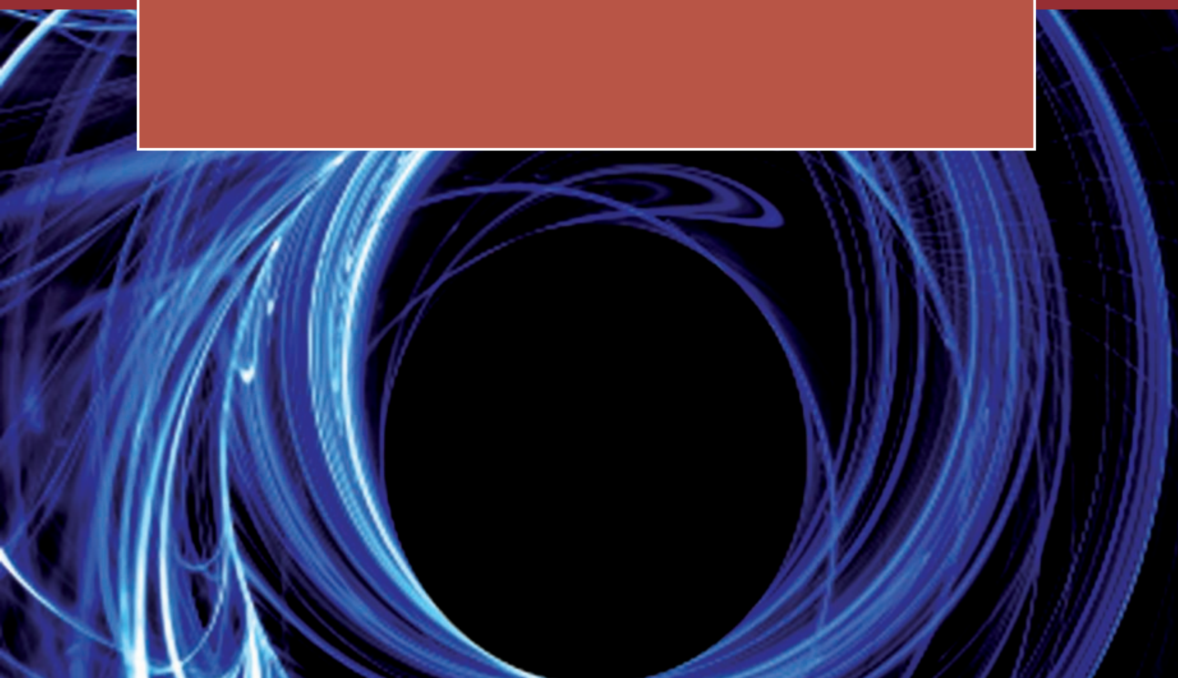
# Towards Scientific Literacy

## A Teachers' Guide to the History, Philosophy and Sociology of Science

Derek Hodson



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*To Susie, for your unwavering love, inspiration and support*

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# PREFACE

My interest in history of science came early. As a schoolboy in the 1950s I always looked forward to the frequently dull science lessons being enlivened by the stories about scientists that sprinkled the pages of science textbooks by E.J. Holmyard and F. Sherwood Taylor. Later, as an undergraduate at the University of Manchester Institute of Science and Technology (UMIST)), I had the great good fortune to attend a series of lectures on the philosophy of science by David Theobald (a natural products chemist) and a wide-ranging course in history of science, from Thales to Dalton, by Brian Pethica (a physical chemist). These were arranged as part of a general studies course requirement, a curriculum planning decision by UMIST for which I will always be grateful. Subsequently, I attended a course in history of technology at UMIST taught by D.S.L. Cardwell, pioneer of history of technology and author of *The Organization of Science in England* (1957) and *Turning Points in Western Technology* (1972). Later still, as a student teacher at the University of Exeter, I was privileged to study with the eminent historian of science, H.J.J. Winter, author of *Eastern Science: An Outline of its Scope and Contribution* (published in 1952). I hereby acknowledge my gratitude to the dedicated and inspired teaching of all these scholars. These rich learning experiences have led me to a lifelong interest in the history and philosophy of science, and more recently in the sociology of science, and to efforts over many years to instill elements of these vast subject areas into school science curricula, courses for teachers at both pre-service and graduate level, professional development programmes for serving teachers, and research agenda of graduate students. This book is an outcome of those efforts. It is intended as a journey through the literature, picking and choosing items that I consider of particular importance in developing students' scientific literacy, as defined in chapter 1, and teachers' capacity to present curricula that afford a much higher profile to HPS than has been traditional – a goal that is in line with much recent writing in science education and a number of prominent reports on science education published in recent years in the United States, United Kingdom and elsewhere.

There are a number of books that cover essentially the same ground – notably works by Chalmers (1978, 1999), O'Hear (1989), Olby et al. (1990), Riggs (1992) and Ladyman (2002). In contrast to the approach taken by these authors, this book is written specifically from the perspective of science education. Its principal concern is to identify what teachers, teacher educators, curriculum developers and science education policy makers should know about the history, philosophy and sociology of science in order to teach more effectively about the nature of science and scientific activity. It is important to state at the outset that this is not a 'how to' book. It does not focus specifically on ways to design effective teaching and learning activities, although such a book is currently in preparation. Rather, it is a 'what' and 'why' book, intended as a guide for making an appropriate selection from the history, philosophy and sociology of science literature for presentation to students.

Although the original sources of the figures used in chapter 3 have been acknowledged, I wish to state here that many of them first came to my attention in the marvellous collection of images, photographs and quotations assembled by David Wade Chambers (1984a,b) under the titles *Putting Nature in Order* and *Is Seeing Believing?* These books constitute an invaluable resource in the design of courses on the nature of science.

Derek Hodson
Toronto
November, 2007

# ACKNOWLEDGEMENTS

Writing can be a very solitary pursuit, though it was not so in this case. In preparing this book I drew on a lifetime of reading, thinking, teaching, researching, writing and arguing about issues in science, philosophy of science, history of science, sociology of science and science education, and on a lifetime of thinking about how to organize and present these ideas to students at primary, secondary, tertiary and graduate study level. So many memories of lively and interesting people, encounters and incidents came flooding back – some pleasant, some stressful and emotionally challenging, some amusing and some sad, but always enlightening. In my mind's eye, many people, from many different schools and universities, were my constant companions as I struggled to make coherent sense of difficult issues. I am immeasurably indebted to all those people and events, spread over many years, for informing and influencing my thoughts *about* science. There is no doubt that my thinking has been sharpened and my views refined through numerous discussions with colleagues and graduate students, particularly at the Ontario Institute for Studies in Education and the University of Hong Kong. I hereby acknowledge my indebtedness to all those people, too numerous to identify by name.

I also extend my thanks to the British Psychological Society, Houghton Mifflin Harcourt Publishing Company, Wiley-Liss Inc., University of California Press, University of Illinois Press and Dr. Richard Duschl for permission to reproduce figures and tables previously published elsewhere.

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Most importantly, no words can fully express my gratitude to my wife, Sue Hodson, for her constant and unwavering love, support and encouragement throughout our years together. You, Susie, make everything worthwhile.

CHAPTER 1

# IN PURSUIT OF SCIENTIFIC LITERACY

## *The Case for History, Philosophy and Sociology of Science*

Nearly forty years ago, as a young and idealistic science teacher, I enthusiastically embraced the Nuffield Science Teaching Project's catchphrase "Being a scientist for the day".[1] Since those heady days, other slogans and rallying calls have come and gone, with varying degrees of impact on classroom practice – among them: *Process, not Product*, *Science for All*, *Less is More* and *Children Making Sense of the World*. Since the early to mid-1990s, the most prominent has been the call for greater *scientific literacy*. Indeed, the notion of scientific literacy has assumed centre-stage in science education debate in several parts of the world and organizations such as the American Association for the Advancement of Science (AAAS, 1989, 1993), the Council of Ministers of Education, Canada (CMEC, 1997) and UNESCO (1993) have used it to frame major efforts to reform the science curriculum. Three questions immediately spring to mind:

– What is scientific literacy?
– Why do we need it?
– What are the curricular implications?

Given its lengthy history in the rhetoric of science education, we could perhaps expect there to be a clear and well articulated definition of scientific literacy. Sadly, this is not the case. While the attainment of scientific literacy has been almost universally welcomed as a desirable goal, there is still little clarity about its meaning (Jenkins, 1990, 1994a, 1997; Krugly-Smolska, 1990; Eisenhart et al., 1996; Millar, 1996; Sutman, 1996; Galbraith et al., 1997; Graber & Bolte, 1997; Hurd, 1998; DeBoer, 2000; Kolsto, 2000; Laugksch, 2000; Solomon, 2001; Tippens et al., 2000; Cajas, 2001; Ryder, 2001; Rudolph, 2005), little consensus about why we need it, and little agreement about precisely what it means in terms of curriculum provision. As Laugksch (2000) observes, significantly different answers to these questions are proferred by the various stakeholders in education, or "interest groups" as he calls them. For example, he argues that the science education community (science teachers, teacher educators and curriculum developers, for example) regard scientific literacy as a kind of code for the goals of science education and frame their discussion in terms of curriculum content, pedagogy and assessment/evaluation procedures, while those with responsibility for science policy are more concerned with public perception of, and support for, the scientific enterprise. Yet others are concerned with the nature of control and priority setting for science, access to science, or keeping the wider public up-to-date on significant scientific development via the media, zoos and museums. As will become apparent in this and succeeding chapters, I have interests in common with each of Laugksch's "interest groups". My principal goal is that *all* students, regardless of gender, ethnicity, religion, sexual orientation, geographical location and current attainment levels, achieve a measure of critical scientific literacy. I also subscribe to the view, outlined at length in Hodson (2003), that science education is incomplete if it does not involve students in preparing for and taking action on matters of social and political importance – a position that Miller (1993) characterizes as *transformational* education.[2]

My use of the term "*universal* critical scientific literacy" signals my rejection of the longstanding differentiation of science education into high status, academic/theoretical courses for those deemed (on the basis of attainment tests) to be 'high ability students' and low status courses oriented towards 'life skills' for the rest (Hodson & Reid, 1988). In my view, we should draw later science specialists from a much wider pool – hopefully approaching 100% of each age cohort – of successful, enthusiastic students who have already achieved critical scientific literacy. If the knowledge, skills and attitudes embodied in the notion of scientific literacy are important, as I claim, they are important for *everyone*. Use of the term "universal *critical* scientific literacy" carries with it a commitment to a much more rigorous, analytical, skeptical, open-minded and reflective approach to science education than many schools provide and 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).

It almost goes without saying that scientific literacy presupposes a reasonable level of literacy in its fundamental sense (Wellington & Osborne, 2001; Fang, 2005). Engagement in science, contribution to debate about science and access to science education are not possible without a reasonable level of literacy. As Anderson (1999, p. 973) states: "reading and writing are the mechanisms through which scientists accomplish [their] task. Scientists create, share, and negotiate the meanings of inscriptions – notes, reports, tables, graphs, drawings, diagrams". Scientific knowledge cannot be articulated and communicated except through text, and its associated symbols, diagrams, graphs and equations. 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. Indeed, it could be said that learning the language of science is synonymous with (or certainly coincident with) learning science, and that *doing* science in any meaningful sense requires a reasonable facility with the 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.

Because of the dependence of science on text, *access* to science also depends on basic literacy, and those whose ability to read and write is poorly developed are unlikely to achieve even a rudimentary level of scientific literacy, despite the prodigious efforts of some teachers to convey scientific understanding through drama, dance, film and other media. Proficient reading of science text involves more than just recognizing all the words and being able to locate specific information, it also involves the ability to infer meaning from the text – in particular, the meaning intended by the author – and to establish relationships between ideas, link personal experiences with text, and transfer understanding from one context to another. Thus, it involves analysis, interpretation and evaluation. In consequence, it depends (in part) on what the reader brings to the task in terms of text interpretation strategies. Despite the often considerable substantive content and the highly specialized language of science, the abilities required to extract meaning from scientific text are largely those required to extract meaning from *any* text, and while content knowledge is vitally important, it is by no means sufficient for a proper understanding of scientific text. Indeed, Norris and Phillips (1994) and Phillips and Norris (1999) have shown that high school students who score highly on traditional measures of science attainment sometimes perform very poorly when asked to interpret media reports of scientific matters. To paraphrase the conclusions of Norris and Phillips (2003), understanding of science text resides in the capacity to determine when something is an inference, a hypothesis, a conclusion or an assumption, to distinguish between an explanation and the evidence for it, and to 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. Put simply, learning to think and reason scientifically requires a measure of facility with the forms and conventions of the language of science. It is not solely a matter of recognizing the words, and using them appropriately, but also the ability to comprehend, evaluate and construct arguments that link evidence to ideas and theories. Thus, teaching about the language of science, and its use in scientific argumentation should be a key element in science education at all levels and there is a clear need for much closer cooperation between science teachers (who need to know much more about the role and function of language) and language arts teachers (who need to know much more about the specific characteristics of scientific language).

If it is correct that most people, including many still in school, obtain most of their knowledge of contemporary science and technology from television, newspapers, magazines and the Internet (National Science Board, 1998; Select Committee, 2000), then the capacity for active critical engagement with text is not only a crucial element of scientific literacy, it is perhaps the *fundamental* element. In that sense, education for scientific literacy has striking parallels with education in the language arts. At the very least, students need to be able to read, understand and evaluate scientific text in a wide variety of forms and styles (textbooks, teacher handouts, newspaper and magazine articles, press releases and news briefs, Internet postings and product labels, as well as graphs, diagrams, tables, chemical equations and mathematical representations), convert empirical data acquired in laboratory and fieldwork activities into text, and articulate and communicate their thoughts, ideas, beliefs and feelings in ways that are intelligible to the intended audience, whether it be peers, parents, teachers or the wider public. 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. In the words of Yore and Treagust (2006), "No effective science education programme would be complete if it did not support students in acquiring the facility of oral science language and the ability to access, produce, and comprehend the full range of science text and representations" (p. 296). What both these authors and I have in mind is a science education very different from the traditional uncritical and unquestioning approach that presents science as dogmatic, fixed and certain.

Scientific literacy also presupposes some basic understanding of mathematics, such as familiarity with simple algebraic equations, the capacity to interpret graphical and statistical data, and sufficient knowledge of the mathematics of probability to understand issues of risk and cost-benefit analysis. It also presupposes some understanding of the dependence of science on mathematics. For example, Kepler would not have derived his Laws of Planetary Motion without Greek knowledge of conic sections accumulated some 1800 years earlier, Hilbert's theory of integral equations was essential for quantum mechanics and Riemann's differential geometry for Einstein's theory of relativity. We can reasonably conclude that the great surge in scientific knowledge since the $17^{th}$ Century can be attributed, in large part, to developments in mathematics and, in particular, the invention of differential and integral calculus.

What else should be regarded as crucial to a claim of being scientifically literate? Understanding the nature of science? Understanding the major theoretical frameworks of biology, chemistry and physics? Understanding the complex relationships among science, technology, society and environment? Knowing about the historical development of the 'big ideas' of science and the circumstances that led to the development of key technologies? Being aware of contemporary applications of science? Having the ability to use science in everyday problem solving? Holding a personal view on controversial issues that have a science and/or technology dimension? Possessing a basic understanding of global environmental issues?

## WHAT IS SCIENTIFIC LITERACY?

The term *scientific literacy* seems to have first appeared in the US educational literature in papers by Paul Hurd (1958) and Richard McCurdy (1958).[3] It was enthusiastically taken up by others as a useful rallying call (see Roberts, 1983, 2007), but had 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 – with the first three categories being designated as the most significant. Almost a quarter century later, *Science for All Americans* (AAAS 1989, p. 4) 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."

However, to suggest that debate had been stagnant during the intervening years would be to seriously misinterpret matters. Indeed, following the work of Milton Pella and his co-workers, there was a period of intense debate, definition and counter-definition, marked by notable contributions from Daugs (1970), Agin (1974), Showalter (1974), Klopfer (1976), O'Hearn (1976) and Pella (1976), and culminating in Gabel's (1976) detailed analysis of the literature in terms of eight dimensions (organization of knowledge, intellectual processes, values and ethics, process and inquiry, human endeavour, interaction of science and technology, interaction of science and society, interaction of science, technology and society) and nine categories of educational objectives (Bloom's six categories of cognitive objectives plus three affective objectives – valuing, behaving and advocating). As Roberts (1983) comments, "What is immediately striking about Gabel's model is that it includes, under the definition of scientific literacy, every category of science education objectives… it now means virtually everything to do with science education" (p. 22).

Of course, interest in the notion of scientific literacy has not been restricted to those concerned with science education in school and university. As 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" (Fitzpatrick, 1960, p. 169). At about the same time, Alan Waterman (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).

In the United Kingdom there has been a tradition of concern for the public understanding of science dating back to the early years of the $19^{th}$ Century (Shen, 1975; Jenkins, 1990). In more recent times the Royal Society (1985) noted that "Improving the 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 Royal Society's 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" (p. 9) serves to underline 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. According to Klopfer (1969), this distinction should be reflected in a differentiated school science curriculum: "One curricular stream… designed for students planning to enter careers as scientists, physicians, and engineers… the other… designed for students who will become the nonscientist citizenry… housewives, service workers, salesmen etc…. Differentiation of students (should) begin at about age fourteen when they choose the high school they will attend" (p. 203).

Distinctions are drawn somewhat differently by Shen (1975), who sees scientific literacy as falling into three categories: *practical*, *civic* and *cultural*. Practical scientific literacy is knowledge that can be used to help solve life's everyday problems; civic scientific literacy is the knowledge necessary to play a full part in key decision-making in areas such as health, use of natural resources, energy policy and environmental protection; cultural scientific literacy involves knowing those ideas in science that represent major cultural achievements. Essentially the same categorization lies behind the exercise devised by Robin Millar (1993) for teachers and others in science education to justify (or not) the inclusion of particular topics in the school science curriculum on utilitarian, democratic or cultural grounds. Wellington (2001) makes a similar point when he argues that there are three sets of arguments for justifying curriculum content: (i) the intrinsic value of science education; (ii) the citizenship argument; (iii) utilitarian arguments.

(i) *Intrinsic Value*
– Making sense of natural phenomena; de-mystifying them.
– Understanding our own bodies, our own selves.
– Interesting, exciting, and intellectually stimulating.
– Part of our culture, our heritage.

(ii) *Citizenship Arguments*
– Science knowledge and knowledge of scientists' work are needed for all citizens to make informed decisions in a democracy.
– Key decision makers (e.g., civil servants, politicians) need knowledge of science, scientists' work and the limitations of scientific evidence to make key decisions, e.g., on foods, energy resources.

(iii) *Utilitarian Arguments*
– Developing generic skills that are of value to all, e.g., measuring, estimating, evaluating.
– Preparing some for careers and jobs that involve some science.
– Preparing a smaller number for careers using science or as 'scientists'.
– Developing important attitudes/dispositions: i.e., the 'scientific attitude' of curiosity, wonder, healthy skepticism, an enquiring mind, a critical/analytical disposition.

In contrast to Klopfer's advocacy of a differentiated curriculum, Wellington states that each orientation is important for every student. As a variant on this principle of common provision, 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).[4]

While Branscomb (1981) expanded Shen's categorization into eight forms of scientific literacy (methodological science literacy, professional science literacy, universal science literacy, technological science literacy, amateur science literacy, journalistic science literacy, science policy literacy and public science policy literacy), each related to a particular role in society, Shamos (1995) maintained a three-fold categorization. However, unlike other writers, Shamos sees his categories as hierarchical. For him, *cultural* scientific literacy is the simplest, most basic level of literacy. It comprises the basic understanding needed to (i) make sense of articles in newspapers and magazines, and programmes on television, (ii) communicate with elected representatives, and (iii) 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). Substantially the same hierarchy is proposed by Bybee (1997): *nominal* scientific literacy (knowing scientific words but not their meaning), *functional* scientific literacy (reading and writing science using simple and appropriate vocabulary) and *conceptual and procedural* scientific literacy (a thorough understanding of both the conceptual and procedural bases of science). Bybee adds a fourth category: *multidisciplinary* 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. As Fensham (2002) argues, the first category is no literacy at all, the second is "functional only in a direct vocabulary sense, and not in any generalized operational sense" (p. 17), while the fourth may comprise an unrealistic target for many students.

A general criticism of these attempts to define scientific literacy is that they are couched in terms of what scientists and/or science educators regard as essential knowledge and understanding. An entirely different approach to the notion of functional scientific literacy was taken by researchers at the University of Leeds. Loosely structured interviews were used to ascertain the "practical knowledge in action" assembled and deployed by individuals or groups of adults engaged in understanding and/or acting upon some issue with a scientific dimension, such as managing a domestic energy budget within a low, fixed income or raising a child born with Down's Syndrome (Layton et al., 1986, 1993; Jenkins, 1996a, 1999). It quickly became clear that the science needed for solving the problems of everyday life is very different in form from the science presented in the school curriculum. For example, says Jenkins (1999, p. 705), it makes more sense in a practical context to regard heat as "something which 'flows' rather than in terms of the 'more correct' kinetic theory of matter". The ways in which everyday problems are confronted and solved is also very different from the way problem-solving is approached in school science lessons.

> 'Citizen thinking', i.e., everyday thinking, turns out to be much more complex and less well understood than scientific thinking and, as might be expected, well adapted to decision-making in an everyday world which, unlike science itself, is marked by uncertainty, contingency and adaptation to a range of uncontrolled factors. (Jenkins, 1999, p. 704)

This conclusion, which has much in common with the now extensive literature in situated cognition, has prompted Peter Fensham (2002) to state that it is "time to change drivers for scientific literacy" and to abandon the traditional ways of identifying science content knowledge for the school curriculum. More in line with Fensham's recommendation than most contemporary science education programmes would be a curriculum designed in accordance with the findings described by Law (2002) arising from a study in which she and her co-researchers asked leading scientists, health care professionals, local government representatives, managers and personnel officers in manufacturing industry, and the like, about the kind of science and the kind of personal attributes and skills that are of most value in persons employed in their field of expertise. Similarly, Duggan and Gott (2002) sought to identify the science used by employees in five science-based industries: a chemical plant manufacturing cosmetics and pharmaceuticals, a biotechnology company producing diagnostic kits for medical use, an environmental analysis laboratory, an engineering company manufacturing pumps for the petrochemical industry and an arable farm. What they found was that most of the necessary science was learned on-the-job rather than in school. This finding is mirrored in work by Chin et al. (2004) and Aikenhead (2005). The latter study concluded that school science is "focused predominantly on declarative knowledge while workplace knowledge is focused predominantly on procedural knowledge" (p. 129) – that is, 'knowing *that*' is emphasized in school and 'knowing *how*' in the workplace. These studies raise important questions about the purpose of scientific literacy and the motives of the different stakeholders in promoting it.

Before proceeding to discussion of these matters, it is worth noting that scientific literacy has a significant metacognitive dimension. Students need to know what they know, how and when that knowledge can and should be utilized, how to recognize deficiencies in their knowledge and how to compensate for them. It is metacognitive knowledge and skills that enable an individual to promote and monitor her or his learning. Pintrich (2002) refers to three categories of metacognitive knowledge: (i) *strategic knowledge* – knowledge of general thinking skills to facilitate learning and problem solving; (ii) *knowledge about cognitive tasks* – understanding when and how to apply various strategies; and (iii) *self knowledge* – knowledge of one's own strengths and weaknesses. A number of authors have argued that all meaningful construction and evaluation of knowledge, whether by means of reading, talking or writing, depend largely on metacognition (Holliday et al., 1994; Keys, 1999; Wallace et al., 2003; Wallace, 2004). Effective readers apply a knowledge of their own strengths and weaknesses to organize prior knowledge and relate it to new information, and to elaborate on the ideas they locate in the text; effective writers consistently judge the match between the information and ideas they are trying to articulate and the language they are using to represent them. To construct a scientific argument, whether it is delivered orally or in written form, it is necessary to monitor and evaluate the match among the various components of the argument

## WHY DO WE NEED SCIENTIFIC LITERACY?

Reviewing what they describe as an extensive and diverse literature, Thomas and Durant (1987) identify a range of arguments for promoting the public understanding of science, including benefits to science, benefits to individuals and benefits to society as a whole.

Benefits to science are seen largely in terms of increased numbers of recruits, greater support for scientific research and more realistic public expectations of science. Notwithstanding the massive research endeavours of the pharmaceutical industry, the electronics industry, the armaments and aircraft industry, and other business enterprises, a great deal of the financial support for fundamental scientific research derives from public funds.[5] Thus, it is argued, the self-interests of scientists demands that they keep the tax-payer well informed about what scientists do, and how they validate their research findings and theoretical conclusions, because a well-informed public is more likely to be supportive of such high levels of financial investment. In developing this line of argument, Schwab (1962) advocated a shift of emphasis away from the learning of scientific knowledge (the products of science) towards an understanding of the processes of scientific inquiry because it can 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). Jenkins (1994b) makes the related point that enhanced public understanding of science enables 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 (and science education). A related argument advanced by Shamos (1993) is 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).

Some years ago, Isaac Asimov (1983) suggested that "without an informed public, scientists will not only be no longer supported financially, they will be actively persecuted" (p. 109). More recently, Stuewer (1998) has provided a wonderfully colourful description of the scientist as "exactly what the medicine-man is for the savage: namely, a mysterious ambivalent figure, who is to be worshipped as the carrier of recondite knowledge and the agent of recondite powers; and who is at the same time to be feared, even hated, and to be put in his place. The medicine-man may be a power, but he is a very acceptable sacrifice to the gods" (Wiener (1950), cited by Stuewer, p. 25). While open hostility towards science and scientists is still rare and the prospect of sacrifice remote, there is certainly much public suspicion of science and a significant decline in public confidence in scientists, largely as a consequence of the BSE (bovine spongiform encephalopathy) or ‘Mad Cow Disease’ episode in the United Kingdom, anxiety about the environmental impact of genetically engineered crops, the conspicuous failure of scientists over many years to reach consensus about the causes and significance of global warming and climate change,[6] the appearance of scientists as ‘expert witnesses’ for both sides in legal disputes (for example, concerning the practices of tobacco companies), the use of ‘purpose-built’ scientific research in advertizing to promote particular business interests, increasing domination of scientific research by industrial and military interests, and the sometimes cavalier disregard that some scientists exhibit towards the social and ethical issues raised by contemporary science and technology. As Barad (2000) comments, “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 making his case for increased levels of scientific literacy, 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 is 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, is perhaps much more likely to be skeptical, suspicious or even distrustful of scientists, and much more likely to *challenge* the nature of scientific research and the direction of technological innovation. Of course, while increased critical scrutiny of science may ensue, increased public control of the scientific enterprise is not guaranteed by enhanced scientific literacy alone, even if universal. What is needed is scientific literacy allied to *political* literacy and a commitment to sociopolitical involvement – hence my arguments elsewhere (Hodson, 1994, 2003) for a curriculum oriented toward citizen action.

Arguments that scientific literacy confers benefits on *individuals* come in a variety of guises. For example, it is commonly argued that scientifically literate individuals have access to a wide range of employment opportunities and are well-positioned to respond positively and productively to the introduction of new technologies into 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). Moreover, those who are scientifically literate are better able to cope with the demands of everyday life in an increasingly technology-dominated society, better positioned to evaluate and respond appropriately to the supposed “scientific evidence” used by advertizing agencies and politicians, and better equipped to make important decisions that affect their health, security and economic well-being.

> 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)

There is a cluster of arguments that focus on the intellectual, aesthetic and moral-ethical benefits conferred on individuals by scientific literacy. In the first two arguments there are strong echoes of C.P. Snow’s (1962) assertion that science is “the most beautiful and wonderful collective work of the mind of man” (p. 14) and, therefore, as crucial to contemporary culture as literature, music and fine art. Indeed, Dawkins (1998) asserts that “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). Notwithstanding the sexist language so common forty years ago, Warren Weaver perfectly encapsulates this particular rationale for scientific literacy:

> The capacity of science progressively to reveal the order and beauty of the universe, from the most evanescent elementary particle up through the atom, the molecule, the cell, man, our earth with all its teeming life, the solar system, the metagalaxy, and the vastness of the universe itself, all this constitutes the real reason, the incontrovertible reason, why science is important, and why its interpretation to all men is a task of such difficulty, urgency, significance and dignity. (Weaver, 1966, p. 50)

The assertion that the ethical standards and code of responsible behaviour acquired through scientific literacy will lead to more ethical behaviour in the wider community is a particularly fascinating one. Paraphrasing the arguments of Jacob Bronowski, Shortland (1988) summarizes the 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). Harre (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, 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 ethical principles. Scientific literacy doesn't just result in more skilled and more knowledgeable people, it results in *wiser* people, well equipped to make morally and ethically superior decisions. Given the findings from sociology of science to be discussed in chapter 7, there are good reasons to dismiss this claim as a ludicrous flight of fancy and to argue, instead, that science would benefit from transfer of ethical standards *in the opposite direction.*

Arguments that increased scientific literacy would confer benefits on society as a whole include (i) the familiar and increasingly pervasive economic argument (closely linked, of course, with military and ideological arguments[7]), (ii) claims that it enriches of the cultural health of the nation and intellectual life in general, and (iii) belief in its capacity to enhance democracy and promote responsible citizenship In recent years, the economic argument has become the predominant rationale for scientific literacy in North America (Garrison & Lawwill, 1992). It is a powerful and persuasive one, as illustrated by the Government of Canada's (1991) attempt to establish a link between school science education and a culture of lifelong learning as the key to the country's prosperity.

> 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 (2000a) 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 sustains and develops the economic well-being of a nation. Put simply, continued economic development brought about by enhanced competitiveness in international markets (regarded as incontrovertibly a "good thing") depends on science-based research and development, technological innovation and a steady supply of scientists, engineers and technicians, all of which ultimately depend on public support for state-funded science and technology education in school. Moreover, the argument goes, increased scientific literacy is likely to sustain high levels of consumer demand for technologies perceived by such scientifically literate individuals as desirable. An indication of the extent to which this ideology has permeated the Ontario (Canada) curriculum can be gleaned from a simple count of key words in the Technological Education Curriculum for Grades 11 and 12 (Ministry of Education & Training, 2000b): markets/marketing = 46, consumer = 15, client/customer = 72, management = 59, industry = 217, sustainability = 0, recycle = 0, ecosystem = 0, interdependence = 0, values = 0

(Elshof, 2001). It is also worth noting that the *People and Skills in the New Global Economy* report (Ontario Premier's Council, 1990) was prepared by a panel comprising five academics, seven politicians three trade union leaders and nineteen company presidents (Davis, 2000). It is also noteworthy that there were only four women among the 34 council members.

Before proceeding further, it is worth noting that language is not neutral. Those who gain control of common language usage determine how we conceptualize important issues; they set the agenda for debate and, in effect, determine the way we think and what we value. All language carries a substantial sub-textual cargo of meaning intended to create a particular view of the world.[8] Its power is located in the ways in which it determines how we think about society and our relations with others, and in its impact on how we act in the world. When deployed effectively, it creates a particular social reality. Indeed, rhetoric becomes reality and those who think differently, and have different values, are regarded as deviant or aberrant. Strategies include presenting one's own position as natural or as plain common sense, thus implying that there is a conspiracy among one's opponents to deny the truth or to promote what is fashionable or 'politically correct' (itself a term that has acquired substantial pejorative connotations).

> This is a powerful technique. First, it assumes that there are no *genuine* arguments against the chosen position; any opposing views are thereby positioned as false, insincere or self-serving. Second, the technique presents the speaker as someone brave or honest enough to speak the (previously) unspeakable. Hence the moral high ground is assumed and opponents are further denigrated. (Gillborn, 1997, p. 353)

Hence, when school science lessons present students, almost daily, with a language that (i) promotes economic globalization, increasing production and unlimited expansion, (ii) sees unfettered technological production and spiraling consumption as "progress", (iii) regards job satisfaction as the accumulation of wealth and material goods, and (iv) equates excellence with competition and "winning at any cost", it is co-opted into the manufacture and maintenance of what Bowers (1996, 1999) calls the *myths of modernity*: "that the plenitude of consumer goods and technological innovation is limited only by people's ability to spend, that the individual is the basic social unit… that science and technology are continually expanding humankind's ability to predict and control their own destiny" (1996, p. 5). At risk from this new "reality" are the freedoms of individuals who think differently, the spiritual well-being of those who would live differently, and the integrity of the planet's complex and delicate ecosystems. In Edmund O'Sullivan's (1999) words:

> Our present educational institutions which are in line with and feeding into industrialism, nationalism, competitive transnationalism, individualism, and patriarchy must be fundamentally put into question. All of these elements together coalesce into a world view that exacerbates the crisis we are now facing. (p. 27)

Many in the economically under-developed parts of the world see globalization as a renewed form of colonization, a form of cultural and economic imperialism that threatens to destroy rather than foster their economic and social well-being, that commodifies both natural resources and people, locates them on the periphery of key decision-making (or excludes them entirely) and compounds their powerlessness, poverty and dispossession (Muchie & Xing, 2006). As Roseneau (1992) observes, the self-serving policies of international organizations such as the IMF, World Bank, OECD and G-7 in many under-developed and developing nations constitute "governance without government".

> While neo-liberalism may mean less government, it does not follow that there is less governance. While… neo-liberalism problematises the state and is concerned to specify its limits through the invocation of individual choice… it involves forms of governance that encourage both institutions and individuals to conform to the norms of the market. (Larner, 2000, p. 12 – cited by Bencze & Alsop, 2007, p. 3)

> On the surface, [globalization] is instant financial trading, mobile phones, McDonald's, Starbuck's, holidays booked on the net. Beneath this gloss, it is the globalization of poverty, a world where most human beings never make a phone call and live on less than two dollars a day, where 6,000 children die every day from diarrhoea because most have no access to clean water. (Pilger, 2002, p. 2)

It is clear that little of the world's poverty, injustice, terrorism and war will be eliminated, and few among the litany of environmental crises (ozone depletion; global warming; land, air and water pollution; deforestation; desertification; and so on) will be solved, without a major shift in the practices of western industrialized society and the values that sustain them. Interestingly, one of the keys to ameliorating the current situation may lie in increased levels of scientific literacy among the world's citizens – an idea explored a little in the following section and at length in Hodson (2003).

> The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics and technology and to acquire scientific habits of mind; without a scientifically literate population, the outlook for a better world is not promising. (AAAS, 1989, p. 13)

The case for scientific literacy as a means of enhancing democracy and responsible citizenship, and resisting the consumer juggernaut, 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). Whether *wisdom* is the likely outcome of enhanced scientific literacy in the wider community depends crucially, of course, on how notions of scientific literacy are translated into curriculum practice. In similar vein, Chen and Novick (1984) express concern about the fragility of democracy and see enhanced scientific literacy as 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). This, of course, presupposes that we aim for *universal* scientific literacy, as argued above. What is clear is that democracy is strengthened when all citizens are equipped to evaluate Socioscientific issues (SSI) and make informed decisions on matters of personal and public concern.

Enhancing scientific literacy might also be the most effective way to combat (i) the naïve trust that many students have in the Internet, accepting almost anything and everything as equally valid and reliable, and forming their views on all manner of topics on the basis of half an hour of exploration with Google, (ii) the distrust with which many people regard any argument that deploys statistics (because, they say, "statistics can prove anything!"), (iii) the increasing tendency to succumb blindly to the seductions of the now all-too-prevalent "alternative sciences" such as iridology and reflexology, (iv) 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, and (v) the continuing fascination of so many with astrology, ESP, "ancient astronaut" theories and spurious "mysteries" such as the Bermuda Triangle. Interestingly, and with characteristic idiosyncrasy, Dawkins (1998) develops the argument that enhanced scientific literacy results in better decision making into an assertion that "lawyers would make better lawyers, judges better judges, parliamentarians better parliamentarians and citizens better citizens if they knew more science, and more to the point, if they reasoned more like scientists". This is, in essence, the case being argued in this chapter, although my focus is better decisions by all citizens (whether they are journalists, business people, civil servants, teachers, police officers, or whatever) in the context of SSI. It is also my contention that the kind of critical scientific literacy I have in mind will serve to help *scientists* make better decisions, in the sense that their judgements focus more attention on the economic, social, cultural, political and moral-ethical dimensions of their work.

## WHAT CAN WE CONCLUDE?

Where does all this propaganda for scientific literacy leave us? Can we be confident that almost half a century of debate has finally answered the three questions posed at the beginning of the chapter? It seems that the case for greater scientific literacy, and the kind of curriculum proposals that would follow from it, change with social context. They are a product of their time and place: they do not easily cross national or cultural boundaries (Tippens et al., 2000) and do not transfer comfortably from one era to another. Ogawa (1989), for example, expresses grave reservations about the inherent neo-colonialist aspects of 'transplanting' Western conceptions of scientific literacy into the education systems of non-Western countries, and Clay (1996) remarks: "In its very structure our view of the world is so deeply imbued with the dominant scientific method that to encompass the multiplicity of other equally valid views held in societies beyond our own, we need to encompass different scientific literacies" (p. 190). These issues, the validity of Clay's claim that there are such alternative literacies, and discussion of various attempts to incorporate traditional knowledge into a curriculum that also presents Western science are outside the scope of this book (but see Aikenhead, 2002; Gitari, 2003, 2006; Palefau, 2005).

It almost goes without saying that as science itself changes and develops, so our view about what counts as legitimate scientific literacy also changes. Apart from the need to update curriculum content to keep pace with our rapidly expanding scientific knowledge, there is an urgent need to acknowledge and respond to the many changes in the "social and economic characteristics, ethos, practice, and culture of science" (Hurd, 2002, p. 5). The way science is presented in many conventional science curricula bears very little resemblance to the kind of research carried out in the laboratories of the early 21$^{st}$ century, and the values that underpin this research are very far removed from the traditional portrayal of science as the disinterested pursuit of objective truth. With the increasing industrialization and militarization of the scientific enterprise, for example, previous claims for the cultural and ethical value of scientific literacy seem hopelessly misplaced, if not downright dishonest (Jenkins, 1990), and while the claims that scientific literacy builds economic prosperity may have become more plausible and inviting to some, they have become less morally and ethically defensible in respect of environmental impact and social, cultural and economic consequences for the less fortunate members of society, both within and beyond the developed world.

So are there, one might ask, any elements of scientific literacy that are valid in all contexts and for all time? My answer is "Yes", if scientific literacy means knowing what scientific resources to draw on, where to find them and how to use them (Fourez, 1997) – including the "proper use of scientific experts" (Shamos, 1995, p. 217). My answer is "Yes", if the real function of scientific literacy is to confer a measure of intellectual independence, to help people learn how to think for themselves and to reach their own conclusions about a range of issues that have a scientific and/or technological dimension. My answer is "Yes", if scientific literacy is sought not because it improves the economy, produces more "technological goodies" or provides more job opportunities for individuals, but because it liberates the mind. 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). More recently, the OECD's Programme for International Student Achievement (PISA) proposed 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). There are strong echoes here of Arons' (1983) emphasis on the ability to "discriminate, on the one hand, between acceptance of asserted and unverified end results, models, or conclusions, and on the other, understand their basis and origin; that is, to recognize when questions such as "How do we know?" "Why do we believe it?" "What is the evidence for it?" have been addressed, answered, and understood, and when something is being taken on faith" (p. 93). Similar capabilities have sometimes been included in the notion of *intellectual independence* (Munby 1980; Aikenhead 1990; Norris 1997). Without such capabilities, citizens are "easy prey to dogmatists, flimflam artists, and purveyors of simple solutions to complex problems" (AAAS, 1989, p. 13) – including, one might add, some otherwise respectable scientists, politicians and commentators who seek to intimidate the public through their facility in a mode of discourse unfamiliar to many citizens.

Dearden (1968) argued that personal autonomy (the achievement of which, for him, was the prime purpose of education) has three major elements: first, an independence from authorities; second, a disposition to test the truth of things for oneself; third, an ability to deliberate, form intentions and choose in accordance with a scale of values that is self-formulated. In Guy Claxton's (1991) words, "Nothing could be of greater value than the ability to make your own life up as you go along: to find for yourself what is satisfying; to know your own values and your own mind; to meet uncertainty with courage and resourcefulness; and to appraise what others tell you with an intelligent and healthy skepticism" (p. 130). Of course, in many aspects of modern life we are increasingly dependent on 'experts' and 'authorities' of various kinds. 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 and 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. 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. It is crucial, too, that we understand the ways in which all manner of human interests can and do shape the 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'. In a very real way, critical scientific literacy, and the intellectual independence it bestows, enables us to decide which experts we can trust and rely on. As Ungar (2000) remarks, "after a decade of clipping articles from *Science* and *Nature*, my sense that climate change is real ultimately boils down to picking the experts you think you can rely on" (p. 297). 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, television news and documentaries, for example. 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. There is also 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 build or consolidate confidence in science and scientists. My interpretation of the notion of critical scientific literacy encompasses the capacity to read reports involving science (in all forms of communication in an informed and critical way in order to form one's own judgement about what to believe, what to doubt and what to reject.

Hurd (1998) sums up this *critical* dimension of scientific literacy, and its roots in learning *about* science, when he defines a scientifically literate person as someone who "distinguishes and recognizes expertise, dogma, pseudoscience, the temporal nature of knowledge, effective argumentation, and relationships among claims, evidence, and warrants" (p. 24). What Hurd doesn't mention 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 largely 'technical problems', for which experts can be relied upon to provide the answers. What we should be seeking is political engagement of citizens in monitoring and, to an extent, directing the course of scientific and technological development.

It is timely, 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)

In practice, as Davies (2004) reminds us, 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). I tend to agree that there is a depressing tendency to equate science education for citizenship with the inclusion of common everyday examples 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. However, I am enormously encouraged by the authors of *Science For All Americans* (AAAS, 1989, p. 12), who direct attention towards scientific literacy for a more socially compassionate and environmentally responsible democracy when they assert that science can provide knowledge “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” and without which, they say, “we are in danger of recklessly destroying our life-support system”. I am even more encouraged by the radical scholarship of Roth and Désautels (2002, 2004) and Roth and Barton (2004) – in particular, their vision of science education *as* and *for* sociopolitical action. Not only is responsible social action the motive for achieving scientific literacy it is also, sometimes, the means of achieving it.

What are the essential elements of this kind of scientific literacy? Perhaps, and somewhat paradoxically for an overall argument so politically distant from my own, the answer can be found in the writing of Longbottom and Butler (1999):

> Science education provides ideal opportunities to engage in a wide range of careful investigations and problem-solving activities, where mistakes and wishful thinking are readily exposed. Science education can value creativity but not accept personal theories as an endpoint. The ability to adjudicate between knowledge claims in ways independent of human desires is a special feature of science that has allowed it to build up a public body of reliable knowledge. Science education should convey these aspects of science. (p. 488)

In common with several others, these authors seem to be saying that scientific literacy for active citizenship, responsible environmental behaviour and social reconstruction lies more in learning *about* science and in *doing* science than it does in learning science.[9] No science curriculum can equip citizens with thorough first-hand knowledge of all the science underlying all important issues. Moreover, much of the scientific knowledge learned in school, especially in the rapidly expanding fields of the biological sciences, will be out-of-date within a few years of leaving school. However, science education can enable students to understand the significance of knowledge presented by others and it can enable them to evaluate the validity and reliability of that knowledge and to understand why scientists often disagree among themselves on such major matters as climate change (and its causes) without taking it as evidence of bias or incompetence. Of course, they also need to know that bias and incompetence do sometimes occur. Thus, students need to have a clear understanding of what counts as *good* science (i.e., a well designed inquiry and a well argued conclusion) and be able to detect bias and self-interest. As Geddis (1991) comments students need to be able to “uncover how particular knowledge claims may serve the interests of different claimants… they need to attempt to unravel the interplay of interests that underlie these other points of view" (p. 171).

It is certainly not my intent to argue that knowledge of the major concepts, ideas and theories of science is unimportant.[10] It would be a very curious state of affairs indeed to claim scientific literacy and admit to knowing no science at all! Nevertheless, the science content of scientific literacy is not my concern here. Of pertinence here are those elements of the history, philosophy and sociology of science that would enable 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, a developing capacity to deal with the moral-ethical issues that attend some scientific and technological developments, and some experience of conducting authentic scientific investigations for themselves and by themselves (Hodson, 2006). While we cannot provide all the science knowledge that our students will need in the future (indeed, we do not know what knowledge they will need) and while much of the science they will need to know has yet to be discovered,[11] we *do* know what knowledge, skills and attitudes will be essential to appraising and forming a personal opinion about the science and technology dimensions of real world issues. If students acquire good learning habits and attitudes towards science during the school years, it will be relatively easy for them to acquire additional scientific knowledge later on, as and when the need arises, provided that they have also acquired the language skills to access and evaluate relevant information from diverse sources. Of course, to be scientifically literate in the sense I am arguing for in this chapter, students will also need the language skills to express their knowledge, views, opinions and values in a form appropriate to their purpose and the audience, and to participate in public debate about SSI. Learning *about* science is rather different. Gaining robust familiarity with key issues in the history, philosophy and sociology of science requires lengthy and close contact with someone already familiar with them – that is, a teacher or scientist who can provide appropriate guidance, support, experience and criticism.

Of course, not everyone shares the view that understanding about the nature of science is central to science education and the notion of critical scientific literacy. Without much in the way of justification of their view, Wilson and Cowell (1982) assert that "anyone who believed that what (say) Popper or Kuhn were concerned with was central to *education* in science would, surely, either not know the kinds of issues these philosophers were trying to tackle or not have a firm grasp on the idea of education" (p. 39). I will leave readers to form their own views, content in the persuasiveness of arguments presented in this chapter. Chapters 3 to 8 identify some of the ideas in the vast literature of history of science, philosophy of science and sociology of science that are of value in constructing a science curriculum capable of attaining universal scientific literacy, in the sense defined here. First, though, it is important to consider the understanding that many students currently hold about science and scientists, the views promoted by their teachers and textbooks, and the ways in which this research in this area is conducted.

## ENDNOTES

1 In the Nuffield approach, learning science and doing science were regarded as equivalent activities. Indeed, teachers were encouraged to believe that "intellectual activity is the same whether it is at the frontier or in a third grade classroom… The schoolboy learning physics *is* a physicist" (Bruner, 1960, p. 14, emphasis added). Similarly, students following the ChemStudy courses in the United States were told that "they would see the nature of science by engaging in scientific activity, thereby 'to some extent' becoming scientists themselves" (Pimental (1960, p. 1 and Preface) – cited by Jenkins, 1996b, p. 137). Interestingly, some advocates of constructivist pedagogy adopt an even more ludicrous and educationally dangerous position when they declare that science is "an activity that is carried out by all people as part of their everyday life" (Ministry of Education, New Zealand, 1993, p. 9).

2 Miller (1993) outlines three basic positions for analysing and describing curricula: *transmission*, with its focus on traditional subjects taught largely through traditional didactic methods; *transaction*, in which education is seen as a dialogue between student and curriculum, and through which the student reconstructs knowledge; *transformation*, which is concerned primarily with individual and social change.

3 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).

4 Millar (2006) describes some initial responses to *Twenty First Century Science*, a major curriculum project in England. Aimed at 15 and 16 year olds, the course comprises two equal parts: a "core science course" focused on science education for citizenship, and a more content-oriented "additional science" course, which is offered with either a "pure" or "applied" emphasis. According to Millar, teachers generally perceive the citizenship emphasis of the core science course as having a marked beneficial impact on student interest and engagement, they report favourably on the relevance of the course, incorporation of moral-ethical issues, emphasis on ICT and its use of case studies and debate to promote critical thinking, though the latter activities and the language demands of the curriculum resources are reported to have created major new demands on both students and teachers.

5 In the United States, federal funding for research carried out by the National Science Foundation, the National Institutes of Health, the Department of Defense, the Department of Agriculture and NASA amounts to approximately $80 billion per annum.

6 Thankfully, 2007 saw a welcome but cautious dawning of awareness of these matters, prompted in part by Al Gore's film documentary *An Inconvenient Truth* and the publication of the 4$^{th}$ assessment report of the Intergovernmental Panel on Climate Change (IPCC) under the title "Climate Change 2007". Speaking of the earlier publication of the IPCC Assessment Report for 2007, Achim Steiner (Executive Director of the UN Environment Programme) said: "February 2$^{nd}$ 2007 may be remembered as the day the question mark was removed from whether people are to blame for climate change" (reported by Adam, 2007, p. 7)

7 Nearly 50 years ago, and writing from a US perspective, LeCorbeiller (1959) noted that economic power is underpinned by military power (which, of course, is maintained by advances in science and technology) and that the United States (in common with many other nations) exports scientific, engineering and technological 'know-how' abroad in order to spread American influence.

8 Nowhere is this more in evidence than in *A Nation at Risk* (National Commission on Excellence in Education, NCEE, 1983): "our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world… If an unfriendly power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves. We have even squandered the gains in achievement made in the wake of the Sputnik challenge. Moreover, we have dismantled essential support systems which helped make those gains possible. We have, in effect, been committing an act of unthinking, unilateral, educational disarmament." (p. 5)

9 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.
– *Doing science* – engaging in and developing expertise in scientific inquiry and problem-solving; developing confidence in tackling a wide range of "real world" tasks and problems.

In recent years (Hodson, 2003), 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.

[10] I emphatically reject the argument made by Shamos (1995) that, for the majority of students, science content is *only* of value in its exemplification of the nature of science, though I do share his view that technology is often a more accessible subject area for scientific literacy than is science itself.

[11] The BSE episode provides a graphic illustration. As Solomon and Thomas (1999) remind us, the nature of the prion agent that most scientists consider to be a cause of the disease was unknown to biology when most of today's adults received their science education.

CHAPTER 2

# EXPLORING NATURE OF SCIENCE ISSUES

## *Students' Views and Curriculum Images*

In chapter 1, I argued that a significant element of scientific literacy for the 21st Century comes under the umbrella of what I called learning *about* science – that is, developing an understanding of the nature and methods of science, an appreciation of its history and development, and an awareness of the often complex interactions among science, technology, society and environment. Students can only be considered scientifically literate, I argued, if they possess a robust and authentic understanding of what science is, how science functions, what scientists do, and how science develops and changes over time in response to sociocultural and economic pressures. Indeed, I proffered the idea that in the complex 21st Century world in which we live, this aspect of scientific literacy is at least as significant, if not more significant, than acquisition of conceptual understanding.

It is reasonable to suppose that students' views *about* science are the outcome of two interacting influences:

– *Curriculum experiences* – what students encounter in school science lessons;
– *Informal learning experiences* – what they learn via the popular media (movies, TV and radio, newspapers, Internet sites, advertizing) and from visits to museums, zoos, aquaria, nature reserves, field centres, and the like.

This book is concerned with the learning *about* science content of curriculum experiences: the kind of experiences we provide; the kind of experiences we *should* provide, but don't; the kind of experiences we *do* provide, but shouldn't. Although I am restricting the focus of the book in this way, I remain cognizant of the need for teachers to address the other influences on students' views about science and, whenever necessary, to attempt to counter them.[1] I intend to argue that curriculum experiences are of two kinds: those that we explicitly plan and those that we do not. There are many explicit messages about science in textbooks, especially in those early chapters that tell students what science is about and what scientists do when they are conducting investigations; there are lots of explicit references to the nature of science and the history of science in STS-oriented materials; on occasions, teachers take time and trouble to emphasize particular features of science and scientific inquiry during laboratory activities or in class discussions. Just as frequently, however, 'messages' about the nature of science and scientific practice are *not* consciously planned by the teacher. Rather, they are implicit messages located in the language we use, the kind of teaching and learning activities we employ (especially in laboratory work), the examples of science and scientists we utilize, the illustrative and biographical material in textbooks, and so on. What is at issue here is a very powerful *hidden* or implicit curriculum. In the words of Cawthron and Rowell (1978):

> … any science curriculum and its translation into practice embody images of the nature of man as scientist, of scientific knowledge and of the relationships between them. These are communicated, albeit implicitly and incidentally, just as surely as the subject matter itself. (p. 31)

Because it says *science* on the school timetable, students regard what they experience during that lesson as science, not as *learning* science. Many assume that what they do in science lessons, particularly during hands-on activities, is what scientists themselves do as they conduct investigations. These experiences build, over time, into a particular set of messages about science, scientists and the scientific enterprise. Everything that is part of the science lesson becomes an element in this continuous 'story building' about science, whether it is explicitly planned by the teacher or not. It follows that because many of the individual messages about science are 'transmitted' implicitly, simply as a consequence of teachers' day-to-day, short-term decisions about the conduct of lessons, a major element of the overall story about science is the *teacher's* views about the nature of science. All teachers, therefore, need to be cognizant of the responsibility they carry for helping to form their students' views about science. As a first step in treating that responsibility seriously, teachers should attempt to ascertain, examine and critique their own views.

The traditional way of ascertaining views about the nature of science is by means of questionnaire and survey instruments using multiple choice items or Likert scales. A large number of such instruments, mainly for use with students but perfectly applicable for research on teachers' views as well, have been developed. In fact, even 25 years ago, a literature survey by Mayer and Richmond (1982) identified at least 32 NOS-oriented instruments, among which the best known are the *Test on Understanding Science* (TOUS) (Cooley & Klopfer, 1961), the *Nature of Science Scale* (NOSS) (Kimball, 1967), the *Nature of Science Test* (NOST) (Billeh & Hasan, 1975) and the *Nature of Scientific Knowledge Scale* (NSKS) (Rubba, 1976; Rubba & Anderson, 1978), together with a modified version (M-NSKS) developed by Meichtry (1992). Instruments dealing with the processes of science, such as the *Science Process Inventory* (SPI) (Welch, 1969a), the *Wisconsin Inventory of Science Processes* (WISP) (Welch, 1969b) and the *Test of Integrated Process Skills* (TIPS) (Burns et al., 1985; Dillashaw & Okey, 1980) could also be regarded as providing information on understanding of the nature of science. In general, these instruments are constructed in accordance with a particular philosophical perspective and are predicated on the assumption that all scientists behave in the same way. Hence teacher and/or student responses that do not correspond to the model of science assumed in the test are adjudged to be 'incorrect' (see Lucas (1975), Koulaidis & Ogborn (1995), Alters (1997a) and Lederman et al. (2002) for an extended discussion of this issue). Moreover, as later chapters will show, many of these instruments pre-date significant work in the philosophy and sociology of science, and so are of severely limited value in further studies. Like research in science itself, research in science education is a product of its time and place.

More recent reviews by Lederman (1992, 2007), Lederman et al. (1998) and Abd-El-Khalick & Lederman (2000) describe several additional NOS instruments that take into account the work of more recent, and even contemporary, scholars in philosophy and sociology of science. Most notable among these newer instruments are *Conceptions of Scientific Theories Test* (COST) (Cotham & Smith, 1981), *Views on Science-Technology-Society* (VOSTS) (Aikenhead et al., 1989), the *Nature of Science Survey* (Lederman & O'Malley, 1990), the *Views of Nature of Science Questionnaire* (VNOS) (Lederman et al., 2002) and several subsequent modify-cations (see Lederman, 2007). A particularly useful tool for use with teachers in both pre-service and in-service programs is the *Nature of Science Profile* developed by Nott and Wellington (1993).[2] Its value lies in its ease of administration, wide scope and non-judgmental nature – key factors when dealing with student teachers and their apprehensions about impending teaching practice placements. Of particular value when student teachers have gained some classroom experience is Nott and Wellington's (1996, 1998, 2000) "Critical Incidents" approach. In group settings, or in one-on-one interviews, teachers are invited to respond to descriptions of classroom events, many related to hands-on work in the laboratory, by answering three questions: What would you do? What could you do? What should you do? Responses, and the discussion that ensues, may indicate something about the teachers' views of science and scientific inquiry and, more importantly perhaps, how this understanding is deployed in class-room decision making. Similar approaches using video and multimedia materials have been used by Hewitt et al. (2003) and Wong et al. (2008a,b). An interesting variation adopted by Murcia and Schibeci (1999) uses a science-oriented newspaper article as a stimulus to thinking about questionnaire items.

It almost goes without saying that teachers' views about the importance of NOS in the curriculum will also play a major part in their decisions about the extent to which they will emphasize learning *about* science in their enacted curriculum and the nature of the learning activities they provide (Bell et al., 2000; Schwartz & Lederman, 2002). Interestingly, Nott and Wellington (1995) comment that "teachers' knowledge of the nature of science may be as much *formed by* their teaching of science as *informing* their teaching of science" (p. 865, emphases added) – a conclusion that has major implications for both pre-service and in-service teacher education. There is also a substantial body of research to show that teachers' nature of science beliefs are sometimes over-ridden in the curriculum decision making process by more immediate concerns with classroom management, the priority afforded to concept acquisition and development, apprehension about student interest in philosophical and sociological issues and the lack of good NOS teaching resources (Mitman et al., 1987; Carey & Smith, 1993; Hodson, 1993a; Abd-El-Khalick et al., 1998; Lederman, 1999; Smith et al., 2000; Lederman et al., 2001) – all of which have major implications for teacher education and teacher professional development

## STUDENTS' VIEWS ABOUT SCIENCE AND SCIENTISTS

Three decades of research into students' alternative frameworks of understanding in science have shown us that students come to science lessons with some prior understanding of many of the concepts and ideas included in the curriculum, and that it would be a mistake to assume that these views are identical to scientists' views. Often they are significantly different. It would be a mistake, also, to assume that these views can be easily displaced by the 'correct' or preferred views embedded in the curriculum goals. Often they are very strongly held and resistant to change. Necessarily, the understanding students have of any phenomenon under investigation will profoundly influence the way in which they conduct that investigation, the significance they attach to their findings and the conclusions they reach. It was this realization that led to the development of constructivist pedagogy – an approach that, in many parts of the world, has become the 'new orthodoxy' of science teaching.[3] Its essential steps are:

- 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.

Similar strategies might apply to learning *about* science. At the outset, teachers following such a strategy would ascertain what views about science and scientists students already hold in order to encourage students to explore them, challenge them and perhaps develop, augment or replace them. One could, of course, try to ascertain students' views about science by giving them a questionnaire to complete. As discussed earlier, with respect to teachers' views about science, there are several such instruments in existence, some of which provide much valuable information, others of which do not. Despite some interesting recent developments in questionnaire design, one problem remains unsolved: students do not always interpret questionnaire items in the way the designers intended or, as Lederman and O'Malley (1990) put it, "language is often used differently by students and researchers" (p. 237). The designers of VOSTS attempted to circumvent this problem by using multiple choice items derived from student writing and interviews to provide a number of different 'position statements' (sometimes up to 10 positions per item), including "I don't understand" and "I don't know enough about this subject to make a choice" (Aikenhead et al., 1987; Aikenhead & Ryan, 1992). It is the avoidance of the forced choice and the wide range of aspects covered (definitions, influence of society on science/technology, influence of science/technology on society, influence of school science on society, characteristics of scientists, social construction of scientific knowledge, social construction of technology, nature of scientific knowledge) that give the instrument such enormous research potential. Nevertheless, as Abd-El-Khalick and BouJaoude (1997) point out, VOSTS was conceived and written within a North American sociocultural context and, in consequence, may have limited validity in non-Western contexts.[4] In response to concerns like these, Tsai and Liu (2005) have developed a survey instrument that is more sensitive to sociocultural influences on science and students' views of science. Rooted in similar concerns about the socioculturally-determined dimensions of NOS understanding is the *Thinking about Science* instrument designed by Cobern and Loving (2002) as both a pedagogical tool (for pre-service teacher education programs) and a research tool for assessing views of science in relation to economics, the environment, religion, aesthetics, race and gender.

Lederman and O'Malley (1990) utilized some of the design characteristics of VOSTS to develop an instrument comprising just seven fairly open-ended items (e.g. "Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer"), to be used in conjunction with follow-up interviews. Not all students were prompted to focus their answers on the tentativeness of science, as the authors intended, and although the interview stage was able to go some way towards re-focusing attention, these findings serve to reiterate the difficulty of attempting to interpret students' understanding from their written responses to researcher-generated questions.[5] In consequence, some researchers and teachers believe that more useful information can be obtained, especially from younger students, by relying solely on open-ended methods such as the Draw-a-Scientist Test (DAST) (Chambers, 1983). In his initial study, Chambers used this test with 4807 primary (elementary) school children in Australia, Canada and the United States. He identified seven common features in their drawings, in addition to the almost universal representation of the scientist as a man: laboratory overall; spectacles (glasses); facial hair; 'symbols of research' (specialized instruments and equipment); 'symbols of knowledge' (books, filing cabinets, etc); technological products (rockets, medicines, machines); and captions such as 'Eureka' (with its attendant lighted bulb), $E = mc^2$ and think bubbles saying "I've got it" or "A-ah! So that's how it is".[6] In many ways, little has changed since high school students in the United States told Margaret Mead, almost fifty years ago, that a scientist is:

> … a man who wears a white coat and works in a laboratory. He is elderly or middle aged and wears glasses. He is small, sometimes small and stout, or tall and thin. He may be bald. He may wear a beard, may be unshaven and unkempt. He may be stooped and tired. He is surrounded by equipment: test tubes, Bunsen burners, flasks and bottles, a jungle gym of blown glass tubes and weird machines with dials. The sparkling white laboratory is full of sounds: the bubbling of liquids in test tubes and flasks, the muttering voice of the scientist… He spends his days doing experiments. He pours chemicals from one test tube into another. He peers raptly through microscopes. He scans the heavens through a telescope. He experiments with plants and animals, cutting them apart, injecting serum into animals. He writes neatly in black books. (Mead & Metraux, 1957, pp. 386 & 387)

In the twenty or so years since Chambers' original work, students' drawings have changed very little (Ward, 1986; Fort & Varney, 1989; Symington & Spurling, 1990; Jackson, 1992; Newton & Newton, 1992, 1998; Matthews, 1996; Barman, 1999; Finson, 2002),[7] with research indicating that the stereotype emerges round about grade 2 and is well-established and held by the majority of students by grade 5. Matthews (1996) claims that the stereotype is beginning to be eroded, at least in the United Kingdom, by the increased emphasis on science in the National Curriculum for primary schools, though this view is not shared by Newton and Newton (1998). Not only are these images stable across genders, they seem to be relatively stable across cultural differences (Chambers, 1983; Parsons, 1997; She, 1998; Song & Kim, 1999; Finson, 2002). There are some encouraging indications that students, and especially male students in the age range 9–12, produce drawings with fewer stereotypical features following the implementation of gender-inclusive curriculum experiences (Mason et al., 1991; Huber & Burton, 1995).

It may be, however, that many researchers are seriously misled by the drawings children produce. As Newton and Newton (1998) point out, "their drawings reflect their stage of development and some attributes may have no particular significance for a child but may be given undue significance by an adult interpreting them" (p. 1138). Although very young children invariably draw scientists as bald men with smiling faces, regardless of the specific context in which the scientist is placed; it should not be assumed that children view scientists as especially likely to be bald and contented. Many children seem unable or disinclined to draw a distinction between science in the outside world and science lessons in school, such that their drawings simply reproduce caricatures of school science activities (Brandes, 1996). Perhaps somewhat older students are consciously and purposefully presenting the stereotypical or 'comic book' cartoon image of the scientist rather than giving insight into what they really believe. As Claxton (1990) reminds us, children compartmentalize their knowledge and so may have at least three different versions of the scientist at their disposal: the everyday comic book version, the 'official', approved version for use in school, their personal (and perhaps private) view. It is not always clear which version DAST is accessing, nor how seriously the 'artists' took the task. There is also the possibility, with students in secondary school or university, that the response is intended to make a sociopolitical point – for example, that there are too few women or members of ethnic minority groups engaged in science. One way to clarify matters is to talk to students about their drawings and the thinking behind them, ask them if they know anyone who uses science in their work (and what this entails) or present them with writing tasks based on scientists and scientific discovery.[8] Even very young children will provide detailed explanations when given the opportunity to discuss their drawings and stories with the teacher (Sharkawy, 2006). Interestingly, discussion seems to take a different course when this task is set in science lessons than it does in other areas of the curriculum – perhaps because of the influence of the 'official' or known-to-be-approved view referred to earlier. It is also becoming increasingly clear that young children's responses to open-ended writing tasks involving science, scientists and engineers are not stable and consistent: accounts and stories produced in science lessons are very different from those produced in the language arts (Hodson, 1993a). Interestingly, it seems that students responding to nature of science questions sometimes provide significantly different oral and written responses (Roth & Roychoudhury, 1994).

Despite these caveats, there is still cause for concern about the views expressed by students. There is particular cause for concern about the kind of responses students make when they are asked to "imagine you are a scientist… write about your work, about the discoveries you have made and the things you have invented".[9] Just over 50% of students report accidental discovery or what one might call the 'Alexander Fleming syndrome': materials are left lying around in the laboratory and suddenly, one day, the ‘answer’ appears. There is no suggestion that significant scientific results are a consequence of a carefully planned and systematic inquiry, no suggestion of prior theorizing; instead, scientific breakthroughs just happen, by chance. In addition, science is widely perceived by students to be a solitary activity: the lone scientist labours long and hard to make discoveries of heroic stature – a view that is reinforced by questionnaire studies of students’ views about ‘doing science’ or ‘being a scientist’. Furthermore, scientists are regarded by many students as withdrawn and remote from real life, sometimes selfish and antisocial, and certainly less friendly than ‘normal’ people. Recently, one of my students asked me: “How can you tell when a scientist is an extrovert?” Answer: “He looks at *your* shoes when he is talking to you”. Scientists have few interests, and certainly not in music, movies or the arts in general. Most scientists don’t have a ‘normal’ family life: they may neglect their family (many don’t have a family) because of their preoccupation with work. Indeed, they often go into the laboratory on their day off. Often, they are seen as careless of their appearance, generally untidy and disorganized; sometimes they even forget to eat because of their obsession with work. This image is remarkably similar to that given by Fournier d’Albe (1923):

> To the general public the man of science is a man of mystery, a man of inhuman and somewhat unaccountable tastes. Not everyone goes so far as to maintain that he is a freak because he indulges in an activity “with no money in it”. But it seems to be generally agreed that the “scientist” is a being living outside ordinary human spheres, not amenable to ordinary human standards, a being who is usually harmless but may conceivably *become* dangerous. (cited in Stuewer, 1998, p. 25, emphasis added)

Carl Sagan (1995) describes the common stereotypical image of the scientist in even less complimentary terms: “Scientists are nerds, socially inept, working on incomprehensible subjects that no normal person would find in any way interesting – even if he were willing to invest the time required, which, again, no sensible person would. ‘Get a life’, you might wish to tell them” (p. 362).

And what do students believe that scientists do when they go into the lab? They do experiments; they find out about things; they find out new information and new facts; they find out how things are. Scientists do lots of “finding out” and “working things out”; they also “invent things” and “discover new stuff ”. In a study by Coleman (1998), a number of students regard an explanation as scientific if it includes information that not everyone knows or is immediately obvious, or information that has to be discovered rather than looked up in a book or found from an Internet search. For many students, it is also the case that scientists use “big words that only they can understand”. Predictably, perhaps, many students state that experiments are conducted to *prove* that such and such is the case – a view that is regularly reinforced by the television or newspaper advertisers’ insistence that product X is proven by experiment to do the job better than any similar product. The notion that well conducted experiments reveal the truth is very common. Interestingly, some students take the radically different view that experiments are entirely open-ended, a kind of "shot-in-the-dark" during which "anything can happen" – for example, "they give stuff to rats to see what happens".

Using interview methods and writing tasks, Joan Solomon and her colleagues have researched students' understanding of the nature of theory and its relationship to experiments. Ideas about theories appear to fall into three major categories: (a) a theory is a hunch or guess about what will happen, (b) a theory is an explanation for why things happen (close to the view we might wish students to hold), (c) a theory is a fact. In these studies, students sometimes referred to "proper theories" as those theories that have been shown by tests and experiments to be true (Duveen et al., 1993; Solomon et al., 1994, 1996). Interestingly, some students in my Toronto-based study took the view that theories are just guesses or speculations. Comments such as "that's just a theory… it isn't true" and "It's something that *you* think" were widespread, in some sense reflecting the everyday expression that "it may be OK in theory but it doesn't work in practice". Intriguingly, some students in the Solomon et al (1994) study seemed to see experiment as a 'last resort' when no-one knows what to do – as in, "We'll just have to experiment" (p. 365). Among older students in my Toronto-based study there was sometimes a distinction drawn between "science as it ought to be" (the kind of science that is described in text-books) and "science as it is". Students were not expressing the view that scientists behave differently when self interest, commercial interests or military interests intervene (however desirable this awareness might be); rather, they were suggesting that the ideals of scientific inquiry are so demanding that they are beyond the reach of most 'mere mortals'.

Interviews with students undertaking research projects as part of their final year programme at the University of Leeds revealed that undergraduates resemble secondary school students in regarding scientific knowledge as 'provable beyond doubt' on the basis of experimentally acquired data (Ryder et al., 1999). In most cases, scientific inquiry was seen in terms of individual scientists seeking reliable data (usually via experiment) on which to base their conclusions. Encouragingly, their appreciation of the role of theory in directing the nature of scientific inquiry became markedly more sophisticated during the course of the project work, though they remained relatively unaware of the internal and external social dimensions of scientific practice.

## CURRICULUM IMAGES OF SCIENCE AND SCIENTISTS

Often, the confused and confusing views of science held by students are compounded by conventional science education. There are particularly powerful messages about science embedded in laboratory activities conducted in class. As subsequent chapters will make clear, these messages too often convey distorted or over-simplified views of the nature of scientific investigations, especially with respect to the role of theory. These "folk theories" of science, as Windschitl (2004) calls them, are also held by teachers (as a consequence of their own science education) and have substantial influence on their day-to-day curriculum decision making, thus reinforcing similar messages embedded in school science textbooks and other curriculum materials. Such messages are not restricted to comments on 'scientific method'. More than a quarter century ago, Smolicz and Nunan (1975) identified four "ideological pivots" inherent in the image of science presented through the science curriculum. First *anthropocentrism*: the view of mankind as the technologically powerful manipulator and controller of nature, with science as the means by which we control the environment and shape it to meet our interests and needs.[10] Second, *quantification*: scientists are regarded not just as observers but as measurers and quantifiers. Whatever exists in nature can (and should) be explained in mathematical terms, best of all by means of equations. Hence, Lord Kelvin's dictum that we do not understand a thing until we can measure it. Third, *positivistic faith*: faith in the inevitable linear progress of science towards truth about the world, with the certainty of this knowledge being underpinned by the all-powerful scientific method. Fourth, the *analytical ideal*: the assumption that phenomena and events are best studied and explained via analysis; an entirely mechanistic view of the world which assumes that the whole is simply, and no more than, the sum of its parts. Two major questions spring to mind. First, are these "ideological pivots" promoted through science education? In other words, are Smolicz and Nunan (1975) correct in their analysis? Second, are these the underlying values of science? In other words, is this a faithful representation of science and, therefore, an appropriate set of values to promote?

A decade later, as part of a major survey of Canadian science education conducted by the Science Council of Canada, Nadeau and Désautels (1984) identified what they called five mythical values stances suffusing science education:

– *Naïve realism* – science gives access to truth about the universe.
– *Blissful empiricism* – science is the meticulous, orderly and exhaustive gathering of data.
– *Credulous experimentation* – experiments can conclusively verify hypotheses.
– *Excessive rationalism* – science proceeds solely by logic and rational appraisal.
– *Blind idealism* – scientists are completely disinterested, objective beings.

The cumulative message is that science has an all-purpose, straightforward and reliable method of ascertaining the truth about the universe, with the certainty of scientific knowledge being located in objective observation, extensive data collection and experimental verification. Moreover, scientists are rational, logical, open-minded and intellectually honest people who are required, by their commitment to the scientific enterprise, to adopt a disinterested, value-free and analytical stance. In Cawthron and Rowell's (1978) words, the scientist is regarded by the science curriculum as "a depersonalized and idealized seeker after truth, painstakingly pushing back the curtains which obscure objective reality, and abstracting order from the flux, an order which is directly revealable to him through a distinctive scientific method" (p. 32). In quite startling contrast, Siegel (1991) states that:

> Contemporary research… has revealed a more accurate picture of the scientist as one who is driven by prior convictions and commitments; who is guided by group loyalties and sometimes petty personal squabbles; who is frequently quite unable to recognize evidence for what it is; and whose personal career

> motivations give the lie to the idea that the scientist yearns only or even mainly for the truth. (p. 45)

A number of questions spring to mind.

1. Does the curriculum project the images identified here, and questioned by Siegel's remarks?
2. Are these images faithful to the nature of real science and the characteristics and behaviour of real scientists engaged in 'doing science'? In other words, do these descriptions provide an authentic view of science?
3. Do students internalize these views?
4. Does it matter what image we project or what image of science students acquire?

At the time Nadeau and Désautels were writing, the answer to the first question was undoubtedly "Yes". While much has changed in the intervening years, thanks largely to the STS thrust in curriculum debate, many school science curricula and school textbooks continue to project these images (Lakin & Wellington, 1994; Cross, 1995; Knain, 2001; Clough, 2006). Loving (1997) laments that all too often –

> (a) science is taught totally ignoring what it took to get to the explanations we are learning – often with lectures, reading text, and memorizing for a test. In other words, it is taught free of history, free of philosophy, and in its final form. (b) Science is taught as having one method that all scientists follow step-by-step. (c) Science is taught as if explanations are the truth – with little equivocation. (d) Laboratory experiences are designed as recipes with one right answer. Finally, (e) scientists are portrayed as somehow free from human foibles, humor, or any interests other than their work." (p. 443)

It would be a fairly simple task to locate passages in school science textbooks that continue to promote discredited views about nature of science issues. I have resisted the temptation because I regard it as much more important for readers to look carefully and critically at the science textbooks in use in their own school or recommended by the local Ministry of Education, School Board or Local Education Authority, especially in light of the discussion of issues in the following several chapters. Indeed, this is a task I set for all my graduate students at the outset of my course dealing with nature of science and science education. As an aside, it is perhaps worth mentioning that my own research shows that teachers frequently change the model of science they project through the curriculum in accordance with the particular topic being studied (in particular, its conceptual difficulty) and in relation to the perceived ability level of the students (Hodson, 1993a), sometimes in disregard of the views promoted by the textbook.

My answer to question 2 (with respect to the Cawthron and Rowell image) is an unequivocal "No", as subsequent chapters in this book will demonstrate. The question of whether Siegel's alternative image of science is any more authentic than Cawthron and Rowell's will be considered in chapter 7. Of course, expressing dissatisfaction with current messages about science is all very well, but teachers and curriculum developers need access to an alternative set of messages. This book will attempt to provide such alternatives. What will become apparent in subsequent discussion is that while there is no universally accepted view of the nature of science, especially in regard to the sociocultural dimensions of the scientific endeavour, there is a measure of agreement about a number of key issues relating to the conduct of scientific inquiry and the nature of scientific observation (McComas et al., 1998). Chapters 3 to 8 explore some of the literature in the history, philosophy and sociology of science that I subsequently use in chapter 9 to underpin an alternative view of science, scientists and scientific practice suitable for the school science curriculum.

Given the earlier description of students' images of scientists and understanding of experiments, the realistic answer to question 3 is likely to be "Yes". Although not all students will internalize all the misunderstandings of science embedded in less enlightened science curricula, there is ample evidence that many students do leave school with a confused, confusing, deficient or distorted view of the nature of science and the activities of practising scientists (Ryan, 1987; Carey et al., 1989; Larochelle & Désautels, 1991; Lederman, 1992; Duveen et al., 1993; Abell & Smith, 1994; Solomon et al., 1994, 1996; Griffiths & Barman, 1995; Driver et al., 1996; Lubben & Millar, 1996; Barman, 1997; Leach et al., 1997; Hogan & Maglienti, 2001; Moss et al., 2001). Of course, there are encouraging signs that some teachers, in some schools, are able to ensure that students develop a more authentic view of scientific practice, sometimes as a consequence of an explicit program of study in the history, philosophy and sociology of science, sometimes as a consequence of practically oriented experiences in laboratories, in the field or in zoos and museums.

This leaves question 4: Does it matter what image of science is presented and assimilated? It matters insofar as it influences career choice, and so may have long term consequences for individuals. It matters if the curriculum image of science is such that it dissuades creative, non-conformist and politically conscious individuals from choosing to pursue science at an advanced level. It matters if the image of science is such that it dissuades women, members of visible minority groups and students from lower socioeconomic status homes from entering science-related careers or seeking access to higher education in science and engineering because they don't see themselves included and represented in the science curriculum. It matters if our politicians, public servants and industrialists are so ignorant of scientific and technological issues that their decision-making is ill-informed and uncritical. It matters if the general population is unable to respond knowledgeably and critically to the claims and proposals of those in society who might use scientific arguments (and sometimes pseudoscientific or scientifically spurious arguments) to persuade, manipulate and control. It matters simply because a significant part of humankind's cultural achievement is so poorly understood. To echo and adapt some of the discussion in chapter 1 for the desirability of scientific literacy itself, arguments for equipping students with a more authentic view of science can be made on *intrinsic*, *utilitarian* and *citizenship* grounds. There is ample evidence, for example, that the unfavourable image of science and scientists to which many students are exposed is one of the major reasons why many students turn away from science at an early age (Holton, 1992; Wang, 1995; Gardner, 1998). Thus, it prematurely limits the pool of talent from which future scientists are drawn, with potentially damaging effect on society's economic and cultural well-being. Moreover, failing to provide every student with an adequate understanding of the nature of science runs counter to the demand for an educated citizenry capable of responsible and active participation in a democratic society. As I argued in chapter 1, a proper understanding of science and the scientific enterprise is just as essential as scientific knowledge (i.e., conceptual understanding) in ensuring and maintaining a socially-just democratic society.

> [Scientific literacy] 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. (AAAS, 1989, p. xiii)

## REITERATING THE POLITICAL ARGUMENT FOR NOS UNDERSTANDING

Many of us have realized to our cost that a little knowledge can be dangerous thing. 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 the all-powerful route to certain knowledge via the scientific method. While a lack of public understanding of science is clearly an obstacle to proper democracy, so also is an understanding of science rooted in myths and falsehoods about scientific method. The underlying values and ideological pivots described by Nadeau and Désautels (1984) and Smolicz and Nunan (1975) do not equip students with the critical skills necessary to challenge science and scientists on matters of sociopolitical, economic and environmental significance. Worryingly, through widespread acceptance of the myth of scientific method, scientists can sometimes achieve a level of acclaim that leads the public to seek their advice on matters outside the sphere of science. Nor are scientists themselves always immune to the false logic that high scientific achievement necessarily equates to wisdom on all other matters. As Bauer (1992, p. 40) remarks: "Instances are common enough in which successful scientists succumb to the temptation to see themselves as authorities not only in their own tiny field but over science as a whole and even beyond that". Conversely, belief in the certainty of knowledge produced by the scientific method and the inevitability of successful outcomes to research can lead to unrealistic expectations of science and impatience when scientists do not immediately 'deliver' on society's wants and needs.

Science in textbooks, the only science that some people know, is very different from 'real' science, from science at the theoretical cutting edge or science at the frontier of research and development, and from science that informs (or should inform) key decision-making on matters of public interest. Quite rightly, only knowledge that has stood the test of time as worthwhile knowledge is incorporated into textbooks for the primary and secondary school levels, and because it has proved its value over many years, this knowledge is retained and reinforced. In consequence, it gives the appearance of being objective and true. While scientific knowledge in undergraduate texts, reviews and monographs is closer to ‘real’ contemporary scientific knowledge than the science in school textbooks, only the research literature reveals the true nature of scientific knowledge, with its characteristic subjectivity, inconsistency, controversy and uncertainty. This is not so much an argument for confronting students in school with the primary research literature, though I do see value in providing some guided access to some of that literature, as it is an argument for assisting students to understand 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.

> 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. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appopriately (National Research Council, 1996, p. 22).

These are the elements of scientific literacy to be addressed in the following chapters. According to Kolsto (2001), the aspects of scientific literacy essential for dealing adequately with controversial socioscientific issues are: understanding of science as a social process, recognition of the limitations of science, familiarity with the values of science and the cultivation of a critical attitude. I will argue throughout the course of this book that the last of these elements necessarily presupposes the others and constitutes the principal goal of science education.

However, there are those, such as Michael F.D. Young (1976), who claim that the real goal of science education is scientific *illiteracy* and the cultivation of an *uncritical* attitude. These goals are achieved, Young argues, by making science in the early years of schooling very abstract, boring and difficult, thus ensuring that most students will fail to learn satisfactorily and will leave school afraid of science, unable to read scientific material in a critical way, and easily intimidated by those who are adept at using scientific language. Science can then be used as a tool of policy. When the language of science and technology is used in advertizing, political addresses and official communications of any kind these scientific illiterates are unable to ‘read between the lines’, to question or to oppose what is being presented to them. They have little choice but to accept the word and the decisions of ‘experts’ on seal culling, forestry clear cutting, genetically modified food, BSE, health risks from cellphone use, or any of the other 1001 issues that confront citizens in their everyday lives. They have, in effect, been disenfranchised.

> (They) see themselves as dependent on experts in more and more aspects of their lives… Except in the specific context of their work, and possibly in leisure pursuits such as car maintenance, our increasingly technologically dominated world remains for the majority as much a mystery as the theological mysteries of feudal times. (Young, 1976, pp. 51 & 53)

Arguing along similar lines, 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).

More recently, Bencze (2001) has argued that contemporary science education for the majority of students is, in effect, an *apprenticeship for consumership* – that is, it seeks to create "a large mass of relatively scientifically and technologically illiterate citizens who simultaneously serve as loyal workers and voracious, unquestioning consumers" (p. 350). There are strong echoes here of Michael Apple's (1993) assertion that in the new economy-driven educational climate, students are no longer seen as people who will participate in the struggle to build and rebuild the social, educational, political and economic future, but as consumers: freedom is "no longer defined as participating in building the common good, but as living in an unfettered commercial market, with the education system… integrated into the mechanisms of such a market" (p. 116). In similar vein, Lee and Roth (2002) assert that in contemporary science education "both the subject matter and the method of instruction are not geared toward generating a scientifically literate populace, but rather function like a Fordian production line in a Foucauldian (disciplining) institution that forms employees of a certain class for a limited number of powerful institutions" (p. 42). Marshall (1995) uses the term "busnocratic rationality" to describe the curriculum emphasis on acquisition of skills rather than knowledge building, and on information and information retrieval rather than knowledge, understanding and wisdom, allied with the notion that it should be *consumers* of education (i.e., business interests and employers) rather than the *clients* (students) or *providers* (educators) who determine curriculum, define and measure quality in education, and set standards of attainment. Moreover, he argues, these standards are set in such a way that they ensure a largely uneducated, uncritical and undemanding workforce to fill society's low-paid jobs, with any shortfall being filled by immigration (see also Larner (2000) and Stromquist & Monkman (2000)).

Apple (2001a) sees a powerful alliance among enthusiasts for the neo-liberal marketization of education, neo-conservatives who want "a return to higher standards and a 'common culture', authoritarian populist religious fundamentalists deeply worried about secularity and the preservation of their own traditions, and particular factions of the professionally oriented new middle class who are committed to the ideology and techniques of accountability, measurement and 'management'" (p. 103). Carter (2005) argues along similar lines:

> Neoliberalism 'marketizes' everything, even notions of subjectivity, desire, success, democracy, and citizenship, in economic terms at the same time neo-

> conservatism works to preserve traditional forms of privilege and marginalize authentic democratic and social justice agendas. More sinister still is the success with which both ideologies have colonized the rhetoric so at the very time reforms appear to be more just and equitable, they actually work in opaque ways against those they purport to help… Neoliberal and neoconservative forces work in tandem to marketize and reform and, as reform proceeds, to (re)distribute power back to traditional elites, effectively rejecting recent progressive liberal moves to increase equality and social redress… Democracy [has been] redefined] as largely synonymous with capitalism, so that consumption becomes the new form of democratic participation, and equity becomes isomorphic with increased choice. (p. 571)

In the so-called 'knowledge economy', businesses need only a relatively small number of people who are knowledge creators and managers, whom Apple (2001b) calls "symbolic analyzers" (those who can analyze and manipulate words, numbers, visual representations and other symbols) and a much larger number of less skilled and less knowledgeable workers who can and will follow instructions (Gee et al., 1996; Lankshear, 2000; Bencze & Alsop, 2007). Thus school science education functions to select and educate the "relatively small group of students who may work as engineers and scientists to help companies develop and manage mechanisms of production (and consumption) of goods and services… (and) large groups of citizens who may function best as compliant workers and as enthusiastic purchasers of products and services of business and industry" (Bencze, 2004, p. 193). For the majority, emphasis is not on the development of critical thinking but on the mastery of a given body of knowledge. Assessment and evaluation are seen as a means of monitoring the system to determine its efficiency. The result is an education that focuses on that which is easily and reliably assessed. As Noble (1998) comments, business benefits from "a school system that will utilize sophisticated performance measures and standards to sort students and to provide a relatively reliable supply of… adaptable, flexible, loyal, mindful, expendable, 'trainable' workers" (p. 281). Hence the rush in many countries around the world to establish 'standards of performance' monitored by an imposed regime of systematic and regular assessment via standardized tests. Education authorities insist that students, classes, schools and whole education systems show quantifiable results, with testing regimes monitoring outcomes and positioning everyone so that improvements can be claimed by the authorities and shortfalls or deficiencies blamed on teachers (Carter, 2005). Apple (1999, 2000, 2001a) argues that these educational standards embody both neoliberal concerns for increased accountability, surveillance and regulation and neoconservative desires for a return to 'real learning' and 'real knowledge'. In this kind of technocratic approach to education, efficiency, marketability and accountability are regarded as the ultimate virtues.

While not everyone would subscribe to the view that there is an *intention* to ensure that the vast majority of the population remains scientifically illiterate as a means to control, manipulate and oppress them, many would recognize that this is the *outcome* of much contemporary science education. Scientific illiteracy is, for many students, the consequence of what and how we teach science and technology in school, and makes possible the mass manipulation of scientifically illiterate people via the popular media. 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 recommendations of those they perceive to be experts, or are persuaded to accept as such. Hence my argument is that it *does* matter what we teach students *about* science. It does matter that we teach them to understand the nature of science and the scientific enterprise at a critical level. It does matter that ordinary citizens have the capacity to read scientific text in journals such as *Scientific American, New Scientist*, *Discovery* and *Science Digest* with understanding, and can make sense of scientific arguments wherever and whenever they encounter them. It does matter that citizens have some understanding of the ontological status of scientific knowledge and the ways in which scientific knowledge is generated and validated by the community of practitioners. It does matter that they have some sense of the historical development and cultural context of science. Above all, it matters that future citizens are able to judge the validity of a knowledge claim independently of other people, that they can tell the difference between good science and bad science, and between science and non-science, and can recognize fraudulent science and unwarranted claims when they encounter them. It matters for social reasons; it matters for political reasons; it matters for economic reasons; it matters, perhaps most of all, for environmental reasons. The planet can no longer accommodate a scientifically and technologically illiterate, uncritical, 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)

Beyer (1998) paints a particularly bleak picture of contemporary society when he says that we live "in a democratic-capitalist social order in which commodity fetishism, the rule of the market, patriarchy, and White Supremacy constrain, distort, and oppress the expression of many individuals' humanity and their ability to act democratically" (p. 260). Dobbin (1998) is equally dark in his vision: "Thousands of years of human development and progress are reduced to the pursuit of 'efficiency', our collective will is declared meaningless compared to the values of the marketplace, and communitarian values are rejected in favour of the survival of the fittest. A thinly disguised barbarism now passes for, is in fact promoted as, a global human objective" (p. 1). I don't believe that the world is quite so grim as these authors contend, though I admit that there is no more room for complacency on the sociopolitical front than on the environmental front. It is perhaps an opportune time, then, lest this nightmare vision comes to pass, to restate the argument for enhanced scientific literacy (that is both *universal* and *critical*) in terms of the politicization of students, thus equipping them to resist technological determinism and the culture of consumerism and compliance, to fight for social justice, and to conduct their lives in an environmentally responsible way.

To say that we are living in an era of rapid and far-reaching change, the outcomes of which are 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. These 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. Moreover, we live in an era that generates increasing numbers of moral-ethical dilemmas but offers fewer moral certainties. My argument thus far is that universal critical scientific literacy, interpreted in this book in terms of learning *about* science, is one of the educational imperatives in helping students to cope with life in this constantly changing and uncertain world. It is a way of diverting us from the nightmare world of widespread scientific *illiteracy* 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)

The curriculum I have in mind is aimed at far-reaching social change through critical consideration of socioscientific issues (Hodson, 2003). In a number of respects, it overlaps with futures studies (Lloyd & Wallace, 2004) – particularly in respect of the guiding principles of futures education set out by Cornish (1977, p. 223):

- The future is not fixed, but consists of a variety of alternatives among which we can choose.
- Choice is necessary. Refusing to choose is itself a choice.
- Small changes through time can become major changes.
- The future world is likely to be different in many respects from the present world.
- People are responsible for their future; the future doesn't just happen to them.
- Methods successful in the past may not necessarily work in the future, due to changed circumstances.

As a first step in building a future-oriented curriculum, it is necessary to consider the extensive literature in the philosophy of science, the sociology of science and the history of science, from which an appropriate selection of key issues can be identified.

## ENDNOTES

[1] To intervene effectively, of course, teachers need to be aware of these 'popular images' of science. Sadly, constraints on space preclude a detailed consideration of key aspects of the 'popular images' of science and scientists here. Dunwoody (1993), Gough (1993), Wellington (1993), McSharry & Jones (2002), Dimopoulos & Koulaidis (2003) and Shibley (2003) provide a useful starting point for this exploration.

[2] There may be some value in readers who are so inclined completing this profile now and then doing so again after reading through this book. This is the kind of exercise I encourage my graduate students to undertake. It is interesting that some students change their views substantially in response to the history and philosophy of science issues we discuss, while others are confirmed in the views they held at the outset.

[3] This is not the appropriate place to discuss the nature of constructivist pedagogy, its strengths and weaknesses as an approach to successful learning, or its problematic epistemology. There is already an extensive literature dealing with these matters (see, for example, Faire & Cosgrove, 1988; Saunders, 1992; Appleton, 1993; Bell, 1993; Matthews, 1993, 1997, 1998a; Driver et al., 1994; Fensham et al., 1994; Solomon, 1994; Phillips, 1995; Osborne, 1996; Nola, 1997; Tyson et al., 1997; Hewson et al., 1998; Turner & Sullenger, 1999; Jenkins, 2000; Tobin, 2000; Gil-Perez et al., 2002). My own views are elaborated in Hodson (1998a) and Hodson and Hodson (1998a,b).

[4] VOSTS does appear to be robust enough to function reliably in a British context (Botton & Brown, 1998).

[5] This instrument has subsequently been modified to produce the *Views of Nature of Science* questionnaire (Lederman et al., 2002), and further modified by Lederman and his co-workers (Lederman, 2007) and by Wong et al. (2008a,b).

[6] Interestingly, Chambers found that scientists themselves also tend to draw these stereotyped pictures.

[7] Finson et al. (1995) have developed a checklist for identifying and quantifying the components of students' drawings for more efficient data analysis.

[8] Miller (1992, 1993) advocates the following approach: "Please tell me, in your own words, what does it mean to study something scientifically?"

[9] The views of science and scientists presented here were collected from students aged 11-17 in a number of schools in the greater Toronto area over the 5-year period 1999 to 2004.

[10] I am consciously using *mankind* rather than humankind to lend increased force to Smolicz and Nunan's proposition. They used the term *man*, but at a time when authors were less sensitive to gendered language. Of particular interest in this 'nature in the service of man' view is that we have the *right* to control and manipulate the natural environment.