The Pervading Influence of Cultural Border Crossing and Collateral Learning on the Learner of Science and Mathematics

Anthony N. Ezeife
University of Windsor

Declining enrollment in mathematics, science, and related fields has plagued schools all over the globe for a long time. In recent years, the flight from science and mathematics has more or less turned into an exodus. Hardest hit are schools in developing nations of the world and in cultures different from the Euro-American (Western) culture. Although many students from Western cultural backgrounds also shy away from science and mathematics, the flight from these subject areas and disciplines is concentrated among students from non-Western cultural backgrounds. Jegede and Aikenhead (1999) proposed the constructs—cultural border crossing and collateral learning—to explain how students move between their everyday life-world culture and the culture of school science and how they deal with cognitive conflicts between the two worlds. This article closely examines these constructs in relation to the fields of science and mathematics generally, and in particular with regard to current teaching and learning practices. The main focus is on students from minority and Indigenous cultural backgrounds across the globe, and its goal is to propose classroom strategies and approaches that would make science and mathematics more attractive to these students.

Introduction

Low enrollment in mathematics and science is a disturbing issue that schools have recognized over the years, but have not been able to address appropriately (Ezeife, 1995; Smith & Ezeife, 2000). Related to this issue is the problem of poor performance in examinations by the relatively few students who enroll in these subjects at school, especially students from minority, Aboriginal, and other Indigenous cultural backgrounds (Binda, 2001; Johnson, 1999). Several research studies have examined the issue of declining enrollment in science, mathematics, and related fields across cultures and national borders. The findings have been consistent and point to the fact that the drift from science and mathematics reported in studies in the 1970s and 1980s (Bates, 1977; Ezeife, 1989; Matthews, 1989; Oyanna 1979) has turned into an exodus in recent years (Jegede & Aikenhead, 1999). In addition, it has been found that declining enrollment not only afflicts schools in the developing world, but also in the industrialized nations of the globe. As Matthews (1989) reported,

> The flight from science in the U.S.A. is dramatic. In 1985-86, 7,100 high schools had no course in physics, 4,200 no chemistry, 1,300 no biology. Between 1971 and 1980, there was 64 % decline in the number of undergraduates entering science teaching. It is estimated that 30 % of science teachers are unqualified to teach the subject. Thirty-five States allow graduation from high school with little or no study of science, a fact reflected in a recent national study that found that 50% of 17-year-olds could not find the area of a square given the length of one side. (p. 5)

The situation reported above for science is replayed, perhaps even more vigorously, in mathematics education. As the National Academy of Sciences (1989) noted in its report, "Mathematics is the worst curricular villain in driving students to failure in school. When math acts as a filter, it not only filters students out of careers, but frequently out of school itself" (p. 7). The same report goes on to add:

> Math is seen not as something that people actually use, but as a best-forgotten (and often painful) requirement of school. For most members of the public, their lasting memories of school math are unpleasant—since so often the last math course they took convinced them to take no more. (p. 10)

The drift from mathematics and science that plagues schools even in the industrialized Western world assumes alarming proportions in the developing world and among ethnic minority and Indigenous populations scattered all over the globe. For example, it is widely acknowledged that North American Aboriginal people shy away from and therefore are underrepresented in mathematics, science, and related disciplines. Citing Lawrenz and McCreath (1988), Schilk, Arewa, Thomson, and White (1995) aptly describe the situation, stating: "Native Americans have the lowest representation percentage of all minorities in scientific careers and are at risk in pursuing science in high school and in post-secondary education" (p. 1). Davison (1992) specifically draws attention to the situation in mathematics, saying, "What cannot be questioned is that the mathematics achievement of American Indian students as a group is below that of white students in the United States" (p. 241). The plight of Canadian Aboriginals closely resembles that of Native Americans with respect to low enrollment, substandard achievement, and high dropout rates in science, mathematics, and technological fields, as observed by MacIvor (1995). Low enrollment in science and mathematics also plagues schools in African societies. For example, Nigeria, in sub-Saharan Africa, has been battling not just to arrest the decline, but also to promote the study of science subjects in schools by formulating a 60:40 ratio of science to arts admissions (Federal Republic of Nigeria, 1998). Unfortunately, however, Nigerian universities have not been able to meet this 60 % admission quota for the sciences and related fields of study, because there is a dearth of qualified candidates.

In these traditional and Indigenous societies, the trend is that the majority of students either avoid science and mathematics completely in school or perform poorly in these subjects when they enroll. A good number of students also drop out from these courses but still do well in other subjects and eventually complete their schooling. Why do students find mathematics and science relatively more challenging and taxing than most other school subjects? Why do students from minority and Indigenous cultural backgrounds particularly find mathematics and science as currently taught in schools difficult? With a view to finding reasoned answers to these crucial questions, and exploring the issues further, Jegede and Aikenhead (1999) proposed the construct of "cultural border crossing" and a related cognitive explanation, "collateral learning theory." In response to the authors' suggestion that researchers further investigate these "classroom realities," this article examines the constructs in the light of my experiences and interactions in the teaching and learning of science and mathematics.

Cultural Border Crossing

The alienation felt by many students toward science and mathematics is attributable to the fact that these students perceive a lacuna or chasm between their daily life experiences or life-world and the classroom experiences they encounter as they delve into the world or subculture of science and mathematics. As Aikenhead and Jegede (1999) pointed out, students from Western and non-Western cultures share this feeling of foreignness toward science subjects. However, students from non-Western cultural backgrounds harbor the feeling of foreignness and alienation to a greater degree because of the difficulties they encounter in making the transition from their life-world culture into the subculture of science. Aikenhead (1996) conceptualized this transition between the students' life-world experiences and school science experiences as a cultural border crossing. Expatiating, Aikenhead stated:

> Success in science courses depends on (1) the degree of cultural difference that students perceive between their life-world and their science classroom, (2) how effectively students move between their life-world culture and the culture of science or school science. (p. 3)

The assistance that students receive, or fail to receive, as they make transitions from their life-world culture into the culture of school science is also an important factor in border crossing, according to the same authors.

In another work, Jegede and Aikenhead (1999) used the terms *enculturation* and *assimilation* to describe broadly the ease or difficulty with which students cross cultural borders. They stated,

> When the culture of science harmonises with a pupil's life-world culture, science instruction will tend to support the pupil's view of the world, and the process of *enculturation* tends to occur. This process is characterized by smooth border crossing into school science. However, when the culture of science is generally at odds with a pupil's life-world, science instruction will tend to disrupt the pupil's world view by trying to force that pupil 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 pupils from their Indigenous life-world culture, thereby causing various social disruptions, or alternatively, attempts at assimilation can alienate pupils from science, thereby causing them to develop clever ways (school games) to pass their science courses without learning the content in a meaningful way. (p. 3)

Levels of Difficulty in Border Crossing

Referring to Costa (1995), Jegede and Aikenhead (1999) identified four types of border crossings corresponding to the levels of difficulty students experience while making transitions from the life-world culture into the culture of school science. Four categories of students were also associated with the four levels of difficulty.

Smooth border crossing. Students whose life-world culture (home, peer, communal, societal) and school science culture are congruent easily move from one culture to the other. Such students experience smooth transitions and are referred to as Potential Scientists.

Manageable border crossing. When the life-world culture of the students is not too different (somewhat different) from the culture of science, then such students would undergo manageable transitions and are classified as Other Smart Kids.

Hazardous border crossing. This occurs when the two cultures "are diverse." Hazardous transitions would produce I-Don't-Know Students.

Impossible border crossing. When the two cultures are "highly discordant," students find it impossible to cross from one culture to the other. Thus the transitions are impossible, and the overall effect is the complete alienation of students from science. Such students are referred to as Outsiders.

Collateral Learning

The term *collateral learning* is used to explain the conflicts that inevitably arise from the cultural differences between students' life-world culture and school science. As Jegede and Aikenhead (1999) stated, the theory was first proposed by Jegede (1995) "to explain why many pupils, non-Western and Western, experienced culturally related cognitive dissonance in their science classes" (p. 7). Commenting further on the theory, the same authors stated:

> The *cognitive* experiences of border crossing is captured by the theory of collateral learning. The phenomenon to which collateral learning refers is universal and well known worldwide ... Collateral learning generally involves two or more conflicting schemata held simultaneously in long-term memory. (Jegede & Aikenhead, 1999, p. 7)

Types of Collateral Learning

Aikenhead and Jegede (1999) identify four types of collateral learning, not as separate entities, but as zones or areas along a spectrum. These zones in the spectrum signify or depict the degree to which the conflicts that arise are resolved. In brief, the four types of collateral learning are:

Parallel collateral learning. Here "the conflicting schemata do not interact at all." It is the "compartmentalization technique" in which "students will access one schema or the other depending on the context" (p. 19). Thus students will adduce and use a scientific concept, idea, or explanation of a topic while in school, but then quickly revert to the commonsense or life-world explanation of the same topic in their everyday life.

Secured collateral learning. In this type, "conflicting schemata consciously interact and the conflict is resolved in some manner" (p. 20). The student who achieves secured collateral learning

> 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. (p. 20)

Dependent collateral learning. This type of learning takes place 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). (p. 20)

Simultaneous collateral learning. Fitting "in-between parallel and dependent collateral learning" (p. 24) on the collateral learning spectrum of zones, simultaneous collateral learning describes a rare, usually coincidental situation "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" (p. 24).

> The two sets of schemata established in long-term memory by simultaneous collateral learning may over time: (1) become further compartmentalised, leading to parallel collateral learning, or (2) 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. (p. 25)

Implications of Constructs for Science and Mathematics Teaching and Learning

The key strength of the constructs—cultural border crossing and collateral learning—lies in the fact that these constructs distinctly and unambiguously address issues that have confronted science and mathematics education over a long stretch of time. These issues include low enrollment, poor performance in examinations, alienation of students, and consequent flight from science and mathematics courses. The constructs clearly bring out the fact that not only students from non-Western cultural backgrounds, but also students from Western cultures encounter cultural differences between their life-world and school science-mathematics cultures. However, the degree of cultural dissonance is greater for students from Indigenous and traditional (non-Western) backgrounds.

In making a reasoned, research-supported case why these (non-Western) students have difficulty in science and related fields of study, the constructs (cultural border crossing and collateral learning) have gone a long way toward debunking the "genetic inferiority perspective." Referring to the proponents of this perspective (Jensen, 1969; Loehlin, Lindzey, & Spuhler, 1975), Hollins (1996) stated:

> Proponents of this point of view believe that some races are innately inferior to others … These scholars contended that intelligence is a biologically determined and irreversible condition of birth that cannot be altered by schooling. Thus the logical response for schools is to continue the usual practice of providing the best academic preparation for the most able students, usually from the White race, and appropriate training for those who are less capable, the majority of whom are people of color. (p. 104)

Cultural border crossing and collateral learning postulate that the majority of students from certain cultural backgrounds perform poorly in science and mathematics, not because they are genetically inferior, but because of the mountain of problems that these students have to contend with as they struggle to study these subjects. How can we facilitate the teaching and learning of science-mathematics in the light of the cogent points raised by the constructs of cultural border crossing and collateral learning? This question is addressed below.

Injection of Learners' Life-World Culture Into the Culture of School Science and Math

To my mind, the injection of the student's life-world culture into the culture of school science and mathematics should be the starting point of meaningful and effective science and mathematics teaching and learning in schools. It is when we are able to decipher what the learner already knows (his or her preconceptions), believes, does, and practices in his or her daily life that we can channel our curriculum and instruction efforts to maximize learning and achievement conditions for the learner. Backhouse, Haggarty, Pirie, and Stratton (1992) cited Ausubel (1968), who stated: "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi).

This boils down to the simple, yet all-important maxim of going from the known to the unknown, which in this particular context translates into linking the learners' previous knowledge and preconceptions (drawn largely from their prior experiences and culture) to new learning in mathematics and science. Many researchers (Backhouse et al., 1992; Ovando, 1992; Smith, 1994; Stanley & Backhouse, 1998) generally agree that learning becomes meaningful for most learners if they see the direct relevance of what they are studying in school to their personal lives in the home, community, and society. Cultural border crossing will definitely be facilitated for learners from non-Western cultures if their background knowledge and practices (from their life-world cultures) are somehow integrated into and used as springboards into science and mathematics teaching and learning. How this can be done has been discussed appreciably in recent research literature (Aikenhead & Huntley, 1999; Allen & Pewewardy, 1999; Cajete, 1994, Smith & Ezeife, 2000). For example, it would be appropriate to prepare and use culture-sensitive curricula in teaching mathematics and science in today's classrooms. Most students from non-Western cultural backgrounds feel alienated from science and mathematics partly because the curricula used in teaching these subjects are bereft of cultural knowledge and experiences from Indigenous, minority, and traditional cultures. On the contrary, mainstream (Western) cultural values are given prominence, with sad consequences (hazardous and impossible border crossings) for the students from non-Western cultural backgrounds. Thus students from these non-Western cultures are automatically disadvantaged in the science-mathematics classroom, whereas their Western counterparts enjoy the advantage arising from the fact that their cultural values and teaching-learning styles dominate the classroom environment. The need to develop all-inclusive curricula for mathematics and science teaching becomes more cogent as today's world continues to witness large population shifts, multicultural classrooms, and a higher number of students from minority and Aboriginal communities and cultures.

Modification of Mathematics-Science Teaching Methods

The way science and mathematics are currently taught in schools does not favor the learning styles of students from Indigenous cultural backgrounds. Cajete (1994), based on his own experiences when growing up as a young Aboriginal (also called *Indian* in Canada, the United States, and Latin America) student, and currently as an established science educator and researcher, had this to say:

> For many Indian students, conventional science courses are seen as dry and mechanical, comprised of memorizing facts and formulas, taking tests and answering questions from the back of their textbook. The process has little to do with their lives ... Alienation from science, as it is conventionally taught, is widespread among Indian students. This affects student performance in mathematics and science as indicated by their generally low test

> scores in science and related areas. This alienation from science has resulted in lack of scientific expertise among all tribes, leaving them vulnerable to exploitation and dependency on non-Indian consultants for decisions related to resource development, health, and other areas requiring scientific expertise. (p. 196)

The one-track method of science-mathematics teaching (essentially, the explain-and-solve approach) does not augur well for Indigenous students who tend to prefer the holistic (broader) approach that involves the integration of the cognitive, affective, and psychomotor domains of knowledge. Schilk et al. (1995) reported interesting and revealing findings from their study, which employed "holistic instructional techniques relying heavily on co-operative group work" (p. 3). Biographies of both male and female scientists from all races were some of the reading materials used in the study. It was interesting to read from the research findings that an Indigenous student who had stated before the study that Indians (i.e., Aboriginals) did not do science suddenly developed an interest in studying electricity because he wanted to help people. No doubt the student had realized after taking part in the research study that he could use whatever knowledge he would acquire from learning about electricity to help tackle the continual power outages or failures and low current output in many Aboriginal reserves in North America. The same conditions are true of several rural and Indigenous communities in Africa and other parts of the world. (Apparently, after reading the biography of Michael Faraday as part of the research course requirement, the student saw how Faraday's pioneering work in electricity helped people of his era). Thus the student has now seen a direct relevance between the science knowledge he would acquire in school and his after-school life and aspirations. Several other students in the study also expressed interest in the environment in which they lived, and the quality of air, and so forth. Summing up the results of the study, the authors stated, inter alia:

> Teaching science in a holistic manner had a positive effect on student perceptions of science, as evidenced by student interviews, journals, and work that occurred over the course of the unit. The unit included a broader view of science than the students had been exposed to previously. This broader view led not only to a change in attitude, but also to a change in perception about what can be included under the heading of science. (p. 3)

In mathematics teaching in particular, special efforts should be made not to present mathematics merely as a set of rules, symbols, equations, and formulas. "Rules without reasons," referred to by Backhouse et al. (1992, p. 36), should be discouraged in mathematics teaching. An example of such rules is the one commonly used in solving algebraic equations, which states, "Change side, change sign."

Summary and Conclusion

Jegede's (1995) illustration of simultaneous collateral learning involving an African (Nigerian) student studying photosynthesis, as cited in Aikenhead and Jegede (1999) is an apt example of how a student's life-world culture can reinforce and concretize school science culture. There are so many such examples and illustrations from Indigenous cultures that a seasoned science and mathematics teacher can use to vivify his or her teaching, achieve appropriate collateral learning, and hence facilitate border crossings for students from Indigenous/Aboriginal cultural backgrounds. For example, a student growing up in a typical tropical African environment would most probably come across the chameleon as he or she (the student) played in outdoor gardens and surrounding lawns with peers. This peculiar lizard attracts most curious youngsters because it changes its color as it makes its slow walk through bushes, multicolored flower beds, and shrubs. Hence a biology teacher who uses the chameleon to illustrate the natural, survival-oriented adaptation of animals to their environment would strike a chord with the students from a tropical African background because the students have already learned about this characteristic from their life-world interactions in the environment.

The science-mathematics teacher has to play a major role in guiding students in his or her class to effectively cross cultural borders and attain the desired form of collateral learning. Jegede and Aikenhead (1999), citing Stairs (1995) and Atwater (1996), severally described the teacher fulfilling this role as a culture broker, a coordinator, facilitator, and resource person in multicultural education. To my mind, the teacher is all these and more. To be truly effective in today's multicultural classroom, science-mathematics teachers need to be fully aware of the problems faced by students from cultural backgrounds different from the mainstream (Western) culture. Perhaps a refresher course geared toward the constructs—cultural border crossing and collateral learning—may be necessary for today's science-mathematics teacher to play his or her role effectively.

Sample Lesson

Aikenhead and Jegede (1999) cited Solomon's (1992) investigation as a good example of cross-cultural instruction that resulted in successful border crossing for students. Distinguishing attributes of the instruction are that the lesson "accentuated playfulness" with the science concepts taught, "demanded flexibility in moving between the life-world and science world, and gave students a feeling of ease in the culture of science" (p. 15). Hence playfulness, flexibility, and a feeling of ease, were essential ingredients identified in the successful instruction. It is my considered opinion that in addition to having these noble characteristics, a plan of instruction should also dwell extensively on using what is available in the learner's environment and culture to enhance and vivify instruction. Thus I have tried to develop a sample lesson that has as its goals:

- The integration of the student's background knowledge (from culture, environment, peer group interaction, etc.) into school science and mathematics;
- Making science real to life;
- The adoption of a multisensory approach to teaching-learning; and
- Applying science to students' life-world activities at home, in the community, and even in the school playground.

The lesson plan (in the Appendix) has been fully discussed in Ezeife (1996) and has been used in instructional settings that helped students easily cross cultural borders and achieve desired collateral learning.

Description of Sample Lesson

In this section I endeavor to explain how the sample lesson (Appendix) could be viewed as an example of a lesson plan designed to facilitate cultural border crossing for students and thereby enable them attain the desired level of collateral learning. I also discuss the import of such a lesson for the science teacher engaged in curriculum design and implementation.

Linking the Students' Life-World Culture to School Science Culture

Students for whom the lesson is planned (grade 10, about 14-15 years of age) usually enjoy active lifestyles: swimming, going to beaches and lakes, and so forth. By using the introductory everyday example of a kid running into a pool of water from the shore, the lesson aims at establishing a link at the outset of the lesson between what children do and enjoy in real life (life-world culture) to the science topic—refraction—they are about to study in the classroom. The sequential development of the lesson would involve drawing an analogy between the change of speed and direction of movement (which the students experience physically as they run into bodies of water) and the change in speed and direction that a ray of light undergoes when it travels between two media of different refractive indices—for example, between air and glass or between air and water. Similarly, the common everyday observation whereby a straight stick jutting out of a container of water appears bent at the container/water interface—Objective 1, activity (b) of the sample lesson—would serve as an example where a day-to-day event or phenomenon is used to illustrate and explain a scientific concept studied in the classroom. Indeed each of the activities and learning experiences suggested in the sample lesson is drawn directly from, and somehow linked to, the students' real-life experiences emanating from their life-world culture. By adopting this approach, the lesson tends to emphasize the need for an interaction between the learner's daily life and school science. If such an interaction is effectively and consistently established, then the learner will grow to regard science as a familiar, native subject, and not view it as a far-off, foreign invention (Ezeife, 2002). Such a link is extremely important and beneficial to the learner from a non-Western cultural background. This link and interaction would facilitate cultural border crossing and enhance collateral learning for an Indigenous/Aboriginal learner because such a learner would grow to see science as part-and-parcel of his or her life, no longer as *their* (Western) science.

Multisensory Approach to Teaching-Learning

The sample lesson suggests the adoption of a multisensory approach to teaching science content, a strategy that has been found (Cajete, 1994; Hanson, 1994; Kanu, 2002; Smith & Ezeife, 2000) to favor the learning styles of students from Indigenous cultural backgrounds. These students are high-context, holistic-oriented learners (Ezeife, 2002) who tend to learn best by focusing on how things are interrelated. The multisensory approach to instruction not only brings out the interrelationship between learning activities and concepts, but also enables the holistic learner to use the whole package of "Multiple Intelligences" (Gardner, 1993) he or she is endowed with in constructing meaning in the classroom. For example, the sample lesson plan tries to woo the "Naturalistic" learner by using examples, illustrations, and phenomena from the natural environment: lakes, beaches, light rays, and the rainbow (the multicolored bow that most students must have seen in the sky at one time or another). The lesson aims to draw out the "Bodily-Kinesthetic" learner by incorporating a series of manipulative activities. Furthermore, the "Spatial" and "Logical-mathematical" learner would find interest in the lesson because it involves drawing activities and problem-solving exercises. Similarly, the interactive discussion aspect of the lesson is designed to draw out the "Linguistic" learner. Thus several of the eight Multiple Intelligences identified by Gardner (1993, 1999) have been incorporated into the lesson.

Kanu's (2002) work rightly identifies the Canadian Aboriginal student as a multidimensional learner whose competence peaks when instructional material is presented through stories, observation and imitation, cooperative group work, and so forth. The sample lesson plan given in the present study encourages this diversified, multidimensional approach to teaching the Indigenous student because of the positive effect the approach would have on the student's ability to cross cultural borders and engage in collateral learning. By adopting this diversified strategy of science teaching, the teacher gives the learner the opportunity to learn through the intelligence(s) in which he or she is most gifted. This is consistent with Gardner's suggestion (as cited in Goodnough, 2002) that the learner should be given the challenging, yet inviting opportunity to answer the question: "How am I smart?" (p. 225). Thus when the science teacher is able to convey the message to the Indigenous leaner of science that he or she is smart enough (in some way) to learn science, then the fear of science and the alienation felt toward it by most non-Western students would gradually disappear.

How can a science teacher incorporate appropriate learning experiences into a science teaching curriculum targeted to Indigenous students? How can the teacher steer these students through smooth cultural border crossing to the attainment of secured collateral learning? I attempt to answer these questions by narrating a real-life story of how I achieved these goals in a memorable science teaching-learning workshop some years ago in a tropical African setting. My duty in the workshop was to find innovative ways to teach science to a group of Indigenous elementary school teachers whose subject-matter content was low and who over the years had developed a high degree of apathy toward science and lacked confidence in their ability to teach the subject effectively. Faced with this challenge, I had to come up with a strategy that would somehow tap their traditional (cultural) knowledge and link this culture-based knowledge with the learning experiences I would use in the classroom. Success came quickly in my first unit, which was on "Energy and the Interconversion of Energy." Background research conducted as I was preparing for the workshop had revealed to me that the bow and arrow were so widely used as hunting equipment in the locality that most of the villagers were reputed marksmen and had a variety of bows or arrows in their arsenal for diverse purposes and hunting expeditions. Armed with this useful information, I walked into my first class with a cache of bows and arrows, and introduced the lesson by generally discussing these instruments: how they are made and with what materials, what they are used for, how the dexterity and strength of the user determines the success he or she achieves with the instruments, and so forth. Of course, the students (elementary school teachers) enthusiastically participated and actually led the interactive discussion, because as it turned out many of them were actually noted sharpshooters in the community. After this preamble, I effortlessly linked the highlights of the discussion to the theme of the lesson: Energy. With guiding prompts from me, the students were able to make the connection between the *strength* of the arrow shooter to the *Energy* (capacity to do work) possessed by the shooter. Having established this base, we then went on to talk about various forms of energy, still with reference to the bow and arrow. Thus it made sense to the students when we talked of *Potential Energy* as stored-up energy, because they readily linked this concept to the tension in a drawn (stretched out) bow with an arrow held to the string, and ready to fly off on release. Also, they had no difficulty capturing the concept of *Kinetic Energy* (the energy of motion) as represented by the flying arrow after it is let go from the drawn or stretched bow. Furthermore, the concept of Interconversion of energy (energy change from one form to another) was quickly grasped by the class because they had seen the bow-and-arrow combination convert potential energy to kinetic energy, and finally to sound and heat energies. In the course of the lesson, we had mounted a hard-surface board as a target, and several class members took turns at shooting their arrows at the target. The sound they heard every time the target was hit convinced them that the kinetic energy in the flying arrow was converted into sound energy. In addition, after each hit I prompted the students to go and touch the spot where the arrow struck the target. Of course, they all felt the heat at the hitting point and became convinced that kinetic energy had been converted into heat energy too.

The assenting nods that greeted each step of the lesson and the vivacity with which the students participated in the lesson convinced me that this group of middle-aged elementary school teachers had started looking at science from another perspective—no longer as something you just culled from foreign, hard-to-understand textbooks, but as part and parcel of their culture, their environment, and their life-world. And I was right. By the time the group met for another three-hour session the following day, the class size had doubled: the story of the bow and arrow (in a science classroom?) had gone round the community! Encouraged by this all-important entry-level success, I built more lessons of the Unit (Energy) on the bow and arrow, using real-life experiences of the students to treat related concepts like Work (Force x distance), Momentum (Mass x velocity), and so forth. Follow-up visits to the teachers after the inservice workshop revealed that each of them had developed renewed interest in science and confidence in their ability to teach it meaningfully to their eager young students. The best part of all, to my mind, was that they all became committed to using their students' life-world experiences as launching pads in science teaching, thereby enabling the students not only to cross smoothly from their life-world cultures to the culture of school science, but also to attain the desired level of collateral learning. Science teachers in various Indigenous cultures can easily adopt this strategy. The immediate benefits of such an approach would be noteworthy and the potentials immense.

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Appendix
Science (Physics) Lesson Plan Based on Cultural Border Crossing/ Collateral Learning Model

Date: Oct. 17, 2002.
Duration: 3 hours.
Class: Grade 10
Subject: Physics
Topic: Refraction of Light at plane surfaces.
Objectives: At the end of the lesson, students should be able to

1. give the meanings of the terms Refraction and Refractive index.
2. distinguish between Reflection and Refraction of Light.
3. state the Laws of Refraction.
4. work out numerical problems involving Refractive Index, Real and Apparent depths.
5. relate Refraction to some of their day-to-day observations; name, comment on, and appreciate the uses of Refraction in industry and the society as a whole.
6. perform sample experiments on Refraction and interpret the results.

Materials and Teaching Aids

1. Source books

Di Giuseppe, M. et al. (2003). *Biology 12*. Toronto: Nelson/Thomson Canada Ltd.
The Ontario Curriculum, Grades 1-8: Science and Technology (1998). Toronto: Ministry of Education and Training.
Tillery, B.W. (1999). *Physical Science* (4th ed.). Boston: WCB/McGraw-Hill.
Nowikow, I. & Heimbeckev, B. (2001). *Physics: Concepts and connections*. Toronto: Irwin Publishing.

Long, C.T., & DeTemple, D.W. (2000). *Mathematical reasoning for elementary school teachers* (2nd ed.). Reading, MA: Addison-Wesley.

2. Teaching aids

(a) A chart and an overhead transparency illustrating "refraction through a rectangular glass block."
(b) Stick partly immersed in a container of water.
(c) Rectangular glass blocks, optical pins, drawing boards and sheets, ink mark on plane sheet of paper.
(d) Overhead projector.
(e) The ripple tank and its accessories.
(f) Students themselves.

Entry Behavior

1. Previous Knowledge: It is assumed that
   (a) students have had lessons on "reflection of light";
   (b) can distinguish a plane surface from a curved one.
2. Test of Entry Behavior: Using the questioning techniques, briefly review the previous lesson and refresh the students' memory as follows:
   i. What do we mean by "reflection of light"?
   ii. When does reflection occur?
   iii. In what direction will a ray of light, AB, incident at the point B on this glass surface be reflected? (Draw a diagram on the chalkboard).
   iv. Point out to me (on a diagram) the "glancing angle," the "angle of incidence," and the "angle of reflection."
   v. Give an example of an object that has a plane surface, an object with a curved surface.

Presentation

Objective	*Activity*
1	(a) Introduce refraction by using the idea of variation of speed in different media. Arouse students' interest by choosing an everyday example—a kid running from the shore (air medium) into a pool of water (water medium). What happens to his/her speed, and direction of movement?
	(b) Display the stick partly immersed in a can of water. Let the students observe this and make comments.
	(c) Using a group of students in a straight line, illustrate the bending of the line when the speed of movement of one half of the line differs from that of the other half. Let the students comment on their observations.
	Based on ideas gathered from (a), (b), and (c), guide the class to establish the fact that refraction involves the bending of a ray of light as it goes from one medium to another.
2	Display on the chalkboard the diagram showing refraction through a rectangular glass block. Point out the weak reflected ray.

Lead the students to note the relative magnitudes of the angles of incidence and refraction. Ask them:

(a) Which angle appears bigger?

(b) How do you contrast this with the relation between angles of incidence and reflection?

Hence they should draw the conclusion about an important difference between reflection and refraction, that is, in reflection, angle of incidence = angle of reflection, but this is not the case in refraction; that is, the angle of incidence is not equal to the angle of refraction.

3 & 5 (a) By reminding the students of the relative sizes of the angles of incidence and refraction—as concluded from 2(b) above—establish the fact that the angle of incidence is always greater than the angle of refraction for a ray travelling from one medium to a second medium, which has a higher optical density. Thus the ray is always bent toward the "normal" in this case.

(b) Call out 4 students to work in pairs with rectangular glass blocks and optical pins, tracing the outline of the block, then the paths of the incident and refracted rays as observed through the glass block. By drawing the normal, let them measure the values of angles of incidence and refraction for various traces of the glass block. Encourage them to find the ratio sin i/sin r (where i = angle of incidence, r = angle of refraction) for all the traces. Prompt them to establish Snell's law: sin i/sin r = a constant (the refractive index of glass).

(c) Make an ink mark on a plane sheet of paper. Call on the students to look at it. Then put a glass block over the ink mark. Again let them observe the ink mark. Ask: Do you notice anything? If so, what?

Next, introduce the concepts of real depth and apparent depth. Ask the students to try and recall any occasions in everyday life they had observed the phenomena of real and apparent depths. Discuss these situations and then establish the relation between real and apparent depths:
Real depth/Apparent depth = a constant (the refractive index).

(d) Lead the class to establish the "law of the plane" for refraction.

(e) Ask the students to consider and comment on what they think is the usefulness of refraction generally, and in particular its applications in industry. Engage the whole class in a discussion of the points raised by contributors.

4 *Solve:* A ray of light falls on the surface of a piece of diamond at an angle of incidence 50°. If the refractive index of diamond is 2.4, find the angle of inclination of the refracted ray to the normal.

6 Set up a ripple tank. Give the students a thin slab of glass. Let them set up water waves in the tank, introduce the glass slab, and

spread a thin film of water over its surface. Let them set up the waves again and observe carefully. Ask them: What happens? Why? Encourage the students to repeat the experiment for various positions and different angles of the slab.

Terminal Behavior

1. Test of terminal behavior

i. State the laws of refraction.

ii. How does
(a) refraction resemble reflection?
(b) differ from it?

iii. An ink mark is made on a piece of paper and a rectangular block of glass is placed on the ink mark. An observer then views the ink mark normally through the top of the block. If the thickness of the block is 6 cm, how much nearer will the ink mark appear to the observer given that the refractive index of glass is 1.5?

2. Consolidation exercises and assignment

Arrange for the class to go on an academic field trip to a nearby "clearwater" stream or swimming pool where it is possible to see the bottom clearly. Let the students put small, flat, heavy objects at the bottom and estimate the depth of the stream/pool. Then, ask them to make actual measurements using a string tied to the objects, and compare their estimated and actual values. Which are bigger/smaller? Do you observe any regular patterns with regard to the magnitudes of the estimated and actual values? If so, explain.

Next, let the students wade deeper into the pool/stream, and again place small but heavy objects at the bottom, and then try to hit the objects with long pointed sticks while standing directly above the objects. Is it easy or difficult to hit the targets? Explain.