Looking to the Future
Building a Curriculum for Social Activism
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In advocating an action-oriented and issues-based curriculum, this book takes the position that a major, but shamefully neglected, goal of science and technology education is to equip students with the knowledge, skills, attitudes and values to confront the complex and often ill-defined socioscientific issues they encounter in daily life as citizens in an increasingly technology-dominated world carefully, critically, confidently and responsibly. In outlining proposals for addressing socioscientific issues through a curriculum organized in terms of four increasingly sophisticated levels of consideration, the author adopts a highly critical and politicized stance towards the norms and values that underpin both scientific and technological development and contemporary scientific, engineering and medical practice, criticizes mainstream STS and STSE education for adopting a superficial, politically naïve and, hence, educationally ineffective approach to consideration of socioscientific issues, takes the view that environmental problems are social problems occasioned by the values that underpin the ways in which we choose to live, and urges teachers to encourage students to reach their own views through debate and argument about where they stand on major socioscientific issues, including the moral-ethical issues they often raise. More controversially, the author argues that if students are to become responsible and politically active citizens, the curriculum needs to provide opportunities for them to experience and learn from sociopolitical action. The relative merits of direct and indirect action are addressed, notions of learning about action, learning through action and learning from action are developed, and a case is made for compiling a user-friendly database reflecting on both successful and less successful action-oriented curriculum initiatives. Finally, the book considers some of the important teacher education issues raised by this radically new approach to teaching and learning science and technology. The book is intended primarily for teachers and student teachers of science, technology and environmental education, graduate students and researchers in education, teacher educators, curriculum developers and those responsible for educational policy.

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To Susie – You’re at the heart of everything that matters
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PREFACE

In a number of publications (Hodson, 1992a, 1994, 1998a), I have argued that science education is best regarded as comprising three major elements: learning science – acquiring and developing conceptual and theoretical knowledge; learning about science – developing an understanding of the nature and methods of science, appreciation of its history and development, awareness of the complex interactions among science, technology, society and environment, and sensitivity to the personal, social and ethical implications of particular technologies; and doing science – engaging in and developing expertise in scientific inquiry and problem-solving, and developing confidence in tackling a wide range of “real world” tasks and problems. More recently, I have added a fourth component, engaging in sociopolitical action – acquiring (through guided participation) the capacity and commitment to take appropriate, responsible and effective action on science/technology-related matters of social, economic, environmental and moral-ethical concern (Hodson, 2003). This book is largely located in this fourth category of science education.

This book is the third in a series. In the first book, Towards Scientific Literacy: A Teachers’ Guide to the History, Philosophy and Sociology of Science (Hodson, 2008), I presented a critical reading of the vast and complex literature encompassing the history of science, philosophy of science and sociology of science (HPS). The prime purpose of that book was to identify some key ideas in HPS for inclusion in the school science curriculum, in line with the prominence given to HPS in recent international debate in science education and the numerous influential reports on science education that identify the centrality of HPS to scientific literacy. Discussion focused on those elements of the history, philosophy and sociology of science that would enable all students to leave school with robust knowledge about the nature of scientific inquiry and theory building, an understanding of the role and status of scientific knowledge, an ability to understand and use the language of science appropriately and effectively, the capacity to analyze, synthesize and evaluate knowledge claims, some insight into the sociocultural, economic and political factors that impact the priorities and conduct of science, and a developing capacity to deal with the moral-ethical issues that attend some scientific and technological developments. The second book in the series, Teaching and Learning about Science: Language, Theories, Methods, History, Traditions and Values (Hodson, 2009a), discussed ways in which that particular selection of HPS ideas can be assembled into a robust and coherent curriculum, and presented to students in ways that are meaningful, motivating and successful. The overarching goal is taken to be the attainment of critical scientific literacy, that is, an understanding of some of the major concepts, ideas and theories of science, an awareness of their history and development, and ability to use them appropriately and effectively, together with the capacity to think critically about the nature of any new scientific knowledge presented by teachers or encountered in textbooks, scientific journals, popular magazines, newspapers, television programmes and Internet websites – in particular, how that
knowledge was generated and validated, the evidence that supports it (and opposes it) and the arguments used to sustain it. Such understanding includes layers of refinement relating to the role and status of scientific knowledge, the degree to which scientific knowledge is socially constructed, and its function as both a complex of explanatory systems and a constellation of instrumental devices for prediction and control. Critical scientific literacy also includes an awareness of the institutional characteristics of the community of scientists, including its forms of patronage and control, and some appreciation of the complex interactions of science, technology, society and environment. It includes a comprehensive understanding of scientific language and its deployment, an understanding of the nature of scientific argumentation, and the capacity to read, interpret and evaluate scientific text in whatever form it is encountered. It entails being able to deploy some robust criteria of demarcation in order to distinguish between good science and bad science, detect error, bias and fraud, and recognize pseudoscience and non-science masquerading as science.

One of the major rationales for promoting critical scientific literacy, and for learning about science, scientists, scientific inquiry and scientific argumentation, is the need to furnish students with the knowledge, skills and attitudes to address socioscientific and environmental issues in a critical way and to reach informed decisions on a range of science-related and technology-related issues that impact them, their immediate family and friends, the surrounding local, national and global community, and the planet as a whole. In other words, scientific literacy plays a key role in building informed and responsible citizenship and contributing to environmentally responsible behaviour. Just as the most effective way of learning to do science is by doing science, so one of the best ways of learning to address socioscientific issues is by addressing socioscientific issues (SSI). Put simply, addressing SSI is an essential component of any curriculum aiming to teach students about science and promote critical scientific literacy. It would be difficult to contemplate (and perhaps more difficult to justify) a course on “The Bicycle” that describes the basic structure of the bicycle and the function of each of its components, provides a history of the bicycle and the sociocultural circumstances of its invention (asking questions such as “Why didn’t the Romans invent the bicycle?”), examines the aesthetics of bicycle design and the economics of bicycle manufacture (including the move to Third World manufacture), compares and contrasts bicycle use in various countries for leisure, racing and basic transportation, engages students in case studies such as the Tour de France, the brief life of autocycles and drug use in Olympic cycling, shows movies about cycling, and so on, but doesn’t actually involve students in riding a bicycle. By analogy, we cannot expect students to acquire the necessary knowledge, skills, attitudes and other attributes to examine SSI in later life simply as a by-product of studying HPS issues. We have to provide abundant opportunities in the curriculum to use that knowledge for real problem solving activities in the context of SSI, and we have to provide students with explicit advice and appropriate support in doing so. Traditional science teaching emphasizes the logical progression of particular scientific advances and the overall coherence of scientific knowledge; the controversial nature of science is omitted, except for
reference to one or two famous historical examples. In contrast, the use of SSI emphasizes the problematic, conjectural, interpretive and controversial aspects of science and scientific investigation, and puts pedagogical emphasis firmly on debate, critique and argumentation. As Bell and Lin (2000) and Mason and Boscolo (2002) argue, addressing controversies not only engages students’ NOS understanding and capacity for argumentation but also contributes to their development. Also by teaching through debate and argumentation, students improve their language skills, refine their understanding of the nature and role of debate in science, and are introduced to the disciplines that comprise public discourse about SSI – principally, politics, law, economics and ethics. Regrettably, constraints on space precluded a discussion in the second book of how critical consideration of SSI can be built into the science curriculum. Issues pertinent to building such a curriculum, and its associated politicization of students and teachers, is the focus of this book.

Widely known as the Crick report, Education for Citizenship and the Teaching of Democracy in Schools (QCA, 1998) stated that “We aim at no less than 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” (p. 7). The curriculum advocated in this book reflects a desire to contribute to this goal through science education by: (i) identifying and investigating a series of SSI (many of them to be chosen by the students); (ii) taking account of the beliefs, attitudes, interests and values of the various stakeholders; (iii) evaluating alternative viewpoints with respect to scientific, social, political, cultural, economic, aesthetic, moral-ethical, emotional and historical considerations; (iv) reaching a justifiable position on the issue and formulating a persuasive argument for it; (v) searching for solutions to any problems that arise; (vi) choosing an appropriate and justifiable course of action; (vii) taking action; and (viii) evaluating its consequences. In my view, STS or STSE education has afforded too low a priority to the promotion of critical thinking, and has largely ignored sociopolitical activism. The curriculum advocated in this book seeks to extend the somewhat limited goals of contemporary STS and STSE practice. It is an attempt to foster the understanding, knowledge, skills, attitudes, values and commitments that lead to socially and environmentally responsible civic engagement. It is an attempt to educate and motivate a generation of citizens to build a better world.

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Because my teaching career extends over forty years, and includes spells in UK, Canada, New Zealand and Hong Kong, it is difficult, if not impossible, to identify by name all those who have influenced me and shaped my thoughts and practice as a teacher, researcher and writer. Nevertheless, I do want to acknowledge one or two pivotal influences.

As an undergraduate at the University of Manchester Institute of Science and Technology I had the great good fortune to attend a series of lectures by David Theobald, author of *An Introduction to the Philosophy of Science* (Methuen, 1968). I thank David for triggering my longstanding interest in philosophy of science. My postgraduate years at UMIST and my developing understanding of chemistry were ably and sensitively fostered by Geoff Holt, who later became my PhD supervisor. Above all, Geoff gave me the confidence to admit my ignorance and to take intellectual risks. My early years as a teacher were immeasurably enriched by interactions with the students at Sevenoaks School (Kent). They taught me far more than I taught them. I also learned a great deal about teaching science from two teachers of English at the school: Alan Hurd and Richard Hanson. Teaching at Rannoch School (an independent school in North Perthshire based on the educational philosophy of Kurt Hahn), Welshpool High School (an 11–18 comprehensive school in mid-Wales) and Yale College (a sixth form college in Wrexham) enabled me to test and refine these ideas in three very different educational contexts. Throughout the succeeding years spent in teacher education and educational research my thinking has been sharpened and my views extended and further refined through discussions with colleagues and graduate students, particularly at the Ontario Institute for Studies in Education, the University of Hong Kong and the University of Auckland. I hereby acknowledge my indebtedness to all those people, too numerous to mention by name.

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If we teach today as we taught yesterday, we rob our children of tomorrow

John Dewey

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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. 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 advertising 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)

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)

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)

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
evanescence 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 school³. 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.
CHAPTER 1

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).

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 advertising, 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.


– 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,
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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, advertising, 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,
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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)). 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 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.
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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. 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. 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 ecosystem, 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’.

Foureze (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
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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”; 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). 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
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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). 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.
CHAPTER 2

CONFRONTING SOCIOSCIENTIFIC ISSUES

It seems almost self-evident that the most effective way of learning to confront SSI is by confronting SSI, provided there are appropriate levels of guidance and support. What I have in mind is a 3-phase approach involving modelling (the teacher demonstrates and explains the desired or appropriate approach), guided practice (students perform specified tasks with help and support from the teacher) and application (students perform independently of the teacher). Teacher modelling (phase 1) is predicated on the assumption that careful observation of someone skilled in the approach will facilitate the learning of successful strategies for addressing SSI. In the second phase (guided practice), students work through a carefully sequenced programme of investigative exercises, during which the teacher’s role is to act as learning resource, facilitator, consultant and critic. The assumption is that students will become more expert in addressing SSI as a consequence of practice and experience, through evaluative feedback provided by the teacher and generated in inter-group criticism and discussion, and through intra-group reflection on the activity, both as it progresses and on completion. This is the stage during which teacher and students are co-investigators, with both parties asking questions, contributing ideas, making criticisms and lending support. This means that teachers are learning, too! To be intellectually independent, however, students must eventually be able to manage without teacher assistance and take responsibility for planning, conducting and reporting their own inquiries (the application stage). In other words, learning as assisted performance must enable students, in time, to use their knowledge to address new issues, build new understanding and make decisions on where they stand in relation to an issue.

It also seems self-evident that if students are to get to grips with SSI at any level beyond the merely superficial they need relevant scientific knowledge. Common sense would seem to indicate that content knowledge is crucial, and that those who know more about the topic/issue under consideration will be better positioned to understand the underlying issues, evaluate different positions, reach their own conclusions, make an informed decision on where they stand in relation to the issue, and argue their point of view. It is unsurprising, therefore, that consumers’ ability to make sense of advertising claims for cosmetics and so-called “functional foods” (e.g., those touted as useful for lowering cholesterol or “balancing your stomach’s good and bad bacteria”), and to reject those making spurious claims, is closely linked to their level of education in science (Dodds, et al., 2008). Similarly, Keselman et al. (2004) found that the capacity of Grade 7 and Grade 9 students to reason about information concerning HIV-AIDS, accessed via a simulated Website, and to deal with myths about HIV-AIDS11, bore a direct relation to the
nature and extent of their knowledge of biology, particularly the characteristics of viruses, mechanisms of infection, and the nature of the immune system. In a subsequent study, Keselman et al. (2007) found that structured writing activities involving a measure of role play had substantial positive impact on students’ acquisition of scientific knowledge relevant to consideration of the myths, and on their capacity to use it appropriately. Earlier, Wynne et al. (2001) had shown how a group of high school students were able to use their knowledge of meiosis, often in “very sophisticated ways”, to address some complex issues in genetics, and Lewis and Leach (2006) had found that the quality of discussion of issues relating to genetic engineering is substantially enhanced by basic understanding of genetics. The latter authors note that the necessary level of understanding is “relatively modest” and fairly easily achieved. Similarly, Sadler and Zeidler (2005) note that students with deeper understanding of genetics made fewer errors of reasoning and made more frequent and explicit reference to content knowledge in their reasoning about gene therapy and cloning than students with more naïve understanding. A study by Sadler and Donnelly (2006), also in the context of gene therapy and cloning, concludes that a minimum level of basic biological knowledge is essential if students are to understand the nature of the problem and what might constitute appropriate evidence on which to base their decision-making. Beyond that, the authors say, there is little evidence that background knowledge in genetics impacts significantly on ability to build arguments and establish points of view. What may be much more important is context knowledge – in this case, specific knowledge of gene therapy and cloning. In a closely related study, Sadler and Fowler (2006) show that College-level science majors with advanced biological knowledge (that may have included knowledge of genetic technologies) significantly outperformed both non-science majors and high school students in the sense of making repeated, explicit and appropriate reference to scientific knowledge in construction and criticism of arguments. In other words, when students’ science content knowledge is extensive in depth, breadth and organization it does make a difference to their ability to deploy it effectively in unfamiliar contexts (Ryder, 2001). Yang’s (2004) study of Taiwanese Grade 10 students indicates that male students are more likely than female students to have background knowledge relevant to SSI contexts, and to have more confidence in their ability to deploy it in social contexts. Interestingly, they are also more likely to be naively trusting of experts. Studies by Patronis et al. (1999), Hogan (2002a), Dawson and Schibeci (2003), Sadler (2004), Sadler and Zeidler (2004), Zeidler et al. (2002, 2005) and Dawson (2007) provide further confirmation of the importance of science content knowledge.

Sometimes specialized knowledge well beyond science is needed. For example, in order to address the “septic tank crisis” in their school (see discussion in chapter 9), students in Pedretti’s (1997) study needed to know about the water cycle, of course, but also about septic tank systems, waste management practices, filtration methods, environmental hazards and local government regulations. In Hogan’s (2002) study of Grade 8 students addressing water management issues concerning the impact of invasive zebra mussels on the Hudson River ecology, students had difficulty in adapting their scientific knowledge and understanding to a real world and changing context. They were intent on looking for simple, rather than multiple
cause and effect relationships and seemed unable to take the long-term perspective demanded by systems thinking. As will be discussed in chapter 8, the shift to systems thinking is key to the critical scientific literacy necessary for addressing environmental issues. Also of relevance here is the study of problem-solving strategies employed by 14–17 year-old students conducted by Reid and Yang (2002). The authors concluded that knowledge seems to exist in long term memory as relatively independent “islands”. Students have great difficulty in linking these islands of knowledge; they have problems in accessing usable knowledge when the problem situation is novel to them (i.e., they have problems in applying knowledge); they frequently make inappropriate or unhelpful links. Common sense suggests that students will become more expert in accessing and deploying their knowledge through teacher guidance, support and criticism, further experience, and critical reflection.

A key question concerns the manner in which relevant scientific knowledge should be acquired. Should it be through prior instruction or on a ‘need to know’ basis when dealing with a particular issue? As is so often the case in education, there is no universal answer; different situations demand different approaches and different SSI create widely different knowledge needs. Clearly, the notions of cultural scientific literacy and practical scientific literacy require that a substantial amount of scientific content is taught, but this book is not concerned with the selection of that science content, nor with discussion of how to bring about an appropriate level of understanding of the important ideas, principles, models and theories of science. My only comment on the matter at this stage is that I wish to endorse my previous promotion of a personalized approach to learning (Hodson, 1998a), that is, attending to the particular needs, interests, experiences, aspirations and values of every learner, and to the affective and social dimensions of learning environments. The key to successful learning of science content (or anything else, for that matter) lies in the creation of a supportive and emotionally safe learning environment for all students. The notion of scaffolding is particularly helpful (Wood et al., 1976; Collins et al., 1989; Stone, 1993, 1998; Hogan & Pressley, 1997). Scaffolding involves the teacher (or a knowledgeable ‘other’) adjusting the complexity of the learning task so that the learner is able to solve a problem, perform a task or achieve a goal that would be beyond their unassisted efforts. Scaffolding should not alter the overall structure of the learning task. Rather, it should adjust the precise nature of the learner’s participation as the teacher assumes responsibility for those aspects of the task that require knowledge or skills that the learner doesn’t yet possess. In a scaffolded task, teacher assistance is only considered productive if the learner has fully comprehended the purpose and structure of the task, understands why the particular strategies were employed, and appreciates how the conclusions have been reached. Only in these circumstances will assistance be educative, criticism productive and feedback effective. These matters are discussed at greater length in Hodson and Hodson (1998a,b). One further point is worth making: as the literature on problem-based learning makes abundantly clear, content learning is often more secure, more robust and ‘longer lasting’ when it is embedded in open-ended problem situations. By grounding content in socially and personally relevant contexts, an SSI-oriented approach
provides the motivation that is absent from current abstract, de-contextualized approaches and forms a base from which students can construct understanding that is personally relevant, meaningful and important. It also provides increased opportunities for active learning, inquiry-based learning, collaborative learning and direct experience of the situatedness and multidimensionality of scientific and technological practice.

As an aside, it is both interesting and important to note that Aikenhead (2005, 2006) identifies seven categories of scientific knowledge: wish-they-knew science is the high status academic knowledge needed for successful university study and a future career as a scientist; functional science is the science needed by those who use science-related and technology-related knowledge in their day-to-day work (such knowledge is often learned on-the-job); need-to-know science is that used by the lay public in confronting real life SSI (described by Layton et al. (1993) as “practical knowledge for action” – see later in this chapter); have-cause-to-know science is knowledge designated by experts as necessary for dealing with real life matters (it often contrasts sharply with knowledge in the previous category, as discussion later in the chapter makes clear); enticed-to-know science is knowledge that attracts attention through its prominence in the media, including the Internet (it often focuses on issues of risk and moral-ethical dilemmas); personal-curiosity science is knowledge identified by individuals as important for all manner of personal or idiosyncratic reasons; science-as-culture is the knowledge needed for active and effective participation in particular sub-cultural or community groups and/ or effective communication with those employed in those groups (including, for example, the public health system, local council planning services and environmental activist groups). The notion of critical scientific literacy developed in the previous chapter encompasses knowledge embedded in several of Aikenhead’s seven categories.

NATURE OF SCIENCE

It is clear that no science curriculum can equip citizens with thorough first-hand knowledge of all the science underlying every important issue. Indeed, much of the scientific knowledge students need to know in order to make important decisions on the many important SSI they will encounter during their lifetimes has yet to be discovered. However, we do know what knowledge, skills and attitudes are essential for appraising scientific reports, evaluating scientific arguments and moving towards a personal opinion about the science and technology dimensions of real world issues. It includes understanding of the status of scientific knowledge, the ways in which it is generated, communicated and scrutinized by the community of scientists, and the extent to which it can be relied upon to inform critical decisions about SSI. As the authors of the American National Science Education Standards document comment: “A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it” (National Research Council, 1996, p. 22). In other words, students need to have a clear understanding of what counts as good science, that is, a well-designed inquiry and a well-argued conclusion. They need to be able to interpret reports, make sense of disagreements, evaluate knowledge claims, scrutinize arguments, distinguish among facts, arguments
and opinions, make judgements about good science, bad science and non-science, detect error, bias and vested interest, and so on. Clearly, students’ NOS knowledge and views will impact on the way they address SSI, but not always in a simple, straightforward and predictable way (Ryder, 2001; Zeidler et al., 2002). There is a complex, reflexive interaction: more sophisticated NOS views open up new possibilities for scrutinizing SSI; engagement with important and personally significant SSI enhances and refines NOS understanding.

The traditional school curriculum emphasis on what we know rather than how we know too often leaves students only able to justify their beliefs by reference to the authority of the teacher or textbook. As Östman (1998) points out, the constant focus on a “correct explanations” approach encourages and reinforces the “companion meaning” that the products of the scientific enterprise are “something that everyone will agree upon, if they just use their senses to smell, taste, listen to, and look at nature” (p. 57). In other words, science is seen as a simple and straightforward route to the truth about the universe; scientific knowledge is seen as authoritative; students are steered towards conformity with received “official” views rather than towards intellectual independence. As a consequence, they do not attempt to justify their beliefs in terms of careful consideration of the evidence and arguments. Instead, they simply assert their beliefs, and possibly cite the teacher, textbook or Internet site as an authority. They do not recognize that differences of opinion result from adoption of different theoretical perspectives and different interpretations of data. Rather, as Smith et al. (2000) note, “they assume that these differences stem from inadequate knowledge, deception, or deceit, and will ultimately be resolved when all the facts are known or when one looks at the facts in an unbiased manner” (p. 352). Driver et al. (1996) and Larochelle and Désautels (2001) also remark on the widespread tendency for students to believe that disagreement between scientists is a consequence of insufficient data, and that disputes will be resolved satisfactorily when additional data are accumulated. Although the openness of science to criticism is seen by scientists and philosophers of science as one of its major strengths, it is seen by some members of the public, and by many students, as a sign that all is not well. As Ziman (2000) comments: “Nobody expects a group of lawyers, politicians, theologians or doctors to have identical expert views. But any outward sign of disagreement amongst scientists is taken as a grave weakness” (p. 254). In Bader’s (2003) study, students urged scientists who disagreed (in this case, on climate change) to “work together” and conduct their research “at the same place”, while Frewer et al. (2003) observe that many scientists have become reluctant to make any public statements on uncertainty in science on the grounds that it might further undermine the credibility of science and scientists.

The key point is that every citizen needs sufficient understanding about the relevant science (if not understanding of the science) in order to play a part in public debate about SSI. Every citizen needs to develop what Lorraine Code (1987) calls “a policy of circumspection” and what McPeck (1981) calls “reflective skepticism” – that is, the disposition to question and to seek the opinions of others on the science that underpins the issues they confront in everyday life. Duschl et al. (2007) express very similar views: “Students need to develop a shared understanding of the norms of participation in science. This includes social norms for constructing
and presenting argument and engaging in scientific debates. It also includes habits of mind, such as adopting a critical stance, willingness to ask questions and seek help, and developing a sense of appropriate trust and skepticism” (p. 40). Citizens who do not understand how scientific research is done, and how scientific research is scrutinized for validity and reliability, have little option but to accept the pronouncements and recommendations of those they perceive to be ‘experts’ or are persuaded to accept as such (an issue raised in chapter 1 and discussed further in chapter 4). Abd-El-Khalick (2003) makes the point that students who believe that decisions about scientific knowledge are always rational, value-free and unproblematic (i.e., they hold a highly stereotyped view of scientific rationality) may come to regard scientific thinking as inapplicable or irrelevant to the messy and uncertain business of everyday decision-making. In other words, they will regard decision-making with respect to SSI as qualitatively different from decision-making in science. Moreover, there is a danger that those who have understood that science is sometimes tentative, provisional and impregnated with human values may come to believe that science cannot provide any answers at all, and that any view is as good as any other. This kind of naïve relativism is just as harmful as scientific views that science is all-powerful and all-knowing. Zeidler et al. (2005) express the view that students with naïve, distorted and confused NOS views are just as likely to dismiss scientific knowledge as irrelevant to decision-making about SSI because “they tend to distort whatever data, evidence, or knowledge claims are available to them for the purpose of supporting a predetermined viewpoint with respect to the issue under consideration” (p. 363). Fundamental to the ability to deal critically with SSI is the kind of understanding of scientific argumentation and scientific justification discussed at length in Hodson (2009a).

Kolsto (2001) sums up the NOS knowledge and understanding needed for addressing SSI in terms of eight major elements: (i) the ability to distinguish between science-in-the-making, where dispute, disagreement and uncertainty are to be expected, and ready-made science, on which we can rely; (ii) recognizing that sociocultural, political, economic and religious factors can impact on “the science that gets done”, to use Robert Young’s (1987) memorable phrase, and on the knowledge claims that are accepted; (iii) ability to evaluate the quality of scientific and statistical evidence, and to judge the appropriateness of anecdotal and experiential knowledge; (iv) ability to appraise the degree of support for a knowledge claim and the quality of the argument that establishes the warrant for belief; (v) a skeptical approach that includes both a critical, questioning stance and a commitment not to jump to conclusions until compelling evidence and arguments have been assembled; (vi) awareness of the importance of contextual factors when evaluating knowledge claims, including the social status of the actors and their institutional allegiance; (vii) sensitivity to the underlying values, ideologies and potential for bias in the design and reporting of scientific investigations; and (viii) awareness of the constraints that might limit the application of generalized theoretical knowledge to particular real world situations. With regard to reports of specific research studies, a simple checklist of questions can be enormously helpful. For example, who conducted the research and where was it conducted? How was the research funded? Was the research sponsored and, if so, by whom? What is being claimed?
What evidence supports the claim? How was the evidence collected? How was the evidence interpreted? What assumptions are made and what theories are used in arguing from evidence to conclusion? Do the authors use well-established theory or do they challenge such theories? Are alternative interpretations and conclusions possible? What additional evidence would help to clarify or resolve issues? Have there been other studies conducted by these scientists or by others?

Students’ ability to interpret and make appropriate use of scientific reports hinges, in part, on their understanding of “concepts of evidence”, which Gott and Duggan (1996) and Gott et al. (2003) see as comprising three broad categories: (i) concepts associated with design, including variable identification, fair test, sample size and variable type; (ii) concepts associated with measurement, including relative scale, range of interval, choice of instrument, repeatability and accuracy; and (iii) concepts associated with handling data, such as use of tables and graphs. Similar thinking underpins the notion of evidentiary competence (Jeong et al., 2007). The thirteen components of evidentiary competence postulated by the authors relate principally to experimental investigations. At the planning stage, they include identification of data relevant to the investigation, understanding of dependent and independent variables, choice of appropriate sample size and design of fair tests. At the data collection stage, they include the need for objectivity and accuracy in data collection and establishment of reliability through successive replication. At the interpretation stage, they include the ability to interpret graphs and tables of data, how to code their own data in these ways, and how to deal with anomalous data. This kind of NOS understanding is, of course, enormously enhanced by opportunities for students to do science for themselves and by themselves, that is, choosing the focus for the investigation, designing and conducting the inquiry, interpreting and reporting the findings, and arguing for the significance of the conclusions.

Over the past two decades, understanding the nature of science (NOS) has become accepted as a major component of scientific literacy and an important learning objective in the science curriculum of many countries. However, while there have been numerous efforts to develop more effective NOS-oriented curricula, robust understanding of NOS for all is still far from being achieved. Indeed, it has been consistently reported that both students and teachers have inadequate, incomplete or confused NOS understanding (Lederman, 1992; Rampal, 1992; Driver et al., 1996; Moseley & Norris, 1999; Ryder et al., 1999; Abd-El-Khalick & Lederman, 2000a,b; Hogan & Maglienti, 2001; Moss et al., 2001; Finson, 2002; Lunn, 2002; Kang et al., 2005; Irez, 2006; Akerson & Hanuscin, 2007; Apostolou & Koulaidis, 2010). Although there are occasionally some striking differences, students from a wide variety of cultural contexts tend to share common misunderstandings about science, scientists and scientific practice (Chambers, 1983; Griffiths & Barman, 1995; She, 1995, 1998; Sumrall, 1995; Parsons, 1997; Song & Kim, 1999; Mbajorgu & Iloputaife, 2001; Finson, 2002, 2003; Fung, 2002; Liu & Lederman, 2002, 2007; Rubin et al., 2003; Dogan & Abd-El-Khalick, 2008; Koren & Bar, 2009). Two points are worth making. First, it is evident that the goal of improving NOS understanding is often prejudiced by stereotyped images of science and scientists consciously or unconsciously built into school science curricula (Hodson, 1998b; Milne, 1998; Bell et al., 2003) and perpetuated by science textbooks (McComas,
This should be a relatively easy problem to fix. Second, research has shown that, in general, an explicit approach is much more effective than an implicit approach in fostering more sophisticated conceptions of NOS among students, preservice teachers and practising teachers (Abd-El-Khalick & Lederman, 2000a; Abd-El-Khalick, 2001, 2005; Khishfe & Abd-El-Khalick, 2002; Bell, 2004; Khishfe, 2008). This distinction resides not so much in differences in the kind of activities used (hands-on inquiries, historical case studies, lectures and readings, for example) as in the “extent to which learners are provided (or helped to come to grips) with the conceptual tools, such as some key aspects of NOS, that would enable them to think about and reflect on the activities in which they are engaged” (Abd-El-Khalick & Lederman, 2000a, p. 690). In an explicit approach, NOS understanding is regarded as ‘content’, to be approached carefully and systematically, as with any other lesson content. It should be noted that regarding NOS knowledge as content does not entail a didactic or teacher-centred approach or the imposition of a particular view through exercise of teacher authority, but it does entail rejection of the belief that NOS understanding will just develop in students as a consequence of engaging in other learning activities. Most effective of all are approaches that have a substantial reflective component. For example, Lucas and Roth (1996) report substantial gains in NOS understanding during a course incorporating readings on NOS, reflective essays and class discussions, and opportunities for self-directed laboratory experiences; Akerson et al. (2000) report substantial improvements in elementary student teachers’ NOS views when the science methods course required reflection on NOS, both orally and in writing, following a series of readings, case studies, debates and other activities. Akerson and Volrich (2006) note substantial improvement in the NOS understanding of Grade 1 students when the teacher made repeated and explicit reference to NOS issues (focused largely on scientific observation, the tentativeness of scientific knowledge and creativity in science), encouraged students to keep a journal related to any NOS issues arising, and finished each lesson with class discussion triggered by the question, “How is what we did like what scientists do?” Heap (2006) also points out the centrality of reflection (in her case, the use of reflective journals) in changing, developing and consolidating NOS understanding. When coupled with opportunities to conduct both teacher-guided and student-designed investigations, explicit and reflective instructional approaches can even bring about favourable shifts in NOS understanding in children at the Grades 1 and 2 level (Akerson & Donnelly, 2010).

Howe and Rudge (2005), Adúriz-Bravo and Izquierdo-Aymerich (2009) and Rudge and Howe (2009) argue that an explicit reflective approach is particularly effective when guided historical case studies are used to engage students in the kinds of reasoning used by scientists originally struggling to make sense of phenomena and events and construct satisfactory explanations. Three other research studies are noteworthy: Schwartz et al. (2004) found that preservice teachers’ NOS understanding was favourably enhanced when their course included a research component and journals-based assignments; Morrison et al. (2009) report that substantial gains in NOS understanding are achieved when explicit, reflective instruction in NOS is
CONFRONTING SOCIOSCIENTIFIC ISSUES

augmented by opportunities to interview practising scientists about their work and/or undertake some job sharing; while Abd-El-Khalick and Akerson (2009) report similar major gains in the NOS understanding of preservice elementary teachers when explicit, reflective instruction is supported by use of metacognitive strategies (especially concept mapping), opportunities to research the development of their peers’ NOS understanding, and use of case studies of elementary science classes oriented towards NOS teaching. Again, there are clear messages from the research about how best to proceed. My own views on how we can build and implement a curriculum to achieve enhanced levels of NOS understanding are discussed at length in Hodson (2009a).

It is both notable and disappointing that the gains in NOS understanding consequent on exposure to explicit, reflective instruction are considerably less substantial in relation to the sociocultural dimensions of science than with other NOS elements. Moss et al. (2001) state that, in general, Grade 11 and 12 students’ understanding of the nature of scientific knowledge (for example, that it requires evidence, and is tentative and developmental) is more complete than their understanding of the scientific enterprise. If the term “scientific enterprise” is taken to include internal and external social factors that impact on the conduct of science, and is not restricted to the specific methods employed in particular scientific inquiries (or to what some teachers continue to refer to as “the scientific method”), then I would readily concur. Many students continue to believe that science occurs in something of a sociocultural vacuum – a view held by both preservice and inservice science teachers in Tairab’s (2001) study and reinforced by the almost exclusive content orientation of many school science textbooks. Even when curriculum materials put emphasis on NOS understanding, the focus is almost exclusively on epistemological issues, with a consequent neglect of the social dimensions of scientific practice (Zemplén, 2009). Akerson et al. (2000) speculate that poor understanding in this aspect of NOS is a consequence of the subtleties of the subjective and sociocultural influences on scientific practice being impossible to capture in a short course (in their case, for preservice teachers). One or two brief examples will not achieve it; detailed and richly textured case studies (both contemporary and historical) may do so. Dass (2005) reaches essentially the same conclusion when accounting for why a semester-long undergraduate history of science course focused on the sociocultural and political context of major scientific advances achieved only “modest gains”. I would argue that disappointing outcomes are also a consequence of uncertainty about intended learning outcomes in this particular NOS domain, the inadequacy of assessment procedures for capturing student understanding, low levels of confidence in teaching these aspects of the curriculum, and the pervasiveness and power of images of science and scientists acquired through informal learning channels. If teachers are unclear about precise learning goals relating to the sociocultural dimensions of science, as many are likely to be, there is likely to be a lack of clarity in lesson design. Hodson (2009a) addresses these matters at greater length.

It is also the case that students’ understanding of the nature of technology (NOT) and of the relationships between science and technology are just as poorly developed as their NOS views. Students often see technology solely in terms of
computers, televisions and mobile phones, emphasize the products of technology to
the virtual exclusion of technology as a creative and socially embedded practice,
and see technology primarily as applied science (De Klerk Wolters et al., 1990;
Burns, 1992; Rennie & Jarvis, 1995a,b,c; Jarvis & Rennie, 1996; Jones, 1997;
McCormick, 1997; Cajas, 2001; DeVries, 2005; Scherz & Oren, 2006; Constantinou
et al., 2010). Not surprisingly, students are often unclear about the distinctions
between and the relationship between science and technology, using *ad hoc* criteria
to address particular cases. Only when prompted do they realize that many tech-
nologies pre-date the science that now explains them. Two points are worth making.
First, students’ conceptions of technology will influence the ways in which they
address technological aspects of SSI, just as teachers’ conceptions of technology
will influence their design of learning experiences and selection of curriculum
materials. Second, students’ views of technology can be changed quite substantially by
curriculum interventions focused on NOT, just as their NOS views can be changed.

**PRACTICAL KNOWLEDGE FOR ACTION**

Of course, knowledge requirements are not restricted to science and nature of
science or nature of technology. Those wishing to assess likely risks from the
proximity of overhead power lines or nuclear power stations, the dumping of toxic
waste and the frequent use of mobile phones, for example, will need considerable
relevant technological knowledge. Trying to ascertain ahead of time exactly what
technological knowledge will be required to address a range of SSI is virtually
impossible, especially since many of the SSI being studied will have been chosen
by the students. The practice of enabling students to access knowledge as the need
arises would seem to be the only practical solution. Although it is possible to build
a curriculum that includes some basic technological knowledge, it makes eminently
greater sense to focus this part of the curriculum on learning about technology, as
encapsulated in notions of technological competence (see chapter 1).

An intriguing study by Layton et al. (1993) investigated the kind of knowledge
accumulated and deployed by non-scientists to address specific needs, interests and
issues, and to solve problems in everyday life. The study focused on four groups:
parents of children with Down Syndrome (or Down’s syndrome, as it is more
commonly known in the United Kingdom); elderly people trying to cope with
domestic energy problems (and seeking to reduce their power bills); local govern-
ment officials responsible for waste disposal; and people working at, or living close
to, the Sellafield nuclear processing facility in West Cumbria (UK), who might
be considered at risk from potential radiation leaks. What is striking about the
research findings is the way in which concerned citizens built “practical knowledge
for action”. Applicable only in the particular situation under consideration, this cluster
of knowledge and skills often constituted understanding that was very different
from the scientific knowledge normally presented in school. Although it frequently
included fragments of scientific knowledge, that knowledge was adapted, modified
and augmented to address specific purposes and problems more directly. It was
used alongside *alternative* scientific knowledge (what some have called “folk
science”) and highly idiosyncratic judgements deriving from personal experience.
For example, the knowledge commonly deployed in addressing domestic energy problems had more in common with caloric theory than kinetic theory, and many of the elderly people who were interviewed perceived cold as an entity with distinct properties of its own, rather than recognizing it as the absence of heat. In other words, they developed an explanatory system rooted very firmly in personal experience of living in a draughty home. As Jenkins (2000) observes, the scientific knowledge learned in school is often irrelevant or no more than marginal to decisions about practical action: “Addressing satisfactorily the coldness of a room by closing a door, double glazing one or more windows, or insulating the walls and ceiling does not require an understanding of cold as the absence of heat conceptualized in terms of molecular motion” (p. 210). In evaluating the usefulness of scientific knowledge, non-standard criteria were often employed. For example, open fires were often preferred to more efficient forms of heating because they are “cosy”, and draught excluders were rejected on grounds of social acceptability (“they are naff!”). Brian Wynne (1989, 1991, 1995, 1996) provides a number of striking examples of the gap between scientific knowledge and lay knowledge. For example, his study of the “radioactive sheep” crisis following the Chernobyl nuclear power station accident (in 1986) reveals that British Government scientists had seriously under-estimated the likelihood that sheep in Cumbria and Wales had been contaminated. Their initial assessments had to be substantially revised, resulting in a two-year ban on sale and slaughter of sheep for human consumption. In contrast, the local sheep farmers initially had more reliable knowledge deriving from first-hand experience of the terrain, local waterways, plant behaviour (especially uptake of nutrients) and sheep grazing habits. This gap between the abstract and formalized knowledge of experts and the context-based knowledge of the farmers led to the conviction among local residents that the Government was concerned to “hush up” the affair. Also relevant here is Irwin’s (1995) analysis of the treatment of British farmworkers by an expert committee examining the safety of organophosphate pesticides. The committee concluded that the materials were safe so long as they were used properly; the farmworkers, who believed that their health was at risk, rejected this assertion on the grounds that the so-called ‘proper procedures’ were impractical in a real farming situation. It is disturbing to note that the farmworkers’ views were dismissed as “anecdotal and unreliable”. A further example is Bloor’s (2000) study of a group of coal miners fighting conventional scientific understanding of pneumoconiosis (“black lung”). Faced with a similar situation to the farmworkers in Irwin’s story, the miners succeeded in publicizing their views about the connection between coal dust and pulmonary disease by recruiting and coaching their own ‘expert witnesses’. As Irwin (2008) comments, they were successful in gaining compensation for industrial injury because they combined highly personal knowledge, scientific knowledge and knowledge of how to “work the system”.

In everyday situations, scientific knowledge delivered by supposed ‘experts’ can sometimes be rejected or regarded with deep suspicion because it is not tailored to specific needs, interests and social circumstances, or because it fails to take account of other agendas. It may also be rejected because the ‘experts’ who deliver scientific knowledge are sometimes regarded as not entirely trustworthy, that is, they are seen to be biased or to have a vested interest. In the case of the Down
CHAPTER 2

Syndrome parents, knowledge delivered by means of information leaflets was seen as singularly unhelpful. As Layton et al. (1993) comment, it was too often “a message of despair when they were desperate for one of hope” (p. 57). Knowledge was offered “in the wrong form, reflecting priorities different from those of practical action; in the wrong way, discounting understandings which parents had wrought from experience; and, often, at the wrong time, serving the convenience of donors, ignoring emotional traumas which parents might be undergoing, and undiscerning of the moment of need” (p. 58). Thomas (1997) cites a study reported by Irwin et al. (1996) in which residents in housing complexes located close to potentially hazardous industrial sites also responded negatively to expert scientific knowledge. Because it was couched in inaccessible language and seemed unable to answer their most pressing questions, it simply promoted dissatisfaction, elevated anxiety levels and exacerbated feelings of powerlessness. From the perspectives being addressed in this book, it is noteworthy that reports of potential health hazards associated with use of mobile phones is summarily dismissed by most people because of the perceived social value of the technology (Burgess, 2004; Drake, 2006), just as publicizing the known health risks associated with smoking fails to deter many young people from taking up the habit because of the social cachet smoking brings in some youth cultures. Wynne (1995) refers to episodes like this as the social construction of ignorance: the deliberate avoidance of scientific knowledge because it is perceived as contrary to one’s interests or too much in the other party’s interests (as in, “they are just trying to sell us something”). For example, workers at the Sellafield nuclear processing plant told researchers that they avoided scientific knowledge that could have helped them to assess health risks more effectively because trying to resolve the various controversies would be too time-consuming, and being too conscious of risks would raise anxiety levels. In addition, they didn’t want to signal mistrust of the staff whose job it is to assess risks and institute safety procedures. In a study conducted by Lambert and Rose (1996), most of the patients diagnosed with familial hypercholesterolaemia (a genetically transmitted inability to metabolize lipids that greatly increases an individual’s susceptibility to cardiac arrest) constructed personal knowledge for action that sought to balance scientific knowledge concerning above-average risk of premature death with consideration of the implications of a more restricted lifestyle, opting for a compromise between risk-reducing action (particularly, strict dietary control) and maintaining an enjoyable social life.

What these studies show is that people faced with making important decisions in everyday life may not always use ‘pure’ scientific knowledge. They may use restricted or adapted scientific meanings; they may incorporate knowledge from areas outside science; they may rely heavily on hunch, intuition, personal experience and testimony from other non-scientists. This complex of knowledge is assembled into a highly personal and context-specific repertoire for thinking about issues, solving problems and reaching decisions. To be useful in practical contexts, abstract, idealized science has to be adapted and modified to take account of the complexity and non-uniformity of the real world. In David Layton’s (1991) words, “the scientific knowledge offered or accessible to people is rarely usable without being reworked and contextualized. This involves, at least, its integration with
other, situation-specific knowledge, often personal to individuals, as well as with judgments of other kinds” (p. 58). To address SSI in class in any meaningful way students may need to engage in a similar kind of re-working of scientific knowledge to that of engineers addressing complex practical problems and lay people confronting science-related dilemmas in daily life: “Adjusting the level of abstraction, ‘repackaging’ knowledge to bring together components of scientific knowledge that pedagogical and disciplinary considerations have uncoupled, and ‘recontextualizing’ scientific knowledge to reassimilate the messy realities that have been idealized in order to shape and address a problem with the rigour deemed necessary to move towards a scientific solution” (Jenkins, 1994b, p. 601).

In an attempt to theorize these matters, and explain the ways in which a group of residents in an area with a high level of background radiation learned about radiation hazards and evaluated the potential threat to their health, Alsop (1999) developed what he calls the Informal Conceptual Change Model (ICCM). The model, which has ready application to all SSI, comprises three theoretical dimensions: the cognitive (the way learners make sense of the relevant science and their views of its consistency, reliability and truthfulness), the affective (the way they feel about the issue and how their emotions influence their learning) and the conative (the usefulness of scientific information in meeting their specific needs and concerns)14. The cognitive dimension includes the relevant science and NOS understanding related to consistency and reliability of the data and rationalizations. Drawing on earlier work by Watts and Alsop (1997), Alsop explains the affective dimension in terms of how salient (noticeable, prominent or important in some way), palatable (appealing or agreeable) and germane (personally relevant) a particular idea is perceived to be. The conative perspective focuses on questions such as: How can I use this knowledge? Does it empower me to act? Does it help me to solve problems? Alsop (1999) describes the conative perspective in terms of three major components: trust (the extent to which knowledge provided by ‘experts’ can be relied upon), control (the extent to which an individual feels that knowledge can be used to influence or change a particular situation) and actionable (an idea that is very closely related to the notion of practical knowledge for action discussed earlier).

**LANGUAGE ISSUES**

If students are to address SSI thoroughly and critically, they also need the language skills to access knowledge from various sources and the ability to express their knowledge, views, opinions and values in a form appropriate to the audience being addressed.

Beyond vocabulary and background facts, there are discourse-specific ways in which arguments are made, in which certain kinds of information must be foregrounded and used as evidence. There are discourse-specific ways in which you must infer connections or ‘get the point’. Different discourses require very different ways of ‘reading between the lines’… Becoming literate in any particular domain involves learning a specific discourse – particular ways of thinking, acting, valuing. (Michaels & O’Connor, 1990, p. 12)
We need to focus students’ attention very firmly on the language of science, scientific communication and scientific argumentation. As Goldman and Bisanz (2002) note, there are three major categories of communication of scientific information in our society: communication among scientists through research journals and conference papers; popularization and dissemination of information generated by the scientific community via newspapers, magazines and television; and formal education via textbooks and other curriculum materials. We need to ensure that students develop the necessary critical reading skills for all three types of text. Proficient and critical reading, whether first order or second order literature, involves more than just recognizing all the words and being able to locate specific information; it also involves the ability to: (i) determine when something is an observation, an inference, a hypothesis, a conclusion or an assumption; (ii) distinguish between an explanation and the evidence for it; and (iii) recognize when the author is asserting a claim to ‘scientific truth’, expressing doubt or engaging in speculation. Without this level of interpretation the reader will fail to grasp the essential scientific meaning. In practice, many students are unaware of inconsistencies in what they read, unable to assess the reliability of data and detect bias, and only moderately capable of relating what they read to what they already know. In general, they are poor at distinguishing claims from evidence, evidence from conclusions, and beliefs from inferences (Goldman & Bisanz, 2002). Like everything else in science education, critical reading skills need to be modelled and taught, carefully and systematically. Specifically, students need advice, criticism and support in their efforts to connect items of information within and across texts, evaluate the validity and reliability of all information used, weigh the rival merits of alternatives, assess consistency and inconsistency, and seek to resolve inconsistencies by gathering further information.

What is too often unrecognized by science teachers, science textbooks and curricula, and by the wider public, is that dispute is one of the key driving forces of science. Real science is impregnated with claims, counter claims, argument and dispute. Arguments concerning the appropriateness of experimental design, the interpretation of evidence and the validity of knowledge claims are located at the core of scientific practice. Arguments are used to answer questions, resolve issues and settle disputes. In everyday life, decision-making on SSI is based largely on evaluation of information, views and reports made available via newspapers, magazines, television, radio and the Internet. Citizens need to understand the standards, norms and conventions of scientific argumentation in order to judge the rival merits of competing arguments and engage meaningfully in debate on socioscientific issues. The ability to judge the nature of the evidence presented and its validity, reliability and appropriateness, the interpretation and utilization of that data, and the chain of argument substantiating the claims, are crucial to good decision-making. Students need to know the kinds of knowledge claims that scientists make and how they advance them. In particular, the form, structure and language of scientific arguments, the kind of evidence invoked and how it is organized and deployed, and the ways in which theory is used and the work of other scientists
cited to strengthen the case. Neglect of scientific argumentation in the school science curriculum gives the impression that science is the unproblematic accumulation of data and theory. In consequence, students are puzzled and may even be alarmed by reports of disagreements among scientists on matters of contemporary importance. They are also unable to address in a critical and confident way the claims and counter claims impregnating the socioscientific issues with which they are confronted in daily life. Being able to assemble coherent arguments and evaluate the arguments of others, especially those appearing in the media, is crucial if students are to understand the basis of knowledge claims they encounter and make decisions about where they stand on important issues.

A number of science educators have recently turned their attention to these matters and to what had previously been a shamefully neglected area of research and curriculum development. The research agenda set out by Newton et al. (1999), Driver et al. (2000), Osborne (2001), Duschl and Osborne (2002), Erdurgen et al. (2004), Osborne et al. (2004), Simon et al. (2006), Bricker and Bell (2008), Duschl (2008), Jiménez-Aleixandre and Erduran (2008), Berland and Reiser (2009), and others, focuses on the following questions: Why is argumentation important? What are the distinctive features of scientific argumentation? How can it be taught? What strategies are available? To what extent and in what ways are the strategies successful? What problems arise and how can the difficulties be overcome? This research is discussed at length in Hodson (2009a) and will not be reviewed here, save to note its key features and to emphasize its obvious relevance to SSI-oriented teaching and learning.

Many science educators have used Stephen Toulmin’s (1958) description of the structure of an argument in terms of six components:

- **Claim** - makes an assertion or states a conclusion.
- **Data** - states the evidence used to provide support for the claim.
- **Warrant** - explains or justifies the relationship between the evidence and the claim.
- **Qualifier** - indicates the degree of reliance to be placed on the conclusions and/or the conditions under which the claim is to be taken as ‘true’.
- **Backing** - states the additional evidential, theoretical and methodological assumptions underlying the warrant and establishing the validity of the argument.
- **Rebuttal** - identifies circumstances in which the claim can no longer be sustained or introduces reservations that question the data, warrant, backing or qualifier of an argument.

The six components comprise two levels of argumentation: first, the construction of a basic argument establishes the relation between a claim and the evidence in support of it, and states the justification for this relationship; second, backing, rebutting and qualifying the justification complements and extends the basic argument. Each component in the model, in effect, an answer to a question: what is being asserted? *(claim)*; what evidence supports the claim? *(data)*; what reasons, principles, rules or values justify the conclusion? *(warrant)*; how likely is it that the conclusion is true? *(qualifier)*; what theoretical assumptions justify the line of reasoning and establish the trustworthiness of the claim? *(backing)*; under what circumstance(s) would the argument break down? *(rebuttal)*. In constructing a 5-level analytical framework for assessing the quality of an argument, Zeidler et al. (2003), Erduran...
et al. (2004) and Osborne et al. (2004) place considerable emphasis on the systematic consideration of rebuttals. Thus, level 1 arguments comprise a simple claim versus a counter-claim, or a claim versus a claim; level 2 arguments consist of claims with data, warrants or backings, but no rebuttals; level 3 arguments involve a series of claims or counter-claims with data, warrants or backings and the occasional weak rebuttal; level 4 arguments have a clearly identifiable rebuttal, and may have several claims and counter-claims as well, though this is not necessary; level 5 or extended arguments have more than one rebuttal.

Research findings from studies using the Toulmin framework are somewhat mixed. For example, Bell and Linn (2000) conclude that students tend to rely on data to support their claims, but rarely use warrants or backings, while Jiménez-Aleixandre et al. (2000) found that many students don’t even use data to support their claims. One major problem is that the Toulmin model is deceptively simple and straightforward, and its deployment in science education research to monitor the development of students’ argumentation skills is beset with difficulties – most notably, the difficulty of determining exactly what counts as claim, data, warrant and backing in a particular set of circumstances (Erduran et al., 2004). Thus, ascertaining the extent to which students have made use of data, warrants, backings and qualifiers to support arguments, and the extent to which they use rebuttals to elaborate and extend or oppose an argument, can be problematic. Even with written arguments, the deployment of Toulmin’s model as a research tool can sometimes be difficult; with verbal arguments, it is even more problematic. The natural flow of conversation can serve to disrupt the logical structure of the argument. Moreover, students often use language that is vague or ambiguous, and they frequently contradict themselves as they struggle to sort out their ideas. Boundaries between the categories of argument become blurred and fluid, with key elements in the argument being implied rather than explicitly stated. They may even be conveyed by gesture. In addition, elements of an argument may be omitted because the arguer simply assumes that it is already well-known and doesn’t need to be re-stated. In short, real face-to-face argument is dynamic and interactive. Moreover, in trying to ascertain students’ capabilities it is essential to take account of the context in which the argument is located, and its familiarity and interest for the student. Even with written arguments, the venue can impact substantially on the way the argument is presented, with important variations among research articles, conference presentations, email communications, grant proposals, textbooks and magazine articles.

In an attempt to sidestep these problems, Zohar and Nemet (2002) collapsed data, warrants and backings into a single category of justifications. McNeill et al. (2006) also reduced Toulmin’s model to just three components: claim, evidence (or data) and reasoning (a combination of warrant and backing, deployed as considered appropriate). In the Zohar and Nemet scheme, the criteria for the classification of justifications is: (a) no consideration of scientific knowledge; (b) inaccurate scientific knowledge; (c) non-specific scientific knowledge; and (d) correct scientific knowledge. Schwarz et al. (2003) advance a case for evaluating arguments in terms of argument type, soundness of argument, overall number of reasons, number of reasons supporting counter-arguments, and types of reasons (including logical, concept-rich and theory-based reasons, appeals to authority, everyday common sense and personal experiences,
and attempts to tease out the consequences of holding a particular view or engaging in a particular kind of action). Their notion of a hierarchy of arguments ranges from simple assertions (a conclusion unsupported by any kind of justification) through one-sided arguments (for which one or two reasons may be advanced) and two-sided arguments (including reasons that both support and challenge the conclusion, but do not weigh their rival merits) to compound arguments (replete with multiple reasons and critically evaluated counter-arguments). Sandoval and Millwood’s (2005) approach focuses attention on two components of the argument: (i) the epistemological quality of the argument, that is, the extent to which the student has cited sufficient data in warranting a claim, written a coherent explanation and made appropriate use of inscriptions (graphs, tables, equations, etc.); and (ii) its conceptual quality and appropriateness, that is, how well the student has articulated the claims within an appropriate theoretical framework and warranted those claims using appropriate data. Sampson and Clark’s (2006) detailed review of the field expresses dissatisfaction with all schemes so far used by science educators to evaluate the quality of scientific arguments. They suggest that instead of focusing on technical issues relating to the precise structure of an argument, teachers should pay attention to such matters as: the kinds of claims advanced and whether they are well supported by the evidence; whether all the evidence has been utilized and discrepancies accounted for; whether the sources of data and the methods by which data were accumulated have been critically examined; how (or if) alternative claims are acknowledged, their weaknesses pinpointed and conclusions rejected. Before leaving this discussion it is worth mentioning Jiménez-Aleixandre and Federico-Agrasso’s (2009) advocacy of a framework broadly similar to “epistemic quality” comprising three criteria: pertinence - the extent to which evidence relates directly and unambiguously to the claims; sufficiency – whether the evidence is sufficient to support the claims; and coordination – whether the items of evidence are coordinated across different epistemic levels. This latter criterion relates to the ways in which details of procedures, data readings, data trends, graphs, and so on, are related to theoretical propositions. Falk and Yarden (2009) identify two kinds of coordination practices: research-oriented coordination, which links research questions, hypotheses, methods, data, theoretical issues and application of findings; and text-oriented coordination, which focuses on the function, organization and genre of the text. Not surprisingly, the authors found that when evaluating specially adapted primary literature (in biotechnology), students used the former coordination practices for appraising the Research Design and Results sections and the latter practices for judging the quality of the Discussion section.

Research shows that students do improve their capacity for constructing and presenting effective arguments through practice, though not always as rapidly and predictably as we might wish (Jiménez-Aleixandre et al., 2000; Zoller et al., 2000; Osborne et al., 2004; Garcia-Mila & Andersen, 2008). What is clear is that development of those skills is a long-term undertaking, and one or two brief experiences will not suffice. As with NOS, teaching of argumentation needs to be explicit and systematically planned. A number of researchers have shown how the quality of students’ arguments can be considerably enhanced by judicious scaffolding, use of writing frames, encouraging student reflection, fostering metacognition and providing
timely and constructive feedback (Kuhn et al., 2000, 2008; Bell, 2002; Cho & Jonassen, 2002; Engle & Conant, 2002; Zembal-Saul et al., 2002; Nussbaum & Sinatra, 2003; Felton, 2004; Nussbaum & Kardash, 2005; Sandoval & Millwood, 2005; Erduran, 2006; Chinn, 2006; Kenyon et al., 2006; McNeill et al., 2006; Andriessen, 2007; McNeil & Krajcik, 2007, 2008; Reigosa & Jiménez-Aleixandre, 2007; Chinn & Samarapungavan, 2008; Jiménez-Aleixandre, 2008; Varelas et al., 2008; Berland & Reiser, 2009; McNeill, 2009; Dawson & Venville, 2010; Kuhn, 2010). Of particular value in this context is the learning progression devised by Berland and McNeill (2010) as a description of how students’ argumentation skills develop and as a set of guidelines for how teachers can support and enhance that development. It comprises three dimensions: instructional context, argumentative product and argumentative process. In terms of the first dimension, the instructional context must be rich enough to enable multiple perspectives and must require the use of evidence to resolve any significant differences in perspective. The authors identify four “leverage points” impacting the complexity and, therefore, the fruitfulness of the problem: the complexity of the problem, the size of the data set, the appropriateness of the data, and the sophistication and availability of scaffolds. Key factors relating to the product include the ways in which arguments are supported and whether they include rebuttals, and the appropriateness and sufficiency of the supporting data. The argumentative process is described in terms of argumentative functions and the spontaneity of student contributions. The authors identify four utterance functions, arranged as a hierarchy: (i) individuals stating and defending claims; (ii) individuals questioning one another’s claims and defence; (iii) individuals evaluating one another’s claims and defence; and (iv) individuals revising their own and others’ claims. With regard to spontaneity, there is a progression from activities that are initiated or prompted by the teacher, through those that are negotiated between teacher and students, to those initiated, conducted and evaluated by students.

MEDIA LITERACY

Because much of the information needed to address SSI is of the science-in-the-making kind, rather than well-established science, and may even be located at or near the cutting edge of research, it is unlikely that students will be able to locate it in traditional sources of information like textbooks and reference books. It will need to be accessed from magazines, newspapers, TV and radio broadcasts, publications of special interest groups and the Internet, thus raising important issues of media literacy. Being media literate means being able to access, comprehend, analyze, evaluate, compare and contrast information from a variety of sources and utilize that information judiciously and appropriately to synthesize one’s own detailed summary of the topic or issue under consideration. It means recognizing that the deployment of particular language, symbols, images and sound in a multimedia presentation can each play a role in determining a message’s impact, and will have a profound influence on its perceived value and credibility. It means being able to ascertain the writer’s purpose and intent, determine any sub-text and implicit meaning, detect bias and vested interest. It means being able to distinguish
between good, reliable information and poor, unreliable information. It involves the ability to recognize what Burbules and Callister (2000) call misinformation, malinformation, messed-up information and useless information. Students who are media literate understand that those skilled in producing printed, graphic and spoken media use particular vocabulary, grammar, syntax, metaphor and referencing to capture our attention, trigger our emotions, persuade us of a point of view and, on occasions, by-pass our critical faculties altogether.

Overall, research paints a pretty depressing picture of the ability of students, at both school and university level, to read media reports with the kind of understanding encapsulated in the notion of critical scientific literacy (Norris & Phillips, 1994, 2008; Korpan et al., 1997; Phillips & Norris, 1999; Norris, et al., 2003; Penney et al., 2003). Phillips and Norris (1999) identify three major student ‘stances’ towards reports of science in newspapers and magazines. In the critical stance, readers attempt to reach an interpretation that takes account of the text information and how it is presented in relation to their own prior beliefs, sometimes producing a new mental model or representation of the phenomenon or events under consideration. Those readers adopting the domination stance allow prior beliefs to overwhelm text information, reinterpreting it (sometimes implausibly) to make it consistent with their existing frameworks and beliefs. In stark contrast, the deferential stance allows the text to overwhelm prior beliefs, resulting in blind (though perhaps only temporary) acceptance of views expressed in the text and implicit trust in the author. Disturbingly, this latter position seems to be the most common stance among high school students.

Many students accept media-based information at face value; they focus on superficial features of the material and are easily seduced by the razzamatazz of presentation. Students need to be made aware, if they are not already aware, that the popular press invariably over-simplifies complex issues and that information from such sources is often incomplete, sometimes purposefully so, and often highly selective. It may be confused, confusing or deliberately misleading, as in the case of government-sponsored reporting in the UK at the time of the Chernobyl nuclear power station disaster in the mid 1980s and the BSE episode in the 1990s. Unbalanced reporting can arise because of journalists’ honest attempts to be even-handed and to present “both sides of the story”. Science is built on skepticism, and presentation of conflicting data, counter arguments and alternative conclusions is a key element in the public scrutiny that eventually leads to consensus. But consensus is not unanimity; dissenting voices can always be found, even for well-established scientific knowledge, and laudable efforts by journalists to be ‘objective’ in their reporting can sometimes result in outlandish views, poorly substantiated views and even discredited views being reported as legitimate alternatives to mainstream scientific opinion (Friedman et al., 1999; Weigold, 2001). This commitment to even-handed reporting is sometimes exploited by those with a vested interest in manufacturing doubt about scientific findings perceived to be counter to their interests, as in the case of the tobacco industry’s attempts to cast doubt on the link between smoking and lung cancer (see chapter 7). Coverage of global warming and climate change is another case of the press reporting major differences of opinion on matters where there is clear scientific consensus, as discussed in chapter 8. This is
certainly not to argue for a popular press that is slavishly subservient to the scientific establishment; rather, it is to argue for readers to be constantly vigilant.

An analysis by Zimmerman et al. (2001) of articles and news reports published in a range of newspapers and magazines in Canada and the United States over a one-month period showed that they routinely failed to provide information about where the research was originally published, and who funded it, and only very rarely presented full details of research design or included critical comments by other experts in the research field. Reporters frequently omit discussion of the limitations, subtleties and nuances of the research because such details might detract from a story’s clarity, impact, conciseness and ability to hold the reader’s attention. While numerical data is often used to create an impression of care, precision and authority, carefully selected and sometimes highly dubious statistics are commonly used to mislead or concentrate attention on particular aspects of the report, to the exclusion of others. Hence Benjamin Disraeli’s famous remark, later popularized by Mark Twain, that (in politics) there are three kinds of lies: lies, damn lies and statistics. Also relevant is the old joke that 72.5% of statistics are made up on the spur of the moment. To compound the problems, readers may do little more than ‘skim read’ the report or watch ‘with one eye only’ while attending to other matters or engaging in other activities. Material may be biased and may use a range of journalistic techniques such as emotive language, hyperbole and innuendo, provocative pictures and images, and emotionally manipulative background music, to persuade readers, viewers and listeners of a particular point of view. As Nelkin (1987) observes, “selective use of adjectives can trivialize an event or render it important; marginalize some groups, empower others; define an issue as a problem or reduce it to a routine” (p. 11). In a study of the metaphors used by British newspapers in their reporting of developments in biotechnology, Liakopoulos (2002) found many metaphors intended to convey a positive image of biotechnology (including: revolution, breakthrough, major step, golden opportunity, potential goldmine, miracle, and opening the door) and many intended to create a negative response (including: Pandora’s box, threat, rogue virus, killer plants, Frankenfoods, Nazi-like eugenics, playing God, and unnatural selection). Describing biotechnologists as mad scientists, evil geniuses or Frankenstein figures leaves little doubt about the position the reader is expected to adopt. Jensen (2008) provides similar examples of highly selective language use to support or oppose stem cell research. Somewhat earlier analyses of press coverage of genetic engineering revealed what Mulkay (1993) called an oscillating “rhetoric of hope and fear” and van Dijck (1998) called a hybrid discourse of “promise and concern”. An analysis of more recent British newspaper reports concerning GM foods conducted by Augustinos et al. (2010) reveals a consistent pro-GM position in The Times and The Sun, where opposition to GM foods and concerns expressed by critics about possible environmental and health risks were commonly described as “irrational”, “unscientific”, “scaremongering”, “ignorant” and “anti-science”, and a consistent anti-GM position in The Guardian and The Daily Mail, where reporters tend to emphasize public anxieties (portrayed as “reasonable”), the vested economic interests of biotechnology companies and the political interests of the British government. Essentially the same conclusions concerning the same four newspapers were reached
by Cook et al. (2006). In his survey of newspaper reporting of biotechnology issues in the United States, Germany and UK, Listerman (2010) identifies five distinct ways of framing the discussion: utility – Nature is a resource to be used by people as long as it is beneficial and profitable to do so; risk – complex technology is risky because it has impacts on Nature that cannot always be predicted and managed; control – since each alteration has an impact, the changes on Nature and society inflicted by humanity must be under strict control and carefully regulated through political authority; fate – we cannot control the changes in Nature but only try to cope with the consequences; morality – all technological activities raise moral-ethical issues. American reports tended to emphasize the utilitarian aspect (i.e., benefits to people and the economy), German and British reports put much greater emphasis on risk and moral-ethical issues.

Although newspaper and television news editors necessarily consider very carefully the quality and significance of the science they include, they are likely to be even more strongly influenced by other considerations: (i) what they deem to be interesting to readers/viewers and whether the primary motive is to inform, entertain, provoke, advocate, defend or oppose a particular view/development; (ii) the extent to which sensationalist reporting and emphasis on novelty and rarity might gain additional readers/viewers, or lose some; (iii) the vested interest that newspaper proprietors or broadcast station owners might have; (iv) the need to meet advertisers’ expectations and attract new advertising clients; (v) the strong desire to claim an ‘exclusive’; (vi) how conveniently the item matches the ‘house style’ and the time and space available; (vii) the availability of appropriate experts for consultation; and (viii) the urgency of meeting a deadline. At a general level, students need to consider the following questions. Who determines what we see and hear in the media? How is this information monitored, filtered and edited? Who provides information to the media, and why? Why is a particular story covered? How is a particular story framed and how is a particular position evaluated? Why are some views emphasized or even magnified, while others are downplayed or ignored altogether? While the media can quite rightly be accused, on occasions, of distorting research results, sowing seeds of distrust and acting as an agent provocateur, they also provide much needed recognition for scientific research, raise public awareness of important developments and sometimes ‘blow the whistle’ on overt vested interest, bias and fraud. A democratic and open society is premised on the free flow of information among its citizens. It is here that the media plays a crucial role, but can only do so when there is a wide variety of newspapers, magazines, Internet websites, writers and editors to ensure diversity of views. When control and ownership are vested in the hands of a few individuals and corporations, opponents can be easily discredited, alternative views suppressed and dissident voices marginalized or silenced. In their haste to meet a deadline, or in their desire to present a particular position on an issue, journalists may neglect to include the voices of people who could invest their coverage with alternative perspectives and different experiences. As Conrad (1999) notes, on medical matters, the voices of patients and their carers/advocates are often absent, although a survey conducted by Hivon et al. (2010) of the coverage in Canadian news media of two controversial therapeutic interventions (electroconvulsive therapy (ECT) and the use of cyclo-oxygenase-2 (COX-2) drugs in
treatment of arthritis) and two contentious screening tests (first-trimester prenatal screening for Down syndrome and prostate-specific antigen (PSA) screening for asymptomatic men) showed that the voices of patient associations, patients and their families were well represented, and in the case of ECT they came close to those of scientists and medics in terms of overall representation.

In an extended discussion of the politics of news media, Graber et al. (1998) make a plea for diversity that parallels the argument used throughout this book for diversity within the community of scientists and engineers, and the various funding agencies, and within the bodies that make decisions on curriculum, assessment programmes and other educational issues. As with many aspects of SSI, it may well be that the extent and prominence of media coverage of the views of any particular group of people reflects the political literacy and political power of the group and its ability to contact and influence journalists. Media coverage can be impacted by whether those affected by the condition are numerous and urbanized or isolated and widely scattered, robust and able-bodied or infirm, young or old, men or women, socially privileged or disadvantaged and marginalized. These kinds of issues are discussed in chapter 9 in relation to community-based action. Would-be activists can draw great encouragement from Epstein’s (1995, 1996, 1997) compelling account of how AIDS activists, with virtually no formal education in science, acquired sufficient scientific knowledge and political expertise to become effective and respected participants in the design, conduct, interpretation and reporting of clinical trials of a range of AIDS-therapy drugs and in the design and implementation of treatment protocols. In a later work, Epstein (2008) discusses how other patient and patient advocacy groups have had a profound impact of public perceptions of a wide range of medical conditions, changed the ways in which the condition is characterized and diagnosed, stimulated technological innovation, and brought about significant modifications to the attitudes of health practitioners, management of patients, research priorities and protocols, health policy and the cost and availability of drugs. Also of interest is Jensen’s (2008) account of how patient groups have been instrumental in constructing the generally favourable view of “therapeutic cloning” (the use of embryonic stem cells in medical research) in the British press.

Clearly, a reasonable level of media literacy is essential if students are to confront SSI in a rational and critical way. Bryant and Zillmann (1986), Nelkin (1987, 1995), Dunwoody (1993, 1999), Stocking and Holstein (1993), Stocking (1999), Miller and Kimmel (2001), Spinks (2001), Nisbet and Lewenstein (2002), Reah (2002) and Ten Eyck (2005) provide wide-ranging discussions of journalistic techniques, McClune and Jarman (2010) provide details from interviews with 26 recognized authorities on science in the media focusing on the knowledge, skills and attitudes they consider essential to critical reading of science-based news reports, while Dimopoulos and Koulaidis (2003) show how habits of careful, critical reading of newspaper reports can be successfully taught and can prove invaluable in helping students to identify the key social actors and forces that impact decision-making in both the private and public sectors. Experience in combining informational text with language specifically chosen to engage readers’ attention, surprise or shock them, incite anger, generate sympathy or sway their thinking, is invaluable in understanding
the ways in which the media seek to manipulate public opinion. Students can learn much about media techniques by playing the devil’s advocate - for example, by writing short articles to endorse opinions they do not hold or views they actively oppose. They might learn to detect bias and distortion by engaging in it, that is, by writing text using only data, statistics, examples and ‘expert testimony’ that are favourable to a particular viewpoint, and ignoring all other. Marks and Eilks (2009) describe an interesting project in which Grade 10 students investigated the use of synthetic musk in the detergents and soap industry, particularly in the manufacture of perfumes and shower gels. Although the early carcinogenic nitromusks have now been mostly replaced, the materials currently in use continue to pose health risks, largely through their hormone-activating and allergenic properties, and create a raft of environmental problems, most of which have gone unreported in the news media. They enter wastewater systems in huge volumes, pass through the sewage system largely unaltered and are discharged into streams, rivers and lakes. Increasingly high levels of synthetic musks are now being encountered in the fatty tissues of oily fish and may be responsible for falling fertility levels in male fish. They have also been detected in human tissue – most alarmingly, in breast milk. After studying the relevant chemistry, the students prepared some shower gels and subjected them to tests for consumer preference. Then they worked in groups to compile a video report to reflect the viewpoints of four constituencies: consumer protection agencies, the cosmetics industry, environmental protection groups and the authorities responsible for wastewater disposal.

There is considerable value in encouraging students to collect, display, criticize, compare and contrast samples of writing on SSI from newspapers and popular magazines, textbooks of various styles, science-oriented magazines, academic journals, museum exhibits, works of fiction, Websites and interactive media, together with clips from works of fiction, movies, cartoons, advertisements and product labels. Of course, reading or watching media reports of science may be a new experience for many students, and so provision of guidelines may be essential in ensuring that they direct their attention to key aspects of the report, such as use of provocative headlines and illustrations, editorializing, identification (or not) of information sources, omission of alternative views, portrayal of scientists in favourable or unfavourable light, balance, bias, thoroughness of content coverage, and so on. Some kind of media checklist might be extremely helpful in helping to build up students’ critical reading skills. Who is the author (or speaker) and what is the author’s purpose? Who is the audience? How is the message tailored to that audience? Is the information complete? Are there proper citations of the sources of information? What techniques and what language are used to attract and maintain audience attention? What is assumed or left implicit? Are there any discernible underlying values and attitudes? What information and points of view are omitted? And so on.

In recent years, the Internet has become the dominant medium through which the public (including students) access knowledge and information, in all areas and disciplines. For example, Falk (2009) reports that 87% of a representative sample of US citizens state that they gather scientific information from the Internet, compared with 10% in a similar survey conducted in 2006\(^1\). When students seek
CHAPTER 2

to extract, evaluate and utilize information from the Internet and from multimedia materials, rather than from solely print-based media, movies and television, they are increasingly vulnerable to biased, distorted, confused, inaccurate and untruthful material, and so even more in need of supportive, critical guidance. Like all forms of communication, the Internet is vulnerable to messages that reflect the vested interests of governments, business, media corporations and advertisers; it is subject to the kind of cultural control and censorship that seeks to privilege particular beliefs, values and practice, and to marginalize, exclude or misrepresent others. Those with power and influence may attempt to restrict the messages and voices of those who might wish to express counter views. As discussed in chapter 3, there is enormous potential for both good and bad. In Dahlberg’s (2005) view, the bad seems to be winning: “the Internet’s potential for extending strong democratic culture through critical communication is being undermined by a corporate colonization of cyberspace” (p. 160). Brem et al. (2001) have studied the ability of students in Grades 9, 11 and 12 to evaluate information located on Websites of varying quality, including some hoax sites. Despite lots of preparatory work and continuing support from teachers, students frequently failed to differentiate between the quality of the science and the nature of the reporting and presentation, often equating amount of detail with quality. Students were often unable to assess the accuracy, judge the credibility and evaluate the site’s use of evidence to substantiate knowledge claims. Because students tended to rely on common sense as their principal guide, rather than careful analysis and critical reflection, they were too easily seduced by whatever attractive surface features the authors deployed. In a similar study at the Grade 6 level, Wallace et al. (2000) found that students usually concentrated on the search aspects of the task and their ability to navigate a range of sites, and neglected to evaluate the quality of the science they located. Often they searched for key words and then slavishly copied the chunk of text in which they had located them into their notebooks.

Tsai (2004a, b) and Wu and Tsai (2005) have developed a conceptual framework, named Information Commitments (ICs), to describe and evaluate the strategies and standards used by students in their Internet-based searches. ICs address issues such as use of a simple keywords search versus more sophisticated concept-based searches, the value placed on ease of searching and retrieving information versus relevance and quality of information, whether students considered the reputation of the Website, and whether they cross-checked information against other Websites, printed texts and the findings of their peers. Among students aged 16 to 18 in a number of schools in northern Taiwan, Lin and Tsai (2008) found that those with more sophisticated NOS views tended to adopt more sophisticated ICs, used a greater range of sites, sought to ascertain the trustworthiness and reputation of the sites accessed, and were much more likely to engage in cross-checking of information. This research may provide some useful guidelines for how teachers can provide advice, guidelines and critical support to assist students in enhancing their web literacy.

Although it is well outside the scope of this book, it is important to acknowledge the urgency of broadening our conception of literacy and media literacy. Presentation of information is increasingly multimodal, combining text with complex and overlapping visual and audio messages and creating the need for a new kind of
multimodal literacy. In the words of Carmen Luke (2000), “the cyberspace navigator must draw on a range of knowledges about traditional and newly blended genres or representational conventions, cultural and symbolic codes, as well as linguistically coded and software-driven meanings. Moreover, the lateral connectedness of hypertext information, which users access by clicking on buttons or hotlinks, immerses navigators in an inter-textual and multimodal universe of visual, audio, symbolic, and linguistic meaning systems. In hypertext navigation, reading, writing, and communicating are not linear or unimodal (that is, exclusively language and print-based), but demand a multimodal reading of laterally connected, multi-embedded, and further hotlinked information resources variously coded in animation, symbols, print text, photos, movie clips or three-dimensional and manoeuvrable graphics” (p. 73). When we consider the additional need to understand the specialist registers of various technical and professional communities, the variations in language use introduced by text speak and rap music, the genres favoured by politicians, the military and the world of advertising, and so on, it may well be that it is more appropriate to refer to the need for students to be “multiliterate”.

Kress (2003) notes that while “language-as-speech” is likely to remain the primary mode of human communication, “language-as-writing” is rapidly being displaced by “language-as-images” and combinations of images. Ulmer (2003) likens this shift towards what he calls “electracy” to the shift from orality to literacy at the dawn of the print age. Among the many new demands is the problem of distinguishing among data and images that are uninterpreted, neutral, authentic, manipulated, artificial and sometimes provocatively slanted to express a particular viewpoint and exclude others. There was a time when we could say: “the camera never lies”. Photoshop has changed all that, and as Donna Haraway (1997) comments, “there are no unmediated photographs... only highly specific visual possibilities, each with a wonderfully detailed, active, partial way of organizing worlds” (p. 177). It has always been the case that scientific data obtained by means of sophisticated technology is both theory-impregnated and mediated by the decisions of scientists and technicians about how to collect, organize and display data. This is particularly evident in relation to contemporary medical technology. Computerized tomography, ultrasound, PET scanners and magnetic resonance imaging do not produce photographs, but mathematically constructed representations, as Burri and Dumit (2008) comment in their discussion of MRI.

Scientists and technicians make decisions about parameters such as the number and thickness of the cross-sectional slices, the angle they are to be taken from, and the scale or resolution of the image data. Decisions also have to be made when it comes to post-processing the images on the screen: perspectives can be rotated, contrast modified, and colors chosen for scientific publications. These specific decisions do not depend on technical and professional standards alone but also on cultural and aesthetic conventions or individual preferences. (p. 301)

In elaboration of the ways in which images are manipulated to suit a particular sociocultural context, the authors note some intriguing differences in the ways ultrasound images of early-stage foetuses are deployed in different cultural contexts.
in relation to different levels of anxiety, hope, excitement, privacy and publicity, and are sometimes used by advertisers and anti-abortion groups to project a particular message.

DEALING WITH CONTROVERSIAL ISSUES

Many SSI are highly controversial: GM crops, governmental DNA banks, gene therapy, cloning, stem cell research, health hazards associated with mobile phones and overhead power lines, toxic waste disposal, euthanasia, abortion, nuclear power generation and nuclear weapons, deep space exploration, xenotransplantation, animal experiments, food irradiation, compulsory MMR vaccination, smart ID cards, priorities for deployment of scarce resources for medical services and for medical research, and ways to deal with ozone depletion, desertification, loss of biodiversity and other environmental crises. An issue can be regarded as controversial when: (i) the scientific information required to formulate a judgement about it is incomplete, insufficient, inconclusive or extremely complex and difficult to interpret, and (ii) judgement involves consideration of factors rooted in social, political, economic, cultural, religious, environmental, aesthetic and/or moral-ethical concerns, beliefs, values and feelings, concerning which, people may hold widely varying positions. It is also the case that the dispute should have persisted for some time (brief differences of opinion are not usually regarded as controversial) and should involve more than two people. Implied, too, is public interest in resolving the conflict because of its significance to decision-making about how best to proceed. Dearden (1981) sums up the situation as follows: “A matter is controversial if contrary views can be held on it without those views being contrary to reason. This can be the case, for example, where insufficient evidence is held in order to decide the controversy, or, where the outcomes depend on future events that cannot be predicted with certainty, and where judgement about the issue depends on how to weigh or give value to the various information that is known about the issue” (p. 38).

While these characteristics presuppose that the issue is reasonably well articulated and key differences are open to public scrutiny, it is important to recognize, as Levinson (2006) reminds us, that there can be situations where “a significant group of people might keep their interchanges with the rest of society to a minimum, where there may be no forum for exchange of views or where they might feel intimidated by expressing their opinions” (p. 1204). He continues as follows: “Social consensus could be based around a point of view that is generally seen as commonsense, which an outsider perceives as deeply wrong and possibly offensive, but the modes for articulating disagreement are not available to the outsider” (Levinson, 2006, p. 1204). On occasions, SSI are heavily impregnated with business interests, military concerns and political imperatives that are socially or politically difficult to oppose. In many contexts, independent and critical consideration of SSI is vulnerable to pressure from social groups seeking to advance particular views and values.

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

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

Once teachers decide to include controversial issues in the curriculum, they have to decide the most appropriate way to do so. Should the teacher take a neutral position, adopt the devil’s advocate role or try to present a balanced view? In a deliberate move to renounce the position of the teacher as an authority figure on all matters, the *Humanities Curriculum Project* in the late 1960s and early 1970s proposed that teachers act as a neutral chair during class discussion and debate on controversial issues relating to poverty, race relations and gender inequality (Ruddock, 1986; Stenhouse, 1970, 1983). One form of neutrality, *affirmative neutrality*, describes a situation in which teachers present multiple sides of a controversy without revealing which side they support. In *procedural neutrality*, information about the controversy and different points of view are elicited from the students, possibly after opportunity for library-based or Internet-based research. Without neutrality (procedural or affirmative), Stenhouse (1970) argued, “the inescapable authority position of the teacher in the classroom is such that his [sic] view will be given an undue emphasis
and regard which will seriously limit the readiness of the students to consider other views” (p. 7). Quite apart from the danger of encouraging relativism, where any idea is accepted as long as it is someone’s opinion, this is a position that seriously threatens the teacher’s credibility and invites the reasonable question: Do you not have a view, Miss? It is absurd for teachers to pretend that they don’t have a view. It is deplorable for teachers to refuse to state their view, while simultaneously requiring students to state their views. The guidelines issued by the Qualifications and Curriculum Authority (QCA, 2000, p. 35) on presenting a ‘balanced view’ direct the teacher to avoid bias by resisting the temptation to:

– highlight a particular selection of facts or items of evidence, thereby giving them a greater importance than other equally relevant information;
– present information as if it is not open to alternative interpretation or qualification or contradiction;
– set themselves up as the sole authority not only on matters of ‘fact’ but also on matters of opinion;
– present opinions and other value judgements as if they are facts;
– give their own accounts of the views of others instead of using the actual claims and assertions as expressed by various interest groups themselves;
– reveal their own preferences by facial expressions, gestures, tones of voice, etc.;
– imply preferences through choice of respondents to contribute their views to a discussion;
– allow a consensus of opinion that emerges too readily to remain unchallenged.

The notion of presenting a ‘balanced view’ is extremely problematic. What counts as balance? Whose judgement of balance and selection of perspectives is to count? Who decides what counts as relevant or not relevant, accurate or inaccurate, admissible or inadmissible, important or unimportant? Who decides what should be regarded as facts and what is deemed to be opinion? If all students express similar views, who will provide the alternatives? How should the teacher or the class respond to opinions that seem designed for no other reason than to shock, provoke or ‘wind people up’? The key point is that all views embody a particular position, and that position needs to be rationalized and justified if indoctrination is to be avoided. Both teachers and students need to recognize that although ‘balance’ can never be fully achieved, all parties can be forewarned about bias and distortion and forearmed to recognize and deal with it. This is just as important for teachers selecting curriculum materials as it is for students working with them. Oulton et al. (2004) argue that developing a generic understanding of the nature of controversy and the ability to deal with it is more important than developing students’ ability to address any particular issue. In other words, understanding the nature of controversy is step number one. Teachers need to make it explicit to students that views may differ because they are based on different information, different interpretations of the same information or differences in worldviews, values, attitudes, interests, experiences, feelings or emotions. Students need to know that different value judgements are sometimes a consequence of differences in moral codes or ethical principles deriving from different religious, political or philosophical positions. As Ratcliffe and Grace (2003) comment, following the QCA guidelines to the letter in pursuit of a supposed evenhandedness would prevent students from developing the
critical skills necessary for judging the worth and validity of different positions. Following the guidelines would require teachers to give equal time, consideration and weight to views and arguments that are clearly not of equal merit. Moreover, teachers’ views are likely to be evident to students anyway from the questions they ask and the ways in which they respond to (or ignore) student comments, and through tone of voice, maintenance of eye contact (or not), and the ever-potent and revealing classroom body language.

When they come to approach a particular controversial SSI, students need to ascertain the nature and extent of the disagreement. Is it a consequence of insufficient evidence, evidence of the ‘wrong kind’, evidence that is conflicting, confusing or inconsistent, or too complex and difficult to interpret? Is the problem of resolution located in the absence of clear criteria for making a judgement? Is it the case that different criteria point to different solutions or actions? And so on. They may also need to know in what ways personal feelings and emotions or personal experiences are likely to impact the way the issue, the data or the interpretation and conclusion are evaluated. This applies just as much to their evaluation of the teacher’s views as it does to the evaluation of their own views, the views of other students, and the views expressed in the materials under consideration. Indeed, I am in full agreement with Oulton et al. (2004) when they state that: “acceptance that all materials and judgements about teaching and learning strategies are open to bias leads us to argue that teachers should make their position explicit at the start of the exercise so the pupils are aware of potential bias in the way the teacher has arranged the experience and in what they say and do” (p. 417). These authors proceed to add a rider: “This increased openness would not remove from pupils and teachers alike the right to remain silent on some matters that they do not wish to make public” (p. 417).

While I acknowledge the right of an individual student to remain silent, I would not extend that privilege to teachers. Nor would I be supportive of teachers who used their own views as justification for excluding opportunities for students to address issues such as abortion, birth control, genetic engineering and cloning. I believe that it is incumbent on teachers to make provision for students to address a wide range of controversial SSI, particularly those in which they express an interest and those with direct impact on their lives. And I believe that it is incumbent on teachers to share their views on these matters with students and to make explicit the ways in which they have arrived at their particular position. It is also incumbent on teachers to adopt the same stance of critical reflection and open-mindedness that they demand of their students, and to be willing to change or modify their views in the light of new evidence, a new way of interpreting evidence, a reappraisal of underlying values, or whatever. Some years ago, Kelly (1986) proposed the broadly similar approach of “committed impartiality”, in which teachers present multiple sides of an issue or argument and, at some stage, share their own views with the class. In my view, it is crucial that teachers identify, clarify and challenge the assumptions of all positions (including their own), acknowledge the influence of sociocultural context, religious beliefs, emotions and feelings, address issues of rationality, equity and social justice, and encourage critical reflection. Kelly (1986) argued that when students are encouraged to debate and challenge their teacher’s ideas without fear of sanctions, they not only develop argumentation skills, but also build the courage...
for social commitment. According to Kelly, the balance between personal commitment and impartiality catalyses students’ ability to think and argue critically and to express themselves courageously: “When students are treated as colleagues, they feel more grown up” (p. 194).

In discussing the nature of scientific rationality, Helen Longino (1990, 1994, 2002) identifies four conditions that a community of practitioners must be able to meet if consensus is to count as valid and reliable knowledge rather than mere opinion, illustrating her argument in relation to the social organization of the community of scientists. First, she says, there are public forums for the presentation and criticism of evidence, methods, assumptions and reasoning – in particular, conferences, academic journals and the system of peer review. Second, there are shared and publicly available standards that critics invoke in appraising work, including but not restricted to empirical adequacy. Third, the scientific community makes changes and adjustments in response to critical debate, and is clearly seen by practitioners and members of the public to do so. Fourth, the right to submit work for peer appraisal and criticism is open to all practitioners; so, too, the right to publicly criticize the work of others. Further, the critical scrutiny exerted on scientific ideas by peer review and public critique via conferences and journals is the centrepiece of scientific rationality and a guarantee of the objectivity and robustness of the knowledge developed (see chapter 4 for further discussion).

The formal requirement of demonstrable evidential relevance constitutes a standard of rationality and acceptability independent of and external to any particular research program or scientific theory. The satisfaction of this standard by any program or theory, secured, as has been argued, by intersubjective criticism, is what constitutes its objectivity. (Longino, 1990, p. 75)

In addressing SSI in class, teachers should work to establish similar procedures and standards, with “every member of the community… regarded as capable of contributing to its constructive and critical dialogue” (Longino, 1990, p. 132). Of course, students’ views and the actions that may follow from them are likely to be strongly influenced by emotions and feelings, by personal experiences and the experiences of friends and family, and by socioculturally determined predispositions and worldviews. A student’s sense of identity, comprising ethnicity, gender, social class, family and community relationships, economic status and personal experiences extending over many years, will impact on their values, priorities and preferences. It should go without saying that teachers introducing SSI into the curriculum need to be sensitive to these influences, as discussed in the next section of this chapter.

Because values and moral-ethical concerns and personal experiences will play a crucial role in the way students address controversial SSI, we should take steps to assist them in dealing with these matters in a more careful and effective way. Ralph Levinson (2008) makes a powerful case for the role of personal narratives in teaching and learning about controversial SSI, on the grounds that they act as a bridge between formal science and personal experience, provide graphic illustration of social, cultural, political and religious viewpoints, and help to reinforce or problematize warrants and generate rebuttals. Most importantly, personal narratives help students to see issues and events from the standpoint of those who do not
share their own views or experiences. We also need to assist students in recognizing
the ways in which values impregnate and underpin all SSI and help them to
recognize the value-laden nature of scientific practice itself, including the ways in
which science often reflects the interests, values and biases of those who produce
it. We need to assist students in clarifying their own value positions and in considering
what counts as ‘right action’ in particular circumstances. Values in science and
science education are discussed at greater length in chapters 4 and 5. The teaching
of ethics is discussed in chapter 7.

AFFECTIVE AND SOCIAL DIMENSIONS OF LEARNING

Although some specific pedagogical issues related to an SSI-oriented approach will
be discussed in chapter 6, it is important also to address some more general
teaching and learning concerns, particularly with regard to the affective and social
dimensions of learning. More than 40 years ago, David Ausubel (1968) famously
remarked: “If I had to reduce all of educational psychology to just a single principle,
I would say this: Find out what the learner already knows and teach him accordingly”
(p. 337). Following these comments and the accumulation of a vast body of research
into students’ alternative conceptions in science extending over some two decades19, a
number of so-called “constructivist approaches” to teaching and learning science were
developed and became widely accepted as the new orthodoxy of science teaching in
many countries around the world. While these schemes differ a little in detail, they
have certain features in common, and can be usefully summarized as follows.

– Identify students’ ideas and views.
– Create opportunities for students to explore their ideas and test their robustness
  in explaining phenomena, accounting for events and making predictions.
– Provide stimuli for students to develop, modify and, where necessary, change
  their ideas and views.
– Support their attempts to re-think and reconstruct their ideas and views.

In what is probably the most widely cited science education article of the 1980s
and 1990s, Fosner et al. (1982) argued that new learning can be brought about only
when learners are dissatisfied with their current beliefs/understanding and have
ready access to a new or better idea. Also, to be acceptable the new idea must meet
certain conditions: (i) it must be intelligible (understandable) – that is, the learner
must understand what it means and how it can and should be used; (ii) it must be
plausible (reasonable) – that is, it should be consistent with and be able to be reconciled
with other aspects of the student’s understanding; and (iii) it must be fruitful
(productive) – that is, it should have the capacity to provide something of value to the
learner by solving important problems, facilitating new learning, addressing concerns,
making valid and reliable predictions, suggesting new explanatory possibilities or
providing new insight. In summary, conceptual change is made possible when students
understand the limitations of their current views and recognize the need to replace
them. Dissatisfaction with an existing idea may reside in its failure to predict correctly
or to control events beyond its previous restricted context, that is, it is no longer
fruitful in the new situations the learner has to confront. It may also be located in
recognition that the new view meets the conditions of intelligibility and plausibility
more satisfactorily than the existing idea. Taking this view at face value, Hewson and Thorley (1989) describe the conceptual change approach to teaching and learning science as a matter of changing the status of rival conceptions with respect to the three conditions of intelligibility, plausibility and fruitfulness. Put simply, the teacher’s task is to lower the status of the students’ existing ideas and raise the status of the new one. It is assumed that feelings of surprise, puzzlement, unease or curiosity occasioned by the demonstrated inadequacy of existing ideas to explain the new event or phenomenon will act as both a motivating factor and a stimulus for conceptual change. It is further assumed that the collision of existing ideas with new experiences precipitates what Piaget calls “cognitive disequilibrium”, the resolution of which is achieved by cognitive restructuring.

A necessary condition for cognitive restructuring is an opportunity for repeated, exploratory, inquiry-oriented behaviors about an event or phenomena in order to realize that the intact schema option is no longer tenable, and that the only reasonable option is to revise one’s cognitive structure so as to be more consistent with one’s experience (data, measurements, or observations). (Saunders, 1992, p. 138)

However, a host of writers (including West & Pines, 1983; Salmon, 1988; Claxton, 1991; Bloom, 1992a,b; Pintrich et al., 1993; Demastes et al., 1995; Watts & Alsop, 1997; Dole & Sinatra, 1998; Pintrich, 1999; Alsop and Watts, 2000, 2003; Zembylas, 2002a; Hennessey, 2003; Sinatra & Pintrich, 2003; Kelly, 2004; Alsop, 2005; Sinatra, 2005; Johnston et al., 2006; Nieswandt, 2007; Littledyke, 2008) have pointed out the ways in which this rationalist view of learning fails to acknowledge the complexity, uncertainty and fragility of learning and its susceptibility to a whole array of personal and social influences. Any or all of the following could impact on learning: previous experiences; emotions, feelings, values and aesthetics; personal goals and motivation levels; views of learning; social norms and aspirations; general feelings of well-being and satisfaction. It is easy to see how feelings of wonder, awe, delight, amusement, curiosity, indifference, anxiety, uncertainty, boredom, happiness, sadness, indignation, anger, fear, disgust and horror could impact in different ways on a learning task – sometimes favourably with respect to learning and sometimes unfavourably. So, too, could a student’s level of interest, perception of relevance and self-interest, feelings of satisfaction/dissatisfaction, confidence and pride, and their self-image and sense of identity. Aesthetic, political, economic and moral-ethical concerns also play a role. Put simply, how students feel about the ideas being presented to them, for whatever reasons, will influence their learning. Bloom (1992a) shows how emotions, values and aesthetics can influence not only students’ willingness or reluctance to engage in a learning task, but also the kinds of meanings that they construct – in the case of the data he presents, about earthworms. Students are likely to have strong emotional commitment to ideas that they have used successfully in the past, especially in contexts they regard as personally and/or socially important. Indeed, some ideas are so much a part of the student’s everyday life that they are used automatically and unconsciously. Changing them is not easy, especially when they continue to be used by peers, within family groups and in the wider society. Abelson (1986) describes some views as being like “possessions”;
they have become so much a part of the student’s views of self and sense of identity, sometimes held in the face of otherwise substantial changes, that if ever they were abandoned or replaced it would only be with the greatest reluctance and an acute sense of loss and discomfort. When teachers make the assumption that learning science and learning about science are entirely rational activities, and that a clear understanding of the evidential justification of an idea or the logical case for a particular viewpoint will result in ready acceptance by the student, they fail to account satisfactorily for why some students who seem to have the requisite prior knowledge, and the intellectual capability to appraise the evidence and argument, fail to engage in cognitive restructuring. They also tacitly accept the obverse: that when students decline to accept a particular idea it is because they don’t understand the scientific argument that supports it. As a consequence, they may misdirect their teaching efforts and, in doing so, may reinforce the student’s reluctance to accept it. The substance of the foregoing argument is eloquently summarized by Caine and Caine (1991).

We do not simply learn. What we learn is influenced and organized by emotions and mind-sets based on expectancy, personal biases and prejudices, degrees of self-esteem, and the need for social interaction. Emotions operate on many levels, somewhat like the weather. They are ongoing, and the emotional impact of any lesson may continue to reverberate long after the specific event. (p. 82)

Not only has the rhetoric of constructivism frequently neglected the affective dimension of learning, it has also consistently neglected the social dimension. Many constructivist writers have failed to acknowledge that in addition to being driven by the need to make personal sense of the world around them, learners also have to integrate their understanding into the various social contexts in which they are located in ways that are socially acceptable. While constructivists talk at length about finding effective ways of replacing students’ commonsense, everyday knowledge with scientific knowledge, they fail to afford sufficient importance to the fact that it is consensus within social groups that gives status and stability to knowledge and understanding. After all, it is called common sense because it is the sense that is common to the group. It seems that each of us, whether adult or child, needs the approval and support of someone else in order to feel comfortable with our ideas. Thus, we often talk as much to get reassurance from others about our ideas as we do to convince others of our views. As Solomon (1987) says, “We take it for granted that those who are close to us see the world as we do, but, through social exchanges, we seek always to have this reconfirmed” (p. 67). These social exchanges also serve to establish what others think and, thereby, to assist the learning of knowledge that has been validated and approved by the social groups to which we belong. It follows that if we are to change students’ commonsense knowledge, or expand and develop it in order to incorporate scientific ways of understanding, we need to take account of the social forces that will resist change and those that will assist or promote it, and we need to pay much greater attention to the various social contexts in which students move.

One of those social contexts is, of course, the classroom itself. Classrooms are very public places and much learning occurs in group settings. It would be surprising,
therefore, if school-based learning were not greatly influenced by interactions with peers, just as they are influenced by interactions with teachers. In small-group work, for example, it could be argued that the quality of learning is just as much a function of interpersonal relations as it is a function of the cognitive capabilities of the group members. In other words, the social, affective and cognitive are inextricably intertwined. In whole-class activities, learners struggling to make sense of the lesson do so in an environment in which social interaction plays a profound and complex role. Students have many social goals, including making friends, impressing others and establishing social status, perhaps attracting a boyfriend or girlfriend, and so on, any or all of which can interfere with the supposedly rational processes of learning. These ‘goals for classroom life’ will have significant impact on learning as individuals negotiate for themselves a role that maximizes personal benefits, minimizes risks and threats to feelings of personal well-being, and helps them build a sense of personal identity. They will have a profound influence on the likelihood of students replacing their existing ideas with the idea proffered by the teacher, another student or a textbook.

Changing your mind is not simply a matter of rational decision-making. It is a social process with social consequences. It is not simply about what is right or what is true in the narrow rationalist sense; it is always also about who we are, about who we like, about who treats us with respect, about how we feel about ourselves and others. In a community, individuals are not simply free to change their minds. The practical reality is that we are dependent on one another for our survival, and all cultures reflect this fact by making the viability of beliefs contingent on their consequences for the community. (Lemke, 2001, p. 301)

If students are to understand how scientific knowledge is negotiated and deployed within the community of practitioners, and subsequently used to promote particular positions regarding SSI, they need some direct experience of critique and negotiation. They need the opportunity to construct, discuss and debate the merits of their ideas with others. If they are to achieve the intellectual independence we seek, students have to be afforded a substantial measure of responsibility for their own learning. Student-led discussion in small groups is ideal for supporting students as they generate theoretical explanations, build on each other’s ideas and subject ideas to rigorous criticism. Subsequent large group discussion or formal presentation encourages clarity of expression and careful consideration of possible counter arguments. Van Zee and Minstreel (1997) contrast traditional teacher-dominated classroom talk with what they call “reflective discourse”, during which three conditions are met: “(i) students express their own thoughts, comments and questions, (ii) the teacher and individual students engage in an extended series of questioning exchanges that help students better articulate their beliefs and conceptions, (iii) student/student exchanges involve one student trying to understand the thinking of another” (p. 209). But the kind of productive talk envisaged by van Zee and Minstreel doesn’t just happen; it has to be carefully planned and sustained by judicious teacher interventions. Ultimately, the success of talk-based classroom activities depends on establishing a classroom environment in which student-student interaction is
encouraged and supported. A half century ago, Rokeach (1960) observed that some students are more open to new ideas than others, and that these differences are present from an early age. For some, reluctance to change ideas seems to stem from a deep-seated fear of uncertainty. Such students are distrustful of new ideas unless they are presented authoritatively and they seek certainty in knowledge, rather than the ambiguity, uncertainty, fluidity and context-dependence characteristic of SSI and environmental concerns. A very supportive classroom environment is essential if these students are to accommodate to a learning style in which they are encouraged to express their own views, argue for their developing ideas, consider a wide range of alternatives and engage in the cut and thrust of debate. Students need to feel comfortable to listen to the ideas of others, question them, introduce their own ideas, accept criticism, work with others to articulate, modify and develop ideas, and build towards shared understanding.

My own research with Canadian students in Grades 6 to 12 shows that without considerable groundwork by the teacher, free exchange of ideas and criticism is quite rare and meaning is established only tentatively and hesitantly. On occasions, meaning is imposed by bold assertions from the more confident group members, rather than negotiated within the group. Often, genuine understanding doesn’t develop because the group feels the need to reach early and easy consensus. In other words, their task orientation (commitment to ‘getting the job done’) curtails the time needed for matters to be thoroughly discussed. Depending on students’ previous experience of group learning methods, it may be necessary to lay down robust procedural guidelines. Too often, teachers neglect to do so, and fail to provide students with sufficient explicit guidance. In consequence, students commonly lack clear, shared understanding of the purpose of many of the activities in which they are engaged; they are often confused, unfocused, unproductive and apathetic. When explicit guidance is provided, students can be enthusiastic and effective in sharing, criticizing and re-constructing their views and ideas (Barnes & Todd, 1995; Mercer, 1995, 1996). They need to know, for example, the appropriate way to present an argument, listen to an argument and respond to an argument; they need to know how to criticize, accept criticism, argue and reach consensus. This form of learning can be catastrophically undermined if students don’t have the necessary language and social skills to participate appropriately. It can also be catastrophically undermined if learners are unable to deal with the complex and powerful emotions raised by consideration of SSI (a matter to be discussed in chapter 6).

The social context in which the student is located outside school is also a major factor impacting learning. Rejecting knowledge and beliefs that are strongly held within social groups to which the student belongs, or wishes to belong, may be so emotionally stressful that it becomes virtually impossible. Similarly, accepting views that are in opposition to the dominant views within those groups is likely to be a formidable undertaking. At the most extreme, it can be a matter of acquiring and using an alternative worldview, that is, the scientific worldview rather than the worldview that is dominant within those out-of-school contexts (see discussion in chapter 4). Every individual is a member of several social groupings: family group, ethnic group, friendship group, employment group, possibly a religious group, sports group, leisure pursuits group, local community group or Internet chatroom
and listserv group. Effective participation in these groups requires appropriate subcultural knowledge and skills, shared understanding, beliefs, language, code of behaviour, aspirations, values and expectations. As people move from one social context to another, they are invariably required to change their way of speaking, acting and interacting with others in order to be accepted within the group. School is also a distinctive subculture with its own language, code of behaviour, values, goals and expectations. So, too, of course, is science and the school version of it. The greater the differences between a student’s home and peer group subculture and the subcultures of school and school science, the more difficulties the student will encounter in “crossing the border”, that is, in gaining access to school science and being successful there. Costa (1995) describes the ways in which students from different subcultural backgrounds effect (or not) the transition into the subculture of school science. She describes various patterns in relationships between students’ social worlds and their success in school science in terms of five broad categories of student:

— **Potential scientists** – for whom the worlds of family and friends are congruent with the worlds of school and science, and the transition into the culture of school science is smooth and unproblematic. These students have educational aspirations and career plans in which science has a prominent role.

— **Other smart kids** – for whom the worlds of family and friends are congruent with school, but not with science. These students can manage the transition into the culture of school science without too much difficulty. While science is not personally interesting to them, they recognize its ‘gatekeeper role’ and can make instrumental use of it in pursuit of other educational goals.

— **“I don’t know” students** – for whom the worlds of family and friends are inconsistent with both school and science. Transition into the culture of school science is hazardous, though possible at some personal cost. Often, these students find a way of meeting the demands of the system and obtaining reasonable grades without ever really understanding the material.

— **Outsiders** – for whom the worlds of family and friends are discordant with both school and science. These students tend to be disillusioned with or alienated from school in general, so that transition into the culture of school science is virtually impossible. They neither know nor care about science.

— **Inside outsiders** – for whom the worlds of family and friends are irreconcilable with the world of school but potentially compatible with the world of science. Although these students have a natural interest in the physical world and the intellectual ability to cope with science, transition into the culture of school science is prevented by a lack of support both inside and outside school and by their distrust of schools and teachers.

These five student ‘types’ experience the same science curriculum in very different ways, their experiences being positive or negative to the extent that the values, beliefs and expectations of their family and peer groups are consistent with those of science and the classroom. In Costa’s California-based study, all students in the inside outsider category (the group that is potentially well-disposed towards science but is so hostile to school that border crossings are not even attempted) were African Americans. Just as significant is the observation that most of those...
for whom transition into the world of school science was smooth and unproblematic were from White middle-class family groups. It is also the case that transitions were generally smoother for boys than for girls. Most importantly, the categories are not fixed and may shift quite substantially when the educational situation or scientific context changes.

If successful learning depends on learners exploring and developing their personal store of knowledge, and if a significant part of that personal knowledge is experientially and socioculturally determined, and includes powerful affective components, then a student’s social and cultural identity becomes a significant factor affecting learning. In other words, a student’s gender, ethnicity, religion, moral-ethical values and politics, as well as their emotional well-being, impact very substantially on learning. It is fair to say that many teachers have seriously underestimated the difficulties faced by some students. As Lemke (2001) comments, a student “spends most of every day, before and after science class, in other subject-area classes, in social interactions in school but outside the curriculum, and in life outside school. We have imagined that the few minutes of the science lesson somehow create an isolated and nearly autonomous learning universe, ignoring the sociocultural reality that students’ beliefs, attitudes, values, and personal identities – all of which are critical to their achievement in science learning – are formed along trajectories that pass briefly through our classes” (p. 305). In effect, then, the science teacher’s job can be seen as helping students to gain an understanding of what, for many, are alien cultures (the subcultures of science, school and school science) and to assist them in moving freely and painlessly within and between these subcultures and the subcultures of home and community (Aikenhead, 1996, 1997, 2006; Cobern & Aikenhead, 1998; Aikenhead & Jegede, 1999; Hodson, 2001). Others see the science teacher’s role more as a matter of assisting students in deploying more effectively the cultural resources that they bring with them (Seilor, 2001) or as a matter of seeking to merge the “first space” of school science with the “second space” of the home to create a “third space” that brings together the different knowledges, discourses, relationships, aspirations and values in ways that enable new knowledge and discourse to emerge and new identities to be forged (Gutiérrez et al., 1999; Moje et al., 2001, 2004; Gutiérrez, 2008; Zembylas & Avraamidou, 2008). Calabrese Barton et al. (2008) see the science classroom as creating multiple hybrid spaces, depending on the nature of the activity (whole class settings, small group work, individual study, and so on). Within these different spaces there are opportunities for students to craft new forms of participation and construct new identities or, of course, to consolidate or modify existing identities. Issues of identity are discussed further in chapters 3 and 9.

The foregoing discussion suggests that the list of conditions for conceptual change set out by Posner et al. (1982) needs to incorporate an additional element: that students feel comfortable with the new idea, in the sense that it meets their emotional needs and is “culturally safe” and socially acceptable or, at least, non-threatening. Watts and Alsop (1997) and Alsop (1999) argue that for new knowledge to be acceptable, it needs to be salient, palatable and germane. In other words, material has to be noticeable, engaging, stimulating or startling, it has to be appealing and agreeable (certainly not disagreeable or disturbing), and it has to be recognized
as relevant to the learner’s personal needs, interests and aspirations. If this complex of affective and social factors is as important as I am arguing with respect to learning science content and NOS knowledge, how much more significant is it likely to be with regard to controversial and often emotionally charged SSI and environmental concerns? This fusion of the cognitive, affective, aesthetic and social, too often absent from the science classroom, is essential to the kind of radical shift in attitudes and values on which sociopolitical action depends. Some teachers will see this in a positive light, and will seek to use these affective and social dimensions as a stimulus to engaging students’ interest in SSI, getting them to consider moral-ethical issues, and building their commitment to social action (Macy, 1983; Alsop, 2001; Alsop & Watts, 2002; Matthews et al., 2002). Others will see it as constituting a set of problems: how to deal with controversy, how to create the right learning conditions, how to help students cope with powerful emotions, and so on – matters to which I will return in chapter 6.