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Cross-Cultural Science Education: A Cognitive Explanation of a Cultural Phenomenon

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Abstract: Recent developments in concept learning and in science-for-all curricula have stimulated our interest in two fields of study: how students move between their everyday life-world and the world of school science, and how students deal with cognitive conflicts between those two worlds. In the first field of study, Aikenhead conceptualized the transition between a student's life-world and school science as a *cultural border crossing.* In the second field, Jegede explained cognitive conflicts arising from cultural differences between students' life-world and school science in terms of *collateral learning.* This article (a) synthesizes cultural border crossing with its cognitive explanation (collateral learning) and (b) demonstrates by its example the efficacy of reanalyzing interpretive data published in other articles. The synthesis provides new intellectual tools with which to understand science for all in 21st-century science classrooms in developing and industrialized countries. © 1999 John Wiley & Sons, Inc. J Res Sci Teach 36: 269–287, 1999

One major influence on science education identified by students in developing countries is their feeling that school science is like a foreign culture to them (Maddock, 1981). Their feeling stems from fundamental differences between the culture of Western science and their indigenous cultures (Aikenhead, 1997; Jegede, 1995). Interestingly, many students in industrialized countries share this feeling of foreignness as well (Aikenhead, 1996; Costa, 1995). Cultural clashes between students' life-worlds and the world of Western science challenge science educators who embrace science for all, and the clashes define an emerging priority for the 21st century: to develop culturally sensitive curricula and teaching methods that reduce the foreignness felt by students. Cultural clashes can happen to anyone, as illustrated by the following vignette.

Canadian astrophysicist Hubert Reeves grew up in a family that revered natural beauty in a romantic, almost mystical way. At the same time, his intense curiosity about the natural world predisposed him to an interest in science. Reeves describes himself as having a heart of a poet and a mind of a scientist [Canadian Broadcasting Corporation (CBC), 1995]. He reflected upon a profound experience when he was 18 years old that changed the way he looked at science. The event happened while working at an observatory near Victoria, Canada.

> I watched the sunset over snow-capped summits of the coastal mountains, turning slowly from white to pink, reflected in the calm ocean waters. As I was lost in meditation, a

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> sudden thought broke my mood and wrenched me. . . . Since my last visit to the ocean, something important had happened. As a student in the physics department at the University of Montreal, I had encountered some months earlier Maxwell's equations. . . . His equations provide us with an excellent mathematical representation of light's behaviour. . . . As I contemplated this calm ocean, gloriously tinted by the setting sun, an inner voice spoke, "These designs, these forms, these shimmering hues, are the mathematical solutions to Maxwell's equations, perfectly predictable and calculable, nothing more." Within, I panicked. I feared that the exquisite pleasure I had enjoyed would simply dissipate. . . . Maxwell's equations ... cancelled out, it seemed, the fragile magic of the rose tinted sky and iridescent sea. Shaken by this quandary, I turned my back on a panorama I could no longer bear, and walked home. . . . (CBC, 1995)

Reeves' poetic heart had collided with his scientific mind. His transition from the science-world of Maxwell's equations to his life-world of aesthetic experience was indeed a hazardous transition, because by embracing a scientific worldview he risked diminishing, or even losing, his aesthetic understanding of nature.

Reeves' quandary, however, is not at all unique. It is played out daily in science classrooms around the world, where science students are expected to construct scientific concepts meaningfully even when those concepts conflict with indigenous norms, values, beliefs, expectations, and conventional actions of students' life-worlds (Aikenhead, 1997; Cobern, 1996; Jegede & Okebukola, 1991). These cultural clashes can create hazards for many students, not unlike the one faced by Reeves. In response to such hazards, students understandably invent ways to avoid constructing scientific knowledge, or students conveniently store the constructed scientific knowledge in their minds out of harm's way from interfering with their life-world experiences (as Reeves had great difficulty doing at age 18).

On the other hand, not all people share Reeves' quandary when confronted with two different worlds. Some scientists, for instance, move almost effortlessly between the culture of science and the culture of their life-worlds (Medvitz, 1985; Peat, 1994). They talk about feeling comfortable, although they found themselves thinking differently in each world.

The capacity to think differently in diverse cultures and the capacity to resolve conflicting beliefs between those cultures are familiar human traits. However, these capacities are not equally shared among all people, as anthropologists Phelan, Davidson, and Cao (1991) discovered when they investigated students' movement between the worlds (microcultures) of families, peer groups, school, and classrooms: "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" (p. 224). Costa (1995) studied students' varied success at moving between the culture of their family and the culture of their science classroom. She confirmed Phelan et al.'s findings: these transitions are *smooth* when the cultures of family and science are congruent, transitions are *manageable* whenever the cultures are somewhat different, transitions tend to be *hazardous* when the cultures are diverse, and transitions are virtually *impossible* when the cultures are highly discordant. In other words, success in science courses depends on (a) the degree of cultural difference that students perceive between their life-world and their science classroom, (b) how effectively students move between their life-world culture and the culture of science or school science, and (c) the assistance students receive in making those transitions easier.

Costa (1995) categorized students according to their ease of transitions, based on empirical data from diverse high school science students in California. Four categories are germane here. The first category, Potential Scientists, consists of students who experience *smooth* transitions and require little or no help. Costa's research indicated that Potential Scientists persevere even when science instruction is poor.

For the vast majority of students (perhaps as many as 90%), however, their movement between the microculture of their family and the microculture of school science is not smooth and often limits their success at science. One such category of students, Outsiders, experiences such a discordant culture gap between family and school that moving into the culture of school science seems virtually *impossible.* They might avoid (or drop out of) school science to sustain their self-worth whenever they experience the foreign culture of school science.

In a third category, Costa's "I Don't Know" Students (named by their typical response to a variety of questions about school and science), students' peer and family cultures diverge from the cultures of school and of science. For these students, border crossing into school science is *hazardous.* They do not want to look stupid in school, and so they are usually motivated to do as well as they can. They generally resist being assimilated into the culture of science, but their lack of academic savvy tends to limit their success at school science.

The last category, Other Smart Kids, consists of students whose peer, family, and school cultures are similar, but who find the world of science irrelevant to their personal lives. They are able to *manage* the border crossing into the culture of science without teachers realizing how foreign science appears to them. The way they learn this foreign content makes it accessible to them whenever they need to achieve such social goals as talking with their science teacher or passing examinations, even though that knowledge may contradict or seem irrelevant to their life-world knowledge.

Two major points arise from this brief analysis. The transition from a student's life-world into a science classroom is a cross-cultural experience for most students. This point was explored by Aikenhead (1996, 1997), who recognized the transitions as "cultural border crossings." Second, cognitive conflicts arising from different cultural settings need to be addressed and resolved. This second point was explained by Jegede (1995, 1997) in terms of his "collateral learning theory."

This article seeks to (a) clarify the act of cultural border crossing, (b) explore its cognitive explanation (collateral learning), and (c) synthesize the two ideas in such a way as to provide guidance to culturally sensitive reform movements dedicated to science for all.

Cultural border crossing and collateral learning are constructs grounded in empirical research and warranted in anthropological and psychological paradigms, respectively. Further empirical evidence offered in support of our ideas comes from a reanalysis of published interpretive studies in which the authors had presented evidence rich enough for others to reanalyze.

Cultural Border Crossings

Drawing upon the empirical results of research in cultural anthropology and science education, we hone the concept of cultural border crossing so it can serve science teachers—the pedagogical culture workers who make the culture of science accessible to all their students (Pomeroy, 1997). We begin with definitions of culture and microcultures and then introduce cultural border crossings in the context of everyday living where we examine the key ingredients for successful border crossings. This leads us to the specific case of students' cultural border crossing into the microculture of school science.

Culture and Microcultures

Border crossings take place between cultures or between microcultures (Aikenhead, 1996, 1997). Such cross-cultural experiences are the purview of cultural anthropology, to which we turn for our meaning of culture: "an ordered system of meanings and symbols, in terms of which social interaction takes place"(Geertz, 1993, p. 5). This statement accurately describes the scientific community engaged in Western science, and thus suggests cultural features that characterize science as a microculture. Others have argued that science is a microculture of Western civilization (Maddock, 1981; Ogawa, 1986; Pickering, 1992).

Consistent with Geertz, Phelan et al. (1991, p. 228) suggested that culture be conceptualized as the "norms, values, beliefs, expectations, and conventional actions" of a group. This cogent definition will guide our exploration of cultural border crossing and collateral learning in science education. Canonical science content will be subsumed under "beliefs." (For an overview of other definitions of culture used in science education, see Aikenhead, 1996, p. 8).

Within every culture there are subgroups or social communities that more or less share unique combinations of norms, values, beliefs, expectations, and conventional actions. Border crossings between microcultures can occur whenever someone moves from one social community to another: for instance, when students move from their peer group in the hallway of a school into a different group of students in a science classroom.

Everyday Border Crossings

As we move between microcultures, we often negotiate these border crossings so *smoothly* that we do not recognize that a cultural border potentially exists between the two microcultures: for instance, between home and work. Borders may seem invisible or nonexistent. It is when we begin to feel a degree of discomfort with another microculture that border crossings become less smooth and need to be *managed.* Contributing to our discomfort may be some sense of disquiet with cultural differences or our unwillingness to engage in risk-taking social behaviour (depending on the situation, of course). When our self-esteem is in jeopardy, border crossing could easily be *hazardous* and we would tend to react in various ways to protect our egos. Even worse, if psychological pain is involved (as it was with 18-year-old Reeves), avoidance is our natural response and border crossing may seem *impossible.*

These four descriptors of border crossings can be illustrated by a person from Chicago traveling internationally and attempting to use the local transportation system. Smooth border crossings would likely occur in Toronto, where local customs turn out to be no more than interesting curiosities. Visiting London and negotiating its underground "tubes" may seem more of a risk, but the border crossings into that setting can be managed (as long as you hold on to your ticket). Getting around on public transport in Jamaica, on the other hand, may bring uncertainties that cause some anxiety (will that old car make it or not?), and hence, it could be a hazardous border crossing that requires coping strategies. Finally, if the person from Chicago flew to Abu Dhabi, United Arab Emirates, he or she might arrange to be picked up at the airport by acquaintances because the high risk of appearing incompetent, or the high risk of failing to arrive at one's destination, makes the transportation system seem impossible owing to a totally different language and unfamiliar customs.

In the context of Japanese high-energy physics, border crossing between the Japanese national physics community and the international physics community was documented by anthropologist Traweek (1992). She found that pejorative humor, sarcasm, and cultural reprisals were all intermingled in ways that encouraged conformity with the national physics community and therefore made border crossing into the international community difficult for the Japanese physicists. Hazardous border crossings had to be negotiated with great care and subtlety by using humor, selected conformity, power, and politics.

In the context of the Solomon Islands, border crossing between urban and rural settings caused anguish for some high school students but not others. Science students in the main city of Honiara talked about going to rural villages and encountering the idioms and technologies of magic endemic to the indigenous culture of the Solomon Islands (Lowe, 1995). For students who grew up in a village, the transition back into rural life was automatic, natural, and smooth. However, for students raised in Honiara, the cultural border crossing was difficult and hazardous.

In the context of students learning science, Lee (1997b) and O'Loughlin (1992) argued that the language and conventional actions of many Euro-American teachers in science classrooms may create cultural clashes for students who belong to a culture different from the teacher's. In developing countries, the science curriculum itself may be a problem for students who strongly believe in their community's indigenous belief system, whether it be anthropomorphic Africa (Jegede, 1995) or Solomon Island magic (Lowe, 1995). Science education aims to nurture equitable opportunities for success for *all* students (United Nations Educational, Scientific, and Cultural Organization, 1994). Because success at science depends in large measure on how effectively students can negotiate into the culture of school science, we now consider the key ingredients for successful border crossing between disparate cultures.

Ingredients for Successful Border Crossing

In a venue totally different from learning science, Maria Lugones (1987) revealed a personal account of "traveling" from her own world of a woman of color to the often hostile world of the White Anglo male. Her account will help us appreciate the experiences that many students encounter when they cross borders from their life-world cultures into the culture of school science. Lugones became accomplished in the Anglo male's world without losing her own way of thinking because she learned to cross hazardous or impossible borders effectively. Her experiences suggest ingredients for successful border crossing. "I affirm this practice as a skillful, creative, rich, enriching and, given certain circumstances, as a loving way of being and living" (p. 3). Lugones used the metaphor "world-traveling" when she wrote about the flexibility and playfulness required of her when she shifted from a mainstream life-world, where she was constructed by the mainstream Anglo male as an Outsider, to other situations where she was more or less at home. She advised *flexibility* for both the Outsider and the privileged insiders, "those who are at ease in the mainstream" (p. 3). Flexibility can best be achieved by an attitude she described as "playful." Being *playful* allows us to be a different person in different worlds without losing ourselves, because we always have memories of us in our personal world. Hubert Reeves at 18, for example, had not yet learned to be playful outside his scientific world. Flexibility and playfulness can help reduce cultural discord by reducing the perceived psychological risks associated with participating in another culture.

According to Lugones, we may be playful in one world but not another, because we *feel at ease* in the one world but not the other. Feeling at ease can help us be successful, although Lugones claimed that we can succeed in someone else's world (such as adolescents in the world of science) even though we are not at ease in it. Ease is conceived as a cluster of factors: (a) being a fluent speaker, (b) agreeing with the norms of that culture, (c) being humanly bonded with people in that culture, and (d) having a sense of shared history. The presence of only one factor can cause us to feel at ease. Lugones suggested that we should not look for the "holistic I" (p. 14) in each world we visit (perhaps that was Reeves' mistake), but instead accept the "multiple I." To travel between worlds is to shift from being one person in one context to being another person in a different context, without losing our self-identity as the same person we remember in our most familiar world. To travel between worlds is to cross cultural borders.

Lugones's descriptions of successful border crossings enrich our analysis of students' experiences with school science. Her sense of flexibility, playfulness, and ease clarifies the human capacity to think differently in different cultures, a capacity that has direct implications for students' success at learning science.

School Science

From the viewpoint of cultural anthropology, to learn science is to acquire the culture of science (Maddock, 1981; Wolcott, 1991). To acquire the culture of science, students must travel from their everyday life-world to the world of science found in their science classroom. Students' flexibility, playfulness, and feelings of ease in the world of science will help determine the smoothness with which students cross the border into the culture of science. This smoothness will likely affect the degree of culture acquisition that takes place.

Different cultural processes are involved in the acquisition of science culture. When the culture of science generally harmonizes with a student's life-world culture, science instruction will tend to support the students' view of the world, and the process of *enculturation* tends to occur (Hawkins & Pea, 1987; Wolcott, 1991). This process is characterized by *smooth* border crossings and is experienced by the type of student Costa (1995) called Potential Scientists.

However, when the culture of science is generally at odds with a student's life-world, science instruction will tend to disrupt the student's worldview by trying to force that student to abandon or marginalize his or her life-world concepts and reconstruct in their place new (scientific) ways of conceptualizing. This process is *assimilation.* Assimilation can alienate students from their indigenous life-world culture, thereby causing various social disruptions (Baker & Taylor, 1995; Maddock, 1981); or alternatively, attempts at assimilation can alienate students from science, thereby causing them to develop clever ways (school games) to pass their science courses without learning the content in a meaningfully way assumed by the community.

The game can have explicit rules which Larson (1995) discovered as "Fatima's rules," named after an articulate student in a high school chemistry class. For example, one rule advises us not to read the textbook but to memorize the boldfaced words and phrases. Fatima's rules can include such coping or passive resistance mechanisms as "silence, accommodation, ingratiation, evasiveness, and manipulation" (Atwater, 1996, p. 823). What results is not meaningful learning but merely "an accouterment to specific rituals and practices of the science classroom" (Medvitz, 1996, p. 5). Loughran and Derry (1997) investigated students' reactions to a science teacher's concerted effort to teach for meaningful learning ("deep understanding"). They found a reason for Fatima's rules that helps explain the avoidance of assimilation for some students, a reason related to the culture of public schools:

> The need to develop a deep understanding of the subject may not have been viewed by them [the students] as being particularly important as progression through the schooling system could be achieved without it. In this case such a view appears to have been very well reinforced by Year 9. This is not to suggest that these students were poor learners, but rather that they had learnt how to learn sufficiently well to succeed in school without expending excessive time or effort. (p. 935)

Their teacher lamented, "No matter how well I think I teach a topic, the students only seem to learn what they need to pass the test, then, after the test, they forget it all anyway" (p. 925). On the other hand, Tobin and McRobbie (1997, p. 366) documented a teacher's complicity in Fatima's rules: "There was a close fit between the goals of Mr. Jacobs and those of the students and satisfaction with the emphasis on memorisation of facts and procedures to obtain the correct answers needed for success on tests and examinations." When playing Fatima's rules, students (and some teachers) go through the motions to make it appear as if meaningful learning has occurred, but at best, rote memorization of key terms and processes is only achieved temporarily.

For a large majority of students, science teaching is experienced as an attempt to assimilate them (Costa, 1995; Ogawa, 1995). A vast array of science education research into students' construction of scientific concepts concludes that most students exhibit creativity and intransigence in their quest to circumvent the construction of scientific concepts (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Loughran & Derry, 1977). In other words, many students try to circumvent assimilation and at the same time avoid expending unnecessary effort.

As summarized earlier, Costa (1995) categorized this large majority of students based on the varying degrees of cultural difference between students' life-worlds and the world of science. Other Smart Kids were able to *manage* their border crossing into the culture of science by playing Fatima's rules cleverly and/or by constructing science knowledge in mental schemata and storing them in long-term memory accessible only when cued by a science exam. "I Don't Know" Students also resisted assimilation, but their *hazardous* border crossings were coped with by conscientiously playing Fatima's rules rather than by constructing schemata of scientific concepts. Costa's Outsiders found border crossing into school science virtually *impossible*. Dropping out can be seen as a rational move toward self-preservation for many students—for instance, Native Americans in mainstream high schools (Deyhle and Swisher, 1997).

In-depth research into students' worldviews and into their reaction to science instruction supports Costa's category scheme. In Cobern's (1996) study of student worldviews, a typical Other Smart Kid is exemplified by Ann, who expressed a worldview about nature that conflicted with the worldview of her science teacher, Mr. Hess. However, Ann knew how to achieve at academic classes, and so she was able to *manage* her border crossings into Mr. Hess's science class and earn high marks. From yet a different study comes an example of an "I Don't Know" Student, Melanie, who held on to her life-world concept of heat (degrees of hotness plus degrees of coldness) while she memorized how to calculate specific heat constants accurately and how to engage in scientific and historical inquiry about heat (Aikenhead, 1996). Melanie coped with hazardous border crossings by playing Fatima's rules successfully. Finally, Art is a typical example of an Outsider found in Cobern's (1996) study of student worldviews. Art seemed to be opposed to the organized structures of society although his teacher, Mr. Hess, found him to be a nice person. Art's worldview of nature expressed an extreme alienation from science, so much so that border crossing into Mr. Hess's science class was impossible. Dropping in and out was his method of dealing with school and home pressures.

The reform movement dedicated to science for all will need to recognize that most students belong to one of three categories of border crossings: (a) *managed* for Other Smart Kids, (b) *hazardous* for "I Don't Know" Students, and (c) *impossible* for Outsiders. If these students are going to learn to cross cultural borders effectively rather than play Fatima's rules, then border crossing between a student's life-world and the science world will need to be the object of instruction. Hennessy (1993, p. 9) reviewed a decade of research on situated cognition and concluded, "Crossing over from one domain of meaning to another is exceedingly hard." It is little wonder that border crossing into school science is not smooth for most students. Lugones (1987) might attribute this to a lack of flexibility, a lack of playfulness, or a lack of feeling at ease.

Solomon (1992) investigated students' flexibility in moving between their life-world and the science world. Many students' life-world concept of energy seemed to smother or negate all the physics knowledge they had learned in their physics class. However, Solomon noted:

> What was significant and interesting was that only one pupil, out of the subgroup who seemed to have mastered the art of movement between the domains [life-world and sci-

> ence world domains], reverted to the life-world way of thought. Successful crossing over and back from one domain to another may indicate that more durable learning has taken place, and, perhaps, that a deeper level of understanding has been achieved. In the following year, when all the pupils were taught to answer this kind of question in both ways, deliberately crossing between the two domains, their overall level of success in the two tests increased dramatically. (p. 112)

Solomon's successful instruction accentuated playfulness with energy concepts, demanded flexibility in moving between the life-world and science world, and gave students a feeling of ease in the culture of science. Solomon's success provides a glimpse into the kind of cross-cultural instruction required. Several other examples are found in Aikenhead (1996).

Feeling at ease in the culture of science is undermined by the foreign language and communication conventions that have traditionally mediated instruction in the science classrooms (Atwater, 1996; Lee, 1997b). While the problem exists in Western classrooms, it will be accentuated in many non-Western classrooms (O'Loughlin, 1992):

> The speech genres that working-class children and children of color bring to school as *their only interpretive frameworks* are often negated. These students can experience success only if they can abandon their own sociocultural and experiential frames of reference and begin to function effectively in the abstract, decontextualized canon that is usually the only speech genre available in schools. (p. 815, italics in original)

This marginalization of students might be reduced by introducing explicit border crossings in the science classroom and by coaching students to cross those cultural borders with greater ease (Aikenhead, 1996). To clarify students' cognitive experience with border crossings, we now turn to the theory of collateral learning (Jegede, 1995).

Collateral Learning

Potential Scientists are found in all cultures (Medvitz, 1985; Ogawa, 1995). In Western countries, however, the enculturation of Potential Scientists into Western science likely proceeds more harmoniously than for Potential Scientists in *non*-Western cultures, students who are more likely to confront cognitive conflict between the tenets of their indigenous culture and the tenets of Western science. Consequently, non-Western Potential Scientists will likely construct scientific concepts side by side, and with minimal interference and interaction, with their indigenous concepts (related to the same physical event). This is called *collateral learning* (Jegede, 1995, 1997). Discrepant concepts are stored in long-term memory as cognitive schemata. A simple example of collateral learning is illustrated by a rainbow. In the culture of Western science, students learn that the refraction of light rays by droplets of water causes rainbows; in some African cultures, a rainbow signifies a python crossing a river or the death of an important chief. Thus, for African students, learning about rainbows in science means constructing a potentially conflicting schema in their long-term memory. Not only are the concepts different (refraction of light versus pythons crossing rivers), but the epistemology also differs ("causes" versus "signifies").

Domain of Application

The phenomenon to which collateral learning refers is universal and well known worldwide (Goodman, 1984; Hennessy, 1993). In 1972, for example, Dart noted how easily Nepalese children and adults talked about earthquakes and other natural events using folk-oriented or school-oriented explanations. "Surprising is the fact that each group nearly always gave both of the types of answers and all members generally accepted both" (p. 51). Solomon (1983) in the United Kingdom documented conceptual differences between students' life-world ideas about energy and the scientific concept of energy, and she explored how students moved with great difficulty between the two domains. On the other hand, Ogunniyi (1988) explained that an indigenous cosmology which conflicts with Western science thinking needs not preclude an understanding of science. It is possible to hold simultaneously an indigenous and scientific view of the world. Hodson (1992, p. 16) extended this argument by suggesting that "the task of science teaching is to help all children acquire scientific knowledge, interests, skills, attitudes and ways of thinking without doing violence to their particular cultural beliefs and experiences." Ogawa (1995) in Japan delineated Hodson's idea by proposing three types of science: personal science (the result of personal beliefs and experiences with nature), indigenous science (the communal beliefs and experiences of a microculture or culture, knowledge which may or may not converge with one's personal science), and Western modern science. Ogawa argued that teaching Western modern science is enhanced when students become aware of the personal and indigenous sciences in a classroom ("multiscience teaching"). In other words, Ogawa implicitly acknowledged collateral learning and suggested that students become aware of their conflicting schemata. Waldrip and Taylor (1999) found that Melanesian high school students in a small South Pacific country were aware of conflicting schemata between school science and the indigenous ideas of their village life. These students coped with discrepancies by employing a process Waldrip and Taylor called the "compartmentalization" of school knowledge (a type of collateral learning). Because of students' compartmentalization of school science, Waldrip and Taylor (1999) "obtained disturbingly little evidence of the positive influence of the [Western] school view of science on young people's traditional worldviews" (p. 301). Students and elders alike felt that school knowledge was not useful to village life (except for reading and writing). The researchers' negative view of compartmentalization (a type of collateral learning) was challenged by Lowe (1995). Based on his Solomon Islands research, he concluded, "To compartmentalize the world into domains, each with an interpretive framework [Western science versus magic], is not a perversity but an effective survival technique" (p. 665).

The effectiveness of the technique of compartmentalization is warranted in Lugones' (1987) account of how she survived in the world of the White Anglo male by being a different person in different domains without losing her self-identity in any of the domains. Her effectiveness is mirrored in the Japanese experience of wearing a Western business suit but maintaining a bamboo heart.

An implication for science teaching for the 21st century is clear. Effective collateral learning in science classrooms will rely on successful cultural border crossings into school science. Collateral learning and border crossings are fundamentally interrelated.

Collateral learning was proposed to explain why many students, non-Western and Western, experienced culturally related cognitive dissonance in their science classes (Jegede, 1995). The theory's domain of application has notable delimitations. Costa's (1995) Outsiders and Potential Scientists normally would not engage in collateral learning, each group for different reasons (discussed below). If Western students are to learn science in any meaningful way, they, too, will most likely construct scientific concepts side by side and with minimal interference and interaction with their commonsense preconceptions (their indigenous everyday knowledge). Constructing scientific concepts is a learning experience usually identified as a mode of constructivism, and has been the object of much research (Driver et al., 1994; Tyson, Venville, Harrison, & Treagust, 1997). As described earlier in this article (and consistent with constructivist research), many students avoid constructing scientific concepts by playing Fatima's rules. Playing Fatima's rules is not generally considered to be an instance of collateral learning because no schema is constructed in long-term memory. In summary, three groups of students do not generally engage in collateral learning: Potential Scientists in Western schools, Outsiders, and any student playing Fatima's rules. The theory of collateral learning proposed in this article will apply mainly to all other students.

Types of Collateral Learning

Collateral learning generally involves two or more conflicting schemata held simultaneously in long-term memory. There are variations in the degree to which the conflicting ideas interact with each other and the degree to which conflicts are resolved. Three types of collateral learning are briefly introduced here and then clarified by examples that show what role they play in learning science. Finally, a fourth type of collateral learning is acknowledged. These four types of collateral learning are not separate categories, but points along a spectrum depicting degrees of interaction and resolution.

At one end of the spectrum, the conflicting schemata do not interact at all. This is *parallel* collateral learning, the compartmentalization technique. Students will access one schema or the other, depending upon the context. For example, students will use a scientific concept of energy only in school, never in their everyday world where commonsense concepts of energy prevail (Solomon, 1983).

At the opposite end of the collateral learning spectrum, conflicting schemata consciously interact and the conflict is resolved in some manner. This is *secured* collateral learning. The person will have developed a satisfactory reason for holding on to both schemata even though the schemata may appear to conflict, or else the person will have achieved a convergence toward commonality by one schema reinforcing the other, resulting in a new conception in long-term memory. Various ways to resolve conflicts and to achieve secured collateral learning are described in the next section of this article.

Between these two extremes of parallel and secured collateral learning lies *dependent* collateral learning. It occurs when a schema from one worldview or domain of knowledge challenges another schema from a different worldview or domain of knowledge, to an extent that permits the student to modify an existing schema without radically restructuring the existing worldview or domain of knowledge. A characteristic of dependent collateral learning is that students are not usually conscious of the conflicting domains of knowledge, and consequently, students are not aware that they move from one domain to another (unlike students who have achieved secured collateral learning).

For many students, learning science meaningfully often involves cognitive conflicts of some kind. Therefore, meaningful learning often results in parallel, dependent, or secured collateral learning. Each of the three types of collateral learning will be illustrated by reanalyzing some recently published research studies.

An example of parallel collateral learning is found in Solomon, Duveen, and Scott's (1994) investigation of students' preconceptions about scientists and scientific activities. Students studied stories from the history of science and discussed why scientists conducted the experiments they did, and what scientists expected to find. The researchers discovered that the preconceptions held by students (students' life-world images of the nature of science) were *augmented,* not replaced, by the history of science instruction. Parallel collateral learning had taken place. As a result of the instruction, two sets of images of the nature of science coexisted in the long-term memories of students. Each set was cued by context, as the interviewers discovered.

In an extension of their first study, Solomon, Scott, and Duveen (1996) abstracted from their new interview data three different ways that conflicting knowledge interacted in the minds of their students. Each way corresponds to a different type of collateral learning:

1. Parallel collateral learning: "They might keep the two kinds of 'science' quite separate as if what they did in school was quite different from the activities of remote and knowledgeable scientists" (p. 497).
2. Dependent collateral learning: "They might produce an amalgam or well-stirred mixture of the two kinds of knowledge" (p. 496).
3. Secured collateral learning: "They might be able to reflect on the similarities between their own work in science and that of scientists. This, we thought, would only happen if the students were enabled to discuss the purposes of experiments and the status of theory in their own work" (p. 497).

Dependent collateral learning occurs when a student's preconception or indigenous belief is (a) contrasted with a different conception encountered in the science classroom, (b) given a tentative status, and then either (c) altered by reconstructing the original schema under the influence of the newly encountered schema, or (d) rejected and replaced by a newly constructed schema. In other words, students modify or reject their original schema because it makes sense to do so. Dependent collateral learning is similar to the Piagetian accommodation-assimilation model of information processing associated with Posner, Strike, Hewson, and Gertzoy's (1982) conceptual change model. A critical difference between the two lies in the degree of imposition of conceptual change on students (cultural assimilation). For example, Arseculeratne (1997) identified a problem in Sri Lanka and other developing countries where people do not incorporate modern scientific thinking into their culture, despite using modern technology and scientific techniques. He blamed society's traditional ideas and modes of thinking. His solution was to avoid "imposing alien ideas on different modes of thinking" (as the model of Posner et al. tends to do) "by modifying and elaborating seemingly naive traditional beliefs . . . without arrogance and patronage but with sensitivity" (p. 267). Arseculeratne's solution is an example of dependent collateral learning. From the perspective of cultural anthropology, dependent collateral learning is the cognitive explanation for *acculturation*—the selected modification of currently held ideas and customs under the influence of another culture (Spindler, 1987). In the context of teaching Western science to First Nations (Native American) students in Canada, Aikenhead (1997) described "autonomous acculturation" as one way for First Nations peoples to appropriate knowledge from Western science to fulfill their own practical needs (such as economic development, environmental responsibility, and cultural survival).

Another illustration of dependent collateral learning is found in the case study of a Trinidadian woman, Mrs. S., who combined aspects of Western medicine with her indigenous folk medicine (George, 1995). Mrs. S. offered definitive advice on matters of health. Some advice came from Western thinking; the rest came from her wealth of indigenous knowledge. At no time was she ambiguous over what domain to use, nor did she contrast the two domains of knowledge. Conflicting belief systems can occupy what Rampal (1994, p. 137) called "complementary domains in the space of social cognition." The belief systems are interwoven and interdependent, and there is no conscious awareness of the various belief systems.

Lugones (1987) herself illustrated a clear instance of *secured* collateral learning. Other instances of collateral learning in the research literature tend to concern goals for science education. Lowe (1995), in his Solomon Island study, argued for a sophisticated view of learning beyond the simple dichotomy of "science versus traditional knowledge." Tobin, McRobbie, and

Anderson (1997) raised the issue of empowerment in the context of students settling conflicts between scientific claims and students' everyday notions of common sense. "Empowerment is associated with an awareness that a knowledge claim does not make sense, and with having the discursive resources [cultural capital] to resolve the conflict at an appropriate time" (p. 506). This position was also advanced by Nelson-Barber and Estrin (1995) for First Nations students; and by Atwater (1996), Lee (1997a), and others for marginalized students in North America. Along similar lines, Cobern (1996, p. 604) thought that students should develop "a new or modified understanding of the world based on new concepts and ideas but concepts and ideas interpreted in the light of culturally grounded meaning. One possible result is the development of complementary thinking which is exemplified by the discourse between science and Christian faith." Complementary thinking and other mechanisms for resolving cognitive conflicts will help clarify the meaning of secured collateral learning further.

Before examining such mechanisms, however, a fourth type of collateral learning should be introduced: *simultaneous* collateral learning. This fits between parallel and dependent collateral learning on the spectrum described above. A unique situation can occur in which learning a concept in one domain of knowledge or culture can facilitate the learning of a similar or related concept in another milieu. It does not happen often, but when it does, it is usually coincidental. For instance, suppose a Nigerian student is studying photosynthesis in school and comes across terms such as *chlorophyll*, *denaturing*, and *chloroplast*. Initially, he may likely have problems comprehending these concepts. But suppose that after encountering the concepts in school, the student finds something that makes the school science vivid while helping his mother in the kitchen. In Nigeria, people often blanch green vegetables before adding them to soup. During this preparation the vegetables are left for some minutes to soak in boiling water, and the vegetables lose some of their green coloration (chlorophyll). When people drain the water, all they see is green color. In that situation, a student might simultaneously learn more about the school concepts of chlorophyll, denaturing, and chloroplast while learning to prepare soup with green vegetables at home. In these two settings (home and school), learning about a concept is not usually planned, but arises spontaneously and simultaneously. By reflecting on the two settings and their concomitant concepts (e.g., green blanched water and chlorophyll), a student may easily cross the cultural border between home and school science. The two sets of schemata established in long-term memory by simultaneous collateral learning may over time (a) become further compartmentalized, leading to parallel collateral learning; or (b) interact and be resolved in some way, resulting in either dependent or secured collateral learning, depending on the manner in which the conflict is resolved. Mechanisms to resolve such cognitive conflicts are examined next.

Mechanisms to Resolve Cognitive Conflicts

The apparent conflict between science and Christian faith was studied in depth by Roth and Alexander (1997) in a high school physics class located in a boys' Christian boarding school in Canada. The study explored the mechanisms of conflict resolution employed by students and scientists alike. By reanalyzing this research report, we will revisit some of the major topics introduced earlier and also clarify conflict resolution mechanisms endemic to collateral learning.

Roth and Alexander (1997) observed three different reactions to potential conflict between science and Christian faith: (a) Some students did not resolve their conflict, and this interfered with their learning physics; (b) other students did not experience conflict at all; and (c) others developed mechanisms which allowed them to eschew such conflicts. Three students (Brent, Todd, and Ian) were selected by Roth and Alexander for individual attention because the students' personal thoughts and feelings represented those of the entire physics class.

Brent, a bright student, chapel warden, and choir member, felt that science was only for atheists and that science teachers tried to indoctrinate students. "Religion and science do not connect. . . . Physics offends my beliefs. . . . In science, I feel like I am drawn away from religion" (p. 142). Brent's situation seems identical to African students committed to their tribe's cosmology in conflict with science class content, a situation that led Jegede (1995) to develop his idea of collateral learning in the first place. However in Brent's case, he was so offended by science that he did not seem to participate in any type of collateral learning. This left him the option of either playing Fatima's rules to pass his physics course (as Other Smart Kids might do) or dropping out in some way (as an Outsider might do). Brent seemed to have chosen the latter, as he failed the physics course. In other words, the cultural gap between Brent's Christian faith (heavily influenced by his fire and brimstone home microculture) and school science was so discordant that cultural border crossing into school science was impossible. Brent could not be flexible or playful in the culture of science, and no condition of feeling at ease existed for him. He refused to be assimilated or acculturated into the culture of science. Brent was an Outsider, and little collateral learning occurred.

In contrast, Todd, also a bright student, chapel warden, and choir member, experienced no conflict between science and his Christian faith. He believed that scientific rationality had no ethical dimensions for making informed social choices, and so scientific rationality did not conflict with his religious perspective on ethical choices. "The notion of God became all-encompassing including science and the knowledge constructed through its procedures" (p. 129). The researchers concluded that Todd integrated science and religion in a way that avoided conflict because his "notion of social constructivism allows multiple viewpoints of the same 'object'" (p. 139). Todd would seem to have achieved a form of *secured* collateral learning. He did this more from his epistemology ("science is a language game") (p. 136) than from using any particular mechanism to resolve conflicts (discussed below). Todd had found a convergence toward commonality (secured collateral learning) because his science schemata (e.g., language games) reinforced his religion schemata (e.g., an all-encompassing God). Not surprisingly, "Having been brought up in a household where science and religion were both part of daily life, it was easy for me to bring the two beliefs together. This coexistence of science and religion continued at our school where both chapel services and science are part of the daily experience" (p. 129). In other words, there were negligible cultural differences between Todd's home and school science. His cultural border crossing into school science was so smooth that Todd would probably claim that it was nonexistent. Having gone on to study medicine at university, Todd was likely a Potential Scientist. Most Potential Scientists in Western cultures do not normally experience much cognitive conflict in science classes because scientific thinking enhances their everyday thinking (enculturation). Todd's case shows, however, that some Western Potential Scientists do engage in collateral learning and can achieve secured collateral learning without much conscious cognitive conflict. Todd's way of achieving secured collateral learning is not necessarily the way others achieve it (as shown below).

When Roth and Alexander (1997) discussed the case studies of Brent and Todd, Ian was introduced briefly. "Institutional science and religion were incompatible and he kept the domains clearly separate" (p. 134). In a situation in which both domains could apply (e.g., in genetic engineering), "Ian usually decided to privilege one realm over the other" (p. 134). This is a clear case of *parallel* collateral learning. Roth and Alexander called the conflict resolution mechanism an “incompatibility device.” There are insufficient data to infer Ian’s cultural border crossing into school science other than to suggest he either managed the border crossing as an Other Smart Kid, or he coped with a hazardous border crossing as an “I Don’t Know” Student. The incompatibility device is a managing or coping mechanism (respectively) that allows for parallel collateral learning—an advantage, we submit, over playing Fatima’s rules with little or no collateral learning taking place at all.

In their quest to discover conflict resolution mechanisms, Roth and Alexander (1997) examined how scientists themselves dealt with conflict in two different settings: (a) within science, resolving the conflict between rational and subjective statements; and (b) between science and religion. For the within-science conflict, the researchers invoked a type of incompatibility device that leads to parallel collateral learning (the “truth will out device” discussed below). For the science versus religion conflict, the researchers developed a “complementarity” device to explain how scientists communicated in *Zygon,* a journal dedicated to bridging science and religion. “The complementarity device . . . allows an individual to look at the object of inquiry (such as abortion or euthanasia) from two mutually exclusive viewpoints and integrate these through a dialectical and hermeneutic process” (p. 135). This integration results in *secured* collateral learning. As Roth and Alexander pointed out, this is a different way of achieving secured collateral learning from the one Todd used. Secured collateral learning can also be attained through dialectical and hermeneutical processes.

It is interesting to note that the “truth will out device” is observable in Bajracharya and Brouwer’s (1997) research in Nepal where a student, Harka, attempted to resolve a conflict between his indigenous knowledge and some science content. When another student questioned the science teacher about an indigenous belief (a drink that makes crows eternally pure and lets them avoid a natural death), Harka exclaimed, “Hey, this is science! You shouldn’t be talking such nonsense in science class” (p. 443). When asked about his own belief about crows, Harka replied, “I agree that the crows don’t die a natural death, sir, I have heard about that from my grandfather, but there must be a scientific explanation for that” (p. 443). Harka believed that science will eventually determine the truth. Searching for a scientific explanation of an indigenous belief exemplifies the “truth will out” device. The exchange with Harka signals parallel collateral learning (if we assume he does not play Fatima’s rules).

Roth and Alexander (1997) did not discuss the mechanisms associated with dependent collateral learning—that is, the mechanisms found in Piagetian disequilibrium models of conceptual change (Posner et al., 1982). The characteristics and limitations of conceptual change models have received a great deal of attention in science education research (e.g., Driver et al., 1994; Tyson et al., 1997). The models and mechanisms are not considered here because they only marginally inform dependent collateral learning. Conceptual change models usually aim to assimilate students into Western science (in the anthropological sense of “assimilate”), which is not the purpose of dependent collateral learning, as stated earlier.

Avoidance versus Participation

Two ways to avoid collateral learning are to play Fatima’s rules or drop out of class intellectually or physically. These avoidance behaviors were not adequately explained by psychological conceptual change models. Consequently, theories of social constructivism were proposed (Driver et al., 1994; Hennessy, 1993; Solomon, 1987). In this article, we have embraced an even broader perspective than social constructivism, a perspective from cultural anthropology, from which students’ avoidance of collateral learning is accounted for by:

1. the difference between a student's cultural identity and the culture of school science
2. the effectiveness with which students are able to cross the cultural border between their life-world and school science, and
3. the assistance students receive as they negotiate those cultural borders.

Because of space limitations, only the first two points are addressed in this article.

In addition to Costa's (1995) work, cultural difference and school science avoidance have been studied in terms of students' worldviews (Cobern, 1996), orientations (Snively, 1990), and interpretive frameworks or repertoires (O'Loughlin, 1992). The problem of discordant cultural differences was also identified by Lee (1997b, p. 221) for minority students in North American science classrooms: "When these students' language and cultural experiences are in conflict with scientific practices, when they are forced to choose between the two worlds, or when they are told to ignore their cultural values, the students may avoid learning science." This normal reaction results in avoiding collateral learning, except for some of the most highly motivated Potential Scientists (e.g., Judy, described below) who seek enculturation.

Participation in school science is indeed a complex event. Insights into harmonious border crossings emerge from the testimony of scientists and students who have overcome potentially wide cultural gaps to move in and out of Western science. Medvitz (1985) documented cases of African scientists who moved effortlessly between the microcultures of their scientific laboratories and their tribal villages, even when they recognized the conflicts between the two. "It's not that we are behaving in a different way to please them. It's that we are *thinking* differently" (p. 14, emphasis in the original). These secured collateral learners were very conscious of the two conflicting cultures and, like Lugones (1987), they felt at ease in both cultures. The capacity and the motivation to participate in diverse cultures and to think differently are familiar human attributes. The capacity to think differently requires flexibility and sometimes playfulness (Lugones, 1987). Our motivation to participate in diverse cultures has a great deal to do with our feeling at ease in the new setting. Lugones's ideas help illuminate the complexity of border crossing into school science.

There are also the attributes of curiosity and risk taking. How do we feel about going to foreign places, learning new things, meeting new people, and participating in other cultures? This amounts to a predilection toward feeling at ease, or, alternatively, enjoying a degree of anxiety, in a foreign milieu—in short, a degree of adventurousness perhaps. These fundamental human traits influence our capacity to think differently in diverse cultures and our capacity to resolve conflicting ideas between those diverse cultures (e.g., to engage in parallel, simultaneous, dependent, or secured collateral learning). All the human attributes mentioned above, integrated within one person, lead to an overall feeling of comfort or harmony with the prospects of border crossing into the culture of school science.

Holistic versus Multiple Worlds

There is yet another human feeling to contend with in our understanding the complexity of cultural border crossing into school science: on the one hand, the predilection toward integrating all our knowledge with scientific knowledge, and on the other hand, consciously compartmentalizing knowledge into various different realms. The former (a holistic view of the world) was the stated goal of Waldrip and Taylor (1999) for their Melanesian students. It gives preference to secured collateral learning and was exemplified by Todd in Roth and Alexander's (1997) study. The latter (multiple views of the world) was strongly supported by Lowe (1995) for his

Solomon Island students. It gives preference to parallel collateral learning and was exemplified by Ian (Roth and Alexander, 1997). This preference also includes secured collateral learners, such as Lugones (1987), who are articulately conscious of their multiple worlds and who have comfortably resolved the conflicts between those worlds. Science students with a holistic outlook may tend to ignore cognitive conflicts perceived by other students who have a partitioned multiple-world outlook.

A multiple-world outlook does not necessarily discourage students from learning science. A First Nations educator argued: “It’s okay to be educated in two worlds in two ways. . . . People think differently, that’s okay—differences don’t have to get in the way of bringing things together” (Henderson, 1996, p. 23).

Aikenhead and Binsfeld (1996) reported holistic outlooks expressed by First Nations students in Grade 10 when interviewed about science bringing them closer to, or further away from, their own culture. Lakota spoke for many students when she stated: “Well, I don’t think there really is any difference between my culture and science. Because we still have a lot of things to learn in our culture, and there’s still a lot of things in science we have to learn.”

Lakota achieved secured collateral learning through a holistic outlook toward her thinking. Her appreciation of the complementarity of science and traditional knowledge is echoed in Crozier-Hogle and Wilson’s (1996) *Surviving in two worlds: Contemporary Native American voices*, and by the success of Native American students in science summer programs (Windham, 1997).

Holistic or multiple-world outlooks do not determine the effectiveness of cultural border crossing into school science, but they are important predilections in combination with the other attributes discussed above. The assistance students receive when they attempt to negotiate manageable, hazardous, or impossible cultural borders into school science will help determine the degree of collateral learning achieved.

Conclusions

Why have 2 decades of significant effort into conceptual change instruction not been as successful as anticipated by their authors? McTaggart (1991) suggested that the efforts have been superficial in nature. What efforts promise to be less superficial, then? Of particular relevance to this article are the calls by Hewson (1988) and Solomon (1987) to probe further into what actually occurs in the minds and hearts of learners when they are being taught science.

In the 21st century, the borders around school science need to be reshaped and reconstituted to encourage students classified as Other Smart Kids, “I Don’t Know” Students, or even Outsiders, to participate in collateral learning by helping them negotiate the cultural transitions into newly designed science programs, characterized by their inclusive curricula and culturally sensitive instruction.

We have proposed some intellectual tools for understanding what goes on in the minds and hearts of students when they learn science. We provided a cognitive explanation (collateral learning theory) for a cultural phenomenon (clashes between cultures or microcultures) mediated by transitions between cultures or microcultures (border crossings). Collateral learning can fruitfully probe what occurs in the minds of learners. Cultural border crossing involves flexibility, playfulness, and a feeling of ease, all matters of the heart. Student alternatives to cultural border crossing were captured by Fatima’s rules.

The science education community has been traveling toward two destinations: understanding concept learning and developing science-for-all programs. Obstacles along that road continue to frustrate the efforts of science educators and researchers. Our modest proposal may help reduce these obstacles by treating the two destinations as one in the same, and by embracing a cross-cultural perspective on science education based on the classroom realities of border crossing, collateral learning, and Fatima's rules. These ideas require further investigation, of course. Our own research programs are informed by these constructs. We invite our colleagues to investigate these classroom realities.

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