CHAPTER 1

SCIENTIFIC LITERACY REVISITED

In recent decades, the notion of *scientific literacy* has become increasingly prominent in international debate about science education, a trend mirrored by a similarly expanding interest in technological literacy and environmental literacy[1]. Although a number of writers have traced the history and evolving definition of scientific literacy (Gräber & Bolte, 1997; Laugksch, 2000; De Boer, 2001; Ryder, 2001; McEneaney, 2003; Roberts, 2007; Dillon, 2009), there is some value in revisiting that history and development here, albeit very briefly.

The term seems to have first appeared in the US educational literature about 50 years ago, in papers by Paul Hurd (1958) and Richard McCurdy (1958). DeBoer (2001) also cites the Rockefeller Brothers Fund (1958) report *The Pursuit of Excellence* (p. 369) as a pioneer user of the term: "Just as we must insist that every scientist be broadly educated, so we must see to it that every educated person be literate in science" (p. 586). At about the same time, Fitzpatrick (1960) remarked: "If the Zeitgeist is to be favorable to the scientific enterprise, including both academic and industrial programs, the public must possess some degree of scientific literacy, at least enough to appreciate the general nature of scientific endeavor and its potential contributions to a better way of life… No citizen, whether or not he is engaged in scientific endeavors, can be literate in the modern sense until he has understanding and appreciation of science and its work" (p. 6). He concludes: "The ultimate fate of the scientific enterprise is in no small degree dependent upon establishing a species of scientific literacy in the general population" (p. 169). Similarly, Alan Waterman (at that time, Director of the National Science Foundation) noted that it was a matter of urgency that "the level of scientific literacy on the part of the general public be markedly raised… progress in science depends to a considerable extent on public understanding and support" (Waterman, 1960, p. 1349).

Although the term scientific literacy was enthusiastically taken up by many science educators as a useful slogan or rallying call (see Roberts, 1983, 2007), there was little in the way of precise or agreed meaning until Pella et al. (1966) suggested that it comprises an understanding of the basic concepts of science, the nature of science, the ethics that control scientists in their work, the interrelationships of science and society, the interrelationships of science and the humanities, and the differences between science and technology. Almost a quarter century later, the authors of *Science for All Americans* (AAAS 1989) drew upon very similar categories to define a scientifically literate person as "one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes" (p. 4).

On the other side of the Atlantic Ocean, the long-standing tradition of concern for "the public understanding of science" dates back to the early years of the 19th Century (Jenkins, 1990). As Jenkins notes, science was vigorously promoted through the activities of the numerous Mechanics' Institutes and Literary and Philosophical Societies, and further supported by public lectures, scientific demonstrations and "a remarkable variety of books, journals, tracts, pamphlets and magazines, many of which would be categorized today as 'teach yourself publications'" (p. 43). In the middle years of the 20th Century, inspired in large part by the work of J.D. Bernal, the Movement for Social Responsibility in Science shifted the emphasis for the public understanding of science very sharply in the direction of sociopolitical concerns. In more recent times, the Royal Society (1985) shifted the emphasis yet again, noting that improving public understanding of science is "an investment in the future; not a luxury to be indulged in if and when resources allow" (p. 9). The argument that scientific literacy "can be a major element in promoting national prosperity, in raising the quality of public and private decision making and in enriching the life of the individual" (Royal Society, 1985, p. 9) highlights the key distinction between those who see scientific literacy as the possession of knowledge, skills and attitudes essential to a career as a professional scientist, engineer or technician and those who see it as the capacity to access, read and understand material with a scientific and/or technological dimension, make a careful appraisal of it, and use that evaluation to inform everyday decisions, including those made at the ballot box. Roberts (2007) refers to these contrasting views as "Vision 1" or "literacy *within* science" (focusing on the products of science and the processes by which they are generated and validated) and "Vision 2" or "literacy *about* science" (focusing on the ability to address socioscientific issues). Interestingly, and importantly in the context of this book, Roberts (2007) notes that "Vision 2 subsumes Vision 1, but the converse is not necessarily so" (p. 768).

Debate about what scientific literacy might comprise is necessarily influenced by arguments about *why* we need it and *why* we should promote its attainment in school. Thomas and Durant (1987) have categorized such arguments into three groups: (i) perceived benefits to science, (ii) benefits to individuals, and (iii) benefits to society as a whole. Benefits to science are seen largely in terms of increased numbers of recruits to science-based professions (including medicine and engineering), greater support for scientific, technological and medical research, and more realistic public expectations of science. Little by way of elaboration needs to be said about the first argument, save to note that increased recruitment might also result in increased diversity within the community of scientists. As Helen Longino (1990) and Sandra Harding (1991) argue, increased numbers of women, members of ethnic minority groups and other groups traditionally under-served by science education and under-represented in science-related and technology-related professions would do much to enrich these professions and might serve to re-direct and reorient priorities for research and development - a matter that will be addressed, albeit briefly, later in the book. With regard to the other perceived benefits for science, Jenkins (1994a) makes the related point that enhanced public understanding of science would enable scientists to be more effective in countering opposition from religious fundamentalist groups, animal rights activists and others who might seek to constrain or curtail scientific inquiry. In similar vein, Shamos (1993) states that enhanced scientific literacy is a defence against what he sees as the anti-science and neo-Luddite movements that are, in his words, "threatening to undermine science". The school science curriculum, he argues, "should be the forum for debunking the attempts of such fringe elements to distort the public mind, first by exposing their tactics, and then by stressing over and over again the central role in science of objective, reproducible evidence" (p. 71).

It is probably true to say that there has been a significant decline in public confidence in science and scientists in recent years as a consequence of the BSE episode (the so-called "mad cow disease") in the United Kingdom and concerns about bird flu, swine flu, SARS, West Nile Virus and other transmissible diseases. Skepticism is now rife regarding the bland assurances provided by supposed experts about health risks associated with nuclear power stations, overhead power lines and mobile phones. There is unease about the emergence of so-called 'superbugs' in hospitals, anxiety about the environmental impact of genetically engineered crops, concern about pesticide residues, growth hormones, antibiotics and other contaminants in our food, and so on. There is considerable anxiety about the possibility of a link between the MMR vaccine and autism, and a strong suspicion (rightly or wrongly) that government health authorities do not reveal all that they know. Jasanoff (1997) uses the term "civic dislocation" to describe situations in which a mismatch develops between what the scientific establishment and governmental institutions are supposed to do and are expected to do for the public, in terms of providing guarantees of safety and advice on dealing with increased risks, and what they actually do in times of crisis. At times of civic dislocation, citizens develop a deep distrust of governments and scientists and they look elsewhere for information, advice and reassurance, as evident in the BSE episode in the mid-1990s and the swine flu episode in 2009.

> It is a telling irony that, at the height of the scare over BSE, the British public seemed to get more direct information and advice from their supermarkets than their government… Vulnerable to even the slightest fluctuations in consumer confidence, the food industry was prepared to give more information, promise more controls, and offer more choices to consumers than the government agencies charged with protecting public health. (Jasanoff, 1997, p. 230)

Among some sections of the public there is mounting concern about the increasing domination of scientific and technological research by commercial, governmental and military interests, the increasing vulnerability of science and scientists to the pressures of capitalism and politics, and the increased secrecy and distortion by vested interest that result. The close link between science and commerce in the field of genetic engineering has been a particular trigger for deepening mistrust of scientists. Indeed, Ho (1997) claims, rightly or wrongly, that "practically all established molecular geneticists have some direct or indirect connection with industry, which will set limits on what the scientists can and will do research on… compromising their integrity as independent scientists" (p. 155), while Bencze et al. (2009) state that a close review of 70 research articles concerning the effectiveness of "calcium channel blockers" revealed that 96% of the authors citing positive results had financial ties to companies producing the drugs. As a consequence of revelations such as these, as Barad (2000) notes, "the public senses that scientists are not owning up to their biases, commitments, assumptions, and presuppositions, or to base human weaknesses such as the drive for wealth, fame, tenure, or other forms of power" (p. 229). In its third report, the (UK) House of Lords Select Committee on Science and Technology commented on what it perceives as a "crisis of trust":

> Society's relationship with science is in a critical phase… On the one hand, there has never been a time when the issues involving science were more exciting, the public more interested, or the opportunities more apparent. On the other hand, public confidence in scientific advice to Government has been rocked by a series of events, culminating in the BSE fiasco, and many people are deeply uneasy about the huge opportunities presented by areas of science including biotechnology and information technology, which seem to be advancing far ahead of their awareness and assent. In turn, public unease, mistrust and occasional outright hostility are breeding a climate of deep anxiety among scientists themselves. (Select Committee, 2000, p. 11)

There is some evidence that public trust in science and scientists is linked to the context and institution in which the work is conducted: university scientists enjoy higher levels of trust than scientists employed in industry because they are perceived as more benevolent and more likely to generate outcomes of benefit to the community (Yearley, 2000; Hargreaves et al., 2002; Chalmers & Nicol, 2004; Critchley, 2008).

Confidence and trust in scientists, continuing public support for science, trust in scientists, and the high levels of public funding science currently enjoys, all depend on citizens having some general understanding of what scientists do and how they do it. Since a great deal of financial support for scientific research derives from public funds, the self-interests of scientists would seem to demand that they keep the tax-payer well-informed about scientific research – in particular, about what they choose to investigate, the methods they employ, how they validate their research findings and theoretical conclusions, and where, how and to whom they disseminate their work. In developing this line of argument, Schwab (1962) advocated a shift of emphasis in school science away from the learning of scientific knowledge (the products of science) towards an understanding of the processes of scientific inquiry (how science is done) because that would ensure "a public which is aware of the conditions and character of scientific enquiry, which understands the anxieties and disappointments that attend it, and which is, therefore, prepared to give science the continuing support which it requires" (p. 38). Similarly, Shortland (1988) states that confidence in scientists and public support for science depend on "at least a minimum level of general knowledge about what scientists do" (p. 307). More significantly, support depends on whether the public *values* what scientists do. It would be naïve to assume that enhanced scientific literacy will inevitably translate into simple trust of scientists and unqualified support for the work they choose to do. A scientifically literate population, with a rational view of the world, a predisposition to think critically, and the capacity to appraise scientific evidence for themselves, may prove to be skeptical, suspicious or even distrustful of scientists, and therefore much more likely to *challenge* the nature of scientific research and the direction of technological innovation than to extend unconditional approval. However, between the extremes of simple acquiescence with everything that scientists choose to do and deep suspicion or even open hostility towards what they do, is the goal we should be seeking through school science education: a citizenry able to engage critically with the issues pertaining to scientific and technological practice and the arguments that scientists and engineers deploy. There is also an urgent need for scientists to develop better mechanisms for communication and consultation with the public – see, for example, the recommendations of the Office of Science and Technology and the Wellcome Trust (2001)[2].

Arguments that scientific and technological literacy brings benefits to *individuals* come in a variety of forms. It is commonly argued, for example, that scientifically and technologically literate individuals have access to a wide range of employment opportunities and are well-positioned to respond positively and competently to the introduction of new technologies in the workplace: "More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the process of science contributes in an essential way to these skills" (National Research Council, 1996, p. 2). In recent years, this has been especially true in industries that make extensive use of information and communications technology (ICT). Of course, we should ask whether young people do still aspire to build careers in science. Data compiled by Jenkins and Nelson (2005) suggests that this is no longer the case in the United Kingdom, though other data accumulated by the Relevance of Science Education project (ROSE), of which the Jenkins and Nelson study forms a part, indicates that aspirations for scientific careers are still strongly held in the Developing world. In addition, it is argued that those who are scientifically literate are better able to cope with the demands of everyday life in an increasingly technology-dominated society, although even casual observation of technological innovation shows that advances are generally in the direction of increased user-friendliness, so that in many cases *less* expertise is needed to cope with a new technology than was needed for the old. Moreover, individuals can function perfectly well in their daily lives without knowing very much science because they often have access to expertise whenever they need it, although that raises a key question about trust of experts (see discussion later in this chapter and in chapter 2).

A stronger case is that scientifically literate individuals are better positioned to evaluate and respond appropriately to the supposed scientific evidence used by advertizing agencies and the science-related arguments deployed by politicians, and better equipped to make important decisions that affect their health, security and economic well-being, resulting in better informed consumers and more critical citizens who can use their knowledge and understanding in ways that 'make a difference' to their own and their family's lives. As will be argued in later chapters, the curriculum I advocate in this book seeks to prepare students to deal critically and effectively with social, economic, ethical and environmental issues that are science-related and technology-related, foster a determination to work tirelessly in the interests of social and environmental health, and make positive contributions to the life of the local, regional, national and global community and to the well-being of other species As the authors of *Benchmarks for Scientific Literacy* (AAAS, 1993) suggest, “People who are literate in science... are able to use the habits of mind and knowledge of science, mathematics, and technology they have acquired to think about and make sense of many of the ideas, claims, and events that they encounter in everyday life” (p. 322). The point at issue here is that some scientific knowledge, skills and attitudes are essential for everyday life in a complex, rapidly changing and science/technology-dominated society. As individuals, each of us is faced with making decisions about whether or not to use a mobile phone, eat genetically modified food or give our children the MMR vaccine. As a society, we need to form an opinion and possibly make decisions about cloning and stem cell research, appropriate use of energy, mineral and water resources, toxic waste disposal, and so on. It is alarming to note that research by Kempton et al. (1995) and Hogan (2002a) shows that many adults, as well as school age students, reach important decisions on socioscientific issues on the basis of incomplete or incorrect knowledge, or even no knowledge at all.

To say that we are living in an era of rapid and far-reaching change, the outcomes of which are sometimes well beyond prediction, is not to say anything new or particularly startling. But it is something to which educators, and especially science educators, need to respond. Major social, economic and political changes, many occurring on a global scale, are coincident with equally profound changes in the generation, organization and transmission of knowledge and information. Previous barriers of time and space have been largely overcome. This instant interconnectivity has intensified all aspects of human life, requiring that we respond to changes and proposals for change within a very short period of time. For many, life in this complex and changing world can be cognitively challenging, emotionally unsettling and increasingly stressful. Writing nearly 20 years ago, Anthony Giddens (1991) noted that “the crisis-prone nature of late modernity… has unsettling consequences in two respects: it fuels a general climate of uncertainty which an individual finds disturbing no matter how far he seeks to put it to the back of his mind; and it inevitably exposes everyone to a diversity of crisis situations… which may sometimes threaten the very core of self-identity” (p. 184). We also live in an era that generates increasing numbers of moral-ethical dilemmas but offers fewer moral certainties – an issue to be addressed in chapter 7. Scientific literacy is essential in helping students to cope with life in this constantly changing and uncertain world and is the principal means of averting the nightmare world that Carl Sagan (1995) so gloomily speculated on in his book, *The Demon-Haunted World*.

> I have a foreboding of… when awesome technological powers are in the hands of the very few, and no one representing the public interest can even grasp the issues; when the people have lost the ability to set their own agendas or knowledgeably question those in authority; when, clutching our crystals and nervously consulting our horoscopes, our critical faculties in

> decline, unable to distinguish between what feels good and what's true, we slide, almost without noticing, back into superstition and darkness. (p. 25)

Some years ago, Neil Postman (1992) described American society as a "technopoly" in which citizens are socialized into accepting without question any statement by a supposed scientific 'expert' if it is presented in a way that readers or listeners perceive to be 'scientific' and is claimed to derive from a research study conducted at a reputable university (no matter whether that claim is true or false).

> The world we live in is very nearly incomprehensible to most of us. There is almost no fact, whether actual or imagined, that will surprise us for very long, since we have no comprehensive and consistent picture of the world that would make the fact appear as an unacceptable contradiction. We believe because there is no reason not to believe. (p. 58)

Those with little knowledge of science, especially with little knowledge of the nature of science, can be led to accept as dogma almost any knowledge that they don't fully understand, led to accept way too much on faith and on trust, led to believe that science has all the answers to all of our problems. Central to this disturbing situation, of course, is uncritical acceptance of the myth of an all-powerful route to certain knowledge via the scientific method. It is also the case that those who believe in the certainty of knowledge and in the inevitability of successful outcomes to scientific research, both of which are among the myths perpetrated by traditional science education and are prominent features of the popular public image of science, are likely to have unrealistic expectations of science and to become impatient when scientists do not immediately 'deliver' on society's wants and needs. The following extracts from official documents published over a 25-year period give something of the flavour of this particular argument for scientific literacy.

> Personal decisions, for example about diet, smoking, vaccination, screening programmes or safety in the home and at work, should all be helped by some understanding of the underlying science. Greater familiarity with the nature and findings of science will also help the individual to resist pseudo-scientific information. An uninformed public is very vulnerable to misleading ideas on, for example, diet or alternative medicine. (Royal Society, 1985, p. 10)
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> When people know how scientists go about their work and reach scientific conclusions and what the limitations of such conclusions are, they are more likely to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically. (AAAS, 1993, p. 3)
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> An important life skill for young people is the capacity to draw appropriate and guarded conclusions from evidence and information given to them, to criticize claims made by others on the basis of the evidence put forward, and to distinguish opinion from evidence-based statements. (OECD, 2003, p. 132)
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> There is obviously a need to prepare young people for a future that will require good scientific knowledge and an understanding of technology. Science literacy is important for understanding environmental, medical,

> economic and other issues that confront modern societies, which rely heavily on technological and scientific advances of increasing complexity. (High Level Group on Science Education, 2007, p. 6)

Some have argued for the cultural, aesthetic and moral-ethical benefits conferred on individuals by scientific literacy. It is nearly fifty years since C.P. Snow (1962) asserted that science is "the most beautiful and wonderful collective work of the mind of man" and that it is as crucial to contemporary culture as literature, music and fine art. In similar vein, Warren Weaver (1966) stated that "the capacity of science progressively to reveal the order and beauty of the universe, from the most evanescent elementary particle up through the atom, the molecule, the cell, man, our earth with all its teeming life, the solar system, the metagalaxy, and the vastness of the universe itself, all this constitutes the real reason, the incontrovertible reason, why science is important, and why its interpretation to all men is a task of such difficulty, urgency, significance and dignity" (p. 50). More recently, Richard Dawkins (1998) has remarked: "the feeling of awed wonder that science can give us is one of the highest experiences of which the human psyche is capable. It is a deep aesthetic passion to rank with the finest that music and poetry can deliver" (p. x). Others have claimed, somewhat extravagantly, that appreciation of the ethical standards and code of responsible behaviour within the scientific community will lead to more ethical behaviour in the wider community – that is, the pursuit of scientific truth regardless of personal interests, ambitions and prejudice (part of the traditional image of the objective and dispassionate scientist) makes science a powerful carrier of moral values and ethical principles. Shortland (1988) summarizes this rationale as follows: "the internal norms or values of science are so far above those of everyday life that their transfer into a wider culture would signal a major advance in human civilization" (p. 310). Harré (1986) presents a similar argument: "the scientific community exhibits a model or ideal of rational cooperation set within a strict moral order, the whole having no parallel in any other human activity" (p. 1). The authors of *Science for All Americans* (AAAS, 1989) spell out some of these moral values as follows: "Science is in many respects the systematic application of some highly regarded human values – integrity, diligence, fairness, curiosity, openness to new ideas, skepticism, and imagination" (p. 201). Studying science, scientists and scientific practice will, they argue, help to instill these values in students. In other words, scientific literacy doesn't just result in more skilled and more knowledgeable people, it results in *wiser* people, that is, people well-equipped to make morally and ethically superior decisions.

Arguments that increased scientific literacy brings benefits to society as a whole include the familiar and increasingly pervasive economic argument and the claim that it can enhance democracy and promote more responsible citizenship. The first argument sees science education as having a key role in stimulating growth, enhancing economic competitiveness and reducing unemployment levels to a socially and politically acceptable level. In this scenario, science education is closely linked to the development of the problem-solving capabilities of students, where the problems to be solved are seen in terms of market competition, innovation and entrepreneurship. Thus, the National Science Education Standards (NRC, 1996) state that one of the key purposes of science education is to "increase economic productivity through the use of knowledge, understanding, and skills of the scientifically literate" (p. 13). It is a view long promoted by the Government of Canada:

> Our future prosperity will depend on our ability to respond creatively to the opportunities and challenges posed by rapid change in fields such as information technologies, new materials, biotechnologies and telecommunications... To meet the challenges of a technologically driven economy, we must not only upgrade the skills of our work force, we must also foster a lifelong learning culture to encourage the continuous learning needed in an environment of constant change. (Government of Canada, 1991, pp. 12 & 14)

Similarly, the authors of an Ontario Ministry of Education and Training (2000) document on curriculum planning and assessment state that the curriculum has been designed to ensure that its graduates are well prepared "to compete successfully in a global economy and a rapidly changing world" (p. 3). Thus, scientific literacy is regarded as a form of human capital that builds, sustains and develops the economic well-being of a nation. Put simply, continued economic development brought about by enhanced competitiveness in international markets (regarded as incontrovertibly a 'good thing') depends on science-based research and development, technological innovation and a steady supply of scientists, engineers and technicians, all of which ultimately depend on public support for state-funded science and technology education in school[3]. Moreover, the argument goes, increased scientific literacy is likely to sustain high levels of consumer demand for the technologies that are perceived by such scientifically literate individuals as highly desirable. At some stage in their school science education, students should be asked to consider whether globalization *ought* be regarded as an unqualified 'good thing' and whether the economic benefits of scientific and technological development are equitably distributed (see discussion in chapter 5).

The case for scientific literacy as a means of enhancing democracy and responsible citizenship is just as strongly made as the economic argument, though by different stakeholders and interest groups. Thomas and Durant (1987) note that increased scientific literacy "may be thought to promote more democratic decision-making (by encouraging people to exercise their democratic rights), which may be regarded as good in and of itself; but in addition, it may be thought to promote more effective decision-making (by encouraging people to exercise their democratic right wisely)" (p. 5). In the words of Chen and Novick (1984), enhanced scientific literacy is a means "to avert the situation where social values, individual involvement, responsibility, community participation and the very heart of democratic decision making will be dominated and practiced by a small elite" (p. 425). Democracy is strengthened when *all* citizens are equipped to confront and evaluate socioscientific issues (SSI) knowledgeably and rationally, rather than (or as well as) emotionally, and to make informed decisions on matters of personal and public concern. Those who are scientifically illiterate are in many ways disempowered and excluded from active civic participation. It is little wonder, then, that Tate (2001) declares access to high quality science education to be a civil rights issue. The following remarks can be taken as illustrative of the scientific literacy for democratic citizenship argument.

> Science education must serve as a foundation for the education of an informed citizenry who participate in the freedoms and powers of a modern, democratic, technological society. With the rapid development of scientific knowledge and the advent of new technologies, all members of society must have an understanding of the implications of that knowledge upon individuals, communities, and the 'global village' in which we now live. (Berkowitz & Simmons, 2003, p. 117)

> Few individuals have an elementary understanding of how the scientific enterprise operates. This lack of understanding is potentially harmful, particularly in societies where citizens have a voice in science funding decisions, evaluating policy matters and weighing scientific evidence provided in legal proceedings. At the foundation of many illogical decisions and unreasonable positions are misunderstandings of the character of science. (McComas, 1998, p. 511)

Of course, as both Tytler (2007) and Levinson (2010) remind us, the notion of science education for citizenship raises a whole raft of questions about the kind of citizen and the kind of society we have in mind, and about what constitutes *informed* and *responsible* citizenship. As Davies (2004) points out, not all science educators who are keen to implement science education for citizenship have a clearly articulated notion of what responsible citizenship entails and how science education can play a part in helping students achieve it. He quotes at length from Gamarnikow and Green's (2000) argument that it so often "reproduces a version of citizenship education unlikely to challenge the social mechanisms of inequality reproduction" (p. 1757). There is an all-too-common and depressing tendency to equate science education for citizenship simply with the inclusion of common everyday examples of 'science in the real world' as a way of motivating students and enhancing conceptual (and possibly procedural) understanding. In other words, the citizenship element is a mere enabling tactic; the real goal is enhanced understanding of science content, and the broader underlying goal is education for social reproduction. When education is geared towards preservation of the existing social order, as most education is, students are prepared to be obedient, deferential, compliant and willing to take their place within existing hierarchical social structures. In general, citizens are expected to leave daily decision-making and policy setting to their elected representatives, in collaboration with the industrial, financial and military sectors (see Levinson (2010) for a fuller discussion of this "deficit model" of citizenship and science education for citizenship). However, if education is geared towards social critique and social transformation, as argued throughout this book, students are prepared to be informed, critical and active citizens who expect (and demand) to be full participants in the decision-making processes within local, regional, national and international communities.

Westheimer and Kahne (2004) draw some useful distinctions among three alternative conceptions of citizenship: the *personally responsible citizen*, the *participatory citizen* and the *justice-oriented citizen*. In addition to paying taxes, obeying laws and voting in elections, the personally responsible citizen is strongly motivated to recycle, use public transport, pick up litter, donate blood and contribute to food and clothing banks, and may do volunteer work in soup kitchens and homes for the elderly. The participatory citizen is involved in organizing and participating in community-based efforts to care for those in need, promote social development and clean up the environment. Justice-oriented citizens respond critically to social, political and economic structures, seek out and address areas of injustice, and endeavour to effect systemic and significant change. The stance adopted in this book is that while each of these orientations is important, none is sufficient in itself. Putting emphasis on individual character and behaviour can divert attention from analysis of the social, economic and political forces that underpin SSI and the search for systemic solutions. In its neglect of the forces that shape society, it can create a politically conservative vision of the role of government, foster blind loyalty or unthinking obedience, and stoke up jingoistic sentiments. At a practical level, it fails to appreciate that individual actions are sometimes insufficient to effect significant change, and that only collective actions can succeed. Encouraging participation in collective actions doesn't necessarily develop students' ability to analyze and critique social and cultural practices or to identify the root causes of problems. It doesn't always help them to recognize underlying ideologies and values, detect vested interests or ascertain the ways in which wealth, power, gender and race impact on fairness, equity and social justice. Thus, it can reinforce rather than challenge existing norms and practices. However, emphasis on critique may only succeed in producing 'armchair activists': people who can hold articulate and politically astute conversations with like-minded individuals, or argue persuasively with political opponents, but don't ever do anything about the causes they seem to care so much about. In short, the unthinking participation that can sometimes occur under the participatory citizenship model can become no more than thoughtful inaction under the social justice model. The kind of citizenship envisaged in this book entails all three perspectives. Chapter 7 has a great deal to say about what it means to be personally responsible; chapters 3 and 9 discuss ways in students can be taught about action and learn through action; every chapter promotes, to some extent, the principles of social critique and pursuit of justice, though chapters 3, 4, 5, 8 and 9 have most to say on these matters. Also relevant to this multi-citizenship notion is Battistoni's (2002) discussion of what he calls "civic participation skills", including basic scientific, technological, economic, social and political knowledge, ability to evaluate knowledge and information quickly and critically, and bring it to bear on particular issues and problems, capacity to communicate confidently, effectively and persuasively in public settings, willingness to listen to others, and ability to collaborate in seeking and implementing solutions. Every chapter contributes something of relevance to the development of these attributes.

The authors of *Science For All Americans* (AAAS, 1989), arguing for the role of scientific literacy in fostering a more socially compassionate and environmentally responsible democracy, state that science education can (and should) "help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital" (p. xiii). Moreover, they say, science education can provide the knowledge needed "to develop effective solutions to… global and local problems" and can foster "the kind of intelligent respect for nature that should inform decisions on the uses of technology", without which "we are in danger of recklessly destroying our life-support system" (p. 12). In further elaborating this kind of argument, the OECD's Programme for International Student Achievement (PISA) proposes that a scientifically literate person is "able to combine science knowledge with the ability to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (OECD, 1998, p. 5) and has "a willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen… having opinions and participating in… current and future science-based issues" (OECD, 2006, p. 24). In other words, scientific literacy is the driving force for sociopolitical action – an argument that will be explored at length in later chapters. Roth and Calabrese Barton (2004) make essentially the same point: "critical scientific literacy is inextricably linked with social and political literacy in the service of social responsibility" (p. 10). It should not be thought of as a property of individuals, they argue, but as a characteristic of everyday situations in which citizen science occurs. In common with Roth and Lee (2002, 2004) and Roth (2003, 2009a), they recognize that significant impact on decision-making regarding SSI is more likely through collective action than individual efforts, thus shifting the ultimate focus of education for scientific literacy towards effective public practice, summed up by the increasingly popular notion of *enhanced public engagement with science*.

> First, we propose that scientific literacy is a property of collective situations and characterizes interactions irreducible to characteristics of individuals. Second, we propose to think of science not as a single normative framework for rationality but merely as one of many resources that people can draw on in everyday collective decision-making processes. Third, we propose that people learn by participating in activities that are meaningful because they serve general (common) interests and, in this, contribute to the community at large rather than making learning a goal of its own. (Roth & Calabrese Barton, 2004, p. 22).

> Scientific literacy, to be of any use in the everyday life of individuals and collectives, has to be thought of not as lodged in the heads of people and not as to be found *in* the properties of collectives. Rather, we should think of scientific literacy as *an emergent feature* of *collective praxis* so that it can only be observed while people engage one another and as an effect of these interactions. (Roth, 2009, p. 23)

In other words, scientific literacy is something that emerges and develops as a group of people, some of whom may be scientists, confront a socioscientific issue and collectively work towards a solution. Appropriate expertise develops as the situation requires. While I acknowledge that collective action with regard to SSI is often necessary and is frequently more productive than individual actions (see chapter 3), and while I accept that one can legitimately regard a community as having collective scientific literacy, and while I acknowledge that an individual's level of scientific literacy is likely to be substantially enhanced by participating in collective actions focused on SSI, I do not accept the proposition that individual levels of scientific literacy cannot be discerned and should not be cultivated. Nor do I accept the proposition implied in much of Wolff-Michael Roth's recent work, that science education should be de-institutionalized.

One further argument for seeking enhanced scientific literacy is that it might also be the most effective way to address the naïve trust that many students have in the Internet. It seems that many students accept anything and everything they locate on the Internet as valid and reliable; they form their views on all manner of topics after a few minutes Google searching or consulting Wikipedia. Enhanced scientific literacy is also a powerful means to combat the increasingly pervasive influence of 'alternative sciences' such as iridology, aromatherapy and reflexology, and the increasing susceptibility of people to the blandishments of purveyors of miracle cures, revolutionary diets, body enhancement techniques and procedures, and the healing properties of crystals.

In a succinct summary of the foregoing arguments, Symington and Tytler (2004), writing from an Australian perspective, consider school science education to have five key purposes.

- The *cultural* purpose is to ensure that all members of society develop an understanding of the scope of science and its applications within contemporary culture.
- The *democratic* purpose is to ensure that students develop sufficient scientific knowledge and sufficient confidence in science to be involved in debate and decision-making about scientific and technological issues.
- The *economic* purpose is to ensure a regular supply of people with strong backgrounds in science and technology in business and public life, and in science-related and technology-related careers, to secure the country's future prosperity.
- The *personal development* purpose is to ensure that all members of society benefit from the contribution that the values and skills of science can make to their ability to learn and operate successfully throughout life.
- The *utilitarian* purpose is to ensure that all members of society have sufficient knowledge of science to operate effectively and critically in activities where science can make a contribution to their personal well-being and quality of life.

A few years earlier, Driver et al. (1996) had generated a broadly similar list, save that the personal development purpose was replaced by a moral argument: "that the practice of science embodies norms and commitments, which are of wider value" (p. 11).

SCIENTIFIC LITERACIES

Michaels and O'Connor (1990) make the point that literacy is inherently a *plural* notion.

> We each have, and indeed fail to have, many different literacies. Each of these literacies is an integration of ways of thinking, talking, interacting and valuing, in addition to reading and writing… ways of being in the world and ways of making meaning. (p. 11)

In response to the diversity of arguments for promoting it, Shen (1975) identified three categories of scientific literacy: *practical*, *civic* and *cultural*. Practical scientific literacy is knowledge that can be used by individuals to cope with life's everyday problems (diet, health, consumer preferences, technological competence, and so on); civic scientific literacy comprises the knowledge, skills, attitudes and values necessary to play a full and active part in decision-making in key areas such as energy policy, use of natural resources, environmental protection and moral-ethical considerations relating to medical and technological innovations; cultural scientific literacy includes knowledge of the major ideas and theories of science, and the sociocultural and intellectual environment in which they were produced. The term cultural scientific literacy is used to signal belief that the fundamental theories of science collectively constitute a cultural heritage and resource to which everyone should have access. Layton et al. (1993) have described this aspect of scientific literacy as "recognition and appreciation of 'the cathedrals of science', science as a majestic achievement of the human intellect and spirit" (p. 15). Wellington (2001) reaches a conclusion similar to Shen's when he argues that there are three basic justifications for curriculum content: (i) intrinsic value (cultural scientific literacy), (ii) citizenship needs (civic scientific literacy), and (iii) utilitarian arguments (practical scientific literacy). Shamos (1995) also deploys a three-fold categorization of scientific literacy, but unlike Shen and Wellington he sees his categories as hierarchical. For Shamos, *cultural* scientific literacy is the simplest, most basic level of literacy. It comprises the scientific understanding needed to make sense of articles in newspapers and magazines, and programmes on television, communicate with elected representatives, and follow debates on public issues with a science and technology dimension. *Functional* scientific literacy builds on cultural scientific literacy by "requiring that the individual not only have command of a science lexicon, but also be able to converse, read, and write coherently, using such science terms in a perhaps non-technical but nevertheless meaningful context" (Shamos, 1995, p. 8). *True* scientific literacy, as Shamos calls it, involves knowledge and understanding of major scientific theories, including "how they were arrived at, and why they are widely accepted, how science achieves order out of a random universe… the role of experiment… the importance of proper questioning, of analytical and deductive reasoning, of logical thought processes, and of reliance on objective evidence" (p. 89). Bybee (1997) also arranges conceptions of scientific literacy into a hierarchy: *nominal* scientific literacy (knowing scientific words but not always understanding their meaning); *functional* scientific literacy (being able to read and write science using simple and appropriate vocabulary, but with little understanding of larger conceptual frameworks); *conceptual and procedural* scientific literacy (a thorough understanding of both the conceptual and procedural bases of science); and *multidisciplinary* or *multidimensional* scientific literacy (a thorough and robust understanding of the conceptual and procedural structures of science, together with knowledge of the history of science, an understanding of the nature of science and appreciation of the complex interactions among science, technology and society)[4].

Bybee's notion of multidisciplinary scientific literacy raises some important questions about technology, the relationship between science and technology, and the meaning of technological literacy. While science can be regarded as a search for explanations of phenomena and events in the natural world, technology is the means by which people modify nature to meet their needs and wants, and better serve their interests (see Price and Cross (1995) for an extended discussion of science as *explanation* and technology as *knowhow*). While it is easy to think of technology in terms of artifacts (televisions, computers and microwave ovens; pesticides, fertilizers and antibiotics; automobiles, high speed trains and space stations; high-rise office blocks, water treatment plants and power stations; and so on), it is important to remember that it also includes the knowledge, skills and infrastructure necessary for the design, manufacture, operation and maintenance of those artifacts. Thus, Wajcman (2004) describes technology as "a seamless web or network combining artifacts, people, organizations, cultural meanings and knowledge" (p. 106). In his classic work, *The Culture of Technology*, Arnold Pacey (1983) defines technological products and practices in terms of a *technical* aspect (knowledge, skills, techniques, tools, machines, resources, materials and people), an *organizational* aspect (including economic and industrial activity, professional activity, users, consumers and trade unions) and a *cultural* aspect (goals, values, beliefs, aspirations, ethical codes, creative endeavour, etc.). Similarly, Carl Mitcham (1994) conceptualizes technology in terms of four aspects: (i) as objects, artifacts and products; (ii) as a distinctive form of knowledge, separate from science; (iii) as a cluster of processes (designing, constructing or manufacturing, evaluating, systematizing, etc.); and (iv) as volition (the notion that technology is part of our human will and, therefore, an intrinsic part of our culture). Importantly, in the context of this book, both writers note that technology reflects our needs, interests, values and aspirations. The key point is that technological artifacts are conceived, developed, manufactured and marketed as part of economic and social activity, and often have profound implications and consequences well beyond the immediate sphere of their deployment. For example, the invention of the motor car created the need for driving conventions and road rules, a legal framework for dealing with those who violate the rules, an insurance and vehicle licensing system, a means of training, testing and licensing drivers, the establishment of a car repair industry and an advertizing, marketing and retail industry, all in addition to the research and development activity within the motor vehicle design and manufacturing industry itself.

Although there are some important differences between them in terms of purposes, concepts, procedures and criteria for judging acceptability of solutions, science and technology are closely related. For example, scientific understanding of the natural world is the basis for much of contemporary technological development and, in turn, technology is essential to much contemporary scientific research, and in fields such as high energy physics and nanotechnology it is very difficult, if not impossible, to disentangle science and technology. For these reasons, some commentators choose to speak of *technoscience*. Johnson (1989) sums up the relationship between science and technology as follows:

> Technology is the application of knowledge, tools, and skills to solve practical problems and extend human capabilities. Technology is best described as process, but it is commonly known by its products and their effects on society.

> It is enhanced by the discoveries of science and shaped by the designs of engineering. It is conceived by inventors and planners, raised to fruition by the work of entrepreneurs, and implemented and used by society… Technology's role is doing, making and implementing things. The principles of science, whether discovered or not, underlie technology. The results and actions of technology are subject to the laws of nature, even though technology has often preceded or even spawned the discovery of the science on which it is based. (p. 1 – cited by Lewis & Gagel, 1992, p. 127)

As noted in Hodson (2009a), there is sometimes considerable value in teachers emphasizing the differences between science and technology, and sometimes it is more important and more interesting to direct attention to the similarities. On occasions, it is important for students to think in a purely scientific way; on other occasions, it is crucial that they learn to think in a technological way (e.g., like an architect, doctor or engineer). And sometimes, especially when addressing complex real world issues and problems, it is necessary to draw on knowledge from a range of disciplines other than science and technology.

Discussion of what constitutes technological literacy (and, therefore, priorities for technology education) can be found in Dyrenfurth and Kozak (1991), Lewis and Gagel (1992), Layton (1993), Waetjen (1993), Barnett (1995), Gagel (1997), Jenkins (1997a,b), Bugliarello (2000), Petrina (2000), Cajas (2001, 2002), Gräber et al. (2002), DeVries (2005), Dakers (2006), Jones (2006), France (2007), Rose (2007)), Jones and de Vries (2009) and Williams (2009). While issues of definition will not be revisited here, I do wish to draw attention to David Layton's (1993) classification in terms of six "functional competencies".

- Technological awareness or *receiver competence*: the ability to recognize technology in use and acknowledge its possibilities.
- Technological application or *user competence*: the ability to use technology for specific purposes.
- Technological capability or *maker competence*: the ability to design and make artifacts.
- Technological impact assessment or *monitoring competence*: the ability to assess the personal and social implications of a technological development.
- Technological consciousness or *paradigmatic competence*: an acceptance of, and an ability to work within, a 'mental set' that defines what constitutes a problem, circumscribes what counts as a solution and prescribes the criteria in terms of which all technological activity is to be evaluated.
- Technological evaluation or *critic competence*: the ability to judge the worth of a technological development in the light of personal values and to step outside the 'mental set' to evaluate its wider impact.

A similar approach has been adopted by Gräber et al. (2002), culminating in a 7-component competency-based model of technological literacy comprising subject competence, epistemological competence, learning competence (using different learning strategies to build personal scientific knowledge), social competence (ability to work in a team on matters relating to science and technology), procedural competence, communicative competence and ethical competence. Although these other, more complex characterizations of technological literacy have been advanced, it is sufficient for my purposes to regard it as having the same three dimensions as scientific literacy, as envisaged by Shen (1975) – namely, *practical*, *civic* and *cultural.*

Any discussion of technological literacy inevitably raises important issues relating to computer technology. The World Wide Web, computer-aided design, word processing, data processing and electronic transfer of information have become the engines of economic growth and have fundamentally changed the ways we learn, communicate and do business. The notion of *computer literacy* extends well beyond the acquisition of basic computer skills and the capacity to use computer technology to gather and communicate information. It now encompasses: (i) the capacity to evaluate information for accuracy, relevance and appropriateness; (ii) the ability to detect implied meaning, bias and vested interest; (ii) awareness of the legal issues and moral-ethical dilemmas associated with open access to information, censorship and data protection; and (iv) sensitive and critical understanding of the socio-economic, political and cultural impact of computer technology and the globalization it has accelerated - issues to be addressed in subsequent chapters.

Scientific literacy also presupposes a reasonable level of literacy in its fundamental sense (Wellington & Osborne, 2001; Norris & Phillips, 2003; Fang, 2005; Yore & Treagust, 2006). Scientific knowledge cannot be articulated and communicated except through text and its associated symbols, diagrams, graphs and equations. Thus, engagement in science, contribution to debate about science and access to science education are not possible without a reasonable level of literacy. Moreover, the specialized language of science makes it possible for scientists to construct an alternative interpretation and explanation of events and phenomena to that provided by ordinary, everyday language. It is scientific language that shapes our ideas, provides the means for constructing scientific understanding and explanations, enables us to communicate the purposes, procedures, findings, conclusions and implications of our inquiries, and allows us to relate our work to existing knowledge and understanding. Indeed, it could be said that learning the language of science is synonymous with (or certainly coincident with) learning science.

> Without text, the social practices that make science possible could not be engaged: (a) the recording and presentation and re-presentation of data; (b) the encoding and preservation of accepted science for other scientists; (c) the peer reviewing of ideas by scientists anywhere in the world; (d) the critical re-examination of ideas once published; (e) the future connecting of ideas that were developed previously; (f) the communication of scientific ideas between those who have never met, even between those who did not live contemporaneously; (g) the encoding of variant positions; and (h) the focusing of concerted attention on a fixed set of ideas for the purpose of interpretation, prediction, explanation, or test. The practices centrally involve texts, through their creation in writing and their interpretation, analysis, and critique through reading. (Norris & Phillips, 2008, p. 256)

If it is correct that most people, including many still in school, obtain most of their knowledge of contemporary science and technology from television, newspapers, magazines and the Internet (National Science Board, 1998; Select Committee, 2000; Falk, 2009), then the capacity for active critical engagement with text is a crucial element of scientific literacy. Indeed, it could be claimed that it is the *most important* element.

> To be fully scientifically literate, students need to be able to distinguish among good science, bad science and non-science, make critical judgements about what to believe, and use scientific information and knowledge to inform decision making at the personal, employment and community level. In other words, they need to be *critical consumers* of science. This entails recognizing that scientific text is a cultural artifact, and so may carry implicit messages relating to interests, values, power, class, gender, ethnicity and sexual orientation. (Hodson, 2008, p. 3)

Because meaning in science is also conveyed through symbols, graphs, diagrams, tables, charts, chemical formulae, reaction equations, 3-D models, mathematical expressions, photographs, computer-generated images, body scans and so on, Lemke (1998) refers to the language of science as “multi-modal communication”. Any one scientific text might contain an array of such modes of communication, such that it may be more appropriate to refer to the *languages* of science.

> Science does not speak of the world in the language of words alone, and in many cases it simply cannot do so. The natural language of science is a synergistic integration of words, diagrams, pictures, graphs, maps, equations, tables, charts, and other forms of visual mathematical expression. (Lemke, 1998, p. 3)

Thus, the overall meaning of a scientific text or a science lesson is built by combining a partial meaning from the words with a partial meaning from the diagrams, equations and other “inscriptional devices” (as Latour, 1990, calls them) and a partial meaning from the mathematics. The key to effective communication in science, and to understanding the communications of others, resides in appreciation of how these different forms of representation interact and support each other (Sherin, 2001; Ainsworth, 2006; Moje, 2008; Tang & Moje, 2010). Indeed, Tang and Moje (2010) define scientific literacy as “the cultural practices that encompass specific ways of talking, writing, viewing, drawing, graphing, and acting, within a specialized discourse community” (p. 83). Most significant of all is critical media literacy, an issue to be discussed in chapter 2. For the purposes of this book, I am defining media literacy as the ability to access, analyze, evaluate and produce communications in a variety of forms. A media literate person can think critically about what they see, hear and read (and what they wish to say) in books, newspapers, magazines, television, radio, movies, music, advertizing, video games and the Internet, and can respond critically and appropriately to emerging communications technology. As Hornig Priest (2006) reminds us, media literacy is important “not because media directly determine (or ever fully reflect) public opinion, but because media accounts express relevant values and beliefs, help confer legitimacy to or discredit particular groups by treating them as part of the mainstream or as marginal, and therefore indirectly affect which perspectives do or do not ultimately come to dominate collective discourse and decision-making” (p. 58).

Scientific literacy also presupposes some basic understanding of mathematics, such as familiarity with simple algebraic equations and their manipulation, the capacity to interpret graphical and numerical data, and sufficient knowledge of statistics and the mathematics of probability to understand issues of risk, uncertainty and cost-benefit analysis. It also presupposes some historical understanding of the role of mathematics in both theory building and design of investigative procedures in science, medicine and engineering, and the capacity to recognize situations in which mathematics and/or statistics are being misused. A discussion of what constitutes mathematical literacy is well outside the scope of this book. Noss (1998), English (2002), Jablonka (2003) and Yore et al. (2007) provide some valuable perspectives on the question. As an aside, I would argue that overcoming so-called “maths phobia” and addressing the distrust with which many people regard any argument that deploys statistics (because, they say, “statistics can prove anything!”) are much more important elements of building scientific and technological literacy than many science teachers recognize.

The notion of *environmental literacy* is also enormously helpful in building a comprehensive picture of scientific and technological literacy, especially in relation to critical consideration of environmental issues and other SSI. Indeed, given the accelerating pace of environmental degradation, it is now abundantly clear that the planet can no longer accommodate a scientifically illiterate, technologically illiterate, environmentally illiterate, uncritical and uncaring yet technologically powerful species. In the words of Carl Sagan (1995):

> The consequences of scientific illiteracy are far more dangerous in our time than in any that has come before. It’s perilous and foolhardy for the average citizen to remain ignorant about global warming, say, or ozone depletion, air pollution, toxic and radioactive wastes, acid rain, topsoil erosion, tropical deforestation, exponential population growth. (p. 6)

The consequences of *not* giving prominence to environmental literacy in the curriculum are vividly illustrated by David Orr (1992).

> A generation of ecological yahoos without a clue why the color of the water in their rivers is related to their food supply, or why storms are becoming more severe as the planet warms. The same persons as adults will create businesses, vote, have families, and above all, consume. If they come to reflect on the discrepancy between the splendor of their private lives in a hotter, more toxic and violent world, as ecological illiterates they will have roughly the same success as one trying to balance a checkbook without knowing arithmetic. (p. 86)

Although the term environmental literacy is not universally accepted, with some writers opting for “environmental awareness”, “ecological literacy”, “environmental responsibility” or even “ecological/environmental citizenship” (Hart, 2007), there is some general agreement on its major components. For example, environmental literacy necessarily includes a clear and robust understanding of a range of biological concepts, ideas and theories, including: cycles, flows and fluctuations (energy, weather, etc.); population concepts (including limiting factors and carrying capacity); interactions, interdependence and coevolution; communities and ecosystems; diversity, change, succession and homeostasis; food webs; mechanisms of climate change and ozone depletion; and so on. It includes the ability to adopt systems thinking to address the complex interactions between human society and the natural world. It includes attitudes and values that reflect feelings of concern for the environment and foster both a sensitive environmental ethic and a sense of responsibility to address issues and resolve environmental problems through participation and action, both as individuals and as members of groups. Like scientific literacy, it includes the adoption of a critical attitude towards received information, skepticism about extravagant claims, and a determination to subject all expressed opinions to close scrutiny.

It is interesting to trace the development of the concept of environmental literacy and shifts in views about the aim/purpose of environmental education. As long ago as 1976, the Belgrade Charter stated that the goal of environmental education is "to develop a world population that is aware of, and concerned about, the environment and its associated problems, and which has the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones (UNESCO-UNEP, 1976, p. 2). It is both noteworthy and surprising that words like *society*, *economics*, *politics* and *development* were entirely absent. Nearly 15 years later, Marcinkowski et al. (1990) stated that the aim of environmental education is "to aid citizens in becoming environmentally knowledgeable and, above all, skilled and dedicated for working, individually and collectively, toward achieving and/or maintaining a dynamic equilibrium between quality of life and quality of environment" (p. 1). At about the same time, Brennan (1994) defined an environmentally literate citizen as one who "will have a blend of ecological sensitivity, moral maturity, and informed awareness of natural processes that would make her or him unlikely to contribute to further degradation of natural process at either individual or corporate levels" (p. 5). In an attempt to impose a more rigorous theoretical structure, Marcinkowski (1991) generated a set of nine statements to characterize the nature of environmental literacy.

1. An awareness and sensitivity towards the environment.
2. An attitude of respect for the natural environment, and concern for the nature and magnitude of human impact on it.
3. Knowledge and understanding of how natural systems work, and how social systems interact with natural systems.
4. An understanding of environmental problems and issues (local, regional, national, international and global).
5. The skills required to analyze, synthesize and evaluate information about environmental problems/issues, using both primary and secondary sources.
6. A sense of personal investment, responsibility and motivation to work individually and collectively towards the resolution of environmental problems and issues.
7. Knowledge of strategies available for addressing environmental problems and issues.

8. The skills required to develop, implement and evaluate both single strategies and composite plans for remediation of environmental problems and issues.
9. Active involvement at all levels in working towards the resolution of environmental problems and issues.

Of course, literacy (whether it is literacy in its fundamental sense, scientific literacy, technological literacy or environmental literacy) is not a state that an individual can be deemed to have attained when a particular level of understanding is reached. It is not simply a matter of being literate or illiterate. Rather, there are levels of literacy distributed along a continuum. Accordingly, Roth (1992) developed a framework of knowledge, skills, affective attributes and behaviours arranged into what he calls *nominal*, *functional* and *operational* forms of environmental competence. Those at the nominal level have "a very rudimentary knowledge of how natural systems work and how human social systems interact with them"; at the fundamental level, they are "aware and concerned about the negative interactions between these systems in terms of at least one or more issues and have developed the skills to analyze, synthesize, and evaluate information about them using primary and secondary sources"; and at the operational level, they "routinely evaluate the impacts and consequences of actions, gathering and synthesizing pertinent information, choosing among alternatives, and advocating action positions and taking actions that work to sustain or enhance a healthy environment" (p. 26). This idea of environmental competencies was also used by Lemons (1991): the ability to apply ecological principles to the analysis of environmental issues, including the analysis of alternative solutions to problems; the ability to understand how political, economic, social, literary, religious and philosophical traditions and activities influence the environment; the ability to understand the role of citizen participation in solving environmental problems; and the ability to apply action-oriented problem-solving skills to achieve conduct appropriate to environmental protection. These same elements are included in John Smyth's (1995) hierarchical ordering of environmental *awareness*, environmental *literacy*, environmental *responsibility*, environmental *competence* and environmental *citizenship*. They are reflected, too, in the distinction drawn by Berkowitz et al. (2005) between *ecological literacy* ("the ability to use ecological understanding, thinking and habits of mind for living in, enjoying, and/or studying the environment") and *ecological citizenship* ("having the motivation, self-confidence and awareness of one's values, and the practical wisdom and ability to put one's civics and ecological literacy into action" (p. 228)[5]. Drawing on a perceived parallel with notions of functional, cultural and critical literacy (Williams & Snipper, 1990), Stables (1998) postulates three dimensions of environmental literacy: *functional* environmental literacy – understanding of the language, concepts and principles used to describe and theorize the natural and built environments, together with the skills needed to gather further knowledge and information; *cultural* environmental literacy – an understanding of how the natural environment has been shaped by human beings as well as by weather, glaciation and volcanic activity, together with appreciation of the significance of natural images and landscapes in human culture; *critical* environmental literacy – understanding of the economic, social and political factors that contribute to environmental change, how decisions that impact the environment are made and how decision-making might be influenced and re-directed.

It would be a relatively straightforward matter to incorporate this 3-fold classification, together with elements of the notion of environmental competencies advanced by Lemons (1991) and Roth (1992), into an extended definition of practical scientific literacy, civic scientific literacy and cultural scientific literacy.

Before leaving this discussion, it is important to note that Stables and Bishop (2001) draw a distinction between what they call “weak environmental literacy”, as defined by Marcinkowski (1991) and Roth (1992), and their own notion of “strong environmental literacy” based on a broad view of literacy in its fundamental sense. The gist of their argument is that we can consider the environment as *text*[6]. Like text, the sense that we make of ‘environment’, both individually and collectively, is infused with a raft of historical, cultural and aesthetic dimensions, as well as scientific aspects. It follows that there is no one ‘correct way’ of understanding the environment; different cultural and social groups will hold different views and will identify different aspects as significant and different issues as problematic. Some key differences in how environmental literacy is perceived are evident in the wide range of approaches to environmental education. Lucie Sauvé (2005) identifies as many as fifteen overlapping approaches or “currents of intervention”, as she calls them, each of which embodies a particular conception of the environment, a distinctive aim (although it may be implicit rather than explicit) and a preferred pedagogy[7]. As will become evident in subsequent chapters, the approach to science and technology education advocated in this book includes elements of almost all of these approaches, most notably the scientific, problem-solving, socially critical and values-centred “currents” will be utilized in chapter 3, the naturalist, feminist, ethnographic, values-centred, holistic, sustainability and eco-education “currents” will be discussed in chapter 8, and the humanist/mesological, bioregionalist and praxic “currents” will be prominent in chapter 9.

Also before leaving this discussion, and as a way of preparing the ground a little for discussion in chapters 3, 5, 8 and 9, it is important to comment on the problematic nature of concepts such as “sustainable development” and “education for sustainable development”. Perhaps the most widely quoted definition of sustainable development is that proposed by Brundtland (1987):

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs… Sustainable development requires meeting the basic needs of all and extending to all the opportunity to fulfil their aspirations for a better life. (p. 8)

In a broadly similar definition, the UK Government (1996) stated that sustainable development means reconciling two aspirations: (i) achieving economic development to secure rising standards of living both now and in the future, and (ii) protecting and enhancing the environment now and for the future. A decade later, the Forum for the Future (2007) defined sustainable development as “a dynamic process, which enables all people to realize their potential and improve their quality of life in ways which simultaneously protect and enhance the Earth’s life support systems” (www.forumforthefuture.org/what-is-sd). As Dissinger (1990), Shiva (1992), Smyth (1995), Dobson (1996), Stables (1996), Palmer (1998), Bonnett (1999, 2002, 2007), Sauvé (1999), Stables and Scott (1999), Rauch (2002), Robinson (2004), Elshof

(2005), Jickling (2005), Ashe et al. (2007), Jickling and Wals (2008), Kahn (2008), Stevenson (2008), Räthzel and Uzzell (2009) and Selby (2010) point out, such definitions are not just problematic, they are internally contradictory. Indeed, Bonnett (2002) remarks that the wide appeal of the term "sustainable development" is rooted in its ambiguous and paradoxical nature.

> By seeming to combine the highly desired goal of development with the equally highly desired goal of conservation of valuable things endangered, it is… set up as a goal which is so obviously attractive as to divert attention from its problematic nature. Sustainable development is something *everyone* can subscribe to, from enlightened captains of modern industry to subsistence farmers – the former concerned to create the conditions for sustained economic growth, the latter concerned to survive into the future and perhaps better their material lot there. Any problems are perceived not with the goal itself, but only with the means of achieving it. (p. 11, emphasis in original)

Exploiting such ambiguities enables politicians, industrialists and policy makers to give the impression that they wish to sustain natural ecosystems while pursuing development policies that are almost guaranteed to exacerbate the problems of environmental degradation. The problems, inconsistencies and irreconcilabilities of "sustainable development" begin to show up when questions are asked about precisely what is to be sustained, for whom, and for how long, by what means, and under what conditions. Gilbert Rist (1997) comments as follows: "For ecologists… sustainable development implies a production level that can be borne by the eco-system, and can therefore be kept up in the long-term… The dominant interpretation is quite different. It sees 'sustainable development' as an invitation to keep up 'development', that is, economic growth… The thing that is meant to be sustained really is 'development' not the tolerance capacity of the eco-system or of human societies" (pp. 192–194). This commitment to continued or even extended economic growth raises all kinds of questions about what "protecting and enhancing the environment" might mean. Yet the term *sustainable development* continues to be widely used and widely applauded as a desirable goal. As Jickling and Wals (2008) observe, "the interests of groups with radically different ideas about what should be sustained, are masked by illusions of shared understandings, values, and visions of the future" (p. 14). They liken this situation to Orwellian "double-think" in which people hold contradictory meanings for the same term and accept them both. Chapter 5 will address curriculum issues relevant to inculcating a more critical and politicized approach to questions of economic growth and sustainability, while chapter 8 will explore notions of sustainability and education for sustainability in greater depth. The link between environmental education and sustainable development is clearly spelled out in *Agenda 21*, the report of the 1992 Earth Summit.

> Education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues… It is critical for achieving environmental and ethical awareness, values and attitudes, skills and behaviour consistent with sustainable development and for effective public participation in decision-making. (UNCED, 1992, chapter 36: 2)

A follow-up document to chapter 36, *Reshaping Education for Sustainable Development*, stated: "The function of education in sustainable development is mainly to develop human capital and encourage technical progress, as well as fostering the cultural conditions favoring social and economic change… ensuring rapid and more equitable economic growth while diminishing environmental impacts" (Albala-Bertrand, 1992, p. 3). However, the precise nature of the relationship envisaged between environmental education and sustainable development is somewhat unclear. As McKeown and Hopkins (2003) point out, some writers, commentators and educators see education for sustainable development as an overarching umbrella, to which environmental education, science, mathematics, economics, social studies and many other disciplines can contribute. Others see consideration of sustainability issues as a part of environmental education. John Elliott (1999) draws an important distinction between an approach to environmental education in which students are expected to acquire a pre-specified body of knowledge, adopt a particular set of attitudes, subscribe to a prescribed set of values, and engage in a raft of designated behaviours, and an approach in which the goal is to foster a rational and critical approach to consideration of environmental issues and to their solution at the local, regional, national and global levels. My advocacy of this second approach, which Elliott calls the democratic approach, carries with it an acknowledgement that the idea of sustainable *development* as envisaged by Brundtland et al. (1987) is a nonsense and should be replaced by the notion of *sustainability*, not least because it raises important questions about our conception of the natural environment and our role/place within it. It is both interesting and encouraging that Canada's national environmental education plan is titled "*A Framework for Environmental Learning and Sustainability*" (Government of Canada, 2002).

Finally, Hart and Nolan (1999) note that although the field of environmental education appears to be fragmented, and beset with some radical differences in approach, researchers are interweaving their work in ways that advance environmental education discourse. Sammel (2003) goes further, suggesting that "the existence of conflicting paradigms in environmental education may drive the process of change in much the same way as debates about the appropriateness of competing paradigms in science drives the process of scientific advancement" (p. 31).

EXPERTS AND AUTHORITIES

In the contemporary world we are increasingly dependent on experts. As Jasanoff (1997) comments, "Without authoritative, expert institutions, we could not be reasonably sure that the air is safe to breathe, that aeroplanes will take off and land safely, that new medical treatments will not unexpectedly kill patients… that the food we buy is safe to eat. Lives lacking such assurance would be impossibly difficult to cope with, both pragmatically and psychologically" (p. 223). When dealing with socioscientific issues and appraising new technologies, individuals will only rarely have access to all the relevant data. In consequence, we depend on others to inform us and advise us. For example, we are increasingly dependent on scientists, the inquiries they conduct, and the agencies that report their studies, to tell us about the safety hazards associated with various products and procedures, the toxic effects of pesticides, pharmaceuticals and other materials we encounter in everyday life, the risks associated with post-menopausal HRT, the optimal frequency of mammograms, the threats to our health posed by the proximity of toxic waste dumps, nuclear power plants and overhead power lines, and the large-scale compromising of environmental health through loss of biodiversity, increasing desertification, pollution and global warming. However, it is highly undesirable to cede all deliberation and *all* policy decisions to a particular small group of experts. We need to know when to accept and when to question, when to trust and when to distrust. It is crucial, therefore, that each of us understands how reliable and valid data are collected and interpreted, and that each of us recognizes the tentative character of scientific knowledge. Hence the emphasis given to NOS understanding in earlier discussion. It is crucial, too, that we understand the ways in which all manner of human interests can and do shape scientific inquiry and its interpretation and reporting. Without this insight, we have no alternative but to take reports that blame or exonerate at face value, and to accept all claims to scientific knowledge as ‘proven’.

Fourez (1997) argues that knowing when scientists and other ‘experts’ can be trusted and when their motives and/or methods should be called into question is a key element of scientific literacy. His point is that while there is often a need to access and utilize expert opinion, we do not need to do so uncritically. We can evaluate the quality of data and argument for ourselves, we can look at the extent of agreement among experts and the focus of any disagreements, and we can look at the ‘track record’ of all those who profess expertise. Walton (1997) provides a list of questions we should ask when addressing an expert’s claim(s). Is the utterance within the scientist’s field of expertise? Is the cited expert really an expert (as distinct from someone with a well-publicized but unsubstantiated opinion that is quoted because of popularity or celebrity status)? How authoritative is the expert? Is the expert recognized by colleagues as a leader in the field? Is the expert recognized as honest and reliable? If there is disagreement among scientists, are alternative views acknowledged and addressed Is supporting evidence available and the utterance in accordance with this evidence? Is the expert’s utterance clear and intelligible, and correctly interpreted? In similar vein, Norris (1995) makes the point that “nonscientists’ belief or disbelief in scientific propositions is not based on direct evidence for or against those propositions but, rather, on reasons for believing or disbelieving the scientists who assert them” (p. 206). Ungar (2000) wryly observes that with increasing research specialization, the domain covered by any claimed expertise is continuously shrinking, creating a “knowledge-ignorance paradox” in which the growth of specialized knowledge results in a simultaneous increase in ignorance of related fields, requiring us to consult an ever-expanding range of experts.

Clearly, the independent justification of most of our beliefs is just not possible. Even those at the cutting edge of research must take on trust much of the knowledge they deploy, including the knowledge underpinning the design and utilization of the complex modern instrumental techniques on which so much contemporary research depends. To deal with this situation, Hardwig (1991) proposes the *principle of testimony*: “If A has good reasons to believe that B has good reasons to believe p, then A has good reasons to believe p” (p. 697). In essence, he argues that A’s good reasons depend on whether B can be regarded as truthful, competent and conscientious. In short, it isn't possible to draw a sharp distinction between evaluation of the research and evaluation of the trustworthiness of the researcher. This principle of testimony also applies to the relationship between laypersons and 'experts'. Generally, neither members of the public nor journalists and documentary makers have access to original empirical data, or to details of research methods, and so must decide the extent to which they can trust particular researchers and research groups to be honest in their reporting. Code (1987) notes that "one of the most important and difficult steps in learning who can be trusted is realizing that authority cannot create truth" (p. 248). Balance is the key: not blind acceptance of the views espoused by those who are seen, or see themselves, as experts; not cynicism and distrust of all experts. Guy Claxton (1997) captures the essence of this position particularly well: "[students] need to be able to see through the claims of Science to truth, universality, and trustworthiness, while at the same time not jumping out of the frying-pan of awe and gullibility, in the face of Science's smugness and superiority, into the fire of an equally dangerous and simplistic cynicism, or into the arms of the pseudo-certainties of the New Age" (p. 84, capitals in original). Balance is encapsulated in the notion of intellectual independence. As Munby (1980) notes: "One can be said to be intellectually independent when one has all the resources necessary for judging the truth of a knowledge claim independently of other people" (p. 15). Ratcliffe and Grace (2003) cite a study published by the Office of Science and Technology and the Wellcome Trust, in 2000, indicating that people tend to trust sources seen as neutral and independent, such as university scientists, scientists working for research charities or health campaigning groups, and presenters of television news broadcasts and documentaries. The least trusted sources are politicians and newspapers. Sources seen as having a vested interest, such as environmental activist groups, well-known scientists and the popular scientific press, rank somewhere in between in terms of trustworthiness. In Elliott's (2006) study, students were particularly skeptical about the relationship between science, the media and government. Often, there is an 'asymmetry of trust': episodes that weaken or threaten trust in science tend to receive greater exposure in the media and live longer in the public memory than episodes that seek to build or consolidate confidence in science and scientists. Chapter 6 includes details of some research findings relating to the trust that students and teachers place in published material relating to SSI, and their reasons for doing so. Chapter 6 also engages in discussion of how students' levels of critique and discernment can be enhanced.

Given the increasing calls for public consultation on matters such as funding priorities for scientific research and the acceptability of developments in genetic engineering (including calls such as those made in this book), it is pertinent to ask about the confidence and trust that scientists, politicians and business leaders have in the lay public to undertake these monitoring tasks responsibly and effectively. The scientists interviewed by Michael and Brown (2005) about issues relating to xenotransplantation tended to regard the public as insufficiently prepared, especially on technical matters, unsystematic and likely to conflate issues that they believe should be kept separate, fickle, unpredictable, and likely to be swayed by strong rhetoric. Moreover, they said that the tendency to generalize from one or two unfortunate examples has resulted in the increasingly distrustful public noted in earlier in this chapter. Bucchi and Neresini (2008) argue that experts themselves may reinforce the perception of the public as “ignorant”. They report on a Canadian study of communications between doctors and their patients that used questionnaires to assess patients’ medical knowledge and doctors’ estimates of patients’ knowledge. While 75.8% of patients were seen to be “well-informed”, in the sense of providing correct answers to questionnaire items, less than 50% of doctors were able to estimate their patients’ knowledge accurately. Moreover and alarmingly, the authors report, even when doctors realized that patients didn’t understand they failed to adjust their style of communication. By making no attempt to communicate effectively, they compounded their patients’ ignorance.

Of particular relevance here is Michel Callon’s (1999) 3-fold characterization of laypersons’ involvement with scientists in the management of SSI. In the *deficit model*, it is assumed that only scientists are able to grasp the full complexity of the science and citizens have to be properly informed or “brought up to speed”[8]; in the *public debate model*, citizens’ knowledge is recognized as different from scientists’ knowledge but valuable for enriching and contextualizing the issues and problems; in *the co-production of knowledge model*, citizens are regarded as having a key role in defining the issues/problems, identifying both the kind of knowledge to be accessed and the particular scientists and engineers consulted, and producing and disseminating the report, conclusions and policy decisions. These three models of citizen involvement will be revisited in chapters 4 and 9.

CRITICAL SCIENTIFIC LITERACY

As noted in earlier discussion and will become more apparent in chapters 3 and 5, I share the views of Tate (2001) and Calabrese Barton (2002) that the science curriculum should be concerned with civil rights and civil responsibilities, and should be framed around ideas of equity and social justice. I also share the views expressed by Lee and Roth (2002) that science education should not be seen as a preparation for a future life but as an active participation in the community here and now. To fulfill this role, students need to be able to judge the validity of a knowledge claim independently of other people, tell the difference between good science and bad science, and between science and non-science, and recognize misuse of science, biased or fraudulent science and unwarranted claims whenever and wherever they encounter them. It is for these reasons that I choose to adopt the term *critical scientific, technological and environmental literacy*, though for convenience and economy of space I will shorten it to critical scientific literacy. Its repeated use throughout this book carries the message that the most important function of scientific literacy is to confer a measure of intellectual independence and personal autonomy: first, an independence from authority; second, a disposition to test the plausibility and applicability of principles and ideas for oneself, whether by experience or by a critical evaluation of the testimony of others; third, an inclination to look beyond the superficial and to address the ideological underpinnings of science and technology, the economic and political structures that sustain them, and the norms and practices that accommodate some views and some participants but marginalize or exclude others; fourth, sensitivity to the complex interactions of class, race, gender, language, knowledge and power; fifth, an ability to form intentions and choose a course of action in accordance with a scale of values that is self-formulated; sixth, a commitment to criticism and constant re-evaluation of one's own knowledge, beliefs, attitudes and values. In other words, the fundamental purpose of critical scientific literacy is to help people think for themselves and reach their own conclusions about a range of issues that have a scientific, technological and/or environmental dimension. Use of "critical" as a qualifier for the term scientific literacy also carries with it a commitment to a much more rigorous, analytical, logical, thorough, open-minded, skeptical and reflective approach to school science education than is usual. It signals my advocacy of a much more politicized and issues-based science education, a central goal of which is to equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern (Hodson, 1999, 2003). This position aligns very closely with that advocated by McLaren and Lankshear (1993): "Critical literacy, as we are using the term, becomes the interpretation of the social present for the purpose of transforming the cultural life of certain groups, for questioning tacit assumptions and unarticulated presuppositions of current cultural and social formations and the subjectivities and capacities for agenthood that they foster. It aims at understanding the ongoing social struggles over the signs of culture and over the definition of social reality – over what is considered legitimate and preferred meaning at any given historical moment" (p. 413).

Hurd (1998) sums up part of this *critical* dimension of scientific literacy, and its roots in learning *about* science, when he defines a scientifically literate person as someone who "distinguishes experts from the uninformed, theory from dogma, data from myth and folklore, science from pseudo-science, evidence from propaganda, facts from fiction, sense from nonsense, and knowledge from opinion… Recognizes the cumulative, tentative, and skeptical nature of science, the limitations of scientific inquiry and causal explanations, the need for sufficient evidence and established knowledge to support or reject claims, the environmental, social, political and economic impact of science and technology, and the influence society has on science and technology" (p. 24). What Hurd doesn't emphasize to any significant extent is that this kind of understanding needs to be developed in such a way that students can see the sociopolitical embeddedness of science and technology. If science continues to be presented as an exercise in abstract puzzle solving, devoid of social, political, economic and cultural influences and consequences, citizens will continue to see contemporary SSI as predominantly technical problems, for which experts can be relied upon to provide the solutions. What we should be seeking instead is political engagement of citizens in monitoring and, to an extent, directing the course of scientific and technological development. It is both timely and encouraging, then, that the so-called Crick Report, *Education for Citizenship and the Teaching of Democracy in Schools*, has prompted the establishment of citizenship education comprising three strands – social and moral responsibility, community involvement, political literacy - as a mandatory part of the curriculum of all subjects in England and Wales. The declared aim of this initiative is:

> … a change in the political culture of this country both nationally and locally: for people to think of themselves as active citizens, willing, able and

> equipped to have an influence in public life and with the critical capacities to weigh evidence before speaking and acting; to build on and to extend radically to young people the best in existing traditions of community involvement and public service, and to make them individually confident in finding new forms of involvement and action. (Qualifications & Curriculum Authority, 1998, p. 8)

The focus of this book is the kind of science education that is necessary for active and responsible citizenship, a form of science education that can equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern. In other words, the principal concern of this book is civic scientific literacy, as defined by Shen (1975) and Wellington (2001), and now re-defined as *critical* scientific literacy. While I recognize that civic, cultural and practical scientific literacy overlap, and that all three are important focuses for the school science curriculum, I believe that civic scientific literacy does warrant some measure of priority. In similar vein, the authors of *Beyond 2000: Science Education for the Future* (Millar & Osborne, 1998) state that science education between the ages of 5 and 16 (the years of compulsory schooling in the UK) should comprise a course to enhance general scientific literacy, with more specialized science education delayed to later years: "the structure of the science curriculum needs to differentiate more explicitly between those elements designed to enhance 'scientific literacy', and those designed as the early stages of a specialist training in science, so that the requirement for the latter does not come to distort the former" (p. 10)[9]. Similar sentiments are expressed by Smith and Gunstone (2009).

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 different interpretations, curriculum emphases and pedagogical approaches, and much has changed over the years in terms of its priorities and relative emphases (Fensham, 1988; Cheek, 1992; Bybee, 1993; Layton, 1993; Solomon, 1993; Yager & Tamir, 1993; Zoller, 1993; Bybee & DeBoer, 1994; Solomon & Aikenhead, 1994; Yager & Lutz, 1995; Yager, 1996; Kumar & Berlin, 1998; Kumar, 2000; Kumar & Chubin, 2000; Gaskell, 2001; Aikenhead, 2003; Pedretti, 2003; Solomon, 2003; Barrett & Pedretti, 2006; Tal & Kedmi, 2006; Nashon et al., 2008; Turner, 2008; Lee, 2010). Aikenhead (2005, 2006) describes how the early emphasis on values and social responsibility was systematized by utilizing a theoretical framework deriving from the sociology of science: (i) the interactions of science and scientists with social dimensions, issues and institutions *external* to the community of scientists, and (ii) the social interactions of scientists *within* the scientific community. Driver et al. (1996) refer to these two elements as "science *in* society" and "science *as* society" (p. 12). Both emphases have remained strong, though much has changed with respect to the sociopolitical and economic contexts in which educators and scientists work and in our understanding of key issues in the history, philosophy and sociology of science. Much has changed, too, in our theoretical knowledge concerning the ways in which students learn science and learn *about* science. 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).

Ratcliffe and Grace (2003) have identified a number of key features of socioscientific issues. They have a basis in science, frequently at the frontiers of scientific knowledge, where data and evidence may be incomplete, conflicting or confusing; they involve the formation of opinions and making of choices at a personal and societal level; they address local, national and/or global issues, with attendant political and societal implications; they involve some cost-benefit analysis in which probability and risk interact with values; and they often feature prominently in the media. Zeidler et al. (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)[10]. 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). In consequence, they say, STS education has become marginalized. Similar arguments can be found in Zeidler and Sadler (2008a,b) and Zeidler et al. (2009). Authors of pioneering initiatives such as *Science and Society* and *Science in a Social Context* (SISCON) in the UK, *PLON* in the Netherlands, and *Science: A Way of Knowing* in Saskatchewan (Canada), might be very surprised to read that their courses (even back then) did not include such matters, and many others currently teaching and researching in STSE education may be surprised to hear that they have been "marginalized". In an interesting reversal of these propositions, Hughes (2000) argues that STS has marginalized SSI, and simultaneously reinforced gender inequity by promoting a masculinist 'hard science' view to the exclusion of the 'softer' socioscience orientations (her words, not mine) that allow for contextualized examination of issues and values implicit in scientific development.

> When socioscience is the icing on the cake, not an essential basic ingredient, part of a good-quality product but not fundamental to teaching science, dominant discourses of science as an abstract body of knowledge are not destabilized and implicit gender hierarchical binaries are readily reinforced. (p. 347).

As Bingle and Gaskell (1994) note, STS education tends to emphasize what 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). Interestingly, 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 et al. (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). It is also important to consider the myriad ways in which the concerns and priorities of the SSI-oriented approach overlap with those of many other movements and initiatives – principally, science education for citizenship, science education for public understanding, public awareness or public participation, education for sustainability, multicultural and antiracist science education, global education and peace studies.

It is not my intention to become embroiled in a 'turf war' or to engage in evaluation of claims by rival camps that ought to be 'fighting the same battle'. My view is that neither STSE nor SSI-oriented teaching go far enough. For my taste, both are too conservative. My inclination is towards a much more radical, politicized form of SSI-oriented teaching and learning in which students not only address complex and often controversial SSI, and formulate their own position concerning them, but also prepare for, and engage in, sociopolitical actions that they believe will 'make a difference'. Of course, adoption of this curriculum stance raises some important pedagogical issues, which will be addressed in chapters 2 and 6.