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Increasing the Relevance of Science and Technology Education for All Students in the 21st Century

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ABSTRACT *Since 1990, country after country has revised its national curriculum for science to bring it into line with a policy statement that acknowledges that science in schooling is important for every student, and not just the minority who will go on to further tertiary and career studies in the science. This curricular aims of this acknowledgement of Science for All is often phrased as scientific literacy. The development of the science to be learned for scientific literacy has been a matter of considerable debate and contention between scientists and science educators. Both these groups, however, see contemporary society and the world in science-biased way. As Richard Feynman put it, The world looks so different after learning science. After a brief review of these perspectives and the resulting attempts to define the science curriculum for schooling, an alternative perspective will be provided. In a study in China, social experts have been the source of what science knowledge and what features of science are relevant to the lives of citizens. These findings suggest some interesting and very different emphases for school science.*

KEY WORDS: *scientific literacy, science for all, science curriculum, relevance*

Introduction: The Conception of a New School Science

In this paper, I wish to present an alternative perspective on the curriculum for school science. The empirical basis for this new perspective is derived from a major study with which I have been involved over the past three years in China. First though, I shall put the case that a new perspective is needed, if the agreed intentions for school science in the compulsory years of schooling are to be met. The present era for school science had its conception, but not its birth in the early 1980s. By 1980, the social, economic, and environmental concerns in a number of countries and in UNESCO led high level groups to review the state of science education in schooling, and to assess to what extent it was contributing to meeting and resolving these societal concerns. As a consequence of their study and analysis, these groups all acknowledged that there was an urgent need of new goals for school science. In these reports (UNESCO, 1983; National Science Foundation, USA, 1983; Science Research Council, Canada, 1984; The Royal Society, Britain, 1985), the new goals were only spelt out in very general terms under the slogan of ***Science for All,*** or some variant of it like the one in Canada, which was *Science for All Canadians.* These reports acknowledged that the most recent formulations of the curriculum for school science in the 1960s and 1970s (and operating in schools in the 1980s) had been designed essentially for the preparation of future scientists – the dominant demand in 1960. By 1980, the students who would proceed from senior secondary school to university studies in a science-based faculty like Science, Engineering, Medicine, Agricultural Science, etc., were a decreasing minority of the students who were now completing secondary education. The needs of the majority of students in secondary schooling had not been in the forefront of the minds of the curriculum designers; and they were being poorly served by the abstract and academic content that had become the essential nature of school science.

Probably the best of these reviews is the one conducted by the Science Council of Canada. It had an active research component compared with most of the others that relied on passive existing statistics about participation in science education, available resources, teacher supply, etc. This Canadian report set out four aims or purposes for school science.

1. *Develop citizens able to participate fully in political and social choices facing atechnological society.*
2. *Train those with a special interest in science and technology education for further study.*
3. *Provide an appropriate preparation for modern fields of work.*
4. *Stimulate intellectual and moral growth of students.*

We shall return to these four purposes several times as they, in fact, relate in a very interesting way to the debate that has been occurring since 1990 about *scientific literacy,* the term that has been used in the serious attempts to make Science for All a reality. They are also, in another sense, the four dimensions of the study in China in which I have been engaged for several years. That study can be seen as an attempt to investigate how these four purposes manifest themselves in the lives of citizens, and, hence, what they mean in terms of the content that should have emphasis in school science today.

By 1990 in many countries, there was official commitment to the ***Science for All*** these reports had recommended, and the intention that school science in the compulsory years should benefit all students was no longer an issue. Rather the issue had become: What does Science for All mean for the curriculum of school science, and for its teaching and learning?

The first responses

Even before there were national agreements on this new priority for school science, a number of projects in different countries began to produce new materials for school science. Most were in modular form that could be used for a few days or weeks alongside the existing curriculum, but some could be used as a year-long curricula for schools and teachers keen to make their science teaching and learning more relevant to a wider cross section of students. Since these various attempts all included some degree of relating science to technology and to society, this movement has been described as the *Science/Technology/Society (STS) movement*

An example of this movement was an approach to curriculum that made significant social contexts, such as Communication, Sport, Clothing, Drinking, and Driving, the topics to be studied by means of the set of science, technological, and socio-scientific concepts that were relevant, together with methods for the scientific investigation of aspects of the topic. This *Concepts in Contexts* approach was just beginning to be operationalized, when it was overtaken by what seemed like grander opportunities for science educators to influence what happened in school science.

More determined responses

Towards the end of the 1980s, the first countries began to move to make *Science for All* a reality in their schools. Firstly, it was agreed that science should have a significant place in all the compulsory years of schooling, beginning in the first years of the primary school. Science had had a nominal place in the primary years of schooling since the 1970s, but in many countries only the more enthusiastic teachers took this seriously. The new decision to make science a visible and compulsory component of primary schooling, thus, raised very serious problems. In most countries, primary teachers tend to be persons with weak personal backgrounds in the sciences, and with rather negative attitudes towards science – a combination that means they have little confidence about teaching science, compared with most of the other subject areas they and their young pupils engage in together. Secondly, in a number of these countries, a decision was taken to make Technology a new subject area in its own right. This meant that the momentum that the *STS movement* had been gathering as a way forward for school science was stopped in its tracks. If the *T* for technology was removed from the *S* for science, then the natural link that *T* provided between the science *S* and the society S was broken, and the debate about the content for the curriculum was a debate in the narrow bounds of disciplinary science. Thirdly, the pioneering curricula, in Britain, Canada, USA, and Australia for this new school science, took the form of three or four strands of slightly disguised disciplinary science content now stretched across the ten or eleven years of compulsory schooling, plus a strand about scientific processes. No clear distinction was made between the emphasis in science learning to be achieved in any of the levels of compulsory schooling. The intended learning of science content in these new curricula amounted to an amount for most students that was at least as much or more than had been expected of the more serious science students in the old curricula.

The National Curriculum for Science in England and Wales was established in 1991, and was very influential in these more committed national responses to Science for All students. The committee for this curriculum initially came up with a set of 21 (then 19) strands of knowing in the first two drafts of the National Curriculum for Science in England and Wales (NCC, 1989). So many strands defied them being seen simply as the three disciplines of chemistry, physics, and biology that had been the traditional subjects for introductory science learning in that country. This proposal was also far too confusing when these strands were all spread across ten levels of schooling for the curriculum bureaucrats and for teachers. By some devious educo-politics, this innovative starting point for opening an agenda for discussion was quickly quashed. The new curriculum was finalized in 1991 with just three sequential strands that are simply the three traditional science subjects renamed, together with a fourth strand, *Scientific Investigations*, which is essentially the old science processes of the 1970s. The other broader ideas about the nature of science in the initial drafts were quietly forgotten. Across the eleven years of compulsory schooling, the four strands made a formidable list of learnings.

Very similar curricular outcomes quite quickly appeared in several states in USA and Australia, in some Canadian provinces, in New Zealand, and in Sweden and Korea. Sociologists of education have ascribed these similarities to the dominance of economic rationalist social perspectives and to the other influences of globalization that have been prominent in the 1990s. One exception was Denmark where the new subject for the primary years, Natur/Teknik, prescribed no content at all, but rather required teachers with their students to carry out scientific investigations of phenomena in the near, further, and human influenced environments that had meaning for the growing students. *If these investigations were carried out well, then appropriate content would be learnt.*

Scientific literacy

Soon after these first new curricula, the term *Scientific Literacy* began to be used as the shorthand new slogan for the goal of new science curricula. An immediate confusion was created by the association of science learning in school with the notion of literacy. It may be that this association was created to give *Science for All* a more operational sense. It may also have been an educo-political ploy to give school science, particularly in the primary years of schooling, something of the priority status and importance that language literacy and number literacy (numeracy) have in the minds of teachers, pupils, their parents, and the general community. If so, this curriculum ploy has failed because of the lack of an agreed understanding of what are the corresponding modest science learning targets compared with the much clearer sense everyone has of these in relation to language and number.

Is scientific literacy a scientific equivalent to the basic beginnings of reading and writing, or of counting and the basic number operations? or *Is it about becoming literate in science in the sense that persons with a considerable mastery of the use of words are said to be literate?* Whichever of these one chooses, there are further questions to answer: *(a) What does this mean for school science? (b) What content should now be taught in school science? (c) How can schools encourage the learning of this literacy?* There has been a continuing debate in scientific and educational communities throughout the last decade about all of these questions, but no clear consensus about answers has been forthcoming from this debate (see for example, Bybee, 1997).

Underlying Assumptions

In the 1980s reviews and reports, there are references to two assumptions and these have become much more explicit in the rationale that was set out by education systems to justify the prominence science was now being given throughout compulsory schooling. (i) The pragmatic assumption: *Because societies everywhere are increasingly being permeated by the ideas and products of science in the form of technologies, all future citizens will be better able to cope if they have some knowledge and confidence about science.* (ii) The democratic assumption: *Quality science education in schooling will enable citizens to participate meaningfully in the many decisions that societies and politicians now must make about a complex set of socio-scientific and socio-technical issues.*

In hindsight, it may seem strange that there was little, or no reference, in these discussions of school science for all students, to science as a fascinating field of human inquiry that can be of interest to pupils as it is to many adults. The media have long understood the wonder and fascination humans have about the natural world, and that science's probing of it can be entertaining as well as instructive. Very popular and successful programs are regularly shown on TV about science. Newspapers regularly report a variety of science items, from those that could affect readers to the quite useless, but intriguing latest discovery or theory about the universe and cosmology. There has also been a spate of best selling books about serious science and its relations to other powerful human belief systems, like religion, cultural myths, and moral philosophies.

Questioning the Assumptions

Atkin and Helms (1993) were perhaps the first in the science education community to begin to challenge the pragmatic assumption about scientific literacy. They asked: "*If the concept of scientific literacy is analogous to language or cultural literacy, do citizens need to know science in the same sense that one needs to know their mother tongue?* and *"Is the ability to use scientific knowledge in the way one uses language essential for adequate functioning and responsible citizenship?"* Their own answer to these two questions was *No*. There are too many leading citizens in all societies who do not only have weak scientific knowledge, but actually acknowledge it without embarrassment.

This critique of the underlying assumptions was reinforced when a book entitled *The Myth of Scientific Literacy* by Shamos (1995) appeared. He argued that universal scientific literacy is a futile goal, because it cannot be reached, and the attempt will waste human and other resources on a grand scale. The vast majority of students come out of science classes with neither an intellectual grasp nor a pragmatic appreciation of science. It is interesting to note that these critics of scientific literacy, as it was being suggested, did not stop there. They went on to give their own priorities for school science in the years of schooling that are compulsory. Atkin and Helms suggested that school *science should be more concerned with science as a human activity powered by both internal and external forces (i.e., its intellectual and social history), practical reasoning, and habits of mind.* Shamos (1995) suggested *an appreciation of science as an ongoing cultural enterprise, an awareness of technology's impact on ones personal health, safety, and surroundings, and the need to use experts wisely in resolving science/society issues,* a functional and societal set that was almost exactly reproduced by Millar and Osborne (1998) in discussing a science curriculum for public understanding of science.

The democratic assumption is built on the thought that societies will be more orderly, or somehow more rationally responsive, to socio-scientific issues if more citizens understand the science involved. This is very attractive to politicians, because they are repeatedly found to be using such an argument when launching new initiatives in relation to school or public understanding of science. Such wishful thinking shows their own ignorance of the complexity of the science that is usually involved in such issues, and a quite unrealistic hope that the level of science (even in the best of schooling) could achieve such critical competence to evaluate the opinions of conflicting groups of science experts.

Science Experts as the Source of Answers

The lack of consensus, among those who seemed to be the natural decision makers about scientific literacy, has reached an impasse of compromise that will only be broken, when a quite different approach and new authorities are involved in answering the questions that I have raised. *The two rather obvious groups – academic scientists in the physical and biological sciences and science educators – have been asked se-*

parately, or together, in committees in different countries to answer the questions about the content and teaching and learning for this new intention for school science. They are the persons with expertise in science, with experience of education at the university and school levels, respectively, and with involvement in the education of science teachers. Other more applied academic scientists and applied scientists outside of education have not usually been consulted.

One other group has, as I have already hinted, exercised influence in the answering of the questions. These were the curriculum bureaucrats whose job it was to ensure that the decision-making committees would finish their work on time, and deliver it in formats that conformed to some overall structure that had been determined elsewhere in the curriculum organization. The curriculum bureaucrats usually controlled the writing processes between meetings of the committee– a powerful position when most committee members are heavily committed in their normal positions and take on the curriculum committee as an extra.

Most of the academic scientists and some science educators argued for the maintenance of the established types of science content (relating to the second Canadian aim), often calling in somewhat different ways on a liberal education perspective as their warrant. They conceded, however, that the learning of science should be extended by adding other strands, *such as Nature of Science and History of Science* together with more *Applications of Science.* Others among the science educators argued for a serious thinking and substantial revamping of the existing curricula, if they were to justify any claim that they are preparing students for life, as citizens in tomorrow's society. These experts tried to weld together a liberal perspective of science as a great human and social endeavor, and a personal and societal pragmatism that recognizes that knowledge has value for most people because of its usefulness – the first and third, and perhaps fourth of the Canadian reports' purposes.

An example of academic scientists answering the questions is to be seen in the *Benchmarks of Scientific Literacy* produced by the AAAS Project 2061 in 1993 in USA. There are seven major sequences of Science content benchmarks and two Technology sequences. Six are new strands to add to the traditionally familiar. The Physical Setting (physics + chemistry, and some earth science), The Living Environment (biology) and The Human Organism (biology and some earth science). The seven Science strands have within them 41 substrands, and the two Technology ones add nine more. In one of these substrands alone, 22 benchmarks for learning are listed. For example, *Materials may be composed of parts too small to be seen without magnification; When elements are listed in order by the masses of their atoms, the same sequence of properties appears over and over again, etc.*

The total arithmetic of these benchmarks defies belief as a credible answer to basic scientific literacy. It amounts to more science than we have ever been able to teach to the elite group of students, who continue with the study of the senior disciplinary sciences. Furthermore, 40% of these benchmarks are listed for teaching and learning in the elementary school years, despite the well-known and serious limitations constraining quality science education in these years. The National Academy of Science in the USA, soon afterwards, has provided another list of categories of science knowing that has also been largely generated by scientists. This list is almost as formidable, with eight major categories that seem again to extend the traditional content of school science considerably, without clearly indicating what should be omitted to make room for the new topics. Without such a clear direction, it can only be concluded that scientists have a quite unrealistic sense of what school science can hope to achieve.

Science Educators' Answers

A promising basis for the development of a curriculum for scientific literacy was provided by Roberts (1983), in an internal paper about scientific literacy he wrote for the Science Council of Canada's review of science education. Building on a 1982 paper in which he identified seven possible curriculum emphases (deliberately not called "aims" or "purposes" to indicate the need for selection) for school science, he related them one by one to what they meant for scientific literacy. Each could, if one wished, be used as the basis for designing science teaching and learning for a school science curriculum. Roberts pointed out that to attempt all seven with every topic (or in each level of schooling) is a sure way not to emphasize most of them, especially if the testing of the learning has a bias towards one or two of them. He argued that there is no reason why the emphases could not take turns in being prominent, as students progressed through the years of compulsory schooling, depending on their social needs and interests.

With variations in what might be emphasized, the Roberts' idea of different emphases at different stages of schooling has been, what many science educators have argued for, as the answers to the curricular questions when school science is intended to meet all students' interests. Since, many science educators had been talking and writing in the 1980s that: *only with less content can better quality learning be achieved* (see the discussion of this issue by Eylon and Linn, 1988). Why committees on which such persons often sat came to affirm these overcrowded and traditionally structured curricula for school science is not yet clear. At least in some cases, as deadlines approached, the curriculum bureaucrats forced compromises of a conglomerate set of intentions for school science that, in practice, was weighted heavily towards the maintenance of the traditional content and structure. On the other hand, the long lists of science learnings – quite impossible to achieve in all students – may simply be a case of the science-tinted glasses with which science experts view modern society. They see almost everything inevitably in scientific terms, and can hence provide justification for every traditional science topic, as well as many others not previously included.

A confessional statement

Beyond 2000, is the report of a project in Britain that set out to think beyond the current school science curricula, and to provide a framework for an attempt in the medium term future to answer the questions about scientific literacy for all students? Its editors, Millar and Osborne (1998) point out how society has changed, and is continuing to change, under the influence of science and technology. Hence, students need of science is quite different from what it was in the 1960s. Millar and Osborne (1998) acknowledge that the structural place of science in schooling has been changed in ways that are responsive to the societal changes, but they lament that *the best efforts in the 1990s have retained the science content of the 1960s, as the intended learning in today's curriculum.*

A quite different approach

A quite different approach to exploring scientific literacy began to be discussed during the 1990s. It involves identifying the need for scientific knowledge that adults have as they function in the variety of societal contexts that make up life in increasingly technological societies. Layton et al. (1993), as a result of case studies of groups who were in a position where they had an urgent need to know some science, came up with the term, *practical-science-knowledge-in-action* rather than scientific literacy, and what Irwin and Wynne (1996) refer to *citizen science.* Practical/science-knowledge-in-action had a challenging set of criteria to meet. These were, *obvious relevance, helpful and useful, a trustworthy source, relatable to other social knowledge, and in a communicating language form that was a translation of its formal science statements.* These are not easy for school science education to achieve, but they may be important aspects for any alternative curriculum to try to include. Jenkins (1997) pointed out that there are two implicitly related notions in this approach. The first is that there are a number of distinct, segmented 'publics', differentiated by interest and situational need. The second is that it perceives science to be made up of a multiplicity of types of knowledge and understandings, which are essentially functional and directed towards specific social purposes.

The approach introduces the notion of *Science for Citizenship* located in the multiple societal contexts within which citizens are involved - at home, in their neighborhood, in their work, at leisure, and as members of local, regional and national communities. The basic question this approach asks and must answer is: *"What kind of science related knowledge and abilities does the general public need to know to function effectively and with quality of living in these multiple contexts?"* It is a question expecting an empirical answer rather than answers that are merely the opinion of scientific experts, however well intended and interested. This approach requires some means of asking a society itself to identify, and its multiple publics to define their needed science knowledge.

An analogy for the different approaches

An analogy may be useful at this point to distinguish between the approach that has been made to answer the questions of scientific literacy and the approach to the question of science for the citizen. Think of science like soccer football. Both are inventions of human society, one for understanding and living in the natural world, the other to engage more of the world's people as players and spectators than any other leisure pursuit. Now think of the outcomes of science as like a soccer football, essentially a sphere, but one that has its external surface made up of many different facets. These facets are the products, in a broad sense of the term, that science offers to society. It is through interactions with these products that citizens encounter science. Science like the soccer ball has an inside that is not visible from positions outside the ball. Inside the ball, the large space contains the fine detailed knowledge of science, the associated intellectual processes, and technical skills that produce new knowledge, etc. These details are not of great or immediate concern to citizens. The important thing for society about this inside is that schooling in science for all students will attract an appropriate minority to consider careers in science, so that this particular way of understanding and engaging with the natural world will continue. This minority, in due course, will be introduced to this inner set of science knowings and procedures.

When the problem of the two sets of science of science learnings is thought of in this way, it follows that some of the external surface of the ball (the scientific literacy learnings) must be associated with the excitement and wonder and challenge of science. It will be through their encounter with these features of science that both enough of a minority and the right sort of creative persons will be attracted to undertake this more in depth and systematic set of science learnings. Scientists and science educators, because of their privileged but science-blinkered position within the ball, are very biased judges of what its surface is like. This part of the ball can be seen much more clearly by using societal experts to describe what the science interface with society (and hence with ordinary citizens) is like.

Society as a Source of Science for Citizens

In the next section of this paper, I outline the methodological attempt to ask society to be the defining source of science for its citizens. We began by identifying four social purposes of Science for Citizenship – *Personal Well-being, Democratic Well-being, Socio-economic Well-being, and Science Disciplinary Well-being* – and they are shown diagrammatically in Figure 1. They can again be fairly directly linked to the four Canadian purposes in the Introduction.

The following methodology has been applied in a research study that is based in the Department of Curriculum Studies at the University of Hong Kong. The study involved three cities in China and involved collaborating colleagues in Guangzhou and Beijing, since the three large cities of Hong Kong, Guanzhou and Beijing were the three social units of our study (Law et al, 2000).

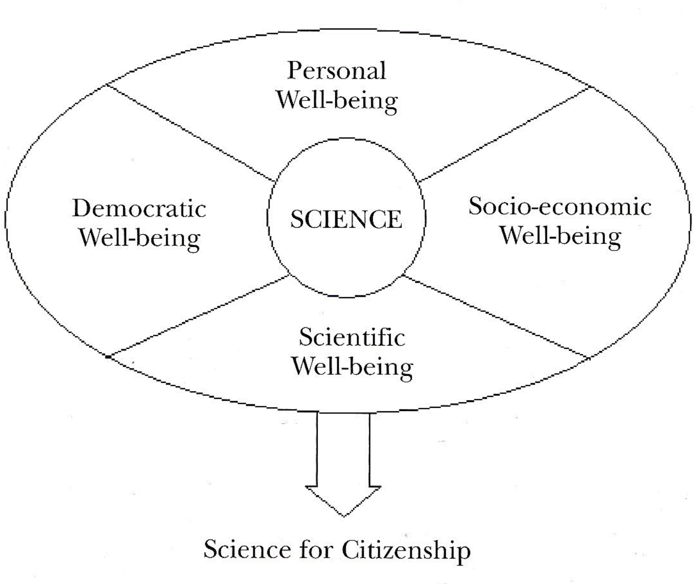

Figure 1. *Four Social Purposes Involving Citizens with Science.*

Step 1: Having Society Defined

Social and economic analysts, both inside and outside China, report on the differences and similarities in the three cities – Hong Kong, Guangzhou, and Beijing. The priority purposes of their respective economies are readily identified from these analyses, as are the social and cultural contexts they share, and those that are more prominent in one or more of these cities (see Figure 2).

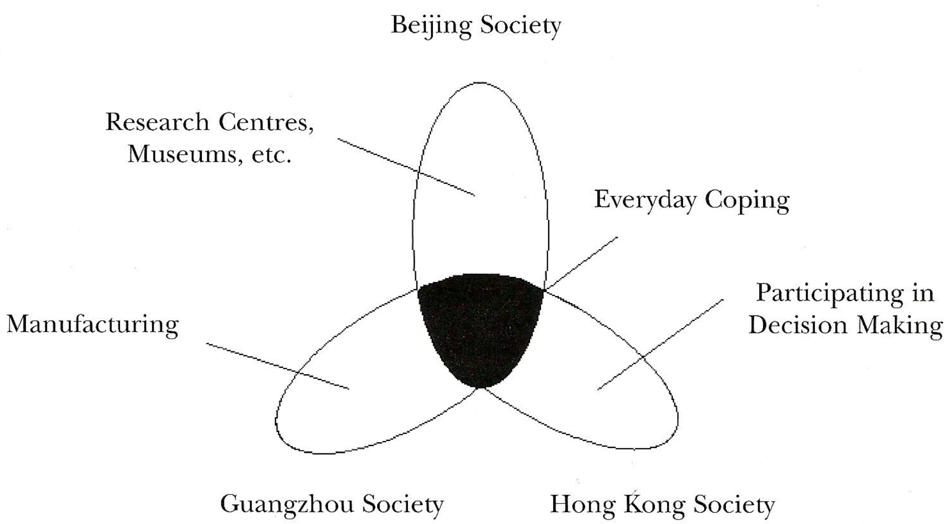

Figure 1. *The Three Cities and Their Shared and Spcial Characteristics.*

This enabled us to link the three cities with our four social purposes. The many shared experiences for individual citizens in each of these three large Chinese cities could be linked to *Personal Well-being*, and Hong Kong was chosen to explore this for reasons of convenience. Hong Kong was also linked with the social and political participation in science-based issues that we mean by *Democratic Well-being*. Guangzhou, with its heavy concentration of citizens working in manufacturing industries, was linked with *Socio-economic Well-being*. Finally, Beijing was linked with the purpose of *Scientific Well being*, because of the presence there of major research universities, institutes, and museums.

You may already be wondering why we included scientific research as a societal aspect that has any bearing at all on *Science for Citizenship*. A little later in the paper, I shall justify this and make clear how this does, indeed, bear strongly on our alternative perspective for a science curriculum for all students. It is implicit in this research paradigm that citizens in other social contexts may need some other science learnings, and, hence, have other curricular implications. But first, we needed to explore how common these contextual needs are for the four contexts we had chosen.

Step 2: Asking and Listening to Society

The next step took us to another set of "societal experts" in each of the three cities. These were persons who were knowledgeable about the problems that citizens face in relation to the four aspects we have defined as being shared and characteristic of our three cities.These "societal experts" are dealing day-by-day with cases of citizen problems. For example, to explore the purpose of *Personal Well-being* (that is, citizens coping with everyday life), we identified five "societal experts." These were a medical doctor working in a large general hospital emergency ward, a medical doctor involved in preventive care and community health education, an official in the Consumer Council in Hong Kong, a nutritionist, and a youth worker. From them we were seeking their experience of citizen problems in relation to *home and workplace safety; medical health and hygiene problems; nutrition and dietary habits; selection and proper use of consumer products (consumer wiseness); and leisure and entertainment.*

We interviewed each of them, using the following set of broad questions, with probing as the responses opened up issues of interest. *1. Please tell us about the problems of citizens that you are dealing with? 2. Can you describe the broad categories of problems that you deal with in your work everyday? 3. For each category of problem named, can you provide some descriptions of the typical situations and details about why those problems occur? 4. For each category of problem named, is the occurrence related in anyway to the knowledge and understanding (or lack thereof) of the people involved? 5. How can such occurrence be prevented?* The interviews were recorded and transcribed.

Step 3: Analysis of Responses

The analysis of these primary data began by delineating main categories for the citizens' problems that were referred to by each "societal expert," using what they deemed to be a typical case. The reasons the informants suggested for the occurrence of these problems were listed along with any specific issues of particular concern. In the second stage of analysis, the researchers went through the list of problem categories to see which of them involved some understanding, process, or quality that could be related to science. Problems that were social, economic, and personal relational, with no apparent science aspect, were discarded. In other words, problems were noted if there was anything that an education in science could have provided that may have meant avoiding the problem, or at least ameliorated. We are not suggesting that such science learning would have guaranteed the avoidance of the problem, but simply that it may have.

Step 4: Identify the Science Involved

In this stage, we identified the science involved, and, of course, usually this bore on several of the traditional fields of science. For example, for the common occurrence of breaks and sprains to the human body in high rise living and construction, we identified the impact of forces on flexible bodies like human skeletons.

Step 5: Expressing the Science as Curriculum Topics for Learning

Sometimes, this could be done in a way that relates to the subject disciplinary strands of existing curricula. For example, the problem of reading instructions for pieces of technology relates to the use by manufacturers and retailers of the discourse of commercial physics. Since the discourse of academic physics is currently taught and learnt in the physics strand, this other discourse could be included, if the will to do so is there. The topic, *the impact of forces on rigid bodies* is in the physics strand of most science curricula, but *the impact of forces on flexible bodies like human skeletons* involves both physics and biology. Thus, it does not fit easily into the way most science curricula are at present structured.

The Findings about Science

Personal Well-being

The presenting problem situations involved science related to a variety of specific science topics, for example, the impact of forces on flexible bodies (like human skeletons), chemicals as poisons, principles of electricity and electronics, and nutritional value of foods. A common feature in many of the problems, however, was the inability of citizens to comprehend the information of a scientific type that was provided to the public about these matters – technical instructions, labeling of foods and household chemicals, safety warnings, etc. This was very reminiscent of the 'Inarticulate Science' that the citizens in the Leeds case studies encountered, as they sought urgent knowledge to meet their needs. For an educator who has been accustomed to thinking of the intended learnings in a science curriculum under the headings of *Knowledge, Skills,* and *Attitudes,* I was surprised to find that the science needs of citizens did not all neatly fit such headings. One categorization of these science needs is shown in Table 1 for the common problem occurrence in Hong Kong of accidents due to falls in its many high rise buildings.

Table 1
The Contextual Science (Knowledge Awareness, Policy/Legislation, Values Commitment) for Falling from High (a Kind of Industrial Accidents) in Everyday Coping

Scientific and Technological Knowledge	Scientific Awareness	Scientific Policy and Legislation	Scientfic Values and Commitment
Acceleration of rigid and flexible bodies due to Gravity.	The importance of following safety legislations and wear safety belt at all times	Policy and legislation about use of safety devices and their proper location on human bodies	Value issues in the need to train workers in the proper use of safety devices
The effect of impact forces on skeletal structures.	The importance of following the proper using safety belt.	Regulations and guidelines for proper use of safety devices	Value issues in workers' willingness to use them properly as legislated.
Choice of materials and design of safety devices and their proper location on human bodies.			

In this categorization, we use the adjective Scientific in each category, because they are all associated with the underlying science dimension of the social situations of the citizens. In the first category, *Scientific and technological knowledge,* some of the items may look as if they are separable into *Knowledge and Skills.* However, the sense in which they were presented indicated such an intimate relationship between the conceptual knowledge and the procedural action that have been kept in the single category. This is similar to the sense in which Layton and his colleagues had coined the phrase *practical science knowledge in action,* for the science the members of their case studies had acquired. The second category, *Scientific awareness,* was chosen to indicate the need citizens have to be alert to features of a situation that have a science-base, and the third category, *Scientific policy and legislation,* highlights the importance of knowledge of science-based legislation that citizens need to know and heed. The final category, *Scientific values and commitment,* was needed to include certain characteristics of the scientific way of thinking that are close to the elements that Atkin and Helms (1993) describe as *Habits of Mind,* as important features of scientific literacy problem.

Participating in Social Decisions: *Democratic Well-being*

The science needs of citizens with respect to the examples of social decision making that were described by the societal experts for the purpose of *Democratic Well-being* also needed different categories. Table 2 presents the science needs for the case of the use genetic biotechnology in food.

Again, the problem of translating science writing into information that can be comprehended by citizens came up as a major source of the problems. The magnitude of this task of translating the discourse of science was underscored in these discussions, because very deliberate attempts had, in some cases, been made by the government agencies concerned to popularize their communication to citizen groups and NGOs involved in these issues. These attempts were steps in the right direction, but still left some groups confused and uncertain of the issue. When comprehending the issue is clear, there is then the problem for citizens of which group of science experts to believe and trust, since they can give rather different accounts having quite different consequences. An interesting feature of the discussions around some of these issues was a time projection about the consequences for the public of the present state of scientific knowledge. In the case of genetically (GE) modified food, in addition to their political and socio-economic concerns, one science question that citizens were interested in was: *"Suppose we agree to their introduction now, but in ten years time they turn out to have deleterious effects, is the situation scientifically reversible?"* It is interesting to extend this question to cellular phones and other recent or proposed technological innovations that some believe have health hazards. The scientific answers are probably No and Yes, respectively.

Participating in Work: *Socio-economic Well- being*

The societal experts, who were interviewed in Guangzhou, were factory managers and people concerned in these companies with the personal needs of the workers at different levels. In each case, there were examples of highly specific knowledge and skills that workers needed, and some of this was science or technology-based. These science learnings were not usually seen by the societal experts as pre-requisite to employment; rather they were learnt by the workers in the context of the company. The needs that were noted as transcending the particular situation were:

1. Awareness that markets for products and technologies change over time, and that these changes are interactive. (Changes in technology enable new products which can then generate new markets. Conversely, new societal demands can lead to developments in technology).

Table 2

DEMOCRATIC WELL-BEING

The Contextual Science (Knowledge Awareness, Policy/Legislation, Values Commitment) for Biotechnology (Food) in Participating in Social Decisions

Purpose and format of	Social Participation as Problem Solving Process at the Community Level			
Social Participation	Scientific and Technical Knowledge	Scientific Awareness	Scientific policy legislation	Scientific values and commitment
• The purpose is to help the consumer to be familiar with the new scientific revolution and to protect their own rights • To study the ethical and other impacts brought about by the new technology to the society • Format: Prepare a position paper on how the community and the government should react to the biotechnological revolution	• Genetic engineering • Possible problems arising from and solutions with genetically - modified foods	• Possible impacts of GE on everyday life of different groups is society • Realities of controlled development of GE foods and being able to stop it	• About direction and extent of controlled developments of GE • Labelling of foods • Procedures for proper participation of public with experts in GE decision processes • Rights of the public to know about GE developments that impact them	• About GE developers and consumers' rights • Possibility that GE scientific technology developments may not be good

2. Capacity to see technical situations from different perspectives to generate innovative/creative ideas and solutions. 3. Habits of mind that are associated with the operations in technological situations.

Participating in Scientific research: Science Disciplinary Well-Being

It is necessary now to explain why we were interested in interviewing directors of high level scientific research institutes, when our concern is with citizens' science, and how schools may more effectively teach science to all students as future citizens. The science subjects in school have a reputation for being among the more difficult to learn. Furthermore, through the levels of schooling their increasing association with quantitative measures and mathematical reasoning compounds this sense of difficulty. At present in most countries, the sense of achievement in science is very largely *meted* out through success in formal tests and examinations, which are almost entirely composed of questions about the established textbook knowledge of science. The acquisition of knowledge of this static type is the main selection criterion for moving from school science to university science studies and eventually to a career in science research. It is also, judging from the tests now being employed at the lower levels of schooling, even in the primary years, the dominant indicator of a student's successful participation in school science.

The research institutes in Beijing are able to recruit to their staff some of the very highest achievers in the science knowledge stakes that are, in China as in many countries, intensely competitive via national and regional examinations during schooling and university assessments, as students progress through the levels of undergraduate and post-graduate study. It was not this type of knowledge of science that was our concern in our interviews with these directors about their staff and their recruitment issues. Rather, we were interested to look beyond high levels of this knowledge and to learn from these directors about other qualities that they saw as important ingredients in research scientists, especially ones they saw as lacking in candidates for recruitment. If such qualities exist and are important, then it can be argued they should be clearly manifest in the school science for all students, so that they will, in turn, be seen by students in schooling as part of what one needs to be a scientist. If they are not present in the *Science for All,* they cannot be come part of the selection processes for future scientists. Seven of these qualities recurred in the responses of the directors. Some of them tend to overlap or be combinations of others, but for clarity they are listed separately in Table 3.

Table 3

Scientific Qualities that Are Important for the Well-being of Science

creativity	personal interest
desire to inquire	perseverance
ability to communicate	social concern
team spirit	

Implications for the science curriculum

I now turn to the implications this societally-derived perspective of science for citizenship has for school science. In drawing these implications, I have imposed the constraint that what I am suggesting must be already present, at least to some extent, among the international curricula for scientific literacy with which I am familiar. In other words, I am not making suggestions for which there is, at yet, no practical evidence that they are possible in school science teaching.

Personal well-being

There has been a strong move in the last decade towards students learning the discourses of science as an important objective. The use of language in the science classroom is now one of the new research frontiers. There is a great interest in the idea promoted by Olson (1994) that *to understand a discipline is to be able to participate in its discourses.* One of the discourses that is receiving much of this attention is *scientific argumentation,* and there are studies of this in classrooms from junior primary to senior secondary. Furthermore, the current OECD/PISA international comparative testing of 15 year olds in Science is based on the ability to recognize scientific questions and the association between a science claim and evidence for it, when the presenting material is a media report involving science (Fensham & Harlen, 1999). It is only a short step from this type of science discourse to the discourse involved in translating science statements about socio-scientific issues or science-based instructions, so that they communicate to various non-science target groups. Promoting science reporting in the media to a central role in teaching and learning, as it is now happening in some countries and has been recommended by Beyond 2000, would be a simple but radical way to start.

The topic example of the impact of forces on flexible bodies, like human skeletons, is a particularly interesting one for countries like Australia, Greece, and China where the Olympic Games have been or will be. I suspect that it is not part of the science curriculum in any of these countries. However, because of the Olympic Games in Australia in 2000, there was a lot of money for the development of curriculum materials on Sports Science or Human Movement. These materials are all about the impact of forces on flexible bodies. The educators involved were physical educators not science educators, and this topic is in their subject's curriculum. To be in the science curriculum, it would involve an integration of physics and biology of the type pioneered in the late 1980s in the PLON project's module, Ionizing Radiation. It is time the curriculum for science to take this type of interdisciplinary integration seriously, because most real world situations involving science are multi-disciplinary.

The topic of chemicals in the home will also require a shift in the resource materials for chemistry teachers. I remember asking a class to bring me the names of chemicals listed on labels they found in the kitchen or the bathroom. A very substantial organic chemistry book only made reference to less than 10 of the list of more than 100 names that the class produced. I was saved by the Pharmacopoeia and a copy of the Merck Index that belonged to a pharmacist friend. It was a salutary lesson about how far, the chemistry I knew so well and was teaching, was removed from the reality of the chemicals my students and their parents encountered day by day.

Democratic Well-being

There has also been a growing interest in some innovatory curricula in decision-making about socio-scientific issues. The studies that have been done indicate that there has been a certain naivete about the suggestion that better science education will lead to more rational decision making by citizens. Such wishful thinking shows an ignorance of the complexity of the science that is usually involved in such issues, and a quite unrealistic hope that the level of science (even in the best of schooling) could achieve such a critical competence that students could evaluate the science of expert groups.

Indeed, the reason that different groups of scientists can often differ in their assessment of such issues is not so much that one group is right and the other wrong. Rather, it is that both are right, but about the different aspects of the issue they have given weight to in their studies (Gaskell, 1994). In other words, there is a problem about assessing such complexity as a whole, and the chosen aspect depends on wider value positions of the groups themselves. The study of Bingle and Gaskell (1994) of how third parties make a decision between such conflicting expert advice indicates that identification of these value positions and the trust each group of scientists inspires are as important determinants as the science itself. Despite this difficulty, a recent study by Kolsto (2001) in Norway is encouraging that secondary students can be helped to become better informed about the positions these different groups of scientists hold, and what aspect of the science they see as central to the issue. Eijkelhof (1990) in the Netherlands has also provided examples of how the important notion of social risk can be taught in conjunction with these socio-scientific issues.

Socio-economic Well-being

A curriculum example that seems to relate closely to the awareness of trends in technology and the market is a German text for a curriculum in which several market/technology areas were studied in some depth and historically. One was the making of shoes, and the different technologies and styles of shoes over several centuries made a fascinating study in which different scientific principles came into application as the technology and market demands changed. At each new stage, the curriculum also encouraged the answering of the questions, *What did this change mean for those employed in the industry?* and *What difference did it make to the customers?*

A sequence of tasks, in the new Grade 8 curriculum in Alberta, provides an example of *seeing things from different perspectives to generate innovative solutions.* The students began with experience of several machines, so that they became aware that a machine is a device that enables humans to do something they want to do. They were then asked to design a container to stop ice cubes melting as long as possible. A range of materials was available, and much learning about thermal conductivity occurred. The need to have an indicator of when the melting was complete added some quite different science to the task.

After some learning about machines as science-based devices for human achievements and several other open projects, like the ice box, the students in groups were then asked: *To design and make a machine.* The natural question from them was: "What is the machine to do?", but the teacher's reply was "That's up to you." What followed was fascinating, as groups made interesting choices of simple or complex tasks for their machines. Some of the complicated tasks had to be modified to make the machine possible, and, for the simple ones, there were the hard choices about the nature of the machine, and its materials and energy supply.

Habits of mind was one strand of the *Benchmarks for Scientific Literacy* set out by the authors of the AAAS (1993) project. If it had not been squeezed in with eight other traditional and the new strands, it may have stood out in the way Alkin and Helms suggested it should. Open-ended investigations that link to the real world are key elements in developing these scientific habits of mind. Such investigations, as indicated above, are central to the curriculum for the years of the new Danish curriculum for primary science (Andersen, Schnack, & Sorensen, 1993). With its lack of concern with predefining content, the curriculum developers wished to convey the messages that regular experience of scientific investigations will lead to good conceptual learning, to confidence in the learners about approaching problems, and to the appropriate scientific habits of mind.

Science Disciplinary Well-being

We had argued for the Beijing part of our study that if a more all round selection of future scientists is to be achieved, then the science for all students must itself encourage the qualities that were identified by the research directors. If these qualities - *creativity, interest, willingness to inquire, persistence, team work, social concern* - could be the values and characteristics that school science gave priority to as its learning outcome goals, rather than the accumulation of static science knowledge, a revolution would have been achieved. We would have also established in all our students (and in them as future citizens) an interest in lifelong learning of science that the popular media cater for, despite the neglect of it in present schooling.

At present with the knowledge-dominated curriculum, we know teachers, particularly in the primary years, largely adopt a transmissive style of pedagogy. Prior to the mandating of science as part of the primary curriculum, it was common to find students entering secondary schooling with very positive expectations of the new subject, Science. For many, these hopes were usually dashed by the end of the first year, as they learnt science was just as bookish, but more abstract and difficult than the other subjects were. In the succeeding years, the majority learnt to fail to understand science, and increasingly described it as "boring" – the outcome of a combination of low interest and too high a cognitive demand. The tragedy, with mandated science now occurring for the odd hour or two a week in the primary years, is that these students learnings of failure and disinterest are now well entrenched before the students reach secondary school, with its much better resources for teaching science in much more novel ways than is customary with our present knowledge heavy curricula.

Where the qualities listed for scientific well-being have been achieved in schooling, there has been more consultation with students about the real world topics that are to be the teaching/learning contexts, and with individual students about which scientific and non-scientific aspects they wish to investigate. Extended time is needed for such investigations, so the one or two lessons per week will need to be abandoned, and replaced by more substantial blocks of time. Several curriculum developers have in the 1990s recognized that the curriculum as stories of science is a way to generate interest that has been so lacking (e.g., Millar & Osborne, 1998). The way television producers create programs that give science a detective-like, investigative quality is another example school curriculum developers might well copy. The shift from a knowledge heavy curriculum for school science to a procedural and discursive one will not be easy, but it is being explored in many places. The shift to one in which scientific values play a prominent part will undoubtedly be even more difficult to implement, but the rewards for the students, our future citizens, would be very great – a sense of failure about science would be replaced by confident interest.

Science for Citizenship

To avoid the confusion that *Scientific Literacy* has caused in the debate during the 1990s, I suggest that *Science for Citizenship* be seriously considered for the slogan for our efforts in the next decade. It sets a clear message that is different from traditional school science, and makes clear that it is a different purpose from the preparation of future science oriented students. It needs its own place in the curriculum of schooling, and already in The Netherlands (and soon in England) that will have been provided for all students in the last year of compulsory schooling. All students will take this new subject, and those wishing to pursue disciplinary studies in the sciences will take those in addition. *Science for Citizenship* will no doubt need to have new pedagogies for some of its desired learnings, but these will be developed once the new aims and content are clearly defined.In Table 3, I set out a possible structure for school science that has clear intentions for what is trying to be achieved in the learners at each block of years of schooling.

Table 3
A Possible Structure for 12 Years of Schooling that Differentiates Science Education in Terms of the Contexts and Foci/Emphases for Learning.

	Context for Learning	Focus/Emphasis
Years 11/12	Optionals ciences: disciplinary and	Preparatory and scienctific well being
Years 10	Science for Citizenship	PISA Science literacies, awarencess, and decision making
Years 7-9	Science themes with relevant applications	Motivated learning and persistent engagement
Years 4-6	Relevant themes and Science in technologies	Concern, expectation, and success
Years 1-3	Relevant exciting themes	Wonder, creativity

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