that the famed "Damascus Steel," used in Middle Eastern sword making from about 1100 to 1700AD, owed its legendary combination of sharpness and strength to the presence of carbon nanotubes and nanowires. In ordinary steel production of that period sharpness and strength would be opposing tradeoffs: increasing carbon content for sharpness would make it more brittle, and decreasing carbon content for strength would prevent it from holding an edge. We now know that it was a special type of steel ("wootz") from India—developed perhaps as early as 300 BC—that was used to forge the blades. Indian metallurgists used ores from particular mines that included alloying trace elements such as vanadium and molybdenum (Verhoeven et al 1998). The name "Damascus steel" may have originated in association with the forging of blades in Damascus, Syria, but another possibility is that it was named after the characteristic pattern of wavy lines seen on the blade (in Arabic "damas"). The disappearance of wootz steel in the 18th century is attributed to the diminishing supply of Indian ores with the proper trace elements. Bladesmiths continued to mimic the wavy line pattern by forge welding alternating sheets of high- and low-carbon steels, but the extraordinary material properties of wootz were no longer present.

It has been known for some time that the wavy pattern in blades of wootz steel origin was due to bands of iron carbide particles ("cementite"), Fe_3C. But cementite is typically brittle; somehow the trace elements, together with the particular heat treatments, were preventing the cementite from weakening the blade. Recently high-resolution transmission electron microscopy was used to examine a sample of Damascus sabre steel from the seventeenth century: it showed the presence of carbon nanotubes as well as cementite nanowires (Reibold 2006).

This is a remarkable result in itself, and nicely illustrates the idea that traditional knowledge can include manipulation or use of material properties relevant to nanotechnology. But if we stop there, we leave the impression that wootz was simply an interesting artifact from the ancient past, and science merely tells us what the ancients failed to understand. Such a view leaves out the active role that wootz has played throughout the history of metallurgic science. Scientific analysis of wootz is nothing new; Europeans have long been aware that there was something special about it, and this mystery has inspired a great deal of important metallurgical research. Michael Faraday, for example, is best known for his foundational work in electrical and chemical physics, but previous to those experiments he sought to discover the secret of wootz (not a surprising move given his father's employment as a blacksmith). His study proved that the wavy pattern on wootz blades was due to an inherent crystalline structure and not a mechanical mixture of substances. Faraday's later experiments with metallic colloids, in which he suggested that size differences in extremely small metal particles could produce color changes, has been cited as the birth of nanoscience (Edwards and Thomas 2007). Other European wootz experimenters included Giambattista in Italy (1589), Reaumur in France (1722), Bergman in Sweden (1781), Anossoff in Russia (1841), and Smith in the US (1960) among many others. In their review of this history two professors of materials science in India, Sharada Srinivasan and Srinivasa Ranganathan, conclude that several important innovations in metallurgical science—most strikingly the role of carbon in steel—have been associated with wootz research. They also point out that discoveries in this historical trajectory are still on-going. For example Reaumur proposed that the properties of steel are determined at several scales, from microscopic "grains" to a hypothesized nano-scale of "periodic spheres". At MIT in the 1960s Cyril Smith, sometimes referred to as a "philosopher-metallurgist," recovered the work of Reaumur, translating it into the modern idiom of a multi-scale architecture where crystalline, molecular and atomic processes have mutual influence on each other. Professor of material science Greg Olsen, inspired by Smith as a student, later developed software to "design" steel using this model of multi-scale processes. Recently Olsen's work was celebrated for its mixture of humanities and technology, as he hired bladesmith Richard Furrer, an expert in the reproduction and use of wootz steel, to make a "mythic" blade using his computationally designed steel, Ferrium C69 (Davis 2001). In summary: wootz steel as an example of nanotechnology in traditional knowledge is not merely an matter of historical curiosity, but rather a "boundary object" (Star and Griesemer 1989) through which western and non-western metallurgists have maintained a dialog over the last 400 years; one still relevant today.[iii]

Another remarkable example of "retrospective" nanotechnology is Maya blue pigment. First formally identified by Harvard archaeologist R. E. Merwin at Chichén Itzá in the 1930s, it is notable for its stability. Why this mixture of indigo and white clay (palygorskite) did not fade, maintaining a brilliant blue color despite centuries of exposure to heat and moisture in a tropical climate, was a mystery. Miguel José-Yacamán, a materials scientist then at the University of Mexico, proposed nano-sized channels in the palygorskite protected the indigo and metal combination (Jose-Yacaman et al 1996). Recent evidence suggests that the indigo is actually embedded in surface grooves, rather than interior channels (Chiari et al 2008), and that the carbonyl oxygen of the indigo is bound to a surface Al^{3+} (Polette-Niewold et al 2007). José-Yacamán found an almost identical composition in eight paint samples, even though they came from sites dozens of kilometres apart, and concluded that there was a remarkable level of "quality control" in the paint production.

Again this retrospective view—remarkable as it is—is not the end of the story. Maya blue is not only resistant to heat and moisture, it is also resistant to biocorrosion, mineral acids, and alkalis (Sanchez del Rio 206). Researchers at the University of Texas at El Paso noted that since indigo could be substituted by other organic dyes, its chemistry not only offered a new class of organic/inorganic complexes for research, but also exciting new possibilities for application, since current pigments are mostly based on either environmentally unfriendly heavy metals, or strategic metals that are in short supply (Polette-Niewold et al 2007). They recently formed a private company, Mayan Pigments Inc, and have already received NSF funding for their research as well as contracts with industry for their services.

Finally, it is important to note that although popular representations "freeze" the use of Mayan blue as an artifact from the pre-colonial past, Mayan blue pigment continued to be used even after colonization. It was applied in the 16th century in Catholic convents in Mexico; the best examples are in the paintings of Native American Juan Gerson in Tecamachalco. Although its use apparently ended after that point in Mexico, in Cuba its use continued up to 1830 (Chiari et al 2000).

Connections to nanotechnology in the traditional knowledge of non-state indigenous societies

While indigenous societies that did not constitute a state typically lacked the labor specialization we associate with knowledge production, they still managed to refine their use and manipulation of materials over many centuries. Perhaps one of the best known is that of obsidian tools, which among Native Americans reached a highly sophisticated state of craft. Anthropologist Payson Sheets of the University of Colorado in Boulder was excavating obsidian glass blades in El Salvador during the early

1970s. Sheets investigated the blades' cutting properties, replicating the fracturing process used in ancient indigenous cultures of Central America. Using an electron microscope, he compared the cutting edges of the obsidian blades to those of modern disposable steel scalpels and to diamond scalpels, the sharpest surgical tools available. The obsidian blades turned out to be two to three times sharper than diamond scalpel blades—down to 3 nanometers across—but at 1/100th the cost, and have since gone into commercial production (Sheets 1989). One study comparing wound healing using obsidian and steel scalpels have found that the extremely thin edges of obsidian create statistically significant wound healing advantages (Disa et all 1993).

A significant contradiction exists between the popular press reports of this technology and the actual history of native flint knapping. For example the Michigan University Record (September 10, 1997) titled its article “Surgeons use Stone Age technology for delicate surgery,” and ended with a comment about “our Paleolithic ancestors.” While the contrast of pre-historic and modern works well to grab readers attention, it misleads the popular audience into thinking that this technology stopped advancing when glaciers receded. Flint knapping was widely in use by Native American groups well into the 19th century (and in some cases beyond). Non-native admiration for obsidian tools was dramatically increased when flint knapping took hold as both a hobby and aid to professional archaeologists (such as Payson Sheets) wishing to reconstruct original methods to better understand these tools. Some of the most highly crafted projectile points are still beyond the skill level of all but a handful of dedicated artisans. Computational models for flint knapping have been applied to fracture mechanics in dentistry, metal fatigue, tribology, and other areas of contemporary concern (cf. Fonseca et al 1971).

Another mineral-based case of indigenous connections to nanoscience can be found in the Native American use of quartz crystals to generate flashes of light for ceremonial purposes. Piezoelectric crystals are often used in nanopositioning systems: energy inputs create mechanical movement. The Native American use is the reverse: the light is energy output generated by the piezoelectric effect of mechanical stress on the crystals. This is accomplished by placing the crystals in translucent rattles. Again the popular representations are at odds with the actual practice. The phenomenon first received wide coverage when it was described in a Wikipedia page on the Uncompaghre Ute Indians (Colorado-Utah area), and quickly became a standard “human interest” component for popular accounts of the piezoelectric effect. Plenty magazine for example reported that “Thousands of years ago, the Ute Indians of Colorado cleverly filled rattles with pieces of quartz that glowed when shaken together to create the world’s first flashlight, no batteries required” (Clark 2007).

However a review of the literature on Ute traditions has not revealed any mention of it. Two ethnographers contacted by this author have confirmed reports among Southwestern groups (eastern Pueblo and northern Ute), but it appears that this was adopted in the 20th century through “pan-Indian” syncretism (Cornell 1988). The only well-documented reports of traditional use of the piezoelectric effect appear to be in the Lakota *yuwipi* (“stone power”) ceremony. Descriptions of this ceremony typically report sparks at the crucial moment when all light is extinguished; the sound of rattles accompanied by these blue flashes of light is said to indicate the presence of spirits (cf. Powers 1986). An Assiniboine spiritual leader in northern Montana (culturally of close relation to the Lakota) described how a medicine man would send a request to ants: “please mine white quartz,” and then return a week later to ant hills to gather the stones, which he said were valued because they produce flashes of light in the dark during the yuwipi ceremony (Mayor 2005).

Two aspects of this story are particularly significant in making the case for indigenous knowledge of the piezoelectric effect. First, this shows how the root metaphor of personhood in non-humans (in this case ants) can work for traditional knowledge concerning inorganic physical phenomena. Ants are spiritually significant because they connect the subterranean world, identified with sacred origins, and the world that humans inhabit. Mayor notes that in addition to sorting out quartz for the yuwipi ceremony, ant mounds also sort out tiny fossils that have ceremonial use among the Sioux as well as the Cheyenne. He also describes similar use of ant mounds by paleontologists, who found them so useful in sorting out tiny fossils that they would bring soil samples from other areas to ant mounds to be sorted for them, and even packed ant mounds in crates and had them shipped to sites. Pickering (1995) would describe such scientific phenomena as a “mangle” – capturing non-human agency in ways that change both scientific practice and the non-humans. Mangle here seems an apt way to identify the Native American root metaphor as well, although they would likely reject Pickering's use of the term "capturing" as identifying a more European-American attitude than the collaborative approach they emphasize with personhood.

A comparison of Native American and European histories of piezoelectricity is also illuminating. Katzir (2006) notes:

> Various references in ancient and mediaeval literature suggest the possibility that the phenomenon was observed in the West long before. However even if the attraction of tourmaline was known before… it was forgotten and had no practical tradition. No one knew how to identify the stone or stones mentioned in the books (pg 24, footnote 27).

This stands in contrast to the Native American practice which had both practical application (yuwipi) and a systematic method for identifying the particular stones that were most effective in producing the piezoelectric effect (searching ant mounds). The books that Katzir refers to are ancient Greek descriptions of pyroelectricity, a related phenomenon in which crystals create an electrical charge when heated. This was rediscovered by Dutch gem cutters in the early 18th century, but it was not until 1880 that Jacques and Pierre Curie found that applying mechanical stress to crystals could also create an electrical charge. Not only did the Native American observations of the piezoelectric effect predate that of the European discovery by many centuries, but more importantly their root metaphor (or mangle) proved more reliable in allowing others to replicate the phenomenon than did that of the ancient Greeks, who failed to transmit the ability to replicate a similar phenomenon (the pyroelectric effect) to later generations. One might defend the Greeks as having a difficult cultural barrier in communicating with Dutch and French scientists centuries later, but the Ute adopters and the Lakota originators were also from widely disparate cultures. While the popular accounts (as in the case of obsidian) portray the practice in terms of a frozen pre-historic past, in fact this case of indigenous knowledge shows a dynamic history.

Both examples of exploiting nanoscale properties of obsidian and quartz are merely the tip of the iceberg for the intimate knowledge of physical and chemical phenomena that indigenous societies have accumulated through centuries of experimentation. The Gwich'in Athabascan tribe in Alaska, for example, has over 60 artifacts/products they produce from the birch tree (Engbloom-Bradley 2006). They not only differentiate use between botanical parts of the tree (bark, roots, etc) but also more subtle variations: for example they use the north side of the tree to make arrows because of its greater hardness, and the south side to make bows because of its greater flexibility. Plant extracts such as resins and saps are one of the most common indigenous encounters with chemistry: traditional uses include adhesives for crafting artifacts, water-proofing for containers, incense for religious ceremonies, medicinal compounds, and many other applications (Langenheim 2003).

As in the previous examples of wootz and obsidian, indigenous use of plant extracts has also been in a long-term conversation with western science: imagine what the history of technology would have been without rubber, a plant extract introduced to Europeans by South American Indians? Synthetics did not simply replace these natural extracts, since some required plant extracts as part of their production (eg the addition of camphor to make celluloid), and many of these plant extracts are still in use today (e.g. shellac). As Peters (1994) notes, resin tapping "probably comes the closest to conforming to the ideal of sustainable non-timber forest product extraction" and shows great promise for linking indigenous economic development with forest conservation. One exemplar in this case is investigation of Spiniflex resin through collaboration between the indigenous people of the Myuma Group in northwest Queensland and the Aboriginal Environments Research Centre at the University of Queensland's School of Architecture. The Research Centre's Director, Professor Paul Memmott, notes that the project includes experts botany, bio-nano engineering, chemistry and architecture, as well as Aboriginal community members ranging from elders with traditional knowledge to postgraduate student Malcolm Connolly, who conducts experiments in harvesting and regrowth of the plant.

One special category in the relation of nanoscale effects and indigenous knowledge is constituted by the cases in which there is a contrast between our normal expectations of physical phenomena, and the counter-intuitive physics enabled by certain specific nanoscale structures. For example, the indigenous descriptions of the Lakota *yuwipi* ceremony specifically mention the blue color of the sparks, differentiating them from sparks generated by combustion. This special category—indigenous knowledge which derives from counter-intuitive physics— is particularly important because of its potential for establishing the kinds of cultural connections that could be applied to educational contexts. In the west we think of magic as something requiring illusion or fakery; something hidden up the sleeve or done with mirrors. But many traditional examples of African "magic" are performed openly, and depend on counter-intuitive physics. Some of these are related to nanoscale phenomena. For example, Anthropologist Paul Stoller reported that during his apprenticeship to a Songhay sorcerer, he witnessed his teacher spread a fine powder on the surface of a bowl of water, and then retrieve an item from the bottom of the bowl without getting his fingers wet (Stoller 1987). Such demonstrations of surface tension are common in contemporary science classes (where lycopodium powder is typically used). Another example occurs in the Bayaka society of central Africa, where fluids from a luminescent fungus are used as body paint during a night-time ritual (Sarno 1993). This author has observed percolation of smoke through compacted damp soil (perhaps depending more on microscale than nanoscale pores) used by a healer in Cameroon to invoke spiritual forces.

Connections to nanotechnology in traditional knowledge at the macroscale

Finally, certain macroscale structures found in traditional knowledge systems also offer important cultural connections to nanoscale phenomena. The relation between fullerene molecules and the geodesic domes of Buckminster Fuller is well known. Less well known are the use of similar structures in baskets and other indigenous artifacts. Paulus Gerdes, professor of mathematics in Mozambique, has studied the use of hexagonal weaving patterns in Africa and indigenous cultures elsewhere (India, Brazil, Malaysia, etc.), and has investigated their use in modeling fullerenes (Gerdes 1998). As a flat sheet the weave resembles the structure of graphite; rolled into a cylinder it resembles a nanotube. Gerdes notes that weavers introduce a pentagonal weave when they need a corner. Figure 1 shows a Malaysian sepak ball in which the pentagons and hexagons tile the surface, creating a structure isomorphic to that of a $\mathbf{C_{60}}$ fullerene molecule (i.e. both are truncated icosahedrons). Gerdes' work demonstrates how all the fullerene structures can be generated using this indigenous weaving technique.

Figure 1a Malaysian sepak ball

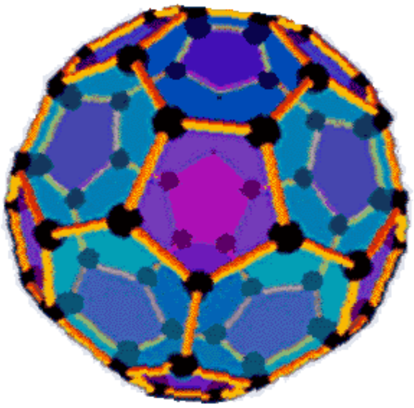

Figure 1b $\mathbf{C_{60}}$ fullerene molecule

Other macroscale connections can be found under the rubric of self-organization, which is used in both nanotechnology (molecular self-assembly) and indigenous social organization. A particularly vivid example of indigenous self-organization can be found in the fractal structure of African settlement patterns, where consistent geometric patterns occur over several magnitudes of scale (Eglash 1999). Coppens (2009) provides an extensive list of fractal nanostructures with implications for improving environmental sustainability.

It is important to distinguish between the previous examples based on knowledge of physical properties— wootz steel, Lakota rattles, etc.—and these examples of macro-scale structures. There is no evidence that any indigenous group had knowledge of nanoscale geometry, and the pop-culture texts that claim such knowledge for ancient Hindus or Zen Buddhists are detrimental to scholarly work. Macro-scale structures are significant because they show indigenous knowledge of relations between geometry and physical properties (eg the structural integrity afforded by a hexagonal mesh). The fact that analogous relations between geometry and physical properties can also apply at the nanoscale is not part of any traditional knowledge, but that does not mean the analogy cannot be applied to nanoscale science education.

Applications of traditional knowledge to nanoscale science education

Research by many scholars indicates that some of the statistically poor record of achievement and participation in science, technology, engineering and math (STEM) disciplines by African American, Latino, and Native American youth can be attributed to cultural barriers. One barrier can be found in myths of genetic determinism, which lowers expectations for minority students and thus becomes a self-fulfilling prophecy. Another barrier can be found in myths of cultural determinism. For example African American students sometimes perceive a forced choice between Black identity and high scholastic achievement (Ogbu and Simons 1998). Many high-achieving African American students report that they have been accused of “acting white” by their peers (Austen-Smith and Fryer 2005). Similar assessment of cultural identity conflict in education has been reported for Native American, Latino, and Pacific Islander students.

Cultural connections to science and technology can be important resources for defeating these barriers. Both myths of genetic determinism and myths of cultural determinism can be contradicted by evidence for sophisticated bodies of knowledge from the heritage cultures of these students. Again, it is important to note that the epistemological status of the traditional practice is critical to this use: merely showing that one can carry out a nanoscience analysis of an indigenous material is far weaker than showing an indigenous knowledge system which makes intentional use of a nanoproperty. Case studies have shown effective culturally situated learning for minority students (cf. Lipka and Adams 2004) when using the epistemologically stronger examples of intentional knowledge. In one recent study black middle school student responses to nanotechnology education were less engaged than those of white peers; researchers concluded that experiences that were more “connected to students’ lives” would stand the best chance of addressing this disparity (Jones et al 2007).

Our own research results in math education also support this culturally situated framework. Culturally Situated Design Tools (CSDTs) are web applets based on ethnomathematics: in particular the mathematical knowledge embedded in cultural designs such as cornrow hairstyles, Native American beadwork, Latino percussion rhythms, urban graffiti, and others (http://www.csdt.rpi.edu/). CSDTs allow students to use these underlying mathematical principles to simulate the original cultural designs, create new designs of their own invention, and engage in specific math inquiries. Preliminary evaluations with minority students indicate statistically significant increase in math achievement, attitudes towards math, and attitudes toward technology-based careers (Eglash et al 2006).

Surprisingly we did not see a strong correlation between design tool selection and heritage identity: minority students who had been trained in the use of all the tools, and were allowed to select any tool for their final project, did not show an overwhelming preference for designs from their own ethnic group. On the other hand we often saw cases of “appropriation”—African American students using the Native American beadwork tool to create something similar to graffiti tags, or Latino students using the graffiti tool (based mainly on samples from New York City) but creating artwork that specifically reflected Latino cultural origins. Such appropriation fits well with the recent studies on the formation of cultural identity by contemporary youth, which replaces older models of ethnicity as a static “given” with portraits of youth in the process of actively constructing their identity, often in terms of hybridity and syncretism (Pollack 2004).

This observation on the importance of creativity and flexibility in culture-based education frameworks creates a challenge for culturally situated nanoscience education, which may lend itself less to design or other potentially expressive activities. In February of 2008 we conducted a brief workshop with African American students at RPI using Gerdes’ African weaving approach. The website includes video clips of Baka women in Cameroon weaving a basket using a hexagonal lattice, visual content showing the connection between the woven artifacts and molecular structures, and finally instructions for creating a $\mathbf{C_{60}}$ fullerene molecule model using paper hexagonal weaves. The workshop successfully competed for students with other programs offered at the same time, drawing approximately 50 African American youth, with a majority of girls (possibly due to the weaving connection to gender). A longer program in summer 2009 at SUNY Albany's "Nanoscale Technology and Youth" program offered middle school students the opportunity to take several different nanotechnology workshops. At the end they selected images from our African weaving workshop over the other workshops as the image for their tee-shirts. Both the 2008 and 2009 sessions indicated that the African weaving approach to creating a $\mathbf{C_{60}}$ fullerene molecule model were sufficiently engaging to compete with other activities. The current technique requires multicolored strands with numbers at specific intersections; this method is probably not the optimal in simplicity, and we suspect that it discourages the students from using the weaving technique creatively, but clearly there is a strong potential for sparking interest through a cultural connection to nanotechnology.

Another site in the CSDT suite offering a nanoscale connection is the Anishinaabe Arcs tool, which offers simulations of wigwams, long houses, canoes, and other structures based on wooden arcs. The arcs are placed in very specific geometric relationships, such that a strong case can be built for indigenous geometric knowledge (e.g. their use of four-fold symmetry maps the western Cartesian system on to Anishinaabe practices, cosmology, etc.). The building materials are carefully selected in terms of species, time of year, etc. to obtain the maximum structural characteristics (elasticity, strength, etc.) as they must be placed into tension to form arcs. We tested our prototype with Anishinaabe students in a summer camp run by the Native American Studies center at Northern Michigan University. In contrast to the African weave, students were highly creative with this tool and produced a wealth of different forms (eg figure 2).

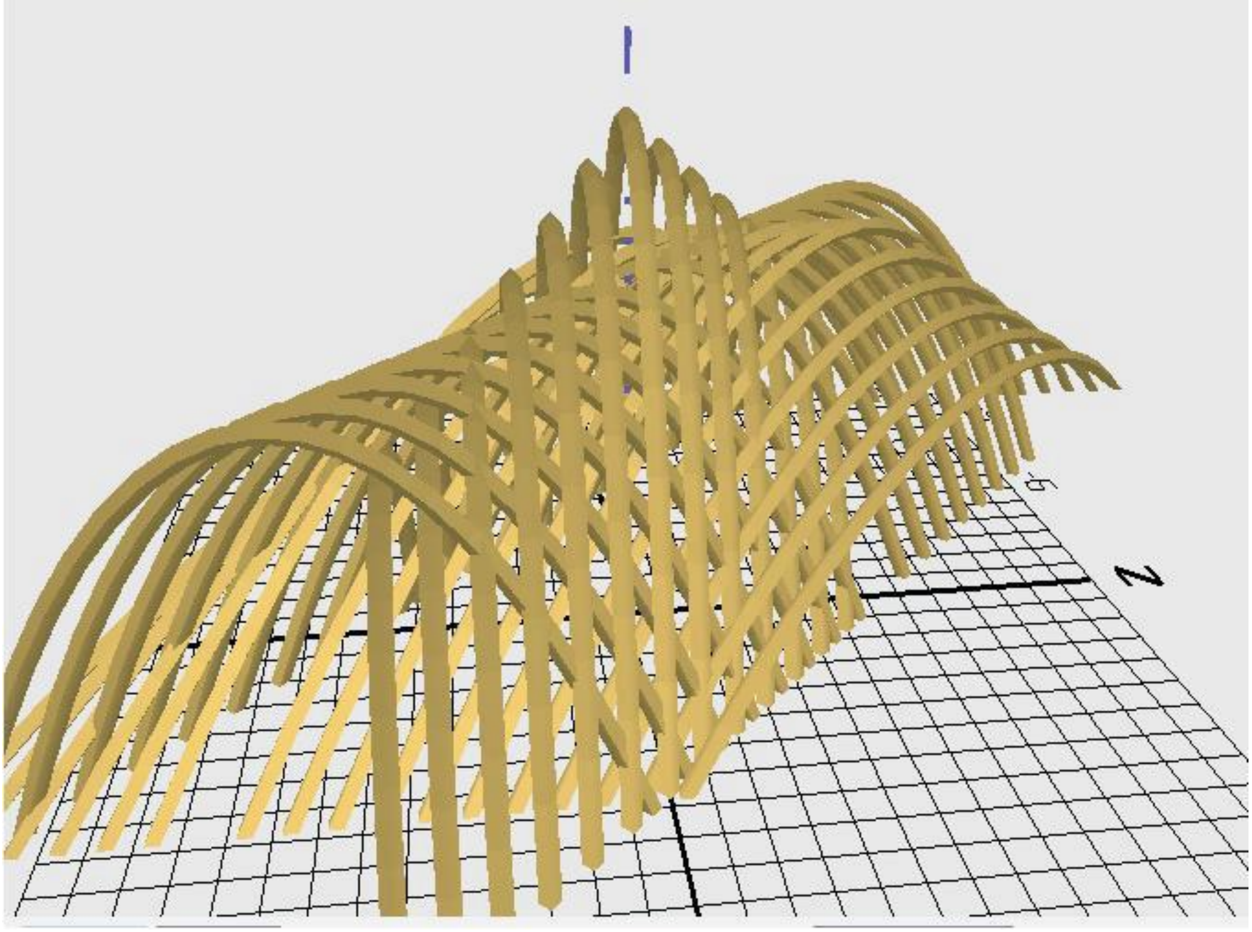

Figure 2: Design created by Potawatomi student with the "Anishinaabe Arcs" tool at www.csdt.rpi.edu.

The combination of computer graphics and creativity was also important in allowing them to master several mathematical concepts (e.g. Cartesian coordinates). However when we asked the students to critique the website, they selected the nanoscale section as the weakest case for indigenous knowledge. That is no doubt a reflection of our own ignorance regarding their knowledge of materials: we had focused on the changes in wood cells that accompany the drying process, rather than more subtle or non-intuitive processes that a deeper knowledge of the materials would have produced.

Finally, we tested Mayan Blue with a mixed group of Latino and African American students during an after-school program (figure 3). Students created their own Mayan Blue mix, heated it in a kiln, and painted it on white tiles. Pre/post test contrasts showed that "preventing pollution" became more strongly associated with nanotechnology after the workshop, although the small sample size (8 students) prevented statistical significance.

Figure 3: students prepare Mayan Blue by mixing indigo with palygorskite clay

Applications of traditional knowledge to intellectual property rights of nanotechnology

In several cases groups opposed to foreign ownership of traditional knowledge have used the legal system to prevent the misappropriation of patents (Ruiz 2002, Hansen and VanFleet 2003, Nicholas and Bannister 2004). The best publicized cases are those of the Turmeric Patent (US Patent No. 5,401,504), the "Neem" (Azadirachta indica) Patents (over 40 in the US), and the "Ayahuasca" (Banisteriopsis caapi) Patent (US Plant Patent No. 5,751). There are five fundamental concerns at work; I will number them as follows for later reference. First, that a patent unjustly appropriates the intellectual resources of the culture which created the knowledge. Second, that non-traditional use may offend indigenous cultural or spiritual sensibility or disrupt the social order. Third, that a patent could block that culture from further development of its traditional knowledge, or even its use. Fourth, that traditional knowledge properly belongs in the public domain, whereas a patent would privatize this knowledge. Fifth, that traditional knowledge practices serve an important role in protecting species, ecosystems and landscapes. These 5 objections are not mutually compatible—indigenous IP rights would undermine public domain claims, for example—but that merely underscores the diversity of cultural traditions and contexts connected to these knowledge systems.

In 1992 the United Nations Convention on Biological Diversity (CBD) used the fifth reason, protection of the ecosystem, to introduce the first regulations involving traditional knowledge. The CBD, coupled with organizing efforts by various indigenous groups and their advocates (Declaration of Belem, Indigenous Peoples Earth Charter, etc.) eventually led to an investigation by the World Intellectual Property Organization (WIPO), which broadened the rationale beyond the fifth to include numbers one to three. WIPO established the Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore. This committee is primarily focused on "negative protection;" that is, a view of traditional knowledge as "prior art." For example, sub-section 102(f) of the US Patent Act (35 U.S.C.) specifies that a patent will not be awarded when the applicant was not the original inventor. Thus any traditional knowledge – whether published or unpublished, whether in the US or abroad—which proves that the applicant is not the inventor could be a basis for rejecting the application. A second form of "positive protection" concerns protective legal rights over traditional knowledge as part of cultural self-determination. In US law for example many Native American tribes have retained their sovereign rights (albeit only in the wake of genocidal policy and extensive legal battles), and have maintained that their knowledge systems fall under these sovereign rights as much as land claims do (Brown 2003).

These strategies have had some success in defeating patent misappropriation (sometimes referred to as "biopiracy"). For example in 1986 American scientist Loren Miller obtained a U.S. patent on a strain of the ayahuasca vine, which had been used by traditional healers in the Amazon for many generations. Antonio Jacanamijoy, leader of a council representing more than 400 indigenous tribes in South America, achieved a rejection of the ayahuasca patent by the U.S. Patent Office in 1999. A U.S. patent for the use of turmeric in wound healing was awarded to the University of Mississippi Medical Center in 1995, despite its much publicized traditional medicine use in India. A complaint was filed by India's Council of Scientific and Industrial Research, and the U.S. patent office revoked the University of Mississippi's patent in 1997. In 1995 the U.S. Department of Agriculture and a pharmaceutical research firm were awarded a patent on an anti-fungal agent from the Neem tree, which was used in traditional medicine in India. Following widespread public outcry, legal action was pursued by the Indian government, and the patent was eventually overturned in 2005.

Could the traditional knowledge involving material nanoproperties—wootz steel, Mayan Blue, obsidian blades, etc.—play a similar role in protecting the intellectual property rights of indigenous groups? At least two barriers are at play in these cases that were not prominent for the "biopiracy" cases. First, recall that the origins of IP protection of traditional knowledge in the United Nations' CBD were purely based on ecological impact; it was only later that other factors were added. Since these "indigenous nanotechnology" cases are more focused on material properties than ecological properties, they may not fit the CBD protections and hence the subsequent protections built on that foundation. Second these nanoproperty cases are often more difficult to connect to current populations, at least in cases in which they are no longer in use. However neither of these barriers are absolute. First, as nanotechnology becomes increasingly blurred with biotechnology, examples such as the Bayaka use of fungi will increasingly link biopiracy with what could perhaps be termed "nanopiracy." Second, cases such as Mayan blue are attractive precisely because they may provide environmentally preferable alternatives. Finally, as we have seen above, the popular descriptions of these nanoscience aspects of traditional knowledge often misleadingly present a portrait of knowledge frozen in an ancient or even pre-historic past, when in fact many of these technologies have been in dynamic play at least until the 19 century if not beyond, and thus are more connected to current populations than it might appear at first glance.

However it may be that traditional knowledge in the nanosciences will have an impact not as positive protection in terms of the sovereign rights of cultural self-determination, but rather as negative protection; constituting "prior art" that prevents patents from occuring at all. In such cases the motivation might be more aligned with number four, traditional knowledge as public domain knowledge. The reasons for this are well explicated in a recently publication by the ETC group's 2005 report on "Nanotech's "Second Nature" Patents: Implications for the Global South." They note, for example, that US patent 5,897,945 on nano-scale metal oxide nanorods covers not just one metal oxide, but oxides selected from any of 33 chemical elements (nanorods comprised of titanium, nickel, copper, zinc, cadmium, etc.) -- nearly one-third of all chemical elements in the Periodic Table in a single patent claim. And many of these nanotechnology patents are assigned to all of the major patent classes – including electricity; human necessities; chemistry/metallurgy; performing operations and transporting; mechanical engineering (lighting, heating, weapons, blasting); physics; fixed construction; textiles and paper. Despite the legal restrictions preventing patents on "natural phenomena," the breadth of nanotechnology patents at this (literally) elemental level, as well as the breadth of their application, suggest that many fundamental aspects of nature itself could become privatized as intellectual property.

The ETC group concludes by noting that "Patent claims on nano-scale formulations of traditional herbal plants are providing insidious pathways to monopolize traditional resources and knowledge," and recommend that protection take place by adding a nanotechnology component to the UN's CBD. However keeping in mind that the CBD was for the purpose of environmental sustainability, such a strategy may only support those cases of indigenous nanoscience that fit under the "biopiracy" rubric. A broader commitment to the protection of indigenous knowledge of nanoproperties, including those of purely inorganic origin (such as wootz) or organic-inorganic hybrids (such as Mayan blue) would provide better protection.

Conclusion

Traditional knowledge of nanoproperties, just like traditional knowledge of medicine, includes unique innovations that have already contributed to contemporary science and technology. But popular representations tend to portray them as curious artifacts frozen in an ancient past; only relevant as proof that science can reveal what the ancients failed to understand. The actual histories and contexts of this new class of traditional knowledge show a much more dynamic, vibrant set of practices that have in some cases provided important dialogs with the development of western science, and in other cases have applications that may lie in the future. Making these indigenous innovations available in a just and responsible manner--either as a component of culturally responsive education, or as protection against misappropriated intellectual property rights—hinges on properly understanding and representing their epistemological status.

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[i] There is a large literature on collective intentionality in philosophy of communication and cognition, but the vast majority concerns the question of its nature as a universal property of humans. For an exception that considers the cultural specificity of collective intentionality see Thalos (2008).

[ii] As Harding (2006) notes, we cannot afford a “tolerant pluralism” that leaves us without a critical apparatus for either scientific or social issues; nor can we simply fall back on a universalism that makes western science the monolithic repository of rationality and truth.

[iii] Although space does not permit a full discussion here, it is worth noting that wootz has not only empowered western science, but also western pseudoscience in the form of rhondite steel. Despite its entry in Wikipedia and various media reports about patent claims and commercial applications, this author’s investigation suggests that rhondite steel does not exist. Just as Bloor points out that we need to avoid the asymmetry that occurs if we only investigate failed science, we also need to avoid the reverse asymmetry of only investigating connections to successful science when discussion traditional knowledge.