Putting Your Money Where Your Mouth Is: Towards an Action-oriented Science Curriculum

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Responses

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Introduction

Over the past decade and a half, understanding the nature of science (NOS) has come to be regarded as a major component of scientific literacy and an important learning objective of science curricula (for example, AAAS, 1993; UNESCO 1993: National Research Council, 1996; Council of Ministers of Education 1997; Millar & Osborne 1998; OECD, 1999; Goodrum, Hackling & Rennie, 2000; Department of Education (RSA), 2002). In making the case for NOS knowledge in the curriculum, Driver, Leach, Miller and Scott (1996) contend that in addition to its intrinsic value, NOS understanding enhances learning of science content, generates interest in science and develops students' ability to make informed decisions on socioscientific issues on the basis of careful and critical consideration of available evidence. However, while there has been extensive research on students' and teachers' conceptions of NOS and numerous efforts to develop more effective NOS-oriented curricula, robust understanding of NOS for all is still far from being achieved. Indeed, it has been consistently reported that both students and teachers possess inadequate, incomplete or confused NOS understanding (Lederman, 1992; Driver et al., 1996; Ryder, Leach, & Driver, 1999; Abd-El-Khalick & Lederman, 2000; Hogan & Maglienti, 2001; Moss, Abrams, & Robb, 2001; Finson, 2002). Regrettably, the goal of improving NOS understanding is often prejudiced by stereotyped images of science and scientists consciously or unconsciously built into school science curricula (Hodson, 1998) and perpetuated by science textbooks (McComas, 1998; Abd-El-Khalick,, Waters & Le, 2008; van Eijck & Roth, 2008; Kosso, 2009). Research has shown that, in general, an explicit approach is much more effective than an implicit approach in fostering more sophisticated conceptions of NOS among students, preservice teachers and practising teachers (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick, 2005; Khishfe, 2008). Most effective of all are approaches that have a substantial reflective component. For example, Lucas and Roth (1996) report substantial gains in NOS understanding during a course incorporating readings on NOS, reflective essays, class discussions and opportunities for self-directed laboratory experiences; Akerson, Abd-El-Khalick and Lederman (2000) report substantial improvements in elementary student teachers' NOS views when the science methods course required reflection on NOS, both orally and in writing, following a series of readings and other activities.

It is interesting and disappointing (in the context of this article) that the gains in NOS understanding consequent on exposure to explicit, reflective instruction are considerably less substantial in relation to the sociocultural dimensions of science than with other NOS elements. Moss et al. (2001) state that, in general, grade 11 and 12 students' understanding of the nature of scientific knowledge (for example, that it requires evidence, and is tentative and developmental) is more complete than their understanding of the scientific enterprise. If the term 'scientific enterprise' is taken to include internal and external social factors that impact on the conduct of science, and is not restricted to the specific methods employed in particular scientific inquiries (or to what some teachers continue to refer to as 'the scientific method'), then I would readily concur. Many students continue to believe that science occurs in something of a sociocultural vacuum – a view held by both preservice and inservice science teachers in Tairab's (2001) study. Akerson et al. (2000) speculate that poor understanding in this aspect of NOS is a consequence of the subtleties of the subjective and sociocultural influences on scientific practice being impossible to capture in a short course (in their case, for preservice teachers). One or two brief examples will not achieve it; detailed and richly textured case studies (both contemporary and historical) may do so. Dass (2005) reaches essentially the same conclusion when accounting for why a semester-long undergraduate history of science course focused on the sociocultural and political context of major scientific advances achieved only "modest gains". I would argue that disappointing outcomes are also a consequence of uncertainty about intended learning outcomes in this particular NOS domain, the inadequacy of assessment procedures for capturing student understanding, low levels of confidence in teaching these aspects of the curriculum and the pervasiveness and power of images of science and scientists acquired through informal learning channels. If teachers are unclear about precise learning goals relating to the sociocultural dimensions of science, as many are likely to be, there is likely to be a lack of clarity in lesson design. If researchers are unclear about the precise goals of NOS-oriented experiences, the assessment instruments they deploy will inevitably lack validity and reliability. If teachers lack confidence in their own NOS knowledge (and, more particularly, in the appropriate pedagogical content knowledge), they may regard the sociocultural dimensions of NOS-oriented teaching as a 'minefield of uncertainty' and a potential source of major classroom problems that is best avoided. With regard to the fourth factor listed above (the power of informal learning), it is crucial that teachers know the kind of views about science and scientists that students encounter outside school, and that they take steps in class to address them, critique them, and when necessary seek to displace them.

The drive to equip students with an understanding of science in its social, cultural, economic and political contexts is, of course, the underpinning rationale of the so-called science-technology-society (STS) approach – more recently expanded to STSE (where E stands for environment). James Gallagher (1971), one of the pioneers of STS education, captures its overall flavour particularly well.

> For future citizens in a democracy, understanding the interrelations of science, technology, and society may be as important as understanding the concepts and processes of science. An awareness of the interrelations between science, technology, and society may be a prerequisite to intelligent action on the part of a future electorate and their chosen leaders. (p.337)

STS has always been a purposefully ill-defined field that leaves ample scope for varying interpretations and approaches, and much has changed over the years in terms of its priorities and relative emphases (Solomon & Aikenhead, 1994; Yager, 1996; Kumar & Chubin, 2000; Gaskell, 2001; Aikenhead, 2003; Pedretti, 2003; Nashon, Nielsen & Petrina, 2008). Aikenhead (2005, 2006) describes how the early emphasis on values and social responsibility was systematized by utilizing a theoretical framework deriving from sociology of science: (i) the interactions of science and scientists with social aspects, issues and institutions external to the community of scientists, and (ii) the social interactions of scientists within the scientific community. Both emphases have remained strong, though much has changed with respect to the sociopolitical and economic contexts in which educators and scientists work, our understanding of key issues in the history, philosophy and sociology of science, and our theoretical knowledge concerning concept acquisition and development. Interestingly, as consideration of the nature of science has become a much more prominent part of regular science curricula, even a central part in many educational jurisdictions, so emphasis in STSE education has shifted much more towards confrontation of socioscientific issues (SSI).

Zeidler, Sadler, Simmons and Howes (2005) contrast SSI-oriented teaching with STS or STSE education in terms of its emphasis on developing habits of mind (specifically, developing skepticism, maintaining open-mindedness, acquiring the capacity for critical thinking, recognizing that there are multiple forms of inquiry, accepting ambiguity and searching for data-driven knowledge) and "empowering students to consider how science-based issues reflect, in part, moral principles and elements of virtue that encompass their own lives, as well as the physical and social world around them" (p.357). They argue that while STS education emphasizes the impact of scientific and technological development on society, it does not focus explicitly on the moral-ethical issues embedded in decision-making: "STS(E) education as currently practiced… only 'points out' ethical dilemmas or controversies, but does not necessarily exploit the inherent pedagogical power of discourse, reasoned argumentation, explicit NOS considerations, emotive, developmental, cultural or epistemological connections within the issues themselves… nor does it consider the moral or character development of students" (p.359). Bingle and Gaskell (1994) had earlier noted that STS education tends to emphasize what Bruno Latour (1987) calls "ready made science" (with all its attendant implicit messages about certainty) rather than "science-in-the-making" (with its emphasis on social construction). Simmons and Zeidler (2003) argue that it is the priority given to science-in-the-making through consideration of controversial SSI that gives the SSI approach its special character: "Using controversial socioscientific issues as a foundation for individual consideration and group interaction provides an environment where students can and will develop their critical thinking and moral reasoning" (p.83, emphasis added). In a further attempt at delineation, Zeidler, Walker, Ackett and Simmons (2002) claim that the SSI approach has much broader scope, in that it "subsumes all that STS has to offer, while also considering the ethical dimensions of science, the moral reasoning of the child, and the emotional development of the student" (p.344).

Knowledge, Language and Values

It almost goes without saying that if students are to get to grips with SSI at any level beyond the merely superficial they need relevant scientific and technological knowledge. It is not surprising that Keselman, Kaufman and Patel (2004) found that the capacity of grade 7 and grade 9 students to reason about information concerning HIV-AIDS, and formulate responsible courses of action, was directly related to the nature and extent of their knowledge of biology, particularly the nature of viruses, mechanisms of infection and the immune system. Similarly, Lewis and Leach (2006) show that the quality of discussion around issues relating to genetic engineering is substantially enhanced by basic understanding of genetics, and note that the necessary level of understanding is "relatively modest" and fairly easily achieved. A key question concerns the manner in which relevant scientific knowledge should be acquired – through prior instruction or on a 'need to know' basis when dealing with a particular issue. As is so often the case in education, there is no universal answer; different situations demand different approaches. Of course, knowledge requirements are not restricted to science. Those wishing to assess likely risks from the proximity of overhead power lines or nuclear power stations, the dumping of toxic waste and the frequent use of mobile phones will need considerable relevant technological knowledge, the capacity to engage in risk-benefit analyses and the ability to evaluate the views of 'experts' and officials. It is often the case that scientific knowledge has to be re-worked and reorganized to make it more readily applicable to real practical situations – what Layton, Jenkins, MacGill and Davey (1993) refer to as "practical knowledge for action". Addressing SSI in class may require students to engage in a similar kind of re-working of scientific knowledge to that of engineers addressing complex practical problems and lay people confronting science-related dilemmas in daily life.

> Adjusting the level of abstraction, 'repackaging' knowledge to bring together components of scientific knowledge that pedagogical and disciplinary considerations have uncoupled, and 'recontextualizing' scientific knowledge to reassimilate the messy realities that have been idealized in order to shape and address a problem with the rigour deemed necessary to move towards a scientific solution. (Jenkins, 1994, p.601)

As noted earlier, socioscientific issues are often located in disputed frontier science (or science-in-the-making) rather than in established textbook science. In such situations, knowledge and understanding about science is crucial. Students need to interpret reports, make sense of disagreements and evaluate knowledge claims, scrutinize arguments, distinguish among facts, arguments and opinions, make judgements about good science and bad science, detect bias and vested interest, and so on. Clearly, students' NOS knowledge and views will impact on the way they address SSI, but not always in a simple, straightforward and predictable way (Zeidler et al., 2002). There is a complex, reflexive interaction: more sophisticated NOS views open up new possibilities for scrutinizing SSI; engagement with important and personally significant SSI enhances and refines NOS understanding. At the very least, then, students need the following: (i) appropriate conceptual knowledge; (ii) robust understanding of the nature of science and scientific inquiry; (iii) reasoning and argumentation skills; (iv) sufficient metacognitive competency to understand, monitor and direct their own thinking processes, deal with disconfirming evidence and conflicting arguments, resolve moral-ethical dilemmas and accommodate emotional responses; (v) familiarity with the language of science and scientific argumentation, and the capacity to use it appropriately and effectively. Since a considerable amount of the knowledge they will need in addressing controversial SSI is likely to come from media reporting (mainly newspapers, magazines, television, radio and the Internet), students will also need a degree of media literacy, particularly the ability to recognize bias and vested interest, incomplete and selective reporting, deliberate distractions such as use of emotive language, hyperbole and innuendo, provocative pictures and emotionally manipulative background music.

Teachers wishing to incorporate SSI into their curriculum cannot avoid consideration of the values inherent in the issues. Indeed, for Zeidler et al. (2005) this is the very raison d'etre for including them. David Layton (1986) identifies three possible stances on values education: (i) inculcation – particular values are instilled through repeated exemplification and reinforcement; (ii) moral development – students are helped to develop more complex moral reasoning patterns; (iii) clarification – students are helped to identify their own values and those of others. As Ratcliffe and Grace (2003) observe, "which of these three dominates [should be adopted] depends on the age of the students, the curriculum context and teacher disposition" (p.23). It also depends, in large measure, on directives issued by school Principals and governing bodies, Ministries of Education and other local education authorities, and their capacity and willingness to use sanctions against teachers who might adopt a contrary position. It is deplorable that all five teachers interviewed by McGinnis and Simmons (1999) felt so intimidated by the prevailing social climate that they supported an STS orientation but avoided controversial topics – especially those that might challenge religious views of a fundamental nature or the practices of local industries. The primary thrust of the politicized science education I am advocating entails being critical of industrial, business, military and wider social practices, and where considered necessary, seeking change. Causing surprise, discomfort or offence to one or two parents, school officials, local residents or business interests is simply the price we have to pay in the struggle to create and sustain a 'better world' and a more just, equitable and honourable society. It is imperative that teachers find the courage, enlist the support of others and mobilize the resources to be much more challenging, critical and politicized in their approach. From my point of view, it is enormously encouraging that the Qualifications and Curriculum Authority in the United Kingdom regard teachers as having a duty to prepare students to deal with controversial issues.

> Education should not attempt to shelter our nation's children from even the harsher controversies of adult life, but should prepare them to deal with such controversies knowledgeably, sensibly, tolerantly and morally (QCA, 1998, p.56)

One of the absurdities of some current science curriculum initiatives is that they utilize elements of the history, philosophy and sociology of science to show how scientific inquiry and scientific practice are influenced by the prevailing sociocultural and economic context but do not use this understanding to politicize students. Many teachers avoid confronting the political interests and social values underlying the scientific and technological practices they teach about, and seek to avoid making judgements about them or influencing students in particular directions. This makes little or no sense. First, it asks teachers to attempt the impossible. Values are embedded in every aspect of the curriculum: content, teaching/learning methods and assessment/evaluation strategies are selected using criteria that reflect and embody particular value positions, whether teachers recognize it or not. Moreover, values are promoted just as much by what is omitted from the curriculum as by what is included. Second, it mistakes the very purpose of the science component of education for citizenship: ensuring a level of critical scientific and technological literacy for everyone as a means of bringing about social reconstruction or social transformation. The purpose of such an education is to enable young citizens to look critically at the society we have, and the values that sustain it, and to ask what can and should be changed in order to achieve a more socially just democracy and to bring about more environmentally sustainable lifestyles, especially in the industrialized countries of the world. This view of science education is overtly and unashamedly political. It takes the Advisory Group on

Education for Citizenship and the Teaching of Democracy in Schools (QCA, 1998) at its word – not just education about citizenship, but education for citizenship.

> Citizenship education is education for citizenship, behaving and acting as a citizen, therefore it is not just knowledge of citizenship and civic society; it also implies developing values, skills and understanding (p.13, emphasis added).

The shift in curriculum perspective I am advocating can be interpreted in terms of Habermas's (1971) theory of knowledge and human interests. Technical rationality and the goal of self-interest is apparent in the economic rationalist goals of efficiency and production, and in the desire to control and exploit the environment in pursuit of short term economic gains (a goal implicit, and sometimes explicit, in many of the curriculum documents produced by the Ontario Ministry of Education in recent years); interpretive or hermeneutic rationality is apparent in the desire to gain a clearer understanding of the multitude of competing human interests from the perspectives of the various actors and, thereby, a better understanding of the underlying causes of social disadvantage and environmental degradation (the goal of some STSE curricula); critical rationality is apparent in the emancipatory goal of self-critical reflective knowledge, free from the ideologically oriented interests of particular individuals and groups, that can form the basis for the kind of social action that reforms society and its practices (the goal of the curriculum I am proposing).

Building a Curriculum

Politicization of science education can be achieved by giving students the opportunity to confront real world issues that have a scientific, technological or environmental dimension. By grounding content in socially and personally relevant contexts, an issues-based approach can provide the motivation that is absent from current abstract, de-contextualized approaches and can form a base from which students can construct understanding that is personally relevant, meaningful and important. It can provide increased opportunities for active learning, inquiry-based learning, collaborative learning and direct experience of the situatedness and multidimensionality of scientific and technological practice. In the Western contemporary world, technology is all pervasive; its social and environmental impact is clear; its disconcerting social implications and disturbing moral-ethical dilemmas are made apparent almost every day in popular newspapers, TV news bulletins and Internet postings. In many ways, it is much easier to recognize how technology is determined by the sociocultural context in which it is located than to see how science is driven by such factors. It is much easier to see the environmental impact of technology than to see the ways in which science impacts on society and environment. For these kinds of reasons, it makes good sense to use problems and issues in technology and engineering as the major vehicles for contextualizing the science curriculum. This is categorically not an argument against teaching science; rather, it is an argument for teaching the science that informs an understanding of everyday technological problems and may assist students in reaching tentative solutions about where they stand on key SSI.

In constructing a new science and technology curriculum for the 21st century, my inclination is to provide a mix of local, regional/national and global issues, and idiosyncratic personal interests, focusing on seven areas of concern: human health; land, water and mineral resources; food and agriculture; energy resources and consumption; industry (including manufacturing industry, the leisure and service industries, biotechnology, and so on); information transfer and transportation; ethics and social responsibility (i.e., freedom and control in science and technology). An integral part of this curriculum is a commitment to a continuing critical consideration of NOS issues, bearing in mind the research data on the need for an explicit and reflective approach. As argued elsewhere (Hodson, 1994, 2003), the kind of issues-based approach I am advocating can be regarded as comprising four levels of sophistication.

Level 1: Appreciating the societal impact of scientific and technological change, and recognizing that science and technology are, in substantial measure, culturally determined.

Level 2: Recognizing that decisions about scientific and technological development are taken in pursuit of particular interests, and that benefits accruing to some may be at the expense of others.

Recognizing that scientific and technological development are inextricably linked with the distribution of wealth and power.

Level 3: Developing one's own views and establishing one's own underlying value positions.

Level 4: Preparing for and taking action on socioscientific and environmental issues.

At the simplest level, case studies of the societal impact of inventions such as the steam engine, the internal combustion engine, the printing press or the computer can be used to foster awareness that science and technology are powerful forces that shape the lives of people and other species, and impact significantly on the environment as a whole. They can also be used to show that scientific and technological developments are both culturally dependent and culturally transforming. In other words, science/technology is a product of its time and place and can sometimes change quite radically the ways in which people think and act. For example, the science of Galileo, Newton, Darwin and Einstein changed our perception of humanity's place in the universe and precipitated enormous changes in the way people address many of the issues encountered in daily life. This 'level 1 awareness' also includes recognition that large-scale technological innovation is a complex, far-reaching and not entirely predictable activity. It can result in unexpected benefits, unanticipated costs and unforeseen risks. The benefits of scientific and technological innovations are often accompanied by problems: hazards to human health, challenging and sometimes disconcerting social changes, environmental degradation, major moral-ethical dilemmas, and sometimes restriction rather than enhancement of individual freedom and choice.

Much of STS, STSE and environmental education, while recognizing these adverse features of development, is currently pitched at the level where decision-making in science and technology is seen simply as a matter of reaching consensus or effecting a compromise among competing interests. In contrast, the intention at level 2 is to enable students to recognize that scientific and technological decisions are taken in pursuit of particular interests, justified by particular values and sometimes implemented by those with sufficient economic or political power to override the needs and interests of others. As a consequence, the advantages and disadvantages of scientific and technological developments often impact differentially. What benefits some may harm others. Case studies can be used to achieve a level of critical scientific literacy that recognizes how science and technology serve the rich and the powerful in ways that are often prejudicial to the interests and well-being of the poor and powerless, sometimes giving rise to further inequalities and injustices. Such studies help students to see that material benefits in the West (North) are often achieved at the expense of those living in the Developing World. A case study of the Bhopal disaster would provide a particularly graphic illustration. It is here that the radical political character of the curriculum begins to emerge. Those curricula that take the trouble to address the symptoms of Third World poverty (malnutrition and famine, inadequate sanitation, and diseases such as rickets, tuberculosis and cholera) usually neglect to include a sociopolitical and historical analysis of the major causes. Often they treat poverty as a simple consequence of climatic harshness, overpopulation and ignorance. By contrast, the approach advocated here recognizes the role played by Western governments and business interests in controlling the production and distribution of resources, including examples of the systematic appropriation of Third World land and water resources for producing cash crops for export – often resulting in lower prices for farmers, increased vulnerability of crops to pests and consequential increasing reliance on chemical controls, soil impoverishment and top soil depletion, increased poverty, insecurity and eventual dispossession. Students would quickly recognize that critical consideration of scientific and technological development is inextricably linked with questions about the distribution of wealth and power. Moreover, they would begin to see ways in which problems of environmental degradation are rooted in societal practices and in the values and interests that sustain and legitimate them.

It is here that the concerns of environmental education should (but often don't) intersect with those of multicultural and antiracist education. The frequency with which environmental degradation impacts the poor, the disadvantaged, the marginalized and the powerless much more than the rich and powerful warrants use of the term environmental racism. For example, substances deemed dangerous to the environment, and hence banned in the countries of the rich North, are still exported to the developing countries of the economically challenged South, and pharmaceuticals banned in the West are routinely sold, distributed and used in developing countries; French nuclear weapons testing was conducted not in the French countryside but in the impoverished islands of the South Pacific still under French control; rainforest destruction in pursuit of profits for logging companies and cattle ranchers often precipitates loss of traditional lifestyle and social disruption among powerless groups of Indigenous people. Indeed, most environmental problems can be interpreted as social justice issues: race/ethnicity, gender and class are major factors determining who controls and benefits from the businesses and institutions that cause environmental degradation and who experiences the adverse impact.

Level 3 is concerned primarily with supporting students in their attempts to formulate their own opinions on important issues and establish their own value positions, rather than with promoting the 'official' or textbook view. It focuses much more overtly on values clarification, developing strong feelings about issues, and actively thinking about what it means to act wisely, justly and 'rightly' in particular social, political and environmental contexts. This phase has much in common with the goals of Peace Education (Brock-Utne, 1987; Hicks, 1988; Reardon, 1988; Smith & Carson, 1998), Multicultural and Antiracist Education (Hodson, 1993, 1999; Sleeter, 1996; Hines, 2003), Global Education (Pike & Selby, 1987; Fien, 1989; Hicks & Steiner, 1989) and Humane Education (Selby, 1994a, 1994b, 1995). It begins with the fostering of self-esteem and personal well-being in each individual, and extends to respect for the rights of others, mutual trust, the pursuit of justice, cooperative decision-making and creative resolution of conflict between individuals, within and between communities, and throughout the world. It is driven by a deep commitment to anti-discriminatory education – that is, exposing the common roots of sexism, racism, homophobia, Eurocentrism and Westism (or Northism) in the tendency to dichotomize and generate a sense of other; working actively to confront the "us and them" mentality that invariably sees "us" as the norm, the desirable and the superior. It culminates in commitment to the belief that alternative voices can and should be heard in order that decisions in science and technology reflect wisdom and justice, rather than powerful sectional interests (Maxwell, 1984, 1992).

The final (fourth) level of sophistication in this issues-based approach is concerned with students findings ways of putting their values and convictions into action, helping them to prepare for and engage in responsible action, and assisting them in developing the skills, attitudes and values that will enable them to take control of their lives, cooperate with others to bring about change and work towards a more just and sustainable world in which power, wealth and resources are more equitably shared. Socially and environmentally responsible behaviour will not necessarily follow from knowledge of key concepts and possession of the 'right attitudes'. As Curtin (1991) reminds us, it is important to distinguish between caring about and caring for. It is almost always much easier to proclaim that one cares about an issue than to do something about it! Put simply, our values are worth nothing until we live them. Rhetoric and espoused values won't bring about social justice and won't save the planet. We must change our actions. A politicized ethic of care (caring for) entails active involvement in a local manifestation of a particular problem or issue, exploration of the complex sociopolitical contexts in which the problem/issue is located, and attempts to resolve conflicts of interest.

From Knowledge to Action

The keys to action on socioscientific and environmental issues are ownership and empowerment. In other words, those who act are those who have a deep personal understanding of the issues (and their social and environmental implications), a personal investment in addressing issues and commitment to solving problems, knowledge of how to ensure that their voice is heard and acknowledged, awareness of the range on interventions that are possible, and confidence that their actions can make a difference. Personal investment in an issue and commitment to problem solving derive, in part, from emotional involvement, identified by Kollmus and Argyeman (2002) as the crucial stage in developing pro-environmental behaviour, which they define as "behaviour that consciously seeks to minimize the negative impact of one's actions on the natural and built world" (p.240). Emotional involvement can be fostered through case studies, drama and role play, literature, art, photographs, movies and music, site visits, interviews, and so on. Informal learning experiences may be more effective than formal schooling in bringing about awareness of issues, attitudinal shifts, values reorientation and willingness to engage in sociopolitical action. With respect to environmental issues, education in, through and with the environment can play a substantial role. Gough (1989), for example, describes how the kind of experiences advocated by the Earth Education movement (van Matre, 1979) can be utilized in re-orienting students' environmental understanding, taking them beyond the superficial to embrace the complexity, diversity, interconnectedness and dynamic nature of the natural environment. Russell and Hodson (2002) suggest that whalewatching and other ecotourist activities can be particularly effective in preparing the ground for a shift from anthropocentrism to biocentrism, while Pedretti and Soren's (2006) discussion of visitors' responses to the Niagara Parks Butterfly Conservatory (in Ontario, Canada) provides further eloquent evidence of the potential of such experiences to shift feelings, attitudes and values. A sense of wonder and feelings of respect and compassion towards other living things can also be fostered by such easily organized activities as investigating a rock pool, noting what lives in a local wall or hedgerow, taking photographs to examine the feathers of birds in suburban gardens, watching a spider spin a web, observing insects through a magnifying lens or pond water under a microscope. Interestingly, Lester, Ma, Lee and Lambert (2006) have shown that carefully designed writing activities can play an important role in developing this personal investment and in increasing students' awareness of the need for sociopolitical action, especially when students assume the role of investigative journalist.

Jensen (2002) has developed a useful framework that categorizes the knowledge that informs and promotes pro-environmental behaviour and other forms of action in terms of four dimensions: (i) knowledge about the environmental issue/problem – principally, its nature and extent, and the scientific and technological knowledge relevant to it; (ii) knowledge about the underlying social, political and economic structures, and how they contribute to creating particular environmental problems; (iii) knowledge about how to bring about changes in society through direct or indirect pro-environmental behaviour; (iv) knowledge about the likely outcome or direction of possible changes. This fourth dimension, argues Jensen, entails formulation of a vision of the kind of world in which we (and our families and communities) wish to live – a clear overlap with futures studies/education (Hicks & Slaughter, 1998; Lloyd & Wallace, 2004) and values education. We certainly need to rake steps to counter the somewhat bleak views of technological determinism portrayed in some science fiction stories and movies – the idea that current technology determines future technology and human beings must adapt to its dictates. Remarks such as "You can't stop progress", "It's inevitable" and "That's what we will have to get used to" are commonplace; they reveal a strong sense of individual and collective disempowerment and a feeling that technological change and development are in the hands of others. An essential step in cultivating the critical scientific and technological literacy on which sociopolitical action depends is the application of a social and political critique capable of challenging the notion of technological determinism. We can control technology and its environmental and social impact. More significantly, we can control the controllers and redirect technology in such a way that adverse environmental impact is substantially reduced (if not entirely eliminated) and issues of freedom, equality and justice are kept in the forefront of discussion during the establishment of policy.

As I noted above, those who act are those who feel personally empowered to effect change, who feel that they can make a difference, and know how to do so. Thus, preparing students for action necessarily means ensuring that they gain robust knowledge of the social, legal and political system(s) of the communities in which they live and a clear understanding of how decisions are made within local, regional and national government, and within industry, commerce and the military. Without knowledge of where and with whom power of decision-making is located, and awareness of the mechanisms by which decisions are reached, intervention is not possible. Thus, the curriculum I propose requires a concurrent programme designed to achieve a measure of political literacy.

The likelihood of students becoming active citizens is increased substantially by encouraging them to take action now (in school), and by providing opportunities for them to do so. And by giving examples of successful actions and interventions engaged in by others. With respect to an environmental focus (by way of illustration), suitable action might include any (or all) of the following: conducting surveys of dump sites, public footpaths and environmentally sensitive areas; generating data for community groups such as birdwatchers and ramblers; establishing neighbourhood 'nature watch' initiatives; instituting recycling programmes; making public statements and writing letters; organizing petitions and consumer boycotts of environmentally unsafe products and practices; publishing newsletters and building informative Websites; lobbying local government officials on policy matters and regulations; working on environmental clean-up projects; establishing an 'adopt a stream' scheme; creating nature trails and conservation ponds; organizing a school 'environmental awareness day'; assuming responsibility for environmental enhancement of the school grounds; monitoring the school's consumption of energy and material resources in order to formulate more appropriate practices.

It is sometimes useful to distinguish between direct and indirect action. The former includes such things as recycling, cleaning up a stream, using a bicycle rather than a car and using 'green bags' at the supermarket; the latter includes organization of petitions, writing to newspapers and making submissions to the local council. Oddly, some environmental educators tend to de-value indirect actions as mere classroom activities, while extolling the virtues of direct action. Before reaching such a judgement we should look carefully at the likely effectiveness and social significance of particular actions, both in the short-term and long-term. While direct action can be enormously important and have some significant impact, it can also divert attention from the root causes of the problem in our social, political and economic activities. The optimum approach would seem to be a blend of the two. Of course, indirect action needs to be authentic action: not just a classroom exercise in which a letter to an imaginary newspaper editor is composed, but a real letter to a real newspaper editor, to express real concerns or to make a series of real debating points or policy recommendations. In these circumstances, a great deal of knowledge is required, including a substantial measure of argumentation and media literacy skills.

To reiterate, it is important for students to learn that scientific/technological activity is influenced by a complex of social, political and economic forces, and it is important for them to formulate their own views on a range of contemporary issues and problems, and to care passionately about them. But the curriculum needs to take them further. Students need to learn how to participate, and they need to experience participation. Moreover, they need to encourage others to participate, too: parents, grandparents, friends, relatives, neighbours, local businesses, etc. It is not enough for students to be armchair critics! As Kyle (1996, p.1) puts it:

> Education must be transformed from the passive, technical, and apolitical orientation that is reflective of most students' school-based experiences to an active, critical, and politicized life-long endeavour that transcends the boundaries of classrooms and schools.

In words that would have substantial currency in my native North of England working class community, students need to "put their money where their mouth is!" Indeed, all of us (students, teachers and other citizens) need to do so. I have much in sympathy with Elam and Bertilsson's (2003) notion of the radical scientific citizen.

The radical scientific citizen is fully prepared to participate in demonstrations… street marches, boycotts and sit-ins and other means of publicly confronting those ruling over science and technology… While the scientific citizen as activist may be taking a partisan position in defence of a particular individual or group in society, they are also understood as assuming a moral stance in defence of general ethico-political principles… which are accepted as existing through many different and conflicting interpretations subjecting them to continuous contestation (p.245).

There is no doubt that political apathy is increasingly widespread and that many citizens have lost faith and trust in politicians. It is also the case that opportunities to participate in key decision-making have declined substantially with the rise of mega-corporations and the increasingly convoluted bureaucracies of local, regional and national governments. What I am advocating in this article, in sympathy with writers such as Elam and Bertilsson, is that citizens seize the opportunity to take control of local matters. If this is to happen on any substantial and meaningful scale, students currently in school need opportunities to assume responsibility for working with others to effect change. As an aside, these ideals of empowerment and participation in informed decision-making should also be reflected in the way schools are organized and managed. What I have in mind is well captured in the principles underpinning Apple and Bean's (1995) notion of "democratic schools": an open flow of information is maintained to keep people fully informed; critical reflection and analysis are employed to assess problems and policies; both individual and collective capabilities are deployed in the resolution of problems; the 'common good' is the principal concern; the dignity and rights of all members are to be respected; democracy represents an idealized set of values and schools actively seek to promote and extend a democratic way of life.

In Summary

It is easy to see the potential for politicization in the seven areas of concern listed above: Human Health (for example, health goals in North America versus those in the Developing World, priorities in health spending, gender issues relating to 'body image', abortion, xenotransplantation, compulsory MMR vaccination, ready availability of Gardasil regardless of parental wishes); Land, Water and Mineral Resources (for example, land usage issues, including Aboriginal land rights and efforts to formulate an Antarctic Treaty, toxic waste disposal, water pollution issues, fluoridation, sustainable consumption, rainforest clearance, loss of biodiversity); Food and Agriculture (including the politics of starvation, factory farming, genetically modified food crops, food irradiation, growing cash crops for Western consumption in the Developing World); Energy Resources (renewable energy sources, the politics of the petroleum industry, consumption and lifestyle issues, nuclear power generation, and so on); Industry (e.g., employment considerations versus environmental impact, sustainability issues, automation and job loss); IT and Transportation (data protection issues, cultural imperialism, vehicle emission controls, environmental and social impact of air travel); Ethics (cloning, stem cell research, 'designer babies', Third World organ donors, Hippocratic oath for scientists and engineers, governmental DNA banks, euthanasia, and countless other issues). It is also relatively easy to see how these areas of concern lend themselves to treatment at four levels of sophistication. At level 1, students are made aware of the societal and environmental impact of science and technology and alerted to the existence of alternative technologies, with different impact. At level 2, they are sensitized to the sociopolitical nature of scientific and technological practice, asking questions such as: Who are the stakeholders? What are their interests? Whose voices are heard and whose are marginalized or ignored? What intentions or motives guide the decision-making? Who benefits? Who is harmed? Is this just and equitable? Does this decision promote the common good or serve the needs of environmental protection? At level 3, they become committed to the fight to establish more socially just and environmentally sustainable practices. At level 4, they acquire the knowledge and skills to intervene effectively in decision-making processes in order to ensure that alternative voices, and their underlying interests and values, are brought to bear on policy decisions. Some of the environmental issues addressed through this curriculum will be global (ozone depletion, acid rain, global warming and climate change) and some will be local (factory-based pollution, road construction issues, loss of recreational space). Similarly, for all other SSI: some local, some national or regional, some universal concerns. For all issues, the common element should be a concern for sustainability and social justice. In other words, how can economic and scientific/technological development be maintained in a way that values and protects (even enhances) the natural and social environment?

In advocating a 4-level model, my intention is not to suggest that all action and preparation for action is delayed until the final years of schooling. Rather, students should proceed to whatever level is appropriate to the topic in hand, the learning opportunities it presents and the stage of intellectual and emotional development of the students. In addition, teachers should bear in mind the simple class management principle of investing each topic with a degree of variety. In some areas of concern it is relatively easy for students to be organized or to organize themselves for action; in other areas it is more difficult. It is also the case that, for some topics, level 3 is more demanding than level 4. For example, it is easier to take action on recycling than to reach a considered and critical judgement of recycling versus reduced consumption versus use of alternative materials. While my inclination would be to give over the entire science curriculum to this kind of issues-based approach, I am not so naïve as to think that is likely to happen any time soon. Indeed, Nashon et al. (2008) note that although "high church" STS (to use Steve Fuller's (1993) term for science studies courses emphasizing academic issues in the history, philosophy and sociology of science) is rapidly gaining popularity at the university level, "low church" or activist STS is losing ground in schools, at least in British Columbia. However, it is possible to implement this kind of issues-based approach alongside a more conventional subject-oriented curriculum, provided that neither students nor teachers see it as a mere 'add-on' or motivational adornment. Confrontation of issues and taking action need to be fully integrated into the curriculum. Whether the kind of curriculum I am advocating would result in a generation of politically active citizens will have to remain untested, at least for now. We can be assured, however, that students exposed to such issues and the treatment of them advocated here, would be much more likely to give serious consideration to the moral-ethical, political and environmental aspects of SSI in their daily lives outside and beyond school.

Of course, there are teachers who will argue that politicization is not a legitimate goal of science and technology education (or of any school-based education, for that matter) and that sociopolitical action has no place in school. There will also be those who support these activities in principle but are uncertain about what constitutes appropriate, acceptable and worthwhile action. Many questions spring to mind. Who decides what is acceptable and responsible action? What are the relevant criteria? What is the balance to be drawn between socially acceptable actions that may be politically ineffective and effective actions that may be socially unacceptable to some? Will teachers be prepared to support student actions that provoke the disapproval of parents, school administrators, local politicians or local businesses? Are we prepared for a situation in which students who are well-coached in action skills choose to direct those skills against aspects of the institution in which they study and/or the community in which they live? Those teachers who promote involvement and develop action skills are 'riding a tiger', but it is a tiger that may well have to be ridden if we really mean what we say about education for civic participation. I do not seek to minimize the difficulties that teachers face in deciding a course of action. All I can do is urge teachers and students to be critical, reflective, robust in argument and sensitive to diverse values and beliefs, but above all to have the courage and strength of will to do what they believe is right and good and just. In the words of Alberto Rodriguez (2001), we need the courage to "expand our gaze… and rise to the challenge of becoming cultural warriors for social change" (p.290).

References

Abd-El-Khalick, F. (2005) Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers' views and instructional planning. *International Journal of Science Education*, 27(1), 15-42.

Abd-El-Khalick, F. & Lederman, N. G. (2000) Improving science teachers' conceptions of the nature of science: *A critical review of the literature. International Journal of science Education*, 22(7), 665-701.

Abd-El-Khalick, F., Waters, M. & Le, A-P. (2008) Representations of nature of science in high school chemistry textbooks over the past four decades. *Journal of Research in Science Teaching*, 45(7), 835-855.

Aikenhead, G.S. (2003) STS education: A rose by any other name. In R. Cross (Ed.) *A Vision for Science Education: Responding to the work of Peter Fensham* (pp.59-75). New York: RoutledgeFalmer.

Aikenhead, G.S. (2005) *Research into STS science education*. Educación Quimica, 16(3), 384-397.

Aikenhead, G.S. (2006) *Science Education for Everyday Life: Evidence-based Practice*. New York: Teachers College Press.

Akerson, V.L., Abd-El-Khalick, F. & Lederman, N.G. (2000) Influence of a reflective activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching,* 37(4), 295-317.

American Association for the Advancement of Science (AAAS) (1993) *Benchmarks for Scientific Literacy*. (New York: Oxford University Press).

Apple, M. & Beane, J. (1995) *Democratic Schools. Alexandria*, VA: Association for Supervision and Curriculum Development.

Bingle, W.H. & Gaskell, P.J. (1994) Scientific literacy for decision making and the social construction of scientific knowledge. *Science Education*, 78(2), 185-201.

Brock-Utne, B. (1987) *Educating for Peace: A Feminist Perspective*. Oxford: Pergamon.

Council of Ministers of Education, Canada (1997) *Common Framework of Science Learning Outcomes*. Toronto: CMEC Secretariat.

Curtin, D. (1991) *Toward an ecological ethic of care*. Hypatia, 6, 60-74.

Dass, P.M. (2005) Understanding the nature of scientific enterprise (NOSE) through a discourse with its history: The influence of an undergraduate 'history of science' course. *International Journal of Science and Mathematics Education*, 3, 87-115.

Department of Education, Republic of South Africa (2002) *Revised National Curriculum Statement for Grades 8-9 Schools*. Pretoria: Department of Education.

Driver, R., Leach, J., Miller, A. & Scott, P. (1996) *Young People's Images of Science*. Buckingham: Open University Press.

Elam, M. & Bertilsson, M. (2003) Consuming, engaging and confronting science: The emerging dimensions of scientific citizenship. *European Journal of Social Theory*, 6(2), 233-251.

Fien, J. (Ed.)(1989) *Living in a Global Environment: Classroom Activities in Development Education. Brisbane*: Australian geography Teachers Association.

Finson, K. D. (2002) *Drawing a scientist: what we do and do not know after fifty years of drawing.* School Science & Mathematics, 102(7), 335-345.

Fuller, S. (1993) *Rhetoric, and the End of Knowledge: The Coming of Science and Technology Studies*. Madison, WI: University of Wisconsin Press.

Gallagher, J.J. (1971) A broader base for science education. *Science Education*, 55, 329-338.

Gaskell, P.J. (2001) STS in a time of economic change: What's love got to do with it? *Canadian Journal of Science, Mathematics and Technology Education*, 1(4), 385-398.

Goodrum, D., Hackling, M. & Rennie, L. (2000) *The Status and Quality of Teaching and Learning of Science in Australian Schools: A Research Report*. Canberra: Department of Education, Training and Youth Affairs.

Gough, N. (1989) From epistemology to ecopolitics: renewing a paradigm for curriculum. *Journal of Curriculum Studies*, 21, 225-241.

Habermas, J. (1971) Knowledge and Human Interests. Boston, MA: Beacon Press.

Hicks, D. (1988) *Education for Peace: Issues, Principles and Practice*. London: Routledge.

Hicks, D. & Steiner, M. (Eds.)(1989) Making Global Connnections: A World Studies Workbook. Edinburgh: Oliver & Boyd.

Hodson, D. (1993) In search of a rationale for multicultural science education. *Science Education*, 77(6), 685-711.

Hodson, D. (1994) Seeking directions for change: The personalisation and politicisation of science education. *Curriculum Studies*, 2, 71-98.

Hodson, D. (1998) Science fiction: The continuing misrepresentation of science in the school curriculum. *Curriculum Studies*, 6, 191-216.

Hodson, D. (1999) Going beyond cultural pluralism: Science education for sociopolitical action, *Science Education,* 83 (6), 775-796.

Hodson, D. (2003) Time for action: Science education for an alternative future. *International Journal of Science Education,* 25(6), 645-670.

Hogan, K. & Maglienti, M. (2001) Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching,* 38(6), 663-687.

Hicks, D. & Slaughter, R. (Eds.)(1998) *Futures Education: World Yearbook of Education 1998*. London: Kogan Page.

Hines, S.D. (Ed.)(2003) *Multicultural Science Education: Theory, Practice, and Promise.* New York: Peter Lang.

Jenkins, E.W. (1994) Public understanding and science education for action. *Journal of Curriculum Studies*, 26, 601-611.

Jensen, B.B. (2002) Knowledge, action and pro-environmental behaviour. *Environmental Education Research,* 8(3), 325-334.

Keselman, A., Kaufman, D.R. & Patel, V.L. (2004) 'You can exercise your way out of HIV' and other stories: The role of biological knowledge in adolescents' evaluation of myths. *Science Education*, 88(4), 548-573.

Khishfe, R. (2008) The development of seventh graders' views of nature of science. *Journal of Research in Science Teaching*, 45(4), 470-496.

Kollmus, A. & Agyeman, J. (2002) Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behaviour? *Environmental Education Research*, 8(3), 239-260.

Kosso, P. (2009) The large-scale structure of scientific method. *Science & Education*, 18(1), 33-42.

Kumar, D.D. & Chubin, D.E. (Eds.)(2000). *Science, Technology, and Society: A Sourcebook of Research and Practice*. New York: Kluwer/Plenum.

Kyle, W.C. (1996) Editorial: The importance of investing in human resources. *Journal of Research in Science Teaching,* 33, 1-4.

Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press.

Layton, D. (1986) Revaluing science education. In P. Tomlinson & M. Quinton (Eds.), *Values Across the Curriculum* (pp.158-178). London: Falmer Press.

Layton, D, Jenkins, E., MacGill, S., & Davey, A. (1993*) Inarticulate science*? Driffield: Studies in Education.

Lederman, N. G. (1992) Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29(4), 331-359.

Lester, B.T., Ma, L., Lee, O. & Lambert, J. (2006) Social activism in elementary science education: A science, technology, and society approach to teach global warming. *International Journal of Science Education*, 28(4), 315-339.

Lewis, J. & Leach, J. (2006) Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education*, 28(11), 1267-1287.

Lloyd, D. & Wallace, J. (2004) Imaging the future of science education: the case for making futures studies explicit in student learning. *Studies in Science Education,* 39, 139-177.

Lucas, B. & Roth, W-M. (1996) The nature of scientific knowledge and student learning: Two longitudinal case studies. *Research in Science Education,* 26(1), 103-127.

Maxwell, N. (1984) *From Knowledge to Wisdom*. Oxford: Basil Blackwell.

Maxwell, N. (1992) What kind of inquiry can best help us create a good world? *Science, Technology & Human Values*, 17, 205-227.

McComas, W.F. (1998) The principal elements of the nature of science: dispelling the myths. In W.F. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 41-52). Dordrecht: Kluwer.

McGinnis, J.R. & Simmons, P. (1999) Teachers' perspectives of teaching science-technology-society in local cultures. *Science Education*, 83, 179-211.

Millar, R. & Osborne, J. (Eds.)(1998). Beyond 2000: *Science Education for the Future*. London: King's College.

Moss, D. M., Abrams, E. D. & Robb, J. (2001) Examining student conceptions of the nature of science. *International Journal of Science Education*, 23(8), 771-790.

Nashon, S., Nielsen, W. & Petrina, S. (2008) Whatever happened to STS? Pres-service physics teachers and the history of quantum mechanics. *Science & Education*, 17(4), 387-401.

National Research Council (NRC)(1996) *National Science Education Standards*. Washington, DC: National Academy Press.

Organization for Economic Cooperation and Development (OECD)(1999) *Measuring Student Knowledge and Skills*. Paris: OECD.

Pedretti, E. (2003) Teaching science, technology, society and environment (STSE) education: Preservice teachers' philosophical and pedagogical landscapes. In D.L. Zeidler (Ed.) *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education* (pp.219-239). Dordrecht: Kluwer.

Pedretti, E. & Soren, B. (2006) Reconnecting to the natural world through an immersive environment. Canadian Journal of Science, Mathematics and Technology Education, 6(1), 83-96.

Pike, G. & Selby, D. (1987) *Global Teacher, Global Learner*. London: Hodder & Stoughton.

Qualifications and Curriculum Authority (QCA)(1998) *Education for Citizenship and the Teaching of Democracy in Schools*. London, QCA.

Ratcliffe, M. & Grace, M. (2003) *Science Education for Citizenship: Teaching Socio-scientific Issues*. Maidenhead: Open University Press.

Reardon, B.A. (1988) *Comprehensive Peace Education: Educating for Global Responsibility*. New York: Teachers College Press.

Rodriguez, A.J. (2001) Courage and the researcher's gaze: (Re)defining our roles as cultural warriors for social change. *Journal of Science Teacher Education*, 12(4), 277-294.

Russell, C.L. & Hodson, D. (2002) Whalewatching as critical science education? *Canadian Journal of Science, Mathematics and Technology Education*, 2(4), 485-504.

Ryder, J., Leach, J. & Driver, R. (1999) Undergraduate science students' images of science. Journal of Research in Science Teaching, 36(2), 201-219.

Selby, D. (1994a) *Humane education: The ultima thule of global education*. Green Teacher, 39, 9-14.

Selby, D. (1994b) *Humane education: The ultima thule of global education – Part two*. Green Teacher, 40, 23-31.

Selby, D. (1995) *Earthkind: A Teacher's Handbook on Humane Education*. Trentham: Trentham Books.

Simmons, M.L. & Zeidler, D. (2003) Beliefs in the nature of science and responses to socioscientific issue. In D.L. Zeidler (Ed.) *The Role of Moral Reasoning on Socioscientific Issues and Discourse in Science Education* (pp.81-94). Dordrecht: Kluwer.

Sleeter, C. (1996) *Multicultural Education as Social Activism*. Albany, NY: State University of New York Press.

Smith, D. & Carson, T. (1998) *Educating for a Peaceful Future*. Toronto: Kagan & Woo.

Solomon, J. & Aikenhead, G. (Eds.)(1994) *STS Education: International Perspective on Reform*. New York: Teachers College Press.

Tairab, H.H. (2001) How do pre-service and in-service science teachers view the nature of science and technology. *Research in Science & Technological Education*, 19(2), 235-250.

UNESCO (1993). *International Forum on Scientific and Technological Literacy for All*. Final Report. Paris: UNESCO.

van Eijck, M. & Roth, W-M. (2008) Representations of scientists in Canadian high school and college textbooks. *Journal of Research in Science Teaching*, 45(9), 1059-1082.

van Matre, S. (1979) *Sunship Earth: An Acclimatization Program for Outdoor Learning. Martinsville*, IN: American Camping Association.

Yager, R.E. (Ed.)(1996) *Science/Technology/Society as Reform in Science Education*. Albany, NY: State University of New York Press.

Zeidler, D.L., Walker, K.A., Ackett, W.A. & Simmons, M.L. (2002) Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343-367.

Zeidler, D.L., Sadler, T.D., Simmons, M.L. & Howes, E.V. (2005) Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, 89(3), 357-377.