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2. CONNECTIONS TO SUPPORT LEARNING ABOUT SCIENCE

INTRODUCTION

This chapter discusses the need for greater levels of scientific literacy in contemporary society. It identifies three major curriculum thrusts that collectively inform scientific literacy – learning science, learning about science, and doing science – with a principal focus on learning about science, often referred to as nature of science (NoS). Particular emphasis is given to the importance of the language of science, the values, norms and traditions of scientists, and the reality of contemporary practice. The remainder of the chapter discusses direct and indirect connections with scientists and the impact of these on developing understanding about science. The chapter concludes with a discussion of the possibilities and pitfalls of such connections.

SCIENTIFIC LITERACY

It is fair to say that, in recent years, there has been a significant decline in public confidence in science and scientists as a consequence of the BSE episode (the so-called “mad cow disease”) in the United Kingdom and concerns about bird flu, swine flu, SARS, West Nile Virus and other transmissible diseases. Skepticism is now rife regarding the bland assurances provided by supposed experts about health risks associated with nuclear power stations, overhead power lines and mobile phones. There is unease about the emergence of so-called “superbugs” in hospitals, anxiety about the environmental impact of genetically engineered crops, concern about pesticide residues, growth hormones, antibiotics and other contaminants in our food, and so on. There is considerable anxiety about the possibility of a link between the MMR vaccine and autism, and a strong suspicion (rightly or wrongly) that government health authorities do not reveal all that they know. Among some sections of the public there is mounting concern about the increasing domination of scientific and technological research by commercial, governmental and military interests, the increasing vulnerability of science and scientists to the pressures of capitalism and politics, and the increased secrecy and distortion by vested interests that result. The close link between science and commerce in the field of genetic engineering has been a particular trigger for deepening mistrust of scientists. Indeed, Ho (1997) claims, rightly or wrongly, that “practically all established molecular geneticists have some direct or indirect connection with industry, which

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will set limits on what the scientists can and will do research on... compromising their integrity as independent scientists” (p. 155), while Bencze et al. (2009) state that a close review of 70 research articles concerning the effectiveness of “calcium channel blockers” revealed that 96% of the authors citing positive results had financial ties to companies producing the drugs. As a consequence of revelations such as these, as Barad (2000) notes, “the public senses that scientists are not owning up to their biases, commitments, assumptions, and presuppositions, or to base human weaknesses such as the drive for wealth, fame, tenure, or other forms of power” (p. 229). In its third report, the (UK) House of Lords Select Committee on Science and Technology (2000) commented on what it perceives as a “crisis of trust”.

It is essential that future scientists and citizens engage in much closer critical scrutiny of the enterprise of science and, where necessary, change their “intellectual allegiances”. My hope is that increased levels of public involvement in the regulation of science and the establishment of research priorities will ensure that future research is more likely to be directed towards matters of public good and less likely to be conducted solely in pursuit of commercial interests. In this respect, I wholeheartedly endorse Helen Longino’s (1997) argument that “research that alleviates human needs, especially those traditionally attended by women, such as care of the young, weak, and infirm or feeding the hungry, should be preferred over research for military purposes or for knowledge’s sake” (p. 23). However, Ziman’s (2000) description and evaluation of post-academic science (discussed later) suggests that research priorities are largely determined by the interests of the military, by the priorities of the pharmaceutical industry, chemical industry, petroleum industry, agribusiness and biotechnology firms, or by the government on behalf of these industries. In consequence, we have “agricultural research that revolves around pesticides, herbicides and growth hormones, and other petrochemicals, of little help to smaller, poorer farmers around the world; and medical research that revolves around expensive high-tech treatments and cures rather than the less lucrative preventive knowledge that would help so many more people, especially poorer people” (Kourany, 2003, p.9). Using Sandra Harding’s (1991) notion of strong objectivity and Sharon Crasnow’s (2008) idea of model-based objectivity to justify replacing one set of social goals by another set that is more favourable to human well-being and environmental health would not pose insurmountable problems for the validity and reliability of scientific knowledge, though it would have enormous implications for the lives of millions of people (see Hodson, 2011, for an extended discussion of these matters). In short, “better scientific knowledge” does not result from trying to eliminate subjectivity, and conforming to some spurious notion of objectivity, but from critical consideration of the contextual values that influence or should influence the scientific enterprise.

If we recognize... that knowledge is shaped by the assumptions, values, and interests of a culture and that, within limits, one can choose one’s culture, then it’s clear that as scientists/theorists we have a choice. We can continue to do establishment science, comfortably wrapped in the myths of scientific rhetoric or we can alter our intellectual allegiances (Longino, 1990, p. 191).
Addressing the “crisis of confidence” and changing “our intellectual allegiances” requires a deepening and broadening of our understanding of what constitutes scientific literacy. In recent years, the notion of scientific literacy has assumed centre-stage in science education debate in many 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. However, while the attainment of scientific literacy has been almost universally welcomed as a desirable goal there is still little in the way of consensus about why we need it and little agreement about its precise implications for curriculum provision. Discussion of these matters is beyond the scope of this introductory chapter, save to note that the benefits of enhanced scientific literacy accrue to individuals (greater employment opportunities, enhanced scientific and technological competence, better informed “consumers” of science and technology), to science (increased recruitment, greater support for scientific, technological and medical research, more realistic public expectations of science) and to society as a whole (more critical and better informed citizens, leading to more responsible decision-making and closer scrutiny of science and technology, possible economic benefits). This diversity of arguments for promoting scientific literacy prompted Shen (1975) to identify three categories of scientific literacy: practical, civic and cultural. Practical scientific literacy is knowledge that can be used by individuals to cope with life’s everyday problems (diet, health, consumer preferences, technological innovation, and so on); civic scientific literacy comprises the knowledge, skills, attitudes and values necessary to play a full and active part in decision-making in areas such as energy policy, use of natural resources, environmental protection and moral-ethical issues relating to medical and technological innovations; cultural scientific literacy includes understanding of the major ideas and theories of science, and the social, cultural and intellectual environments in which they were produced. Fostering all three aspects of scientific literacy necessitates a curriculum of much greater breadth and scope than has been traditional.

To this end, I find it useful to think about curriculum in terms of three major thrusts: learning science (acquiring and developing conceptual and theoretical understanding), learning about science (developing an understanding of the nature and methods of scientific inquiry and the internal and external factors that impact on scientific practice) and doing science (engaging in and developing expertise in scientific investigation and problem solving). While there are many advantages in seeing these curriculum elements as separate, there are some major and significant areas of overlap – for example, by engaging in scientific inquiry (doing science) students necessarily develop their conceptual understanding of the phenomenon or events being investigated and learn more about the conduct of scientific investigations. As noted earlier, this chapter prioritizes issues relating to learning about science.
LEARNING ABOUT SCIENCE

Learning about science is set within a complex and dynamic milieu of language, theoretical views of scientific practice and the reality of such practice. Nonetheless it is often helpful to focus separately on the importance of language, the values, interests, norms and traditions of science, and the need to adopt a critical perspective on contemporary scientific practice.

The importance of language

It is immediately apparent that language is key. Knowledge of science and knowledge about science cannot be articulated and communicated except through text and its associated symbols, graphs, diagrams, tables, charts, chemical formulae, equations, 3-D models, mathematical expressions and computer-generated images. Scientific language shapes our ideas, provides the means for constructing scientific understanding and explanations, enables us to communicate and understand the purposes, procedures, findings, conclusions and implications of scientific inquiries, and allows us to relate current information to existing knowledge and understanding. Indeed, it could be said that learning science and learning about science are largely a matter of learning the language of science.

All of what we customarily call ‘knowledge’ is language. Which means that the key to understanding a ‘subject’ is to understand its language… what we call a subject is its language. A ‘discipline’ is a way of knowing, and whatever is known is inseparable from the symbols (mostly words) in which the knowing is codified (Postman & Weingartner, 1971, p.102).

Two further points should be made. First, if it is correct that most people, including many still in school, obtain the bulk of their knowledge of contemporary science and technology from television, newspapers, magazines and the Internet (National Science Board, 1998; Select Committee, 2000; Falk, 2009), then media literacy and the capacity for active critical engagement with text is arguably the most important element of scientific literacy. Second, the sometimes counter-intuitive nature of scientific explanations, the high level of abstraction of scientific knowledge, its divorce from ordinary daily experience, and its presentation via unfamiliar linguistic conventions are among the factors that make science so difficult to learn and science education so unwelcoming to many students. Teachers need to make strenuous efforts to present science in ways that are more accessible to students (see Hodson, 2009, for an extended discussion of this issue). There is also an urgent need for scientists to develop better mechanisms for communication and consultation with the public – see, for example, the recommendations of the Office of Science and Technology and the Wellcome Trust (2001). Such pleas are not new; it is nearly twenty years since F. Sherwood Rowland (1993), then President of the American Association for the Advancement of Science, argued that “faulty communication” is the major obstacle to scientific progress and urged scientists to “sell the importance of science” through better communication.
Values, Interests, Norms and Traditions

For convenience, the values, interests, norms and traditions of science can be divided into two broad groups: those *internal* to science (that is, the values that govern the conduct of individual scientists and the mechanisms through which the community monitors that conduct and appraises the knowledge generated) and those *external* to science (that is, the values of the wider community that are likely to impact on science, scientific policy and the establishment of research and development priorities). In the terms used by Helen Longino (1990), this is a distinction between the *constitutive* values of science (the drive to meet criteria of truth, accuracy, precision, simplicity, predictive capability, breadth of scope and problem-solving capability) and the *contextual* values that impregnate the personal, social and cultural context in which science is organized, supported, financed and conducted. Allchin (1999) draws a similar distinction between the *epistemic* values of science and the *cultural* values that infuse scientific practice.

With regard to the constitutive values of science, practitioners are expected to display and practice certain personal values: objectivity, rationality, intellectual integrity, accuracy, diligence, open-mindedness, self-criticism, skepticism and circumspection (in the sense of suspending judgement until all the evidence is in hand). In addition, they are expected to be dispassionate and disinterested. All knowledge claims must be treated skeptically until their validity can be judged according to the weight of evidence; all evidence is carefully considered before decisions about validity are made; the idiosyncratic prejudices of individual scientists do not intrude into the decision-making. In choosing to become a scientist, one makes a commitment to “a set of preferences for such things as a non-dogmatic, anti-fideistic, critical attitude in which strength of belief is attuned to evidence, and for ‘open horizons’ over closures” (Suchting, 1995, p. 16). Of course, what an individual scientist regards as important, puzzling or worthy of attention is a consequence of her/his *personal framework of understanding*, an idea developed at length in Hodson (1998a). This unique and complex array of conceptual and procedural knowledge, ideas, beliefs, experiences, feelings, values, expectations and aspirations, what Giere (1988) refers to as “cognitive resources”, will determine the questions that are asked and the problems that are pursued, guide the way investigations are designed and conducted, and influence the way data are interpreted and conclusions are drawn. Further, because scientific practice is located in a social context (at the level of research teams, the wider scientific community, and society as a whole), the ideas, beliefs and values prevailing in those social milieux will impact on scientists and influence their judgements on all manner of things. Thus, the focus of scientific attention and, therefore, the subject matter generated are to some extent a reflection of the needs, interests, motives and aspirations of the scientists themselves, the key decision-makers within the scientific community, and the wider society. In other words, science is to some degree a product of its time and place, and subject to the values that pertain in the society that supports and sustains it. Sociocultural pressures can function to oppose or even exclude particular lines of research and explanation, while encouraging
others. For example, the most strenuous objections to Charles Darwin’s *The Origin of Species* did not concern its empirical inadequacy but the value-laden nature of its theoretical constructs. Similar problems confronted both Newton and Copernicus.

To be admitted to the corpus of approved scientific knowledge, theories have to be socially, culturally, politically and emotionally acceptable, as well as cognitively and epistemologically acceptable. Bloor (1974) comments as follows: “The ideas that are in people’s minds are in the currency of their time and place… The terms in which they think do not emanate from their subjective psyches. They come from the public domain into their heads during socialization” (p. 71). Such is the power of day-to-day socialization processes that many value-laden assumptions remain unrecognized and unchallenged. As Rose (1997) points out, because modern science is hegemonic its underlying assumptions appear to be natural and universal. The great and “ultimately damaging achievement” of science, she says, “is to appear as a culture with no culture” (p. 61). Thus, unless there are substantial moral-ethical issues involved, as in recent research in the biological sciences, the priorities and practices of science usually go unchallenged.

Nearly 40 years ago, sociologist Robert Merton identified four “functional norms” or “institutional imperatives” that govern the practice of science and the behaviour of individual scientists, whether or not they are aware of it (Merton, 1973). These norms are not explicitly taught; rather, newcomers are socialized into the conventions of scientific practice through the example set by more senior scientists. Merton argued that these norms constitute the most effective and efficient way of generating new scientific knowledge and provide a set of “moral imperatives” that serves to ensure good and proper conduct.

- **Universalism** – science is universal (i.e., its validity is independent of the context in which it is generated or the context in which it is used) because evaluation of knowledge claims in science uses objective, rational and impersonal criteria rather than criteria based on personal, commercial or political interests, and is independent of the reputation of the particular scientist or scientists involved.

- **Communality** – science is a cooperative endeavour and the knowledge it generates is publicly owned. Scientists are required to act in the common good, avoid secrecy and publish details of their investigations, methods, findings and conclusions so that all scientists may use and build upon the work of others.

- **Disinterestedness** – science is a search for truth simply for its own sake, free from political or economic motivation or strictures, and with no vested interest in the outcome.

- **Organized scepticism** – all scientific knowledge, together with the methods by which it is produced, is subject to rigorous scrutiny by the community of scientists in conformity with clearly established procedures and criteria.

Two additional norms have been proposed by Barber (1962): (i) *rationality* – science uses rational methods to generate and validate its claims to knowledge; and (ii) *emotional neutrality* – scientists are not so committed to an existing theory or
procedure that they will decline to reject it or adopt an alternative when empirical evidence points to it.

Many contemporary sociologists of science argue that Merton’s norms of scientific conduct do not really guide practice; rather, they are used retrospectively by scientists to dignify what they have done and to impress non-scientists. Mitroff (1974), for example, suggests that the “emotional neutrality” of organized scepticism is frequently over-ruled by the “emotional commitment” of scientists struggling to overcome difficulties and setbacks. Indeed, he postulates a counter-norm for each of the norms listed above.

- **Particularism** – the personal or professional attributes of the researcher and the status of the institution in which it is conducted are frequently taken into account in the evaluation of scientific contributions.
- **Solitariness** – ownership, control and distribution of scientific knowledge reside with the individual scientist or group of scientists who produced it. On occasions, results are withheld until a patent has been secured or delayed until their announcement will have greater impact.
- **Interestedness** – many scientists have a personal agenda for engaging in particular research and may have a vested interest in the outcomes, even more so when research is funded by commercial organizations.
- **Exercise of judgement** – the expert opinion of experienced scientists plays a prominent role in the evaluation of knowledge claims. Moreover, the research of newcomers is subject to much more rigorous checks than the work of established scientists.
- **Non-rationality** – scientists do not always act in a fully functional manner and scientific advances can result from non-rational as well as rational actions.
- **Emotional commitment** – commitment to a theory is essential for its advancement; disinterest leads to stagnation.

Mitroff argues that scientists simply act as they see fit and attempt to rationalize, justify and dignify it afterwards. Hence, he argues, rather than regarding science as a distinctive way of proceeding, to which all scientists have to conform, it makes more sense to regard science as (no more than) what scientists actually do. Conventions such as Mertonian norms do not direct the actions of scientists, they are simply what the collective actions of scientists amount to – at least, in their retrospective rationalizations.

If convention is not a determinant of action, but its product, then the beliefs, practices and values of scientists are reduced to a set of phenomena to be observed (directly or indirectly), analyzed and rationalized. In approaching this description of the scientific endeavour, there are two possible approaches. One is to ask scientists about aspects of their practice, using questionnaires, surveys and interviews; the other is to observe them as they engage in their day-to-day practice in the laboratory, making detailed field notes of events and audiotaping conversations between scientists for subsequent discourse analysis. The former approach, well exemplified by the work of Hagstrom (1965), tends to focus on the
large-scale characteristics of science, in particular its growth, organization and established mechanisms for admitting and en culturating newcomers. It also aims at generalizability: what scientists say about their practice is regarded as applying to each and every situation. In contrast to Hagstrom’s approach, Wong and Hodson (2009, 2010) conducted in-depth interviews with scientists in order to build up idiosyncratic pictures of scientific enterprise. No attempt was made to generalize about scientific practice. Rather, the intent was to ascertain the extent to which individual practice in rapidly developing fields like molecular biology, stem cell research and materials science is similar or dissimilar to approaches described in the science curriculum. In that sense, these studies are closer to observational studies, which tend to be smaller scale studies in which researchers use an ethnographic approach to describe and interpret day-to-day events and interactions between scientists in particular situations. Researchers who adopt this case study approach also make little or no attempt to generalize, regarding it as the reader’s responsibility to determine what, if anything, can be transferred and used to inform and interpret other situations. What these studies reveal is that science is much less linear, much less certain and much more disordered than the conventional image suggests. They also reveal a noticeable mismatch between the rhetoric and the practice of scientists, thus giving good grounds for subscribing to Albert Einstein’s (1933) remark that “if you want to find out anything [from scientists] about the methodology they use… don’t listen to their words, fix your attention on their deeds” (p.270). Ethnographic studies of laboratories (an example of learning from scientists) go beyond concern with the nature and conduct of experiments to shed light on the laboratory as a “cultural space” within which knowledge is constructed by the collective efforts of scientists. They give us some understanding of “the bricolage, tinkering, discourse, tacit knowledge and situated actions that build local understandings and agreements” (Fujimura, 1992, p.170) and the subsequent debating, persuading and political manoeuvring involved in gaining the interest and support of scientists outside the immediate group – support that is essential if the research is to become part of accepted scientific knowledge. Although many scientists would be reluctant to accept the findings of these studies as an authentic or true version of what happens in science laboratories, most practising scientists would readily acknowledge the significant role that can be played by intuition, hunch, luck, greed, personal needs, publishing pressures, and the like (Wong & Hodson, 2009, 2010). They might admit to Knorr-Cetina’s (1995) assertion that scientists can, on occasions, be guilty of practices that are not entirely “open and above board”, such as hoarding of information, implementing personal and group biases, engaging in plagiarism, showing blind trust in their own data or theory while dismissing those of rivals without sufficient consideration.

Critical Perspectives on Contemporary Scientific Practice

In the traditional forms of scientific research envisaged by Merton (1973), usually located in universities and/or government research institutes, so-called “pure scientists” constitute their own sponsors, regulators and audience; they determine
the research goals, scrutinize findings and conclusions, recognize competence, reward originality and achievement, determine what constitutes legitimate scientific conduct and discourage attempts at outside interference. However, scholars in the relatively new hybrid discipline of Science Studies have observed that, in the contemporary world, universities are under increasing public pressure to deliver more obvious value for money and to undertake research that is likely to have practical utility or direct commercial value. There are increasingly loud calls for closer links between academia and industry, and in many universities, the research agenda no longer includes so-called “blue skies” research (i.e., fundamental research); emphasis has shifted to “market-oriented research”, “outcomes-driven research” and ever-shortening “delivery times”. In this changed sociopolitical environment, scientists are now required to practice what Ziman (2000) calls post-academic science and Funcowicz and Ravetz (1993) call post-normal science. Varma’s (2000) study of the work of scientists in industry paints a similar picture of disturbing changes in the way research is conducted: customization of research to achieve marketable outcomes, contract funding and strict budget constraints, flexible but strictly temporary teams of researchers assembled for specific projects, and a shift in the criteria for research appraisal from the quality and significance of the science to cost effectiveness.

The vested interests of the military and commercial sponsors of research, particularly tobacco companies, the petroleum industry, the food processing industry, pharmaceutical companies and the nuclear power industry, can often be detected not just in research priorities but also in research design, especially in terms of what and how data are collected, manipulated and presented. More subtly, in what data are not collected, what findings are omitted from reports and whose voices are silenced. Commercial interests may influence the way research findings are made public (press conferences rather than publication in academic journals, for example) and the way in which the impact of adverse data is minimized, marginalized, hidden or ignored. There are many examples of industry actively using the news media to manipulate public opinion by seeking to discredit science that threatens its interests – most prominently, in recent years, the petroleum industry’s efforts to manufacture doubt about climate change. As Martin (1999) reports, attacks on researchers who accumulate unwelcome data (unwelcome to the company, that is) or express counter views are not uncommon: “Some of the methods used to attack dissenting scholars include ostracism, petty harassment, withdrawal of research grants, blocking of appointments or promotions, punitive transfers, reprimands, demotions, spreading of rumors, dismissal and blacklisting” (p. 346). Underhand tactics are not restricted to manipulation of public opinion through the press. For example, in 2001, TAP Pharmaceuticals was fined US$875 million for health care fraud in relation to its anti-cancer drug Lupron. Angell (2004) reports that changes to which TAP pleaded guilty included bribing doctors with televisions, VCRs, trips to resorts, cash in the form of “educational grants” (to be used for any purpose whatsoever) and free or heavily discounted drugs, for which the physicians were encouraged to bill Medicare at the full commercial price. In September 2009, Pfizer was fined US$2.3 billion for providing financial
rewards and other inducements to encourage general practitioners to prescribe drugs for uses not approved by the FDA, principally the use of Bextra, a drug developed to treat arthritis, as a general analgesic. Interestingly, the drug has now been withdrawn from use altogether. Other charges related to misuse of the antipsychotic drug Geodon, the antibiotic Zyvox, and the epilepsy treatment drug Lyrica.

Although modern communications technology has enabled much more rapid dissemination of research findings and has created the possibility of “open publishing”, through which editors post papers on the Internet and issue an open invitation to other scientists to review the paper, debate the results and conclusions, contribute additional or contradictory data, and generally engage in interactions that are otherwise only available at conferences, there is a counter and very disturbing trend in contemporary science towards the privatization of knowledge. Science is increasingly conducted behind closed doors, in the sense that many procedures and findings remain secret or they are protected by patenting, thus removing them from critical scrutiny by the community of scientists. The scope of what can be patented has been progressively and systematically broadened, such that the very notion of public accessibility to the store of contemporary scientific knowledge is under threat (Mirowski & Sent, 2008). It seems that the realities of contemporary science are in direct contradiction of three, if not all four, of the functional norms identified by Merton. Communality, disinterestedness and organized skepticism have been replaced by “the entrepreneurial spirit and economic growth, such that scientific intellectual creativity seems to have become synonymous with commodity” (Carter, 2008, p. 626). Within this new reality and the blurring of distinctions between university and corporate sponsor, the entrepreneurial enthusiasm and expertise of a new crop of scientists seems to have set aside all scruples about claiming absolute ownership of the knowledge produced by their research efforts. Perhaps the most striking example of the entrepreneurial scientist is Craig Venter, at one time a scientist on the human genome project and now leading the race to create artificial life (see www.jcvi.org).

MAKING CONNECTIONS

Put simply, the goal of learning about science is to understand what scientists do, how they do it, why they do it, what are the circumstances that foster and nurture scientific endeavour and the forces that constrain it, and to what extent responsible and well-informed citizens can begin to exert pressure on the scientific enterprise to ensure particular priorities and different outcomes. This involves making and exploring a range of direct and indirect connections with scientists – that is, bringing various communities together: students, scientists, educators, journalists and members of the Science Studies community (including philosophers and sociologists). Teaching and learning strategies might include talking to scientists, listening to their stories or attending to the words of various experts, theoreticians and commentators. For example, students can learn a great deal about the language,
theories, methods, history, traditions and values of science by attending lectures, seminars and discussions involving scientists (learning from scientists), by observing, interviewing and/or working alongside them (learning with scientists) and from what they read in textbooks, academic journals, newspapers and Internet Websites (learning about scientists). Learning from and learning with comprise activities in which scientists are directly connecting with others, while learning about scientists is normally mediated by others and so can be seen as indirect. The following sections explore such connections, identify some implicit and explicit messages that may be communicated, seek to reveal the problems that may arise from over-simplification, bias, distortion and misrepresentation (both intentional and unintentional). Given the usual strategies for teaching and learning about science, scientists and scientific practice, it makes good sense to begin with consideration of indirect connections.

**Indirect Connections - Learning about scientists**

Learning about scientists, while seemingly simple and straightforward, can be fraught with danger. Whenever the connection between scientists and students is effected via a third party (teacher, philosopher, sociologist, historian or journalist, for example), there is a risk of distortion, misrepresentation and simplification. For example, a quarter century ago, as part of a major survey of Canadian science education conducted by the Science Council of Canada, Nadeau and Désaultes (1984) identified what they referred to as five “mythical values stances” suffusing science education: (i) naïve realism – science gives access to truth about the universe; (ii) blissful empiricism – science is the meticulous, orderly and exhaustive gathering of data; (iii) credulous experimentation – experiments can conclusively verify hypotheses; (iv) excessive rationalism – science proceeds solely by logic and rational appraisal; and (v) blind idealism – scientists are completely disinterested, objective beings. The cumulative message is that science has an all-purpose, straightforward and reliable method of ascertaining truth about the universe, with the certainty of scientific knowledge being located in objective observation, extensive data collection and experimental verification. Moreover, scientists are portrayed as entirely 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. A decade and a half later, Hodson (1998b) argued that ten common myths and falsehoods about science continue to be transmitted by teachers, consciously or unconsciously, and by curriculum materials: (i) observation provides direct and reliable access to secure knowledge; (ii) science starts with observation; (iii) science proceeds via induction; (iv) experiments are decisive; (v) science comprises discrete, generic processes; (vi) scientific inquiry is a simple, algorithmic procedure; (vii) science is a value-free activity; (viii) science is an exclusively Western, post-Renaissance activity; (ix) the so-called “scientific attitudes” are essential to the effective practice of science; (x) all scientists possess these attitudes. Recent curriculum initiatives have attempted to counter these myths and falsehoods by re-orienting the curriculum
towards more extensive consideration of nature of science (NOS) issues. Indeed, NOS has become a prominent part of science curricula in many parts of the world, though research suggests that many students still hold stereotyped views of science and scientific inquiry. As, of course, do many of their teachers.

One major shortcoming in students’ NOS understanding is a direct consequence of the stereotyped description of “the scientific method” still found in some science textbooks and curriculum documents and still promoted by many teachers – that is, scientific inquiry as an entirely logical, systematic and algorithmic progression through a pre-determined sequence of activities leading from hypothesis to conclusion. In practice, science is often a messy, fluid and uncertain activity that cannot be planned in its entirety in advance of the investigation. Scientists refine their approach to an investigation, develop greater understanding of it and devise more appropriate and productive ways of proceeding all at the same time. As soon as an idea is developed and an investigation is begun, ideas, plans and procedures are all subjected to evaluation. Sometimes that evaluation leads to new ideas, to further and different investigative methods, or even to a complete re-casting of the original idea and re-formulation of the underlying problem. Thus, almost every move that a scientist makes during an inquiry changes the situation in some way, so that the next decision is made and the next action is taken in an altered context. The path from initial idea to final conclusions may involve many backtracks, re-starts, short cuts and dead ends. In other words, doing science is an untidy, unpredictable activity that requires each scientist to devise her or his own course of action. In that sense, science has no one method, no set of rules or sequence of steps that can, and should, be applied in all situations. Rather, it requires scientists to think on their feet and adapt their strategy to the changing situation. In doing so, they draw on previous experience, adapt it to the new context, and make extensive use of their intuitive sense of what needs to be done.

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

Because historical accounts and media reports play such a significant role in establishing the indirect connections with scientists that enable productive learning about science, scientists and scientific practice, it is important to discuss some of the key learning issues they raise.

Connecting through history

Historical case studies, biographies and autobiographies constitute an especially powerful way of building up understanding of both the conceptual and methodological issues surrounding significant scientific developments, providing insight into the sociocultural context in which the events occurred, and shedding light on the motives, feelings, thoughts, commitments, apprehensions, triumphs, failures, mistakes, changes of plan and struggles of scientists. Case studies and biographies should be regarded as further opportunities to learn about scientists, while autobiographies may be seen as learning from scientists. For me, an historical approach includes case studies of recent or even contemporary events, in which oral history can play a key role. A useful distinction can be drawn between internalist accounts and externalist accounts. The former concentrate solely on the development of scientific concepts and their role in theoretical explanations, excluding all but the most cursory consideration of the sociocultural context in which the ideas were developed and the socio-economic factors that might have motivated their development. Externalist accounts, on the other hand, seek to describe and explain the growth of science in terms of the personal circumstances of individual scientists and/or the social and cultural climate of the wider society in which the work was conducted. Because we have all been socialized into particular linguistic codes and particular ways of describing and explaining events it isn’t always easy to recognize the forces and influences that impact contemporary scientific practice. They often remain invisible. It is easier to be objective about events that occurred elsewhere and at different times, though it is important to proceed cautiously here, too, as discussed below.

The motives for including history of science will be a powerful influence on the type of history included. Those concerned to assist conceptual understanding may be inclined to interpret scientific history from a 21st Century perspective, frequently ignoring superseded ideas or regarding them as seriously misguided – an approach
that has been termed “Whiggish” history. Such accounts may distort history by criticizing scientists of the past for failing to meet modern standards of data collection and experimental design, and may ridicule those scientists for being unaware of some of our taken-for-granted modern knowledge. They portray scientific knowledge as emerging in simple and predictable fashion from scientists’ struggles to solve theoretical rather than practical problems, with one scientific development leading directly and inexorably to the next until the current position was reached. When current theories are taken as the yardstick, those who initially opposed the ideas that eventually led to those theories are regarded as incompetent or perverse, while those who accepted and developed them are credited with exceptional foresight - a kind of villains and heroes approach to scientific history. Because it is often assumed that there has been one universally applicable method in use since the outset of the scientific endeavour, theories that were once accepted but were subsequently falsified are regarded as the product of scientists’ errors. By evaluating early scientific investigations using modern criteria and standards, Whiggish historians of science ignore altogether any appraisals made at the time about whether an experiment was appropriate and reliable, whether a theory was intelligible and whether an argument was convincing. The fact that a belief doesn’t stand up to critical scrutiny now, in the 21st Century, does not mean that it was irrational to hold such a view at the time it was proposed. We can only understand the past on its own terms; the intellectual standards of the present sometimes have little relevance to a proper understanding of events in the distant past. Accounts that are more faithful to historical circumstances and sociocultural influences entail consideration of the various by-ways, diversions, false paths and dead ends of science, recognition that science is frequently complex and uncertain, and acknowledgement that not all inquiries are fruitful. A “proper” history of science attends to the theoretical and practical problems that motivated new ideas and new procedures, and takes cognizance of the metaphysics and worldview prevailing at the time. In these respects, “time slices” rather than “vertical history” may be more appropriate for the curriculum – that is, consideration of the range of ideas current at any one time, how these ideas were generated and how they were received, interpreted, modified and utilized in further work.

Making sense of media reports

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

Too often, students accept media-based information at face value; they focus on superficial features of the material and are easily seduced by the razzamatazz of presentation. Students need to be made aware, if they are not already aware, that the popular press invariably over-simplify complex issues and that information from such sources is often incomplete, sometimes purposefully so, and often highly selective. It may be confused, confusing or deliberately misleading, as in the case of government-sponsored reporting in the UK at the time of the Chernobyl nuclear power station disaster in the mid 1980s and the BSE episode in the 1990s. Unbalanced reporting can arise because of journalists’ honest attempts to be even-handed and to present “both sides of the story”. Science is built on skepticism, and presentation of conflicting data, counter arguments and alternative conclusions is a key element in public scrutiny that eventually leads to consensus. But consensus is not unanimity; dissenting voices can always be found, even for well-established scientific knowledge, and laudable efforts by journalists to be objective in their reporting can sometimes result in outlandish views, poorly substantiated views and even discredited views being reported as legitimate alternatives to mainstream scientific opinion (Friedman et al., 1999; Weigold, 2001). This commitment to even-handed reporting is sometimes exploited by those with a vested interest in manufacturing doubt about scientific findings perceived to be counter to their interests, as in the case of the tobacco industry’s attempts during the 1950s, 60s and 70s to cast doubt on the link between smoking and lung cancer. Coverage of global warming and climate change is another case of the press alleging major differences of opinion on matters where there is clear scientific consensus. Conversely, in their haste to meet a deadline, or in their desire to present a particular position on an issue, journalists may sometimes neglect to include the voices of people who could invest their coverage with alternative perspectives and different experiences. This is certainly not to argue for a popular press that is slavishly subservient to the scientific establishment; rather, it is to argue for readers to be constantly vigilant and critical.

An analysis by Zimmerman et al. (2001) of articles and news reports published in a range of newspapers and magazines in Canada and the United States over a
one-month period showed that they routinely failed to provide information about where the research was originally published, and who funded it, and only very rarely presented full details of research design or included critical comments by other experts in the research field. Reporters frequently omit discussion of the limitations, subtleties and nuances of the research because such details might detract from a story’s clarity, impact, conciseness and ability to hold the reader’s attention. While numerical data are often used to create an impression of care, precision and authority, carefully selected and sometimes highly dubious statistics are commonly used to mislead or concentrate attention on particular aspects of the report, to the exclusion of others. Material may be biased and may use a range of journalistic techniques such as emotive language, hyperbole and innuendo, provocative pictures and images, and emotionally manipulative background music, to persuade readers, viewers and listeners of a particular point of view. As Nelkin (1987) observes, “selective use of adjectives can trivialize an event or render it important; marginalize some groups, empower others; define an issue as a problem or reduce it to a routine” (p. 11). In a study of the metaphors used by British newspapers in their reporting of developments in biotechnology, Liakopoulos (2002) found many metaphors intended to convey a positive image of biotechnology (including: revolution, breakthrough, major step, golden opportunity, potential goldmine, miracle, and opening the door) and many intended to create a negative response (including: Pandora’s box, threat, rogue virus, killer plants, Frankenfoods, Nazi-like eugenics, playing God, and unnatural selection). Describing biotechnologists as mad scientists, evil geniuses or Frankenstein figures leaves little doubt about the position the reader is expected to adopt. Jensen (2008) provides similar examples of highly selective language use to support or oppose stem cell research. Somewhat earlier analyses of press coverage of genetic engineering revealed what Mulkay (1993) called an oscillating “rhetoric of hope and fear” and van Dijck (1998) called a hybrid discourse of “promise and concern”.

At a general level, students need to consider the following questions. Who determines what we see and hear in the media? How is this information monitored, filtered and edited? Who provides information to the media, and why? Why is a particular story covered? How is a particular story framed and how is a particular position evaluated? Why are some views emphasized or even magnified, while others are downplayed or ignored altogether? While the media can quite rightly be accused, on occasions, of distorting research results, sowing seeds of distrust and acting as an agent provocateur, they also provide much needed recognition for scientific research, raise public awareness of important developments and sometimes “blow the whistle” on overt vested interest, bias and fraud. A democratic and open society is premised on the free flow of information among its citizens. It is here that the media plays a crucial role, but can only do so when there is a wide variety of newspapers, magazines, Internet websites, writers and editors to ensure diversity of views. When control and ownership are vested in the hands of a few individuals and corporations, opponents can be easily discredited, alternative views suppressed and dissident voices marginalized or silenced.
In recent years, the Internet has become the dominant medium through which the public (including students) access knowledge and information in all areas and disciplines. For example, Falk (2009) reports that 87% of a representative sample of US citizens state that they gather scientific information from the Internet, compared with 10% in a similar survey conducted in 2000. When students seek to extract, evaluate and utilize information from the Internet and from multimedia materials, rather than from solely print-based media, movies and television, they are increasingly vulnerable to biased, distorted, confused, inaccurate and untruthful material, and so even more in need of supportive, critical guidance. Like all forms of communication, the Internet is vulnerable to messages that reflect the vested interests of governments, business, media corporations and advertisers; it is subject to the kind of cultural control and censorship that seeks to privilege particular beliefs, values and practice, and to marginalize, exclude or misrepresent others. Those with power and influence may attempt to restrict the messages and voices of those who might wish to express counter views. Brem et al. (2001) have studied the ability of students in Grades 9, 11 and 12 to evaluate information located on Websites of varying quality, including some hoax sites. Despite lots of preparatory work and continuing support from teachers, students frequently failed to differentiate between the quality of the science and the nature of the reporting and presentation, often equating amount of detail with quality. Students were often unable to assess the accuracy, judge the credibility and evaluate the site’s use of evidence to substantiate knowledge claims. Because students tend to rely on common sense as their principal guide, rather than careful analysis and critical reflection, they are easily seduced by whatever attractive surface features the authors deploy. In a similar study at the Grade 6 level, Wallace et al. (2000) found that students usually concentrated on the search aspects of the task and their ability to navigate a range of sites, and neglected to evaluate the quality of the science they located. Often they searched for key words and then slavishly copied the chunk of text in which they had located them into their notebooks. There are clear messages here for teachers seeking to enhance their students’ scientific literacy.

Direct Connections - Learning from scientists

It could be argued that learning more directly from scientists by attending lectures, seminars and panel discussions involving scientists offers the possibility of students building up a more authentic picture of science, scientists and scientific practice, especially if the scientists are discussing their own ongoing research – what Bruno Latour (1987) calls “science-in-the-making”. However, in their attempts to describe the theoretical and procedural issues in a way that is easily understood, scientists engage in a post-inquiry rationalization rather than providing a blow-by-blow account of daily activity. Thus, a different but equally stereotyped view of scientific practice is presented. Indeed, there is a major mismatch between the way scientific inquiry is conducted and the way it is reported, and a similar mismatch between the private language of argument and negotiation within the laboratory (and embedded in laboratory notebooks) and the public language of
scientific argument presented in academic journals. The need to communicate
one’s findings as precisely and efficiently as possible, and to make them
convincing to others, determines the linguistic form of the research report and the
scientific paper. Gone are the references to crises, compromises and intuition;
replaced by an account in which references to human agency are reduced to a
minimum, a text in which the physical world is made to “speak for itself”. Thus,
the emergence of the “correct view” is portrayed as arising unproblematically from
the data. More than 40 years ago, Peter Medawar (1963) asked the provocative
question: “Is the scientific paper a fraud?” In the sense that it is constructed to
persuade readers of a particular point of view rather than to describe the day-by-
day events of the investigation, it is a fraud. It frequently conceals the situationally
contingent and opportunistic logic of the inquiry, renders the choice of method
straightforward and unproblematic and misrepresents the motives for the work in
an effort to provide a clear and logically compelling argument for the validity of
the findings and the author’s particular interpretation and explanation. As Knorr-
Cetina (1981) so disarmingly puts it: “The scientific paper hides more than it tells
on its tame and civilised surface” (p.94). The rationality of the chosen method is
only seen afterwards, when satisfactory conclusions have emerged, as noted by
Nobel Laureates Max Born and François Jacob.

There is no philosophical highroad in science, with epistemological
signposts. No, we are in a jungle and find our way by trial and error, building
our road behind us as we proceed. We do not find signposts at crossroads, but
our own scouts erect them, to help the rest. (Born, 1934, p. 44)

Writing a paper is to substitute order for the disorder and agitation that
animate life in the laboratory… to replace the real order of events and
discoveries by what appears as the logical order, the one that should have
been followed if the conclusions were known from the start. (Jacob, 1988,
p. 318)

Further, and contrary to the impression created by some school science textbooks,
science is not propelled exclusively by its own internal logic or by a simple search
for the truth. Rather, it is motivated and shaped by the personal beliefs, values,
aspirations and political attitudes of its practitioners and the individuals, groups
and organizations willing and able to provide the necessary funding. Necessarily, it
reflects the history, power structure and political climate of the community in
which scientific practice is embedded. Necessarily, it reflects the prevailing social,
economic, political and moral-ethical attitudes and values of that community. In
the memorable words of Robert Young (1987), “Science is not something in the
sky, not a set of eternal truths waiting for discovery. Science is practice. There is
no other science than the science that gets done. The science that exists is the
record of the questions that it has occurred to scientists to ask, the proposals that
get funded, the paths that get pursued…Nature ‘answers’ only the questions that
get asked and pursued long enough to lead to results that enter the public domain”
(pp.18 & 19). What scientists say about their work, at least in formal and public
settings, usually tells little or nothing about these matters. It says little about the
commercial interests, pressures, values and other influences that motivate scientific inquiry. In consequence, as discussed earlier, presenting students with an authentic view of scientific practice necessarily entails moving beyond the descriptions provided by philosophers of science (or the school science curriculum version of them) and the writings and lectures of scientists themselves to take account of what sociologists, historians and ethnographers have to say.

Direct Connections - Learning with scientists

Part of my argument for drawing a distinction between learning about science and doing science (see above) is based on my contention that doing science entails experiential and affective components that can only be acquired by engaging in the activity for oneself and by oneself. Working alongside practitioners is ideal for giving students insight into the realities of day-to-day practice. They can see at first hand the trials, tribulations, challenges, opportunities, constraints, frustrations and rewards of the scientific endeavour. They can see that scientists are ordinary folk, just like them, who have to confront complex issues and deal with myriad problems and influences, just like everyone else. They gain insight into the realities of scientific inquiry, especially its fluidity, reflexivity and uncertainty. They come to appreciate the powerful role played by experience, intuition and emotion. Four kinds of experiences contribute to such understanding. In student-scientist partnerships, scientists work alongside students to support, advise and monitor the design, conduct, interpretation and reporting of students’ own investigations; in an internship, students spend periods of time observing and assisting scientists in their day-to-day practice; in citizen science projects, scientists design investigations and recruit volunteers from the community to assist with data collection and dissemination of findings; in participatory action research (PAR), citizens engage in defining, conducting and evaluating investigations and interventions with the goal of learning more about the immediate environment and finding ways to improve local conditions and situations. The principle underpinning these initiatives is the apprenticeship model of learning. Apprentices learn to think, reflect, argue, act and interact in increasingly knowledgeable and skilful ways by engaging in “legitimate, peripheral participation” (Lave, 1988, 1991; Lave & Wenger, 1991) with people who already have the appropriate knowledge and skills. Apprenticeship is more than internalization of knowledge and skills, it is also a process of becoming a member of a community of practice (Wenger, 1998). Developing an identity as a member of the community and becoming more knowledgeable and skilful are part of the same process, with the former motivating, shaping and giving meaning to the latter: “Newcomers become oldtimers through a social process of increasingly centripetal participation, which depends on legitimate access to ongoing community practice” (Lave, 1991, p.68). In short, when they are given opportunities to participate peripherally in the activities of the community, newcomers pick up the relevant social language, imitate the behaviour of skilled and knowledgeable members, internalize their values, recognize what excites and motivates them, and learn to act in accordance
with the community norms. Clear and skilful demonstration of expert practice and the provision of opportunities for critical questioning, interspersed with opportunities for guided participation by the “novice”, provided they are informed by critical feedback from the “expert”, comprise the stock-in-trade of the apprenticeship approach long used for teaching and learning in the trades and crafts. For centuries, bread, cheese and wine makers, blacksmiths, carpenters and shoemakers have all acquired their expertise this way. However, even something as simple to organize as a series of visits to laboratories and industrial sites can also have substantial impact on students’ views of science, scientists and scientific practice by providing direct connection with scientists, as in Scherz and Oren’s (2006) work with grade 9 and grade 10 students at three Israeli high schools. The key, of course, is to provide students with a working brief that requires them to observe and question personnel, processes and products carefully and systematically, and to present their findings in written, oral or multimedia format.

Barab and Hay (2001) note two key aspects to student-scientist partnerships and internships: first, the mentorship provided by participating scientists; second, the opportunity to design, conduct and report one’s own research, with access to tools and facilities unavailable in schools. The first element, as discussed above, helps students to acquire the language, understand the norms and appreciate the values associated with scientific practice, and build a sense of identity as a scientist; the second element is essential for building a sense of ownership, enhancing confidence and stimulating creativity. Numerous studies attest to the value of such experiences in terms of learning science, learning about science and doing science. Further compelling evidence is provided by a number of contributors to this volume. Of particular interest to teachers thinking about the kind of experiences they can/should provide for their students is Kathleen Hogan’s (2002) report of differences in experience and learning outcomes between a group of students who followed a school-based course on water quality and watershed management and a parallel group who worked in a citizen-run environmental management and advisory organization. Predictably, the school-based programme emphasized theoretical understanding and scientific thinking, while the agency-based experience emphasized what Hogan calls “practical savvy”. In consequence, two very different images of environmental practitioners were promoted: those who are science-based and use careful scientific analysis to link the local or current situation to larger and historical trends, and those who are society-based and need to be able “to juggle and manage multiple projects simultaneously, on small budgets and short timelines” (p. 428). Hogan’s conclusion that the day-to-day business of running the agency can sometimes interfere with the provision of worthwhile educational experiences for the students should serve as a reminder to teachers that a judicious blend of school-based study and hands-on, real world experience may be the ideal.

Through citizen science projects, which can involve scientific organizations, environmental and so-called “green groups”, local universities, colleges and industries, ramblers and bird watchers, local residents’ groups, organizations such as “friends of X, Y or Z”, pond or stream reclamation groups, and other
community-based initiatives, students gain experience of working on real research projects, with opportunity to engage in creative problem-solving, and have the satisfaction of seeing their ideas taken seriously by real scientists. When their work is subsequently presented at conferences and in other public forums, a common feature of many of these initiatives, students receive an enormous boost to their confidence and gain further valuable insight into the workings of the scientific community. Because citizen science projects bridge the gap between school and community, students quickly recognize the ways in which scientific literacy links with responsible citizenship, how personal and community values impregnate all considerations, and just how difficult it can be to resolve moral-ethical dilemmas and the competing needs of industry, community and environmental protection.

At a much more radical and politically active level, PAR puts emphasis on knowledge “from below” (from the grassroots), values knowledge produced through collaboration and action, makes that knowledge freely available within the community, accepts accountability to the people most affected by the issues and problems, and seeks to effect change. While space precludes extensive discussion of specific PAR projects here, some flavour of their potential can be gleaned from Argyeman’s (2008) detailed descriptions of action-oriented projects addressing issues of poor air quality and the incidence of asthma among students at a high school in inner city Boston (Massachusetts) that resulted in much stricter enforcement of vehicle emissions controls and a commitment from the local authority to institute anti-idling legislation. It is noteworthy that the students subsequently became involved in a successful campaign to prevent the siting of a bioterrorism laboratory in their neighbourhood.

Direct connections – Consultation and public participation in science

Discussion of PAR raises the question of increased public participation in the determination of priorities for scientific and technological development and the monitoring of scientific practice. Many research studies over the years have shown that scientists and policy makers frequently conceptualize the public as having insufficient scientific knowledge to reach rational decisions about scientific and technological matters, even those that directly concern them. Public opposition to new science or new technological developments is often attributed to lack of knowledge, fear of the unknown, irrational reasoning, lack of vision or emotionally-driven Luddite tendencies (Gregory & Miller, 1998; Collins & Evans, 2002; Bäckstrand, 2003). Scientists and journalists have been encouraged to make up for this perceived shortfall in public understanding by reducing the complexity of the science presented to the public to a level that is more readily understood and, therefore, more likely to be approved and accepted by the public. Michel Callon (1999) labels this the deficit view or public education model of public participation: not only do scientists believe that they have to teach the public everything they need to know (or that scientists, politicians and corporations want them to know), he says, they also consider that they have nothing to learn from the public. In recent years, there have been some very welcome signs of a shift away from this
deficit model, including the following comment in the Royal Society’s (2004) *Science in Society Report*: “The implied relationship that support for science can be achieved through better communication overlooks the fact that different groups may frame scientific issues differently. The [deficit] approach did not adequately conceptualise how publics’ views and attitudes towards science were embedded within wider social, political and institutional understandings, and risks discounting the role of local knowledge and different public values in science debates” (p. 11). What is needed, as a matter of some urgency, is better understanding and communication across the scientist-public divide.

Callon (1999) postulates two alternatives to the deficit model: the public debate model and the co-production of knowledge model. In the former approach, scientists interact with the public through surveys, referendums, symposia, focus groups, citizen panels, and so on. Of course, citizens are unlikely to be unanimous in their views; rather, they will form sub-groups with divergent interests, needs, experiences and viewpoints. Citizens’ knowledge, while different from that of scientists, is regarded as enriching, complexifying, contextualizing and problematizing scientific knowledge. However, as with the deficit model, the public debate model ascribes roles in the production of scientific knowledge in asymmetric fashion, with the public having some input into the establishment of research and development priorities, and sometimes into the ways in which findings are applied, but little or no involvement in the intervening steps. In the co-production model, there is a wholesale redistribution of roles: scientific knowledge is regarded as the product of processes in which citizens and scientists collaborate closely at all stages. Citizens are seen to possess knowledge and experience that is vital to defining what counts as a problem, relevant to the design, conduct and evaluation of scientific research, and important in determining the composition of research teams and in the dissemination of findings. Through their vested interests, personal involvement and day-to-day experiences, lay persons (whom Callon et al., 2009, call “researchers in the wild”) are able to contribute valuable insights that can and should be used to contextualize and refine the lab-based research findings of scientists.

**DISCUSSION AND CONCLUSION**

The major thrust of this chapter is the argument that more strenuous efforts need to be made to ensure that students gain a robust understanding of the ways in which science is practised in the contemporary world. Traditional stereotyped views of science, scientists and scientific inquiry, and of the ways in which scientific findings are validated and communicated, need to be replaced by alternative views rooted in the realities of daily practice. Is there one definitive account of scientific practice? Of course not! Scientists vary quite markedly in terms of what they know, what interests them, what they have experienced and what skills they possess; scientific problems vary substantially in focus, scope, context, clarity and opportunity. These differences lead to differences in practice. Particularly intriguing are the differences in approach adopted by practitioners in the different
LEARNING ABOUT SCIENCE

sciences – something on which school science is strangely quiet. Bauer (1992) comments as follows: “The differences among adepts of the various sciences go beyond matters of theory, method, and vocabulary to subler habits of thought and even to customs of behaviour, to such an extent that the differences… can aptly be described as cultural” (p.25). The best that can be said is that there is a “family resemblance”, with common interests and some areas of methodological and conceptual agreement - what Loving (1997) calls a “loose configuration of critical processes and conceptual frameworks, including various methods, aims, and theories all designed to shed light on nature” (p.437).

Given the complexity of the scientific enterprise, the myriad of different starting points for an investigation, the major differences in knowledge, experience and personality among scientists, and the likelihood of substantial variations in the range of facilities and resources on which individual scientists can draw, it would be surprising if all scientists proceeded in the same way. Interestingly, young children consider diversity of approach inevitable; they have no expectations of a particular method for doing science (Hodson, 1990). Teachers and science textbooks create the expectation of a single method through their continual reference to the scientific method, perhaps in an effort to simplify teaching. It is also interesting that many teachers vary the model of scientific inquiry they present to students in response to changes in subject matter and perceived academic ability of the students, being more inclined towards an inductivist approach with biology topics and with those students regarded as lower in academic ability. Often these changes in “philosophic stance” (Hodson, 1993) reflect learning opportunities for concept acquisition and development rather than belief in a demarcation in inquiry methods between the biological and physical sciences. The tendency to use inductivist approach with so-called “less able students” seems to be prompted by a widely held view that inductivism is easier to understand than hypothetico-deductivism or the notion of scientists adopting a contextually appropriate approach. While I am arguing in this chapter for a much more fluid and context-dependent view of what constitutes scientific practice, I also recognize that telling students, too early in their science education, that scientific inquiry is context-dependent and idiosyncratic could be puzzling, frustrating and even off-putting. This is a similar point to Brush’s (1974) concern that teaching history of science can sometimes have an adverse effect on young students by undermining their confidence in science and scientists. In the early years, we may find it useful to characterize scientific inquiry as a fairly standard set of steps. Within this simple representation we can emphasize the importance of making careful observations (using whatever conceptual frameworks are available and appropriate to the students’ current stage of understanding), taking accurate measurements, systematically controlling variables, and so on. As students become more experienced they can be introduced to the variations in approach that are necessary as contexts change – for example, the startlingly different approaches adopted by experimental particle physicists, synthetic organic chemists and evolutionary biologists.
One further point should be made: once we choose to present science in the school curriculum as a human practice, embedded in the sociocultural milieu of contemporary society, we necessarily acknowledge that it is vulnerable (on occasions) to bias, the influence of vested interest, distortion and misuse. There are many situations in which scientists, sometimes unconsciously and sometimes deliberately, deviate from the community-approved code of scientific conduct. In urging science teachers to lift the lid of this particular Pandora’s Box, Bencze (2008) itemizes in spectacularly incriminating style the ways in which the cherished Mertonian norms are routinely, systematically and cynically violated in pursuit of company profit. By making students aware, he argues, we forearm them, make them more vigilant, enhance their critical scientific literacy, and increase the likelihood that they will become politically active citizens. While I have enormous sympathy with this view, I believe that it would be a gross disservice to students (and to scientists) to suggest that all contemporary scientists working in industry or industry-sponsored research are routinely engaged in shady and ethically dubious activities, just as it would be a gross disservice to suggest that all scientists are “squeaky clean” in this respect. I am not trying to be deliberately evasive when I state that only the classroom teacher can decide when (and to what extent) it is appropriate to introduce these particular critical dimensions of scientific practice to students.

In essence, this chapter promotes the view that building an authentic view of scientific practice as a key element in scientific literacy requires teachers to build robust and productive connections between students and scientists. For much of the time, these connections will be the kind of indirect connections that I have designated as learning about scientists. To ensure the necessary breadth and depth of perspectives, and to convey to students the complexity and diversity of scientific investigations, it is crucial that a wide range of people effect these connections (teachers, philosophers, sociologists, historians, journalists, etc.). Furthermore, if these indirect connections are to be productive of learning, it is imperative that the curriculum affords a much higher profile to critical reading skills and issues of media literacy. It is imperative, too, that the curriculum fosters and enables a range of direct connections between students and scientists. First, by creating opportunities for students to attend lectures, seminars and discussions involving scientists – that is, learning from scientists. Second, by enabling students to observe, interview and/or work alongside scientists - that is, learning with scientists via student-scientist partnerships, internships, citizen science projects and participatory action research (PAR). Finally, an argument was made that consideration of PAR can be used as a convenient route to discussing greater levels of public participation regarding priorities for scientific and technological research and development, and developing a curriculum that might work towards a more scientifically literate, critical and socially active citizenry.
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