Why We Teach School Science, and Why Knowing Why Matters

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In the past, when Karen Sullenger and I collaborated in delivering the introductory science ed course for pre-service education students at UNB, she would begin the course by challenging students to write an essay on "why should we teach science at all in the public schools?" Because, Karen argued, unless teachers could answer that question persuasively and intelligently, we might as well expunge science from the school curriculum.

Of course, students hated the assignment. They saw it as frivolous and speculative, a distraction from their real mission, which was to learn enough practical techniques to survive in the classroom. If they had energy left over from learning basic survival, then they would willingly concentrate on how to teach science effectively. But they found it frivolous and irritating to be asked to theorize about such "why" questions, when their basic task, as they conceived it, was that of delivering the curriculum as it was delivered to them.

We can all have sympathy for those pre-service teachers, gripped with anxiety about the perils of launching themselves into daunting careers as public school teachers. But it is harder to have the same sympathy for government officials, curriculum planners, textbook writers, experienced teachers, and educational researchers like ourselves, who similarly ignore this most fundamental of all questions related to science education: what are the goals and purposes of teaching school science? Today, I would argue, the most fundamental obstacle facing school science and the challenge of improving it is the pervasive confusion and uncertainty that reigns about why we are teaching science to children in the first place. Until we can have resolved that confusion, or at least have faced its complexities squarely, then we can neither devise effective curriculum, nor plan successful teaching strategies, nor assess performance on the part of our students or ourselves.

I am certainly not alone in advancing this position. The imperative to re-examine the very purpose of school science is currently driving major educational reform efforts in the United Kingdom and parts of Europe. The need to face the question, "why are we teaching science?" is being eloquently articulated today in the writings of important educational researchers and theorists such as Jonathan Osborne, Peter Fensham, and Robin Millar.[i] It is important that Canada and the Atlantic Region not be left behind in the wave that is coming; it is important, as I shall argue later, that NSERC and its CRYSTALS not be left behind, either.

My presentation, therefore, addresses the topic, "why are we teaching science in the schools in the first place?" It represents my own efforts, aided by recent scholarship from science educators and from the public understanding of science, to answer the same dreaded question that Karen imposed upon her students. I address four basic rationales commonly offered for the generous place accorded science in the school curriculum. I ask, what sort of curriculum, and what sort of pedagogy, follows logically from each of these rationales. How would school science today be different, if we seriously let our practice be guided by one rationale rather than another. Anodyne though the question may sound, "why teach science," I assure you that its implications are anything but soothing.

The Economic Argument

Let us begin with what Robin Millar has called the "Economic Argument" for treating science as a compulsory, foundational subject in our schools.[ii] On this view, school science represents one end of a vital (if leaky) pipeline which channels science-oriented students upward from the schools through post-secondary institutions. The pipeline ultimately supplies highly-trained scientific and engineering personnel to the economy, personnel vital to economic well-being and national competitiveness.

The economic argument for school science is especially compelling to government and business interests. It has probably been responsible for the remarkable expansion of science as a compulsory subject in the school curriculum that has occurred around the world over the last twenty years. The history of science education in most countries since the Second World War shows that reform initiatives have coincided closely with recurrent national panics over defense and global competitiveness. Crises (real, manufactured, or imagined) concerning the perceived ability of science education to supply personnel in sufficient quality and quantity to meet national needs have been the principal motor of science education reform. Today, again, much of the impetus for educational reform in science education in the United States and Europe is being driven by concerns over the quality and supply of scientific and engineering personnel. For example, this anxiety is displayed in the 2004 EU report, *Europe Needs More Scientists* and the

U.S. National Science Board's *Science and Engineering Indicators - 2006* and the reports of the Fordham Foundation. Anxiety about science and engineering manpower, especially when it is stoked by international assessment data on student performance from studies such as TIMSS and PISA, is currently feeding crisis-talk about the state of school science in many countries around the world. In media and in political circles, the international ranking of a country's students' achievement in science and mathematics is often made to serve as the accepted policy-barometer, not only of school performance, but of national well-being in the world economy. Canada, despite basking in high PISA scores today, has not escaped this ubiquitous crisis-talk. Statistics Canada, reporting on recent PISA scores, warns direly that "Canadian 15-year olds will need to improve at the rate of other leading countries to ensure Canada maintains its competitive edge." NSERC has implicitly stated that one important motive for the CRYSTAL initiative it has launched is the need to enhance recruitment of students into science-related careers.

I certainly have no intention to dismiss the economic argument for school science holus-bolus, indeed just the contrary. But the argument as employed today is often used to serve vested interests and is not well supported by economic data. In particular, claims of crises in the supply of scientific and engineering personnel appear badly exaggerated in some quarters. In the United States, where such supply-crisis talk is rife, the proportion of American post-secondary students taking degrees in science and engineering, both undergraduate and graduate, has hardly changed in twenty-five years. In the American workforce, only about a third of all workers who hold post-secondary degrees in science or engineering actual work in positions related to their training, and this proportion, also, has been constant for decades.[iii] These data lend no support to claims of a general manpower-supply crisis. Indeed, they bring into question the efficacy and the ethics of policies designed to enhance recruitment into scientific careers, when two-thirds of those obtaining degrees in the field fail to find related employment or voluntarily leave the field. Canadian statistics are less comprehensive than those for the USA, but data from NSERC (scarcely a source likely to minimize the demand for scientifically-trained personnel) show that unemployment in the natural sciences and engineering has precisely followed the general unemployment curve between 1990 and 2006, showing no tendency to decrease.[iv] This result casts doubt on the existence of any unsatisfied and growing demand for NSE personnel in the country, however much temporary shortages may exist in one field or another. I am less familiar with supply and demand statistics for Europe, but an important recent study on science education in Europe, done for the Nuffield Foundation, has reached conclusions similar to these for the United States and Canada.[v]

Criticism is also being directed at how comparative international data on student performance in science is being used in policy debates today. Recent studies raise new questions about the reliability and validity of TIMSS and PISA data.[vi] My concern, however, lies much more in the exaggerated significance that media commentators and some political figures have invested in the ranking outcomes generated by TIMSS and PISA. Indeed, the unstated premise that national economic competitiveness is significantly determined by junior-high school performance in science, or that national economic strength can most efficiently be increased by enhancing by the achievement of fifteen-year-olds on science tests, is a highly questionable assumption that begs for critical scrutiny. More directly, the obsession with rankings deflects attention away from the powerful role of socio-economic determinants on performance outcomes that are revealed by closer and more sensitive analyses of the TIMSS, and especially the PISA, data. Above all, the rankings-obsession endemic to TIMSS and PISA leads to policy prescriptions oriented to "more-of-the-same" – more hours for science, more assessment, more resources, more of what is already happening in science classes. These policy-calls for "the-same-only-more-and-more-intensely" discourage what is most needed in contemporary science education: the will to examine the basic goals and means of school science and plan accordingly.

Rationales for school science based upon the economic argument also reinforce one other, unfortunate curricular effect. The pipeline metaphor implies that the primary responsibility of every science class is that of preparing students for the more advanced class to come. In this way, it reinforces the implicit curricular bias in school science toward the propaedeutic needs of students who will pursue post-secondary study in science-related fields or enter science-related careers. Science content and methods crowd out other potential curricular goals, such as science as preparation for citizenship in a technoscientific world, or science as a vital cultural possession essential to the liberal mind and the examined life, or science as the underpinning for a diversity of non-science related careers. The economic rationale for school science risks sacrificing the interests of the large majority of students – perhaps eighty-three percent in Canada – who will not pursue advanced study or careers in science, and who will "leak out of the pipeline" before high school graduation. Today, I would argue (as do Robin Millar and others) that school science requires a fundamental reorientation toward an "appropriate science." This means a science curriculum that, insofar as it is compulsory, is developed primarily around the life-needs of students for whom science will be neither vocation nor propaedeutic. Ironically, a curriculum oriented toward "science for all" might also turn out to be the curriculum of greatest value to students pursuing science-related careers, as well.

So am I advocating that the economic justification of school science be waved away in a happy paroxysm of educational idealism? Just the contrary. Something is happening in our middle schools today that ought justly to ignite panic in the heart of every advocate of the economic argument, whether scientist, business person, or politician. Every teacher knows that somewhere between the age of eight and sixteen very large numbers of students pass from a state of enthusiasm and engagement with the study of science to a state of indifference or disdain for the subject. What I will call the "Disengagement Problem" is more acute for girls than boys, but it applies strongly to both. Today, a new international study, called Project ROSE, is beginning to reveal the unexpectedly large dimensions of this problem. Project ROSE has surveyed and compared the responses of fifteen-year-old boys and girls in twenty-five countries concerning their interest in science, their trust in science, their views of school science, and their future career hopes.[vii] When ROSE participants were asked how they liked their school science in comparison to other subjects, there was a 0.92 *negative* correlation between their responses and United Nations comparative national Index of Human Development. In short, the more advanced and prosperous a country is, the less its young people are drawn to the study of science, the less they are inclined to trust and value science. Traditionalists and cynics might argue that the outcome merely shows that science is difficult; the spoiled and pampered children of the developed world react against a subject they consider harder and more demanding than most. But TIMSS data reveals that at the level of nation-by-nation achievement, degree of achievement is also *negatively* correlated with positive attitudes toward school science. On a country-by-country basis, strong performance in science does not signify a liking for school science, but a lack of trust and a lack of interest in the field. The ROSE data does not trace students developmentally, but other studies suggest that students' basic attitudes about science and their personal expectations (or non-expectations) of science-related careers is set very early and is unlikely to be changed later. The crucial, limiting age seems to be fourteen, a result clearly indicating the need to refocus attention on the reform of science teaching away from high school, into the middle years.

These are challenging results, only now being realized and assessed by the international science education community. In one sense they should have not have been surprising. The decline of interest, respect, and trust for science during the middle school years, and its inverse correlation with national affluence, closely mirrors results obtained in studies carried out on the (adult) public understanding of science around the world. That fact suggests that the Disengagement Problem is a facet of a larger cultural phenomenon that lies beyond science education itself. But the ROSE data also reveal that students in all countries express more positive attitudes and interest toward science in general than toward school science. That finding not only suggests that school science is currently doing little to reverse students' widespread disengagement from science, but also that school practices may be aggravating the Disengagement Problem. In short, school science seems to be actively turning students away from science; students complain in surveys about its irrelevance, its repetitiveness, its fragmentation, its authoritarianism.[viii] The Pan-Canadian Protocol for Interprovincial Collaboration on School Curriculum ranks "attitudes toward science" as one of the four "Foundation Goals" for Science Learning Outcomes in Canada; the *Foundation Document* for the Atlantic Canada Science Curriculum (1998) similar lists "Attitudes" as one of the four General Curriculum Outcomes. Not only are we failing to realize this set of outcomes in our sciences, but we seem unaware of the problem. Neither Canada not the United States are even participating in Project ROSE, although other studies suggest that its findings are readily generalizable to Canada. For advocates of the economic argument for school science, those who believe that economic well-being depends upon a regular and increasing supply of talented and committed young science-enthusiasts, this is this outcome that should strike terror into the breast. It is not TIMSS and PISA, but ROSE, that should be driving all reform efforts in science education today.

The Democratic Argument

Let us turn now to what Robin Millar has called “the democratic argument” for school science. We live today in an increasingly complex technoscientific world, one in which the political issues that face us as a society, and the personal decisions that we face as individuals, often hinge upon science and its technological, environmental, and medical applications. The main responsibility of school science, according to the Democratic Argument, should be to prepare students to be informed citizens and enlightened consumers who can intelligently negotiate the technoscientific challenges of modern life, politics, and society.

The curriculum and the pedagogy that would flow from full acceptance of the democratic rationale for school science would look substantially different from those in our schools at present. An introduction to basic science principles and content would not be absent, but focus would shift toward contemporary technological and real-world applications of these principles and their intersections with students’ lives. Curriculum-development would be guided by the question of what students need to know in order to participate in discussions of the scientific controversies of our time, including global warming and its causes and solutions, the alleged risks of nuclear power and environmental carcinogens, and the contested impact of diet and personal habits on health and well-being. The so-called "science, technology, society, and environment" (STSE) movement within educational reform has spun off experimental curriculum and courses designed to do just that. These have included efforts in Canada by Glen Aikenhead and Britain's Science for Public Understanding pilots of some years ago. Central to the STSE initiative is the conviction that science-teaching should focus on the uncertainty as well as the certainty of science. School science should help students appreciate the existence and the sources of disagreement among experts concerning scientific and technological issues and their implications -- the better to play their own role eventually as informed citizens and decision-makers. Science education, the democratic argument insists, should be education about science as well as in science.

Can this really be done? Enticing as the STSE option is, it faces serious problems of implementation and delivery in the real world of schools and students. I will mention only three. Its practicality for younger children is probably very limited, although environmental issues do offer a promising vehicle for such approaches among the very young. More complex civic controversies about technoscientific issues quickly turn out on close examination to hinge far more on the political and ethical beliefs of the antagonists than about factual questions of science and technology themselves. This unexpected fact reduces their potential as vehicles for introducing scientific principles per se. Most science teachers are ill-prepared to deal with STS-type issues. Many, especially those who identify strongly with traditional science, are reluctant to open their classrooms to STSE discussions. These are significant problems.

For all the practical difficulties the democratic argument faces, however, it deserves a far more central role as a guiding principle of curriculum development and delivery than it now enjoys. Canada's official curriculum documents, expressing the so-called "intended curriculum," go to great length in touting the importance of STSE learning as a component of school science. The Atlantic Canada Foundation document, for example, ranks Science, Technology, Society, and Environment as one of the four General Outcomes to be sought in science education. But as every experienced teacher will attest, in the classrooms of Atlantic Canada, where the 'enacted curriculum" is realized, the only General Outcome that really matters and is consistently assessed is "Knowledge," meaning "science content." The curriculum materials supplied to teachers reinforce the implicit message that "Knowledge" is the outcome to which most if not all teaching should be oriented. In the "attained curriculum" – what students take away from their school experience – the resulting message all too often is that school science is de-personalized, irrelevant, fragmented, and something no cool kid pursues. This is very unfortunate.   As educational theorists, we need to realize that STSE approaches mobilized in service to the democratic argument, however difficult to implement, may offer the best, possibly the only line of attack, against the so-called Disengagement Problem. If we are to change our students attitudes toward school science, we need to start showing them why science matters to them and to their world.

The Skills Argument

A third important rationale for school science hinges on the claim that certain kinds of science study inculcate desirable transferable skills that include the ability to formulate and conduct experiments, evaluate empirical evidence, appreciate quantitative arguments, carry out inductive generalization, and engage in critical thinking. The transferable skills argument can be said to mirror a longstanding western conviction that scientific reasoning and scientific method epitomizes human rationality itself. The skills argument has recently emerged as the most-often invoked rationale for school science after the economic argument.[ix] Proponents of the skills argument urge a curriculum and a pedagogy that encourage hands-on work, that call on students to collectively negotiate the significance and meaning of data, and even to plan and conduct open-ended investigations in the alleged style of adult scientists. "Skills" is listed as one of the four General Outcomes in the Atlantic Canada Foundation Document, and in the Pan-Canadian Framework document.

Like STSE approaches, skills-oriented pedagogy faces practical limitations and potential theoretical objections. Hands-on activities are costly in time and resources. While they may hold students' interest and attention, they do not always translate into learning, as a large literature on the problems of school lab exercises documents. Given sufficient investments of time, resources, and guidance, students can be brought to conduct their own, open-ended investigations; but whether those investigations provide an authentic approximation to adult science, or are more likely to mislead students about the nature of scientific research and the skills involved in it, is an open and contested issue. Similarly, the kinds of critical skills involved in scientific research and reasoning may not be as readily transferable to other life-situations as tacitly assumed. Critical thinking in real life usually involves reasoning though analogy in highly contextualized situations, usually on the basis of insufficient information. Opportunities to devise and conduct experiments, let alone provide experimental controls, or to exercise inductive reasoning on significant numbers of taxonomic equivalent units, are rarely encountered in real-life situations, however often they present themselves (ideally) in the context of scientific research and study. Science-skills are not necessarily life-skills. Science's claim to possess some unique potential in the inculcation of transferable, critical skills may at least be open to significant challenge from other school subjects. Exercises in critical reasoning based on the interpretation of historical documents, works of literature, or even the functioning of machines in shop class, may present closer approximations to, and better training in, real-world reasoning than the situations typically encountered in science-learning.

The transferable-skills rationale for school science today is closely allied with inquiry-based learning theory and methods. Although experts evince little consensus about exactly what the inquiry-method consists of, its alliance with the transferable skills argument strongly enhances the authority of both. Inquiry-based learning theory can boast a formidable intellectual pedigree leading back to Piaget, constructivism, Rosalind Driver, and (in some versions) Carl Popper and T. S. Kuhn.[x] Inquiry-based methods also present themselves today as the ideal or exclusive vehicles for overcoming the Disengagement Problem. Active inquiry, the argument goes, is the antidote to teacher-centered and transmission-based teaching methods that all too often today instill the image of science as authoritative, impersonal, and boring. Active minds, hands-on activity, problem-solving, and argument-making are, inquiry-advocates contend, the means of sustaining our students' engagement with science through the crucial middle school years.

Is it simply too heretical for me to suggest that we need to take a new, hard look at the focus on inquiry learning in science? All the objections cited above to hands-on activity can be mobilized against inquiry learning, and indeed, the two are commonly considered the same thing. Let me mention three additional arguments against the focus on inquiry learning in science. First, the inquiry method at its most simplistic trades on deeply questionable analogies between individual learning and the historical development of research science. Concepts of the "child as scientist" and school science as somehow isomorphic to research science are to be met commonly in the research literature, in forms that range from the gently metaphorical to the outright fantastic.[xi] Second, inquiry, because it is primarily a learning theory, is indifferent to curricular content. Yet I would argue that the reform of science teaching today requires radical reassessment of content: what science-content we wish to teach, how the content is presented, and how it hangs together as a whole. Third, inquiry methods may challenge and hold students' engagement as no other approach can; but that is no substitute for showing children why science and science study are important to their lives, their society, and their futures. To meet that goal, other approaches, including STSE, may be better suited. I am not urging the abandonment of inquiry methods or the use of hand-on activities, or the study of their use in science education. Indeed, the research of *CRYSTAL Atlantique* is making major contributions to the better understanding of both. I am only urging that we not regard them as fetish or as panacea, that we not succumb to the temptation to focus so exclusively on *how* we are teaching, that we forget the larger debate about *what* we are teaching and why.

The Cultural Argument

The final rationale for school science I wish to consider is the one Robin Millar has called "the cultural argument." Science is, beyond dispute, one of the great intellectual enterprises of modern, especially western, civilization. The vision of nature embodied in modern science defines the universe for us, informs our vision of our human essence, and speaks to the hopes and fears of our world. Science plays a roll for us today somewhat like the great mythologies of the civilizations of the past: it provides the great narrative of truth, meaning, and essence that we live by. The proper goal of school science, according to the cultural argument, is to bring students to understand that great story and the enterprise behind it, so that they might not remain ignorant and alienated strangers to modern, scientific culture.

What kind of curriculum and pedagogy would follow logically from giving the cultural argument for school science a central, guiding role? Proponents of the cultural argument sometimes urge a strong role for the history of science and the philosophy of science in the school curriculum. Advocacy of both has been an important reform current in science teaching for the last thirty years, and as a reform current has sometimes been at odds with it rivals, the STSE reform approach, as well as with inquiry-based approaches. Despite my own career as an historian of science, I am frankly skeptical about whether history, sociology, and philosophy of science have much to offer school science.

Recently, however, educational reformer Robin Millar in the U.K. has begun tentatively to explore a new approach to formulating a science curriculum. That approach, if not inspired by the cultural argument, is at least consistent with its implications. Millar's approach builds upon the frequent criticism that science curriculums everywhere are crowded with too much content. They typically bulge to excess with too many potential outcomes that intimidate and discourage teachers, especially elementary teachers, to say nothing of students. Despite the busyness of the typical science curriculum, students commonly experience such curriculums as fragmented, repetitive, monotonous, and directionless. The typical science curriculum lacks central themes because those who formulate it evince no willingness to set priorities for what is important and what is not.

To remedy these problems, Millar argues, we must re-conceptualize the science curriculum as the opportunity to tell science's great stories about nature, the universe, and our bodies. We must present students with coherent and cohesive world-pictures, tell them stories that transmit science's great visions – its great contemporary visions – of the world as narrative accounts, from quarks to superclusters and genes to gerontology. To do all this, Millar is prepared to jettison an astonishing amount of curricular detail as well as much traditional preparatory material dear to the hearts of science teachers and scientists. He is even willing to sacrifice some of the lab work and other hands-on activities that has allegedly enlivened school science in the past.

The delivery of school school science today, students complain, is monotonous. To relieve that monotony in the curriculum of tomorrow, Millar argues, our narration of science's great stories must be interspersed with material designed to show scientists at work and show how scientists work. It must contain material that links scientific principles to the most contemporary technologies that pervade students' lives. And it must introduce students to technoscientific issues and controversies that inform our times. What school science has to gain from this reconceptualization of its mission, Millar argues, is a school science-for-all, a curriculum suited to the needs of both those who will and will not go on to advanced study in science-related fields.[xii] And it would be a curriculum that might stand a chance of solving or at least ameliorating the serious Disengagement Problem that schools face today. It might be the kind of curriculum that could endow school science with meaning and unity, and demonstrate to students the relevance of the scientific enteprise to themselves and their world.

Let me conclude on a pugnacious note. Recently NSERC officials made a site visit to Fredericton and to *CRYSTAL Atlantique*, to talk to researchers and assess progress. During their standard interview, they asked me a standard question: what I regarded as the weaknesses, if any, of the experimental, CRYSTAL program NSERC had put in place. The greatest weakness, I told them, was the conservative, unimaginative, almost timid approach to science education research and reform embodied in the terms of reference and mission statements that NSERC had adopted. This great federal agency was, I told them, unwilling to "think outside the box" about the crucial issue of science education reform. Fortunately my admirable colleagues in *CRYSTAL Atlantique*, researchers from whom I have learned so much, do not share that conservativism. Today they are boldly re-thinking the value and the nature of school science. Even as we speak the Province of New Brunswick, like other Atlantic Provinces, is also re-thinking the forms of education provided in its schools, and is drafting new and bold changes in school policy. *CRYSTAL Atlantique* hopes that the same bold willingness to ask fundamental questions and to follow where the real needs of children lead, will characterize that policy process and inform the future of science education in our region. At *CRYSTAL Atlantique*, we look forward to playing what role we can in that process, so central to our region and its burgeoning culture of science.

NOTES

i Steven Turner, "School Science and Its Controversies; Or, Whatever Happened to Scientific Literacy?" *Public Understanding of Science"* 17.1 (2008), 55-72.

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v Jonathan Osborne and Justin Dillon. *Science Education in Europe: Critical Reflections.* A Report to the Nuffield Foundation (January, 2008).

vi Peter Fensham, "Values in the Measurement of Students' Science Achievement in TIMSS and PISA," in Corrigan, ed., *The Re-Emergence of Values in Science Education* (Rotterdam: Sense Publishers, 2007), 215-229; Svein Sjøberg, "PISA and 'Real Life Challenges': Mission Impossible?" in Hopman, ed., *PISA according to PISA* (October 8, 2007).

vii Camilla Schreiner and Svein Sjøberg, Svein, *Sowing the Seeds of ROSE. Background, Rationale, Questionnaire Development and Data Collection for ROSE (The Relevance of Science Education) – A Comparative Study of Students' Views of Science and Science Education.* Oslo 2004. In *Acta Didactica* 4 (2004), 126 pp. Www.ils.uio.no/english/rose/key-document/key-doc/ad0404-sowing-rose.pdf. Accessed January 28, 2007. Svein Sjøberg and Camilla Schreiner, "Young people and science. Attitudes, values and priorities. Evidence from the ROSE project," Keynote presentation at EU's Science and Society Forum 2005. Brussels 8-11 March 2005. Www.ils.uio.no/english/rose/network/countries/norway/eng/nor-sjoberg-eu2005.pdf. Accessed January 25, 2007.

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ix Steven Turner and Karen Sullenger, "Kuhn in the Classroom, Lakatos in the Lab: Science Educators Confront the Nature-of-Science Debate," *Science, Technology, & Human Values* 24.1 (1999): 5-30.

x Richard Duschl and Richard Grandy, "Reconsidering the Character and Role of Inquiry in School Science: Framing the Debates," in Duschl and Grandy, eds., *Teaching Scientific Inquiry. Recommendations for Research and Implementation* (Rotterdam: Sense Publishers, 2008), 1-37.

xi William Brewer, "In What Sense Can the Child be Considered to Be a 'Little Scientist'?" in Duschl and Grandy, eds., *Teaching Scientific Inquiry. Recommendations for Research and Implementation* (Rotterdam: Sense Publishers, 2008), 38-49.

xii Robin Millar, "Toward a Science Curriculum for Public Understanding," *School Science Review* 77 (1996): 7-18; Millar "Science Education for Democracy: What Can the School Curriculum Achieve?"in R. Levinson and J. Thomas (eds.), Science Today. Problem or Crisis? (London: Routledge, 1997), pp. 87-101; Robin Millar and Jonathan Osborne, J. (eds.) *Beyond 2000: Science Education for the Future.* The Report of a Seminar Series Funded by the Nuffield Foundation (London: King's College London School of Education, 1998).