Science Education: Border Crossing into the Subculture of Science

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In a seminal volume of Studies in Science Education, Maddock (1981) proposed "that science and science education are cultural enterprises which form a part of the wider cultural matrix of society and that educational considerations concerning science must be made in the light of this wider perspective" (p. 10). In the same volume, Wilson (1981) comprehensively reviewed a diverse literature dealing with the cultural context of science education. Over the ensuing years, research into multicultural science education has enriched Maddock's and Wilson's original work (for example, chronologically, Knamiller, 1984; George and Glasgow, 1988; Swift, 1992; Hodson, 1993). Recently Pomeroy (1994) clarified this accumulated body of literature into nine research agendas, each depicting a different facet of cross-cultural work. All of these studies looked at science education in non-Western countries or in indigenous societies, or science education for minority groups in industrialized countries (groups under represented in the professions of science and technology).

The purpose of this article is to reconceptualize a cultural perspective for science education, one that is informed by, but extends beyond the perspective painted by Maddock, Wilson, Pomeroy, and the others. The cultural perspective proposed here addresses science education for Western students in industrialized countries, and builds on the work of Costa (1995) and Hawkins and Pea (1987). My proposal offers an account of students' lived experiences in a science classroom by considering those experiences in terms of students crossing cultural borders, from the subcultures of their peers and family into the subcultures of science and school science. This theoretical frame of border crossing will provide Western science educators with a new vantage point from which to analyze familiar problems. It considers the typical science classroom as a cross-cultural event for many students, including the majority of Western students. The concept of border crossing may also shed light on the anthropological ideas Maddock (1981) proposed for non-Western, indigenous, and minority students.

In his 1981 article, Wilson challenged: "It is easy to assert that, to be effective, teaching must take full account of the multi-dimensional cultural world of the learner, to apply this principle in a particular situation, and to express it in terms of curriculum materials and classroom methods, is a formidable task" (p. 40). I take up this challenge in part by exploring the practical implications of cultural border crossings in terms of curriculum materials aimed at teaching science and technology for all students, no matter what borders they need to cross. This implication in turn will challenge a traditional goal subscribed to by many science educators, the goal of cultural assimilation of all students into science (AAAS, 1989; UNESCO, 1994).

I shall argue that science educators, Western and non-Western, need to recognize the inherent border crossings between students' life-world subcultures and the subculture of science, and that we need to develop curriculum and instruction with these border crossings explicitly in mind, before the science curriculum can be accessible to most students. The argument proceeds in several stages, moving from the theoretical to the practical: (1) a chronological overview of research on learning and the re-introduction of a cultural perspective for science education, (2) an explication of border crossings, (3) a more detailed description of cultures and subcultures, (4) an empirical description of borders that Western students cross to learn science, (5) a curriculum implication, and (6) critical issues to be resolved, along with some concrete proposals.

Towards a Cultural Perspective for Science Education Research

Let me state a naive yet potent proposition: If only we could understand how students make sense of their natural world, we could design a science curriculum so that science makes sense to all students. The proposition has spawned a ubiquitous research question: How do students make sense out of their natural world? Most research traditions in science education continue to address that question. A chronological and simplified overview of these traditions is provided here. Slightly different but more detailed accounts may be found in O’Loughlin (1992), Cobern (1993), and Solomon (1994b). My purpose here is to re-introduce a cultural perspective for science education, from which we can examine and critique the traditional goal of cultural assimilation for all students.

Behaviourism, assuming a tabula rasa student, investigated drill and practice, programmed learning, and the transmission of facts and principles. Its popularity with the general public as a model for learning is evident in much of the media criticism of education today (Lewington and Orpwood, 1993).

Personal constructivism then became a dominant field of research. Initially based on the work of Bruner, Piaget, and Ausubel, it developed into research on misconceptions, alternative frameworks, commonsense conceptions, untutored beliefs, and preconceptions (Driver and Easley, 1978; Driver and Erickson, 1983; Gilbert and Watts, 1983; Hills, 1989; Mayer, 1984; Pfundt and Duit, 1994). Almost all studies into rational conceptual change show that students successfully resist such conceptual change (West and Pines, 1985). Most students are not about to risk altering a useful commonsense conception in favour of a counter-intuitive abstraction advanced by a teacher or textbook (Cobern, 1994b; Hills, 1989). Students may be uneducated, but they are not stupid.

The research field broadened to take into account non-rational aspects of conceptual change and the context-dependent nature of concept development. Students' social worlds were seen to influence the way students make sense out of their natural world. Solomon (1983a) noted that life-world knowing contrasted and co-existed with science-world knowing, and in 1987 she developed a social constructivist perspective on learning: Science concepts have a socially negotiated meaning shared within a group such as a science class or peer group. Larochelle and Désautels (1991) demonstrated the power of students' epistemologies which they bring to the social setting of the science classroom. Driver (1989) emphasized the role of language and social negotiations in the science classroom. Shapiro (1989) and George (1995) enriched the social constructivist perspective by including a student’s personal orientation towards, for example, the science content, the teacher, and the school or institutional context. “Situated cognition” (Furnham, 1992; Hennessy, 1993; Lave, 1988) became a new current in science education literature and broadened the scope of social constructivism even further. It fostered ideas such as O’Loughlin’s (1992) socio-cultural model of teaching and learning (power, discourse, and culture in the classroom), Shapiro’s (1992) socio-cultural ecology (the personal, school, and political environments that create a type of environmental press on a student), and Jegede’s (1995) socio-cultural paradigm for non-Western students. In short, personal constructivism evolved into social constructivism.

Our perspective on how students make sense of their natural world widens even further if we consider the worldviews that students possess. Cobern (1991, 1993, 1994b) draws upon anthropology to hone a model of worldview comprised of seven "logico-structural categories" (self, other, causality, classification, relationship, time, and space). Worldview "provides a special plausibility structure of ideas, activities, and values, that allows one to gauge the plausibility of any assertion" (1993, p. 57, italics in the original). Worldviews are culturally validated presuppositions about the natural world. To understand a student's worldview is to anticipate what meanings in a science curriculum will appear plausible and which will not. Seen as a "fundamental organization of the mind" (Cobern, 1991, p. 42), worldview connects with cognitive psychology and lends itself to fruitful investigations into various worldviews, including those of Western science. However, as a culturally dependent fundamental organization of the mind, worldview suggests a broader perspective on science education: learning science as culture acquisition.

The view of learning science as culture acquisition affords an intuitive, holistic, and rich appreciation of students' experiences in a science classroom (Costa, 1995; Hawkins and Pea, 1987; Maddock, 1981; Swift, 1992; Wolcott, 1991). It is a practical extension of constructivist theories and plausibility structures. Driver's social constructivism has also moved towards a perspective of culture acquisition: "Learning science in the classroom involves children entering a new community of discourse, a new culture" (Driver, Asoko, Leach, Mortimer and Scott, 1994; p. 11). Research into personal, social, and worldview constructivism will continue to contribute significantly to the broadened conception of learning science as culture acquisition; for example, respectively, the work of Driver, Leach, Scott and Wood-Robinson (1994), Solomon, Duveen and Scott (1994), and Lawrenz and Gray (1995).

The cultural perspective proposed in this article recognizes conventional science teaching as an attempt at transmitting a scientific subculture to students (Hawkins and Pea, 1987). But cultural transmission can either be supportive or disruptive (Baker and Taylor, 1995; Battiste, 1986; Urevbu, 1987). If the subculture of science generally harmonizes with a student's life-world culture, science instruction will tend to support the student's view of the world ("enculturation"). On the other hand, if the subculture of science is generally at odds with a student's life-world culture, science instruction will tend to disrupt the student's view of the world by trying to replace it or marginalize it ("assimilation"). The distinction between the enculturation and assimilation forms of cultural transmission is central to the cultural perspective that I am proposing for science education. Enculturation appeals to students who are science enthusiasts while assimilation attempts to dominate the thinking of students. Both enculturation and assimilation require cultural border crossings into the subculture of science. This idea of border crossing is described in the following section before we consider the nature of culture and subculture.

Border Crossings

Three scenarios illustrate difficulties people encounter when they move between cultures or subcultures. In each scenario a misunderstanding arises because at least one of the players does not recognize a cultural border that needs to be crossed.

1. George and Gracie Smith flew from North America to Spain, physically crossing political borders, but not crossing cultural borders. After waiting 45 minutes for their dinner bill to arrive, George finally became vocally irate over the waiter's lack of service. The waiter, in turn, became hurtfully perplexed over the fact that his impeccable manners were not appreciated.
2. A First Nations student in Margo Zimmerman's 7th grade science class had not obtained the correct lab result. Ms. Zimmerman's frustration peaked after she asked him to explain to her and the class what might have gone wrong (so he could learn from his mistake), and yet again he spoke so quietly that no one could hear him. "You <u>must</u> speak up!" she demanded. The student had crossed physical borders by coming to her science room, but he had not crossed cultural borders into the subculture of her classroom. He felt very uncomfortable expressing himself when directed to do so by the teacher rather than being directed by the need to cooperate with other students.
3. University student Stirton McDougall disobeyed his faculty advisor by avoiding geology courses throughout his university career. Stirton did not want to spoil his aesthetic understanding of nature's beauty by polluting his mind with mechanistic explanations of the earth's landscapes. He understood science all to well and chose not to cross one of its borders. His advisor thought he was soft-headed and not worthy of a science scholarship.

These scenarios point out potential obstacles for students who travel from their own life-world culture to the subculture of a science classroom or to the subculture of science itself. Reinforcing the point Solomon (1983a) made when she first articulated the distinction between life-world knowing and science-world knowing, Hennessy (1993, p. 9) recently concluded, “Crossing over from one domain of meaning to another is exceedingly hard.”

Border crossings need not always be problematic, however. In our everyday lives we exhibit changes in behaviour as we move from one group of people to another; for instance, from our professional colleagues at a research conference to our family at a reunion. As we move from the one subculture to the other, we intuitively and subconsciously alter certain beliefs, expectations, and conventions; in other words, we effortlessly negotiate the cultural border between professional conferences and family reunions. (From a worldview perspective, this alteration in our responses to a changing social situation is explained by Cobern, 1994b, as a shift in our priorities of worldview presuppositions. Worldview presuppositions tend to be reflective analytical entities. From a cultural perspective, on the other hand, features of culture that correspond to Cobern's worldview perspective tend to be intuitive, commonly held experiences. Thus, the idea of border crossing promises greater currency for curriculum developers and teachers than "shifts in worldview presupposition priorities.")

On the other hand, border crossings can be problematic. For instance, the border crossing between humanistic and scientific subcultures has been a concern to science educators ever since C.P. Snow (1964) wrote The Two Cultures. Moreover, research into the difficulties of non-Western students learning Western science has identified obstacles experienced by students who have an indigenous "traditional" background and attempt to learn a subject matter grounded in Western culture (Baker and Taylor, 1995; Dart, 1972; Jegede, 1994; Jegede and Okebukola, 1990, 1991; Knamiller, 1984; MacIvor, 1995; Ogawa, 1986, 1995; Pomeroy, 1994; Swift, 1992). This research on students in non-Western countries can help Western science educators understand how their own students need to cross borders; for instance, from a humanities oriented life-world to the science-world of school science.

Border crossings always involve cultures or subcultures. We now turn our attention to a more detailed description of culture and subculture to clarify what they mean, before we examine research which suggests that a cultural perspective for science education has merit for curriculum developers and teachers.

Cultures and Subcultures

Students' understanding of the world can be viewed as a cultural phenomenon (Spindler, 1987), and learning at school as culture acquisition (Wolcott, 1991), where culture means "an ordered system of meaning and symbols, in terms of which social interaction takes place" (Geertz, 1973, quoted in Cobern, 1991, p. 31). We speak about, for example, a Western culture, an Oriental culture, or an African culture because members of these groups share, in general, a system of meaning and symbols for the purpose of social interaction. Geertz’s anthropological definition is given more specificity by Phelan, Davidson, and Cao (1991) who conceptualize culture as the norms, values, beliefs, expectations, and conventional actions of a group.

Other definitions of culture have guided research in science education; for example, Banks (1988), Bullivant (1981), Ingle and Turner (1981), Jordan (1985), and Samovar, Porter and Jain (1981), from which one could establish the following list of attributes of culture: communication (psycho and sociolinguistic), social structures (authority, participant interactions, etc.), customs, attitudes, values, beliefs, worldview, skills (psycho-motor and cognitive), behaviour, and technologies (artefacts and know-how). In various studies, different attributes of culture have been selected to focus on a particular interest in multicultural science education. For instance, Maddock (1981, p. 20) listed "beliefs, attitudes, technologies, languages, leadership and authority structures" while Ogawa (1986) addressed a culture's view of humans, its view of nature, and its way of thinking.

I have chosen to follow Phelan et al.'s (1991) definition of culture for two reasons. First, it has a relatively small number of categories that can be interpreted broadly to encompass the anthropological attributes listed just above, as well as the educational attributes often associated with science instruction: knowledge, skills, and values. Canonical scientific knowledge will be subsumed under "beliefs" in Phelan et al.'s definition. A second reason for my choice is coherence. My argument for a cultural perspective for science education, along with its border crossing requirements, will be based on some recent research by Costa (1995) who framed her work by Phelan et al.'s definition of culture.

Within every culture group there exist subgroups most commonly identified by race, language, and ethnicity, but who can also be defined by gender, social class, occupation, religion, etc. Consequently, an individual simultaneously belongs to several subgroups; for instance, an Oriental female Muslim physicist or a male middle-class Euro-American journalist. Large numbers and many combinations of subgroups exist due to the associations that naturally form among people in society. In the context of science education, Furnham (1992) identified several powerful subgroups that influence students’ understanding about science: the family, peers, the school, the mass media, and the physical, social, and economic environment. Each identifiable subgroup is comprised of people who generally embrace a defining set of norms, values, beliefs, expectations, and conventional actions. In short, each subgroup shares a culture, which I shall designate as “subculture” to convey an identity with a subgroup. We can talk about, for example, the subculture of females, the subculture of the middle class, the subculture of the media, or the subculture of a particular science classroom. Phelan et al. (1991) used a cluster of four subgroups in their anthropological research with students: families, peer groups, classrooms, and schools. This cluster will provide the generic framework for my analysis of border crossings by students in science classrooms, and is described in a later section.

Subculture of Science

We need to recognize that science itself is a subculture of Western or Euro-American culture (Baker and Taylor, 1995; Cobern, 1991, Ch. 5; Dart, 1972; Jegede, 1994; Maddock, 1981; Ogawa, 1986; Pomeroy, 1994), and so Western science can be thought of as "subculture science." Scientists share a well defined system of meaning and symbols with which they interact socially. This system was institutionalized in Western Europe in the 17th century, and it became predominantly a white male middle-class Western system of meaning and symbols (Mendelsohn, 1976; Rose, 1994; Simonelli, 1994). To emphasize this cultural makeup of science, some authors have represented "science" with the acronym WMS, which either means "Western modern science" (Ogawa, 1995) or "white male science" (Pomeroy, 1994).

Opposition to treating science as a cultural enterprise has arisen, however, mostly because the idea tends to undermine a philosophical presupposition called “the universality of science” -- science is the same everywhere; that is, science uncovers knowledge or solves problems irrespective of the culture, race, or gender of the individual scientist involved (Stanley and Brickhouse, 1994). The debate over the universality of science is not new, but it became contentious in a recent exchange in Science Education (Brickhouse and Stanley, 1995; Good, 1995; Loving, 1995; Stanley and Brickhouse, 1995) and at the 1993 and 1995 annual meetings of the National Association for Research in Science Teaching. Speaking against the universality of science, Munro (1993, p. 4) asked: What does this tell us about those who believe such a notion? Science educators embracing a cross-cultural perspective have published a variety of responses: “naive” (Ogawa, 1986), suffering from "Cartesian anxiety" (Stanley and Brickhouse, 1995), "colonialist" (Brickhouse and Stanley, 1995), or "racist" (Gill and Levidow, 1987; Hodson, 1993). The controversy will surely continue. Accordingly, it is important to acknowledge the fact that a cultural perspective for science education treats science as a cultural enterprise and this represents a radical shift in thinking for some science educators.

Science does have norms, values, beliefs, expectations, and conventional actions that are generally shared in various ways by communities of scientists. Hence, science satisfies the definition of culture established by Phelan et al. (1991). Although these norms, values, etc. vary with individual scientists and situations (Aikenhead, 1985; Cobern, 1991; Gauld, 1982; Ziman, 1984), the following list dominates the literature that describes cultural features of Western science (even though some items on the list turn out to be merely public facades): mechanistic, materialistic, masculine, reductionistic, mathematically idealized, pragmatic, empirical, exploitive, elitist, ideological, inquisitive, objective, impersonal, rational, universal, decontextualized, communal, violent, value-free, and embracing disinterestedness, suspension of belief, and parsimony (Fourez, 1988; Gauld, 1982; Harding, 1986; Kelly, Carlsen, and Cunningham, 1993; Rose, 1994; Savon, 1988; Simonelli, 1994; Smolicz and Nunan, 1975; Snow, 1987; Stanley and Brickhouse, 1994).

To summarize the terminology, subculture science (Western science) possesses cultural features that define the subculture of science (the culture of Western science).

Subculture of School Science

Closely aligned with subculture science is school science which expects a student to acquire science's norms, values, beliefs, expectations, and conventional actions (the subculture of science) and make them a part of his or her personal world to varying degrees (AAAS, 1989; Cobern, 1991, Ch. 5; Gauld, 1982; Layton, Jenkins, Macgill and Davey, 1993; Maddock, 1981; Pomeroy, 1994), as well as to acquire the community's dominant culture (Archibald, 1995; Battiste, 1986; Krugly-Smolska, 1995; Ermine, 1995; Maddock, 1981; Stanley and Brickhouse, 1994). School science has been observed by educational researchers as attempting, but often failing, to transmit an accurate view of science (Cobern, 1991, Ch. 5; Duschl, 1988; Gaskell, 1992; Millar, 1989; Nadeau and Désautels, 1982; Ryan and Aikenhead, 1992; Smolicz and Nunan, 1975). Unfortunately, the "taught" science curriculum, more often than not, provides students with a stereotype image of science: socially sterile, authoritarian, non-humanistic, positivistic, and absolute truth.

When this stereotype of science is transmitted in a science lesson, the conclusion that Krugly-Smolska (1995) drew, erroneously I suggest, is that science is presented as having no culture -- it is "presented aculturally and as `truth'" (p. 45). The instruction described by Krugly-Smolska may have dishonestly <u>pretended</u> that science has no culture, but instruction steeped with stereotype messages about the nature of science <u>does</u> convey norms, values, beliefs, expectations, and conventional actions of scientists, and therefore, such instruction does convey a subculture of science, albeit a mythical, a logical positivist, or a stereotypical subculture. My point is that the subculture of <u>school</u> science always conveys images of science as a subculture, even though science educators may pretend that it does not, or may disagree over those images (for example, note the contradictions in the descriptors of science listed in the previous section). And as a consequence, science educators may transmit to students different views of what the subculture of science is all about (Brickhouse, 1990; Lederman, 1992). To suggest that school science can present science as culture-free is simply to characterize the subculture of science by its stereotype features.

The stereotype image of science tends to affect negatively the career choices made by some bright imaginative science enthusiasts who quickly get out of science upon graduation from high school (Oxford University Department of Educational Studies, 1989). Therefore, one can well imagine the impact that these same images of science might have on students who are less sympathetic to the subculture of science. This issue is taken up later in the article.

Although some culture-related research on school science has been conducted within Western settings (for example, Atwater and Riley, 1993; Barba, 1993; Krugly-Smolska, 1995; Lee, Fradd and Sutman, 1995; Rakow and Bermudez, 1993), most culture-related research is found in non-Western settings (Baker and Taylor, 1995; George, 1992, 1995; Jegede, 1994, 1995; Knamiller, 1984; Maddock, 1981; Pomeroy, 1994; Swift, 1992; Urevbu, 1987; Wilson, 1981) where disparities abound between the subculture of science and the students' traditional cultures. Of interest to this article will be the vantage point achieved by taking a cross-cultural perspective on the daily experiences of many European and North American students in science classrooms.

Science education's goal of cultural transmission runs into ethical problems in a non-Western culture where Western thought (science) is forced upon students who do not share its system of meaning and symbols (Baker and Taylor, 1995). As mentioned above, the result is not enculturation, but assimilation or "cultural imperialism" -- forcing people to abandon their traditional ways of knowing and reconstruct in its place a new (scientific) way of knowing (Battiste, 1986; Jegede, 1994, 1995; MacIvor, 1995). Cultural imperialism, or the "arrogance of ethnocentricity" as Maddock referred to it (1981, p. 13), can oppress and disempower whole groups of people (Ermine, 1995; Gallard, 1993; Gill and Levidow, 1987; Hodson, 1993; Urevbu, 1987). School science traditionally attempts to enculturate or assimilate students into the subculture of science.

School science has other social functions which characterize its cultural makeup, functions familiar to science educators as educational goals. Fensham (1992) pragmatically summarizes these goals in terms of societal interest groups competing for privilege and power over the science curriculum. For example, school science (most often physics) can be used to screen out students belonging to marginalized social groups, thereby providing high status and social power to the more privileged students who make it through the science "pipeline" and enter science-related professions (Anyon, 1980; Giroux, 1992; Jegede, 1995; Posner, 1992) -- those who can "cut the mustard," to use the rhetoric of the scientific community. Fensham (1992) categorizes this societal self-interest as political. His other categories are: economic interests of business, industry, and labor, for a skilled work force; university scientists' self-interests in maintaining their discipline; societal groups' interests for empowerment in a nation whose culture and social life are influenced by science and technology; and students' interests for individual growth and satisfaction. School science is a potent cultural force in any society, a force that impinges upon most students daily.

Another aspect to the subculture of school science should be mentioned. Most students view orthodox science content as having little or no relevance to their life-world subcultures. "Science learned in school is learned as science in school, not as science on the farm or in the health clinic or garage" (Medvitz, 1985, p. 15). Cobern (1994b) similarly talks about students practising "cognitive apartheid," referring to the isolation and segregation of school science content within the minds of students. Jegede (1995) has proposed a “collateral learning theory” to explain various degrees of cognitive apartheid. The foreign nature of science content has been the focus of research in the field of situated cognition (Furnham, 1992; Hennessy, 1993; Ryle, 1954) which concludes that scientific content traditionally learned at school can seldom be applied to the everyday world. This finding seriously compromises Fensham’s economic goal of building a skilled labour force for national development (Layton, 1991; Medvitz, 1985).

Other Subcultures

In addition to the subcultures of science and school science, students must deal with, and participate in, an array of other important subcultures in their lives associated with: (1) the institution of school itself (the community’s instrument of cultural transmission), (2) various peer groups, (3) the family, and (4) the mass media (Furnham, 1992). Participation in different subcultures creates the need to cross borders between these subcultures. Researchers Phelan et al. (1991) have investigated this phenomenon and describe their findings this way:

> On any given school day, adolescents in this society [the United States] move from one social context to another. Families, peer groups, classrooms, and schools are primary arenas in which young people negotiate and construct their realities. For the most part, students' movement and adaptations from one setting to another are taken for granted. Although such transitions frequently require students' efforts and skills, especially when contexts are governed by different values and norms, there has been relatively little study of this process. From data gathered during the first phase of the Students' Multiple Worlds Study, it appears that, in our culture, many adolescents are left to navigate transitions without direct assistance from persons in any of their contexts, most notably the school. Further, young people's success in managing these transitions varies widely. Yet students' competence in moving between settings has tremendous implications for the quality of their lives and their chances of using the education system as a stepping stone to further education, productive work experiences, and a meaningful adult life. (p. 224)

Viewed from this cultural perspective, we see that learning science is influenced as much by diverse subcultures within a student's life-world, as it is by a student's prior knowledge and the “taught” curriculum -- the purview of constructivism and the science-world of the teacher.

Even though students cross cultural borders between their science class, school, peers, and family, these borders can seem invisible to educators; for example, to Margo Zimmerman in the scenario described earlier. Borders can even seem invisible to the "unfortunate" students who find science a foreign experience. This is where non-Western cross-cultural studies in science education can help clarify the border crossing problems for the conventional European or North American student. Ogawa (1995) in Japan, and Kawagley (1990) in Alaska's Yup'ik nation, contemplated why certain groups of non-Western students living with traditional beliefs about the physical world achieved academic superiority over certain groups of Western students, on "Western modern science" examinations. Similarly Krugly-Smolska (1995) was surprised to discover that non-Western immigrants to Canada often did better than their Canadian counterparts in high school science courses. She concluded that the successful non-Western students exhibited culture-related values of cooperation and attentiveness, and that they caught on quickly to "the cultural expectations of the classroom" (p. 56) -- the subculture of school science. Both Ogawa and Kawagley concluded that the culture of Western science is equally foreign to Western and non-Western students, for similar reasons. Non-Western students have acquired a traditional culture of their community, which interferes with learning Western science. In the same vein, Western students have their commonsense understanding of their physical world; that is, their "traditional" science -- their preconceptions -- that makes sense within their life-world subcultures. Thus, Western students also have difficulty acquiring the culture of Western science (Kawagley, 1990; Ogawa, 1995). However, I would quickly add, so do non-masculine students; so do humanities-oriented non-Cartesian thinking students; and so do students who are not clones of university science professors (Haste, 1994; Seymour, 1992; Tobias, 1990).

Within Western culture, and therefore within every European or North American science class, the subculture of science has borders that many students may find difficult to negotiate. We now turn to the empirical evidence that documents this suggestion.

Borders that Students Cross

Phelan et al.'s (1991, p. 228) model of students' multiple worlds helped explore how students move from one world to another. Their data suggested four types of transitions: congruent worlds support <u>smooth</u> transitions, different worlds require transitions to be <u>managed</u>, diverse worlds lead to <u>hazardous</u> transitions, and highly discordant worlds cause students to resist transitions which therefore become virtually <u>impossible</u>.

Guided by this model, Costa (1995) gathered qualitative data (the words and actions of students) on 43 high school students enrolled in chemistry or earth science in two schools with diverse student populations. She concluded: "Although there was great variety in students' descriptions of their worlds and the world of science, there were also distinctive patterns among the relationships between students' worlds of family and friends and their success in school and in science classrooms" (p. 316). Costa described these patterns in terms of five categories. In this article, these categories will help clarify some critical issues that we face when we consider the consequences (to the curriculum) of a cultural perspective for science education. Costa's five categories are:

> Potential Scientists: Worlds of family and friends are congruent with worlds of both school and science.
>
> Other Smart Kids: Worlds of family and friends are congruent with world of school but inconsistent with world of science.
>
> "I Don't Know" Students: Worlds of family and friends are inconsistent with worlds of both school and science.
>
> Outsiders: Worlds of family and friends are discordant with worlds of both school and science.
>
> Inside Outsiders: Worlds of family and friends are irreconcilable with world of school, but are potentially compatible with world of science. (p. 316, italics added).

Each of these categories is briefly described here, transposed to a cultural perspective on learning science proposed in this article.

Potential Scientists

Potential Scientists tend to hold professional career aspirations for which their science classes play a significant role. Even bad experiences with science teachers are overlooked in order to sustain the centrality of science for their career plans. A family member or friend usually serves as a role model, or if not, they at least provide strong encouragement. Generally, Potential Scientists view themselves as having the potential to participate in society's power structures and to generate knowledge. They appear comfortable with the stereotype image of modern science described earlier (in the section "subculture of school science"). They enjoy the challenges of the academic subject matter. The subcultures of school and science are indeed congruent with their subcultures of family and peers. Not surprisingly, Costa found a relatively disproportionately high number of Euro-American males in this group. For Potential Scientists (who may or may not actually become scientists or engineers), school science is enculturation

(Hawkins and Pea, 1987) and a type of rite of passage (Costa, 1993). Border crossing into school science for Potential Scientists is so smooth and natural that borders appear invisible.

Other Smart Kids

Other Smart Kids (a phrase Costa borrowed from Tobias, 1990) do well at school, even in science, although science is neither personally meaningful nor useful to their everyday lives. Science is, however, necessary for their post secondary plans. Like Potential Scientists, Other Smart Kids do not question the traditional stereotype norms, values, beliefs, expectations, and conventional actions of the scientific community. They prefer, however, to engage in creative activities that require self-expression and human interactions, making themselves candidates for C.P. Snow's (1964) humanistic culture. "Science courses seem more fact-oriented, memorization-oriented, more focused, neat and orderly, more predictable and analytic, than their non-science classes" (Costa, 1995, p. 321). Other Smart Kids choose not to take up science once they graduate because they find the subculture of science to be personally unimportant and inconsistent with the subcultures of their school, peers, and family. Other Smart Kids refuse to be enculturated into the subculture of science. But border crossing into school science is managed so well that few students express any sense of science being a foreign subculture.

"I Don't Know" Students

Costa's "I Don't Know" Students were labelled for their ubiquitous response to a host of questions about science and about school, and for their noncommittal overall attitude toward school science. Generally science classes were no different than other classes at school. The subcultures of school and science are equally inconsistent with the subcultures of their peers and family. Although "I Don't Know" Students usually take a minimum number of science courses and tend to occupy lower track classes, they usually achieve reasonably well. School grades have personal meaning -- "I don't want to look like a dummy!" These students have learned to play the school game of passing a course without understanding the content, a game not unfamiliar to Other Smart Kids and to some Potential Scientists as well (Prosser, Trigall and Taylor, 1994). The game can have well established procedures (forming part of the unintended "learned" curriculum) which can be discovered by carefully listening to students. Larson (1995) captured this phenomenon as "Fatima's Rules," named after an articulate student in a high school chemistry class. Latour (1987) anticipated the phenomenon when he observed, "most schooling is based on the ability to answer questions unrelated to any context outside of the school room" (p. 197). Fatima's Rules tell us how to do just that without understanding the subject matter.

"I Don't Know" Students pose little problems for their science teachers, as long as their teachers do not try to assimilate them into the subculture of science; that is, as long as teachers do not expect them to replace their commonsense conceptions with self-constructed scientific knowledge or to engage in scientific inquiry other than going through the motions of getting the right answer. "I Don't Know" Students do not know much about the subculture of science and when asked they simply submit to the wisdom of the media and treat scientists as experts. Border crossing into school science poses real <u>hazards</u>, but these students generally navigate successfully around those hazards. They learn to cope and survive.

Outsiders

Outsiders experience great and unique difficulties in the subculture of school, difficulties that lead to failure, alienation, and problems for teachers. The subcultures of school and science are highly discordant with the subcultures of peers and family. For Outsiders, all school work is busy work and emphasizes compliance to directions from authorities. Like "I Don't Know" Students, Outsiders view scientists as experts who are always right, drab, and boring. Outsiders do not know anything about the subculture of science, but even more importantly, they do not care. Even when science content makes sense to them, they may not care enough to hand in homework or pass examinations. School and science are indeed foreign subcultures. ("I feel like chemistry is another world.") Some Outsiders are savvy enough to figure out the system (Fatima's Rules) and manipulate it enough to pass their science course. But for most of them, border crossing into school science is virtually <u>impossible</u>.

Inside Outsiders

Costa discovered a group of bright students interested in science but who were inhibited from crossing the border into school science because of their school's abject discrimination and a lack of support from peers and family. These students, "Inside Outsiders," happened to be female Afro-Americans in Costa's study. They possess an intense curiosity about the physical world but developed a mistrust for the schools' teachers and administrators. Because of their unconventional lives, these students found border crossings into the subculture of school to be almost impossible, which therefore prevented them from participating fully in the subculture of school science.

Summary

For the five groups of students described above, border crossings into the subculture of science are smooth, manageable, hazardous, or virtually impossible. Costa's (1995) research suggests an empirically based system with which curriculum issues can be examined within the framework of my proposed cultural perspective on science education for Western students in Western schools. I now pursue several curriculum issues, in response to Wilson's (1981) challenge to express a cultural perspective on learning in terms of curriculum materials and classroom methods.

A Curriculum Implication

Based on different but related research programs in Western educational systems, Costa (1995), Cobern (1994b), and Layton et al. (1993, Ch. 8) come to very similar policy recommendations: we should teach science embedded in a social and technological milieu that has scope and force for students' worlds, worldviews, or practical experiences (respectively); and we need to dismantle barriers between students and science. Cross-cultural studies in non-Western settings come to the same conclusion (Baker and Taylor, 1995; George, 1988; Jegede, 1994; Maddock, 1981; Ogawa, 1986; Pomeroy, 1994; Swift, 1992). For example, based on the idea that commonsense "science" for students in the Republic of Trinidad and Tobago was "street science," George (1988, 1992) and Prime (1994) designed and implemented ways of using indigenous resources to mediate a technology-based science experience. Costa's (1995), Cobern's (1994b), and Layton et al.'s (1993) empirical research, along with Ogawa's (1995) and Kawagley's (1990) contemplation (above), provide compelling reasons for us to consider the implications of taking a cultural perspective on science education for Western students.

A cultural perspective recognizes conventional science teaching as an attempt at enculturation or assimilation -- cultural transmission that supports or replaces a person's life-world subcultures, respectively. A cultural perspective considers students' experiences with school science in terms of students crossing borders from the subcultures associated with peers, family, media, and the school, into the subcultures of science and school science. Science instruction becomes a cross-cultural event for most students (Costa's Outsiders, "I Don't Know" Students, and Other Smart Kids). One question begs to be asked: Could science curricula be developed for students identified by their border-crossing needs?

Inroads have already been made in non-Western communities (Baker and Taylor, 1995; George and Glasgow, 1988; MacIvor, 1995; Pomeroy, 1994). At the same time within Western science education, a movement has articulated a policy of teaching science embedded in a life-world milieu that helps students make sense out of their natural, technological, and social worlds. The science-technology-society (STS) conceptualization of science education has come of age after about 23 years of research and development (Gallagher, 1971; Solomon and Aikenhead, 1994). Contrasted with traditional school science's singular view of the natural world from only a scientist's perspective, STS provides multiple views of the natural world but primarily from a student's perspective (Aikenhead, 1994c). This student-oriented multiple-vista conceptualization of science education harmonizes with the cross-cultural approach to science education described above (Jegede, 1994).

Based on many STS curricula around the world, each with its own definition of STS content, Aikenhead (1994c) suggested the following encompassing definition:

> STS content in a science education curriculum is comprised of an interaction between science and technology, or between science and society, and any one or combination of the following:
>
> * A technological artefact, process, or expertise
> * The interaction between technology and society

* A societal issue related to science or technology
* Social science content that sheds light on a societal issue related to science and technology
* A philosophical, historical, or social issue within the scientific or technological community. (pp. 52-53)

This STS content (a combination of social issues and the social studies of science, Bingle and Gaskell, 1994) is integrated with science content (the knowledge, values, and skills of subculture science) in various ways and to varying degrees, described by Aikenhead (1994c).

One general implication of a cultural perspective on learning science is that STS education provides a concrete starting point for us to reflect on better ways to develop and teach a science curriculum. Some critical issues arise, however, and need to be resolved.

Critical Issues

Fensham (1992) described the competition to influence the science curriculum as serving political, economic, academic discipline, cultural/social, and individual interests. He dichotomized these interests into two target groups: (1) "a scientifically based work force;" that is, learning science as preprofessional training -- being enculturated or assimilated into the subculture of science (thereby satisfying political, economic, and academic discipline interests); and (2) "a more scientifically literate citizenry ... who will be prepared to respond appropriately to the changes with a scientific or technological character that increasingly confront society" (p. 793); that is, developing savvy about the subculture of science and how it operates (Prewitt, 1983; Wynne, 1991).

Fensham encourages curriculum developers and teachers to contemplate whose interests are being served by each of his two types of science curriculum. At the same time, Costa's (1995) empirical results encourage curriculum developers and teachers to give particular attention to the impact that a science curriculum has on five groups of students.

Is there a need to develop a curriculum for each of Costa's five categories of border crossings? I do not think so, nor does Costa suggest it. Students who might be categorized as "Inside Outsiders" and "Outsiders" challenge educators far beyond the parameters of this article.

For instance, given the negative, school-wide, hidden curriculum that creates "Inside Outsiders," there is nothing a curriculum specialist can do (Apple, 1979; Posner, 1992). Help must come from vigilant teachers who will risk confronting local norms and taboos.

Given the almost impenetrable border crossing experienced by Costa's "Outsiders," what can be done other than creating revolutionary alternate education programs, as some larger school jurisdictions have done (MacIvor, 1995). Within such programs, a science curriculum would integrate with other subject areas and with a student's street or working life; a topic for a much different article.

This leaves us with three groups of students to consider: "I Don't Know" Students, Other Smart Kids, and Potential Scientists.

"I Don't Know" Students

This group of students need assistance negotiating hazardous border crossings into the subculture of science (Costa, 1995). But we need to ask ourselves a critical question: Should students be forced to cross those borders? In other words, should the school assimilate these students into the subculture of science -- "scientific imperialism" (Battiste, 1986; Jegede, 1995) or the "arrogance of ethnocentricity" (Maddock, 1981)? Rather than respond to this ethical issue with an ethical argument, I want to claim on empirical grounds that attempts at assimilation most often fail, and therefore ought not to be attempted for highly pragmatic reasons.

Against a rich background of research on constructivism that concludes that students' creativity and intransigence abound in ways to circumvent the construction of scientific concepts, I shall sketch the case of one "I Don't Know" Student who illustrates the non-learning that science teachers will only too painfully recognize. Next, I shall summarize some features of a science curriculum that does acknowledge the hazards of border crossing for such a student.

Melanie was a reasonably conscientious grade 10 student in an STS science course. (For a more detailed account of this case study, see Aikenhead, 1996.) Her teacher and I collaborated on research into ways to enhance personal constructivism (the teacher's research agenda). Melanie clearly fit into Costa's category of the "I Don't Know" Student. Her transcripts are riddled with "I don't know." One event exemplifies the difficulty Melanie experienced when her teacher and I tried for five weeks to have her participate in the subculture of science by experimenting and constructing a concept of heat. During a pre-instruction interview, Melanie stated the following (the words are hers but the argument has been collapsed to achieve cogency):

> Heat is the warmth of particles. Temperature is the measurement of heat and coolness. All objects contain both heat and coolness; for example, an object whose temperature is 60 degrees has 30 degrees of heat plus 30 degrees of coolness. (Melanie, April 1992, lines 180-202)

After five weeks of student-oriented group inquiry contextualized in the historical development of heat (Aikenhead, 1992), and after successfully calculating specific heats of materials and deciding what materials are best for different everyday situations (for example, frying pans and solar house designs), Melanie's conception of heat became slightly more sophisticated, but not in any intended way. Her degrees of heat and coolness simply became percentages (May 1992, lines 29-35): An object whose temperature is 60 degrees has 80% heat plus 20% coolness. As well, she expressed heat as caloric (Black's conception) or vibrations (Rumford's conception) depending on the circumstance, in spite of several lessons that explicitly focused on <u>replacing</u> the concepts of caloric and vibrations with Joule's concept of energy (a crude, though historical approach to social constructivism). For Melanie, STS content made her science class more interesting, provided alternative content on which she was evaluated to her advantage, but did not make traditional science content any more accessible. Lijnse (1990) came to the same conclusion based on extensive R&D with STS materials in the Netherlands.

A clue to Melanie's resistance to assimilation into the subculture of science surfaced as she reflected on the nature of heat:

> If I don't know what it is, then I can just leave as it is, and I'll never wonder. Like I'll just say it's that way 'cause it is that way. Same as a person is a way that person is, 'cause of the ways that they're made because; like you may have the eyes of your dad and the chin of your mom and it's just how they are. So you just have to live with it. (Melanie, April 1992, lines 300-304)

Melanie compliantly accepts whatever happens in the natural world, including her own ability to make sense out of that world. According to Melanie, she makes sense out of the natural world by correcting her wrong thinking and memorizing the correct ideas (lines 19-27). Her teacher and I did not appreciate the hazards she coped with when asked to participate in the subculture of science.

A Critical Issue. Whose interests are served by compelling Melanie to construct new, but for her, irrelevant knowledge about heat? Fensham (1992) has argued that this question is paramount. Researchers Songer and Linn (1991) claim that it takes 12 weeks of instruction to teach the concepts of heat and temperature meaningfully, a time allotment that hardly seems justifiable. Taking a worldview perspective, Cobern (1994b) argued "it is not that the students fail to comprehend what is being taught, it is simply that the concepts are either not credible or not significant" (p. 15) because "for students it is aesthetic, religious, pragmatic, and emotional concepts that have scope and force with regard to nature" (p. 12). Thus, a general distaste for mechanistic reductionist concepts (a central feature of a scientific worldview) would explain why students choose not to integrate the scientific concepts of heat and temperature into their everyday notions of hot and cold (Kilbourn, 1980). In the adult world of consumers, Layton et al. (1993) discovered that a scientific understanding of heat energy had no consequence to lay people managing domestic energy problems in their life-world. Layton and his colleagues seriously questioned science education's objective to teach what is rarely usable in the everyday world. In the words of Wynne (1991, p. 120): "ordinary social life, which often takes contingency and uncertainty as normal and adaptation to uncontrolled factors as a routine necessity, is in fundamental tension with the basic culture of science which is premised on assumptions of manipulability and control." Whose interests are served by the assimilation of students into the subculture of science? -- not Melanie's.

An Alternative. For Melanie, what features of a science curriculum might ease her hazardous border crossing into the subculture of science? One possibility is a cross-cultural STS curriculum in which students clarify their own life-world subcultures in the context of learning

STS content. One facet of a cross-cultural STS course is learning the idea that science is a subculture having norms, values, beliefs, expectations, and conventional actions (corresponding to the last category in the definition of STS content quoted above). This facet is similar to Pomeroy's (1994) ninth cross-cultural agenda -- "Explore the beliefs, methods, criteria for validity, and systems of rationality upon which other cultures' knowledge of the natural world is built" (p. 65). Rather than being coerced into assimilating the subculture of science, students in a cross-cultural STS curriculum would learn to recognize features of the subculture science and would practise border crossings into and out of that subculture. Teachers would “help students feel that the school program is a natural part of their lives and help them move more smoothly back and forth between one (sub)culture and the other” (Leavitt, 1995, p. 134). Teachers would play the role of "tour guide" taking students across the border and directing their use of science in the context of the students' everyday world. Conceptual replacement is rejected in favour of conceptual proliferation dictated by specific social contexts (Furnham, 1992; Hennessy, 1993; Solomon, 1987), an idea similar to the suggestion by Dart and Pradham (1967) for African students and by MacIvor (1995) for First Nations students in North America. The curriculum would make science knowledge, skills, and values <u>potentially</u> accessible to students without the concomitant assimilation that has traditionally dominated science curricula. Making science content potentially accessible in this way suggests an alternative to both enculturation and assimilation: “autonomous acculturation” -- a process of intercultural borrowing or adaptation in which one is free to borrow or adapt attractive content or aspects of another culture. (The term “acculturation” by itself can have the negative connotation of coercion; Archibald, 1995, p. 293). A consequence of autonomous acculturation can be found in George’s (1995) insightful case study of “Mrs. S” who, of her own volition, integrated selected content from Western medicine with traditional folk knowledge:

> Throughout her conversations, Mrs. S. used conventional science terms and in so doing, exhibited varying levels of understanding of their meanings. There did not seem to be any conscious distinction made between conventional science terms and traditional ones. Mrs. S seemed to be using whatever terms/concepts she thought could best describe the situation at hand. (p. 254)

The topic of autonomous acculturation will resurface later in the context of Other Smart Kids.

Some classroom examples should clarify what an alternative curriculum for “I Don’t Know” Students might look like. The topic of mixtures, for instance, can make sense to students in various ways. In the everyday context of salad dressings, students can describe their commonsense conceptions (constructed in everyday subcultures) about how to prevent salad dressings from layering -- add ingredients such as egg whites and mustard powder. Family beliefs and conventions have a legitimate place here. Investigations could ensue and might produce consumer reports on the efficacy of various "anti-layer" ingredients or procedures proposed by students. Next, other everyday situations (for example, photographic film, gold jewelry, and milk) are studied for other substances that prevent layering. Milk is a key example because it clearly illustrates a fundamental feature of subculture science and how language is used. In the subculture of the supermarket, milk is (among many other categories) either homogenized or layered. Guided by the teacher who introduces the scientific dichotomous concepts "heterogeneous" and "homogeneous" mixtures, students conspicuously cross the border into the subculture of science, only to discover the contradiction that homogenized milk in the everyday world is not a homogeneous mixture in the subculture of science. One explicit objective in this scenario is to learn that language used in subculture science is tied to scientific classification schemes, which may or may not correspond to commonsense language, and therefore, to cross the border from an everyday subculture into subculture science is to change completely one's personal orientation to language (Lemke, 1990). Classroom content would include other discrepancies in language besides "homogeneous milk;" for example, "energy conservation" has opposite meanings in commonsense and science language registers; and "controlling variables" is a challenge to the commonsense "minimizing influences."

Aikenhead (1994a) discovered that high school students' commonsense conceptions of mixtures were richer and more complex than science's simple dichotomy of heterogeneous and homogeneous. His research revealed that students could easily construct the scientific concept "homogeneous" but resisted constructing "heterogeneous" because their commonsense concepts worked better than the scientific concept. Consequently, in the context of subculture science, heterogeneous was defined simply as "not homogeneous" (Aikenhead, 1991, p. 111). This negotiation of meaning illustrates Pomeroy's (1994) cross-cultural agenda number nine -- explore the beliefs of students and of science, and include both in the curriculum.

If students are going to cross the border between everyday subcultures and the subculture of science, border crossings must be explicit and students need some way of signifying to themselves and others which subculture they are talking in, at any given moment. A legitimate question posed in such a classroom would be, "What subculture are you talking now?" A promising technique to accomplish this clarification emerged from the Melanie study (Aikenhead, 1996). The technique is a concrete example of Hodson's (1993) and Driver, Asoko et al.'s (1994) idea to draw a clear distinction between the language students use to explore and develop their own ideas about natural phenomena, and the language scientists conventionally use. The technique I am suggesting has students divide a page in their notebook in half, labelling the left-hand column "my idea" (personal knowledge of an event or explanation from the point of view of one of the student's life-world subcultures, and using its language) and the right-hand column "subculture of science" (canonical knowledge using appropriate scientific language). This dichotomized page lends credence to students' commonsense ideas that usually work well in certain settings, such as salad dressings and homogenized milk (Aikenhead, 1994a; Hills, 1989; Solomon, 1987), but gives explicit place to students' border crossing into the subculture of science. The task of border crossing is made concrete by identifying it as crossing a line on a notebook page. After phenomena are explored or explanations are discussed in class, students make notes by writing in the "my idea" or "subculture of science" column, or both. Entries in the latter column signify a student’s understanding of the content, not necessarily a student’s belief that the content is universally true (Cobern, 1994a; Ogunniyi, 1988). The dichotomized notebook can serve as a type of journal which may help a teacher guide students' thinking and guide their use of language, just as a cultural tour guide would do. It is up to the teacher to assess the quality of the students' entries in both columns, but both have a place in the assessment.

The teacher's role as a tour guide for "I Don't Know" Students does not imply didactic teaching methods. A wide repertoire of methods is required. For example (continuing the theme of mixtures), students can carry out a traditional laboratory investigation into the behavior of water/alcohol, water/oil, and alcohol/oil, and interpret their observations by drawing a molecular model diagram; and then (in the context of a boy watching his oil stained shirt submerge into an extra amount of soap in a washing machine) be asked to "design a soap molecule (draw one molecule) that you think will attract an oil molecule and a water molecule" (Aikenhead, 1991, p. A58). The students' answers would be written in the "my idea" column. The tour-guide teacher then informs the students about the model that scientists believe (usually one of the students' creations) and this model is included in the "subculture of science" column, not as the truth but as a piece of cultural information. The process of designing theoretical models clearly belongs to the subculture of science; but when it is contextualized in the everyday world of a boy getting an oil stain out of his shirt (as it was in the example just above), "I Don't Know" Students can be very successful. Barba (1993, p. 1065) pointed out "that learning and culture are probably interdependent in that culturally familiar contexts and environments enhance learning," a viewpoint anchored in the Vygotsky tradition of learning. Melanie's cognitive barriers to learning about heat may be a function of cultural barriers she experienced in her science classroom.

The tour-guide teacher makes the subculture of science accessible to the "tourist" students by methods predicated on cross-cultural instruction (reviewed in Pomeroy's third cross-cultural agenda -- "Appropriate teaching strategies for diverse learners," 1994, p. 54). The metaphor “teacher as culture broker” has been used by Stairs (1995) to analyze the teacher’s role in resolving cultural conflicts that arise in cross-cultural education. Similarly, a teacher's tour-guide role is defined here as introducing students to another culture by using a high degree of student guidance. A discussion of specific teaching methods lies outside this article's focus on the curriculum, but a summary review of STS methods may be found in Aikenhead (1994b, pp. 171-172).

The tour-guide teacher could take the same everyday context of salad dressings a step further for the sake of broadening students' literacy concerning mixtures. Classification schemes used in the subculture of science (such as emulsions, suspensions, and colloids) can be presented to students as a framework for learning more about pollution in water and air, but without the need for learning molecular theories, structures, and forces -- topics central to the canonical content of science. These scientific classification schemes, along with their epistemic status of consensual and tentative knowledge, will be tied to context-specific STS issues (for example, industrial processes). The teacher will guide students through appropriate economics, politics, or ideologies associated with the classification schemes (for example: What are the advantages of using a scientific scheme over a commonsense one? Who is served by using each scheme? Who is marginalized?). Students generally demonstrate an alacrity with these social aspects of science in spite of the apparent sophistication of this STS content (Ryan and Aikenhead, 1992; Solomon et al., 1994). The norms, values, beliefs, expectations, and conventional actions of students' life-world subcultures assume a legitimate place in a cross-cultural science curriculum.

The examples of mixtures above (salad dressings, homogenized milk, soap, and industrial processes) could be described as technology content (Fensham, 1992; Medway, 1989; Zuga, 1991), content which naturally holds more place in students' life-worlds than conceptual content from the subculture of science (Shamos, 1983-84). In fact, the salad dressing example above came from a grade 10 textbook Logical Reasoning in Science & Technology, LoRST (Aikenhead, 1991, Unit 5) in a section entitled "The Technology of Salad Dressings." Other STS curricula, such as Britain's SISCON-in-Schools (Solomon, 1983b), Ontario's Science and Society Teaching Units (Roberts, 1981), and British Columbia's Science & Technology 11 course (Gardner, 1993; Gaskell, 1989), provide many more of these kinds of experiences for students. However, no science curriculum in Western countries has treated science explicitly as a separate subculture requiring hazardous border crossings by students.

Another Critical Issue. How is scientific knowledge actually used outside subculture science, in people's commonsense and professional life-worlds? The belief that people directly apply scientific knowledge is a cherished myth in the subculture of science (Aikenhead, 1980; Furnham, 1992; Layton, 1991; Ryle, 1954). Reality is much different. Based on case study research, Jenkins (1992) commented that using science in the everyday world is

> no more a straightforward application of the scientific knowledge acquired at school or in other formal contexts than technology is merely applied science. Rather it is about creating new knowledge or, where possible, restructuring, reworking and transforming existing scientific knowledge into forms which serve

> the purpose in hand. Whatever that purpose (political, social, personal, etc.), it is essentially concerned with action or capability, rather than with the acquisition of knowledge for its own sake. (p. 236)

This conclusion lends credence to social constructivism (Driver, 1989; Shapiro, 1992; Solomon, 1987) with its situated cognition (Furnham, 1992; Hennessy, 1993; Lave, 1988; O'Loughlin, 1992; Ryle, 1954), but it also guides our efforts to help students negotiate hazardous borders. As stated above, one hazard is the fact that scientific knowledge must be deconstructed and then reconstructed in the context of use (Layton, 1991). According to Layton et al. (1993):

> The nature of the transformation needed is not a matter which has hitherto commanded much attention from science teachers, although it has been a preoccupation of engineers for a century or more. ... The essence of the problem is that the concepts developed by scientists in their quest for understanding do not always map with exactitude onto the design parameters in terms of which practical action has to be planned. As a result, for science to articulate with practice, some reworking is often required. (p. 129)

An Alternative. Eijkelhof, Klaasen, Lijnse and Scholte (1990), Fensham and Gardner (1993), and Layton (1991) provide examples of curriculum materials that teach reworked scientific knowledge -- technological knowledge. Students' sense making of the natural world may be far better informed by practical technological knowledge than by pure scientific knowledge (De Vore, 1992; Layton, 1994; Mayer, 1984; Medway, 1989; Shamos, 1983-84; Zuga, 1991). But because students live in a life-world increasingly shaped by subculture science, they still need to learn about science, enough to develop critical border crossing strategies so they will not feel alienated or disempowered within their own life-world.

In summary, the metaphors "cross-cultural education," "comparative religions," and "tourists" capture the essence of the curriculum proposed for "I Don't Know" Students: an STS science and technology curriculum with explicit cross-cultural border crossings based on comparative subcultures and facilitated by "tour-guide" teachers.

Other Smart Kids

Similar to the "I Don't Know" Students, Other Smart Kids find the world of science to be neither personally meaningful nor useful to their everyday lives. School science "represents a distinct and special category of learning, separate from the common-sense solutions they develop in real-life contexts" (Burbules and Linn, 1991, p. 228). Thus, knowledge worth learning for both "I Don't Know" Students and Other Smart Kids will not normally include the canonical knowledge, values, and skills from subculture science. On the other hand, the differences between the two student groups principally lie in their feelings toward other school subjects (interested and highly successful for Other Smart Kids), and the ease with which they cross the border into the subculture of science (managed rather than hazardous). Thus for Other Smart Kids, knowledge worth learning in school science will likely be knowledge organized around everyday issues, derived from critical analysis, and involving reflection, self-expression, and humanistic rigor. For example, Cobern (1994b) describes a highly capable student, Ann, who happens to see the natural world via aesthetic and religious concepts, in direct contrast to her teacher's presentation of conventional scientific concepts -- mechanistic reductionist explanations. "Ann's aversion is rooted in an aesthetic sense of nature that has more scope and force than the science teacher's assurances and explanations" (p. 12). Ann's predicament is not unlike Stirton McDougall's decision not to study geology (described earlier). Border crossing into the subculture of science needs to be managed.

For Other Smart Kids such as Ann, bridges to the subculture of science can be constructed out of technological and social issues, and out of the history, epistemology, and sociology of science (all STS content); and cross-cultural instruction can take place in a manner described by Pomeroy's (1994) eighth cross-cultural agenda -- "Bridge the world view of students and that of Western science" (p. 63).

Some Other Smart Kids may travel across these bridges from their life-world to subculture science and discover a personal attraction to science. For these particular students, school science may become enculturation. However, no student should be coerced into enculturation (that is, no student should be assimilated) if meaningful learning is the objective.

(If game playing for course grades -- Fatima's Rules -- is the objective, then coercion might be appropriate).

As with "I Don't Know" Students described earlier, Other Smart Kids will be invited to add to or modify their life-world knowledge, based on their understandings gained from the subculture of science. This type of instruction, autonomous acculturation, was defined in a previous section.

But acculturation is not always necessary for learning to take place because students need not modify or relinquish features of their life-world subcultures to understand the subculture of science (Solomon, 1983a, 1987); contextualized conceptions from subculture science can be added to what students already know, even when scientific conceptions may appear to contradict life-world ideas. It is possible to understand the subculture of science without necessarily believing it personally (Cobern, 1994a; Ogunniyi, 1988). Content from the subculture of science could be made accessible to Other Smart Kids through everyday events that inform and shape their personal lives. The subculture of science would therefore be seen as "a repository to be raided for what it can contribute to the achievement of practical ends" (Layton et al., 1993, p. 135). This type of instruction is neither enculturation nor autonomous acculturation because students do not assimilate aspects of the subculture of science into their life-world subcultures. By analogy, anthropologists do not need to accept the cultural ways of their subjects in order to understand and engage in some of those ways (Medvitz, 1985). A different type of teaching, one I shall call anthropological instruction of science, puts students in a position not unlike an anthropologist. By treating the subculture of science as a repository to be raided, anthropological instruction addresses the goal of empowering Fensham's (1992) "scientifically literate citizenry." Anthropological instruction certainly differs from the enculturation or acculturation expected of Fensham's "scientifically based work force." Anthropological instruction may seem too academic and too removed from the life-world of most "I Don't Know" Students, and therefore it was not introduced earlier as an appropriate type of instruction for those students.

Jegede's (1995) collateral learning theory explains how students might benefit from anthropological instruction and suggests that the learner be guided through a progression of types of collateral learning, a progression that appears to move from anthropological instruction to acculturation.

Academic bridges for Other Smart Kids will help students manage their border crossings into the subculture of science. These bridges are slightly different from the supportive guidance (guided tours) that "I Don't Know" Students require to negotiate their hazardous border crossings to subculture science. The difference between guided tours and academic bridges is a matter of degrees, not of kind.

One aspect of the difference is the degree of academic abstraction, analysis, and self-initiated participation expected. At one extreme, a guided tour has the expectation that the "tourist" (the "I Don't Know" Student) becomes familiar with, and develops a critical appreciation of, science (as seen in the examples about mixtures above), not unlike a music appreciation course that aims at guiding students through the world of music without requiring them to compose music or exhibit virtuosity with an instrument. At the other extreme, academic bridges would assist the "traveler" (Other Smart Kids) to engage in some key abstractions in the subculture of science and to be articulate in analyzing the subculture itself which Other Smart Kids will see as interacting with other subcultures that form a fairly coherent unity in their lives. Lijnse (1990) reports on a promising three-tiered concept-development model that builds bridges back and forth between (1) students' cultural experiences with energy and (2) scientific concepts of energy.

Another difference between guided tours and academic bridges concerns the roles of students and teachers. As suggested above, "I Don't Know" Students are tourists in an unfamiliar culture and require a high degree of guidance (“bus tours”) from a tour-guide teacher to take them to some of the principal sites and to coach them on what science to look at and how to use it. On the other hand, Other Smart Kids are travelers in an unfamiliar culture but require a lower degree of guidance from a travel-agent teacher who provides incentives such as topics, issues, or events that create the need to know the subculture of science. The teacher’s travel-agent role is one of co-learner facilitating issue-directed learning (Ritchie, 1994). Both roles, tour guide and travel agent, conform with the focus of STS education (Solomon and Aikenhead, 1994) and rely on explicit border crossings by students into the subculture of science.

Many diverse examples of STS curricula for Other Smart Kids are found in Cheek (1992) and in Solomon and Aikenhead (1994), of which Logical Reasoning in Science & Technology, LoRST (Aikenhead, 1991) is a prime illustration. Its development was negotiated with grade 10 students themselves and by the continual R&D on both the science and STS content (Aikenhead, 1994a). LoRST possesses many bridges between the students' life-world and subculture science. For example, the logic of scientific inference is introduced by the need to know about inferences in order to sort out conflict over the safety of "the pill" (epidemiology studies) found in newspaper articles. Concentration problems are cast in the world of recipes, court cases, false advertisements, and toxic chemicals. Equilibrium is taught when students need to know details about how and why blood alcohol content varies with time, and how this three-variable problem relates to being over 0.08 on the breathalyser mentioned in specific court cases. Statistical reasoning and measurement errors are studied when students analyze survey data they collect in the community and when they interpret political polls. Neurological facts are explored in terms of the social and ethical consequences of Hoffman La Roche producing a "sobering up" pill. Students draw diagrams that conceptualize legal and moral reasoning, and concretely sketch in the possible contribution of science and technology to those legal and moral decisions. The bridges between subculture science and the life-worlds of students are made concrete.

With LoRST, students are trained to be more vigilant in detecting human consequences hidden in scientific decisions; human consequences such as a scientist's prestige, credibility, and financial security. The norms, values, and expectations guiding scientific decisions are examined explicitly. For instance, the conventional action of manipulating scientific data, and the explanation for why scientists "fudge" data, become evident during the analysis of an actual research report on the rate at which blood alcohol concentration decreases in the body. Students learn to conceptualize scientific activity in terms of public science and private science by identifying the norms and counter norms associated with each (Aikenhead, 1985). The political nature of R&D comes under scrutiny when students analyze such questions as "Technology can design or produce marvellous things, but for whom? Who benefits?" (Aikenhead, 1991, p. 97).

The human character of science is given explicit attention in LoRST when students experience first hand the social dynamics and subjectivity involved in constructing scientific knowledge. They reflect upon these experiences during classroom discussions which articulate the nature of consensus making in the subculture science. The discussions are followed by an analysis of subjectivity versus objectivity, which is then applied to other areas from mathematics to aesthetics. Although LoRST provides students with many cross-cultural bridges, those bridges remain implicit unfortunately.

More research, as mapped out by Solomon (1994c) or as conducted by Solomon et al. (1994), is required to explore the impact that STS science courses have on students. As indicated above for "I Don't Know" Students, caution is advised over expecting STS content by itself to augment students' scientific conceptualizations. Three decades of research in science education consistently demonstrates that spending class time on STS content neither adversely nor beneficially affects achievement on standard tests of canonical scientific subject matter (Aikenhead, 1994b).

In summary, the essence of the curriculum proposed for Other Smart Kids can be expressed succinctly: an STS science and technology curriculum based on subculture analysis with explicit cross-cultural border crossings via academic bridges, facilitated by "travel-agent" teachers.

Potential Scientists

Potential Scientists enthusiastically engage in a socialization process described by Costa (1993) as a rite of passage into science, or by Hawkins and Pea (1987) as enculturation. These students derive pleasure from playing with abstract decontextualized concepts and solving idealized mathematical problems. Potential Scientists tend to search for a body of knowledge and apprentice-like activities with which to assimilate the norms, beliefs, values, expectations, and conventional actions of their role models. These students often work diligently to ensure possible employment in a scientific or science-related profession.

Consequently, a number of Potential Scientists would see little value in solving life-world, concrete, and consensual problems typically found in STS curricula. Exploring subjectivity, epistemology, or cultural values inherent in the subculture of science would approach heresy. Potential Scientists value preprofessional training in the tradition of "advanced placement" courses in the U.S. Such courses serve these students' short-term interests very well, though it is interesting to note that "Much of the recent research on student learning in the sciences has shown that students exhibit substantial conceptual misunderstandings even after passing university examinations on the topic" (Prosser et al., 1994, p. 230). Science education methods professors confront this fact with their preservice education students who express scientific misconceptions on examinations, lesson plans, and other assignments. Our preoccupation with scientific conceptual fidelity for all high school students was a critical issue raised earlier and it needs our examination and reflection.

Diversity in the ranks of Potential Scientists becomes evident by the number who switch out of science into other fields such as political science, business studies, and law, once they reach post secondary education. Their disenchantment with science was systematically investigated by Bondi (1985), Oxford University Educational Studies (1989), and Seymour (1992), whose research suggests that a wide range of images of science (epistemological, sociological, and cultural) experienced by Potential Scientists in the subcultures of school and university science courses, do not harmonize sufficiently well with their life-world subcultures. As a result, enrolment in university sciences steadily decreases. Contributing to this problem is the lack of clarity in the school's rite of passage specifically designed for Potential Scientists (Costa, 1993). These students require a more carefully crafted socialization or apprenticeship into an authentic subculture of science (Gaskell, 1992; Hawkins and Pea, 1987; Layton et al., 1993). In terms of the "pipeline" into careers of science and engineering, the traditional school science curriculum has not been very successful. This conclusion forms one cornerstone to the rationale for STS education (Solomon and Aikenhead, 1994). Within the STS movement, people have argued that Potential Scientists should have a foundation for the social, political, and ethical responsibilities that they will certainly face as professionals in the 21st century (Aikenhead, 1980; Cross and Price, 1992; Kelly, 1994; Solomon, 1994a). This goal speaks to the long-term interests of Potential Scientists and society.

However, such a humanistic STS science curriculum (Pomeroy's fifth cross-cultural agenda in her 1994 review) presents a challenge to many Potential Scientists, not unlike but opposite to, the challenge faced by the Other Smart Kids (primarily humanists) in a traditional science curriculum. A major difference, however, lies in the fact that schools normally provide Potential Scientists with a privileged position (Gaskell, 1992; Hodson, 1993, Posner, 1992) from which they can demean STS curricula as "soft" or for students who "can't cut the mustard."

Fensham (1992) warned that the science curriculum is a social instrument that serves the interests of those who have a stake in its content. Two interest groups are considered here. The first group includes influential stakeholders who simply want school science to act as society's screening device to maintain an intellectual, social elite, status quo. For example, such stakeholders were evident in a recent study by Wildy and Wallace (1995). The context of the study was an Australian independent girls school dedicated to high marks for university entrance, a classic instance of social screening for the privileged (Anyon, 1980; Apple, 1979). According to Wildy and Wallace, who defined good science teaching as any instruction that caters to “the cultural context of the school” (p. 154), the school’s traditional physics instruction enjoyed the support of the students, their families, their school, and their physics teacher. Therefore, the teacher’s documented rejection of an alternative physics curriculum (an STS course aimed at students constructing personal meaning) was interpreted by Wildy and Wallace to be an exemplar of good science teaching. The stakeholders for social screening had indeed been influential.

A second group of stakeholders has an interest in maintaining a stereotype positivistic view of science as: authoritarian, non-humanistic, objective, purely rational and empirical, universal, impersonal, socially sterile, and unencumbered by the vulgarity of human imagination, dogma, judgements, or cultural values (Duschl, 1988; Gallagher, 1991; Nadeau and Désautels, 1982; Smolicz and Nunan, 1975). Gaskell's (1989, 1992) research, along with the work of many others (for example, Brickhouse, 1990; Lederman, 1992), shows that high school science teachers are among the strongest defenders of this view. Even some STS educators belong to this camp, according to Bingle and Gaskell (1994).

Given the powerful and privileged position that both groups of stakeholders currently enjoy in society, educators who advance the cause of “science for all” are advised to prepare for political action against the traditional preprofessional training curriculum with its social screening and its stereotype image of science. This curriculum, targeted for Potential Scientists representing about 5% to 15% of the high school population in North America, assumes a legitimacy and status that has allowed “science for the privileged” to dictate to “science for all.” However, the long-term interests of an equitable and socially responsible society will only be served when Potential Scientists are required to struggle with a humanistic STS science and technology curriculum, and learn new ideas from travelling through intellectual territory not often explored by these students.

Summary

When conceptual boundaries around cross-cultural education are widened to include Western students in science classes, a new perspective for science education emerges. Learning becomes culture acquisition which requires students to cross cultural borders from their life-world subcultures (associated with, for example, family, peers, school, and media) to the subcultures of science and school science. The border crossings can be smooth, manageable, hazardous, or virtually impossible, according to anthropologists Phelan et al. (1991).

Smooth border crossings are experienced by students whose life-world subcultures harmonize with the subculture of science. For them, instruction is enculturation (Hawkins and Pea, 1987). But for the rest of the students whose life-world subcultures, to varying degrees, are at odds with the subculture of science, conventional instruction in school science becomes assimilation (Battiste, 1986; MacIvor, 1995). Assimilation, also called arrogant ethnocentrism by Maddock (1981), is assiduously avoided by many students who learn to play "Fatima's Rules" (Larson, 1995) or who practise "cognitive apartheid" (Cobern, 1994b), and pass science courses without the comprehension assumed by the teacher or by the community. This state of affairs also constitutes a pervasive conclusion to a myriad of empirical studies on students' construction of scientific concepts (Pfundt and Duit, 1994) and empirical studies on situated learning in science (Furnham, 1992; Hennessy, 1993). On empirical grounds alone, assimilation is highly problematic.

A reconceptualization of Maddock's (1981) and Wilson's (1981) cross-cultural science education, proposed in this article, offers a new vantage point from which to rethink curriculum and instruction; for instance, how can we deal with students who traditionally have been the target of scientific assimilation? We need to develop a curriculum that anticipates and explicitly facilitates their border crossings into the subculture of science, thus engendering autonomous acculturation and/or “anthropological” instruction.

Border crossings will resemble (1) highly structured guided tours for Costa's (1995) "I Don't Know" Students who will be tourists in the subculture of science, with a tour-guide teacher; and (2) less structured academic bridges for Costa's Other Smart Kids who will be travelers in the subculture of science, with a travel-agent teacher. For Costa's Outsiders and her Inside Outsiders, who find border crossings virtually impossible, it is apparent that the territory on both sides of the border needs to be reconceptualized, an issue beyond the scope of this article. For Costa's Potential Scientists, the curriculum debate continues unresolved by the cross-cultural perspective proposed here, but new insights are gained into Potential Scientists' resistance to STS science and to changing their privileged status in the political ecology of their schools. Costa's (1995) research provided a link between Phelan et al.'s (1991) anthropological study of schools and the specific issues faced by science educators.

Border crossings may be facilitated in classrooms by studying the subcultures of students' life-worlds and by contrasting them with a critical analysis of the subculture of science (its norms, values, beliefs, expectations, and conventional actions), consciously moving back and forth between life-worlds and the science-world, switching language conventions explicitly, switching conceptualizations explicitly, switching values explicitly, switching epistemologies explicitly, but never requiring students to adopt a scientific way of knowing as their personal way. This "no assimilation" rule does not preclude teachers from capturing student interest and curiosity in science and then doing a good job at a rite of passage into the subculture of science (for example, Roth, 1993).

There is a type of curriculum that can serve as a point of departure for developing a cross-cultural science and technology curriculum: a science-technology-society (STS) curriculum. A cross-cultural science and technology curriculum, with its guided tours and/or academic bridges, can be built out of STS content, science content, and more technology content than is conventional in STS science courses today. The STS content (defined earlier in the article) includes the social, historical, and philosophical aspects of science as well as science-related societal issues. This is the direction proposed for cross-cultural science teaching in non-Western countries (Jegede, 1994).

I propose a cross-cultural STS science and technology curriculum for Western students as a concrete resolution to Fensham's (1992) critical issue: Whose interests are served by compelling a student to construct a scientific concept irrelevant to, or interfering with, his or her life-world? Other critical issues were identified in this article. Our preoccupation with scientific fidelity seems to be discordant with (1) the real world of the learned curriculum, a world defined by empirical studies into canonical concept construction (Pfundt and Duit, 1994) and situated cognition (Furnham, 1992; Hennessy, 1993), and (2) adult use of scientific knowledge (Furnham, 1992; Layton et al., 1993; Wynne, 1991). The latter research suggests directions to take in redesigning STS science curricula into cross-cultural STS science and technology curricula:

> In all the case studies, ... the lay recipients of scientific knowledge were far from passive; they interacted with the science, testing it against personal experience, contextualizing it by overlaying it with particular local knowledge and evaluating its social and institutional origins. The cognitive deficit model, with its assumption of a one-way flow of scientific knowledge from producers to consumers is an inadequate description of the relationship. (Layton et al., 1993, p. 122)

Rather than insist that students develop knowledge, values, and skills for assimilation into the subculture of science, a cross-cultural STS science and technology curriculum will help students enrich their own life-world subcultures by empowering them to draw upon the subculture of science in appropriate situations, such as: working at a job or profession, forming a defensible view on a science-related personal or social issue, or making sense of one's own community or society increasingly influenced by Western science and technology. The degree to which students actually incorporate scientific knowledge, values, and skills into their life-world subcultures (if at all), reflects the degree to which autonomous acculturation has taken place. However, one’s power to raid the subculture of science does not necessarily depend on one’s autonomous acculturation into the subculture of science. Situated cognition (Furnham, 1992;

Hennessy, 1993) with its collateral learning (Jegede, 1995) accounts for the fact that some students -- for instance, Other Smart Kids (Costa, 1995) -- can understand the subculture of science without integrating it into their life-world. This type of instruction might be called “anthropological” science teaching.

Additional advantages of empowerment will accrue to Western students belonging to groups now under represented in science (Hodson, 1993; MacIvor, 1995; Pomeroy, 1992; Swift, 1992). Jegede (1994) and Rampal (1994) expand and clarify a parallel situation for non-Western students who have already acquired an indigenous "traditional" way of knowing about the natural world.

Seen in the light of border crossings, the goal "science and technology education for all" (UNESCO, 1994) poses new problems concerning what is worth knowing. A cross-cultural perspective for science education suggests that learning results from the organic interaction among: (1) the personal orientations of a student; (2) the subcultures of a student's family, peers, school, media, etc.; and (3) the subcultures of science and school science. Much more research and development is needed to understand this organic interaction more clearly. In non-Western countries, the work already completed or in progress can catalyze the process of redesigning the science curriculum in Western countries (George, 1995; George and Glasgow, 1988; Jegede, 1995). As well, some teachers are already teaching a cross-cultural science curriculum (for example, see MacIvor, 1995). They need to be identified and their practical knowledge shared with other teachers and curriculum specialists.

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