

Engagement with Science: An international issue that goes beyond knowledge

Peter J Fensham

Monash University/Queensland University of Technology

International concern is mounting about the failure of recent school science curricula to foster interest in science as a career or as a lifelong personal interest. This has been acknowledged as a pressing problem in a number of countries. These curricula, despite their broader intentions have maintained the acquisition of scientific knowledge as the dominant learning outcome, but have given little attention to motivational aspects of science. In hindsight they can be seen to have come about through a number of mistakes that were made by the science education community. Some new directions that may be part of the answer to the problem are emerging and some of these are outlined.

In this lecture I want to present three things. The first is what I see as the great contemporary problem facing science education, namely, the disengagement of students with science. The second is how science educators created this problem, and the third is to indicate some of the possibilities that could lead to solutions to the problem.

I. The great contemporary problem - *Interest in Science*

In Japan, students have consistently scored highly in the international science testings of TIMSS, but their liking of the study of science was near the lowest level of the participating countries. In 2002 the National Institute for Educational Policy Research of Japan (NIER) surveyed a very large sample of the entire student population in grades 5 – 9, asking a number of questions (Ogura, 2003).

One of these was: *Do you like the study of (Subject)?*

There was a decline in interest for every subject from grades 5-8 with some slight recoveries in grade 9, when examinations in them to enter senior high school loom. These findings may not, in one sense, be too disturbing, because these declines in interest may be some sort of rebellion of adolescents against schooling generally, and not against science in particular, as has been assumed when similar findings about science alone have been found in other countries.

However, such a comfortable explanation is exploded by the next set of findings from the Japanese survey. The students were asked:

Do you think the study of (subject) is important regardless of its role in university entrance?

In the face of this very meaningful question in the Japanese context, where students have to take examinations in this wide range of subjects to enter any university course, Science and Mathematics continued their downward path, whereas the other subjects, language, humanities, and social sciences all turned upwards.

Among a number of measures to deal with this problem in science and mathematics, Japan established, in each of 2003 and 2004, 26 Super Science High Schools with the express purpose of increasing the number of high performing students who will move from school to university studies in the sciences.

Japan is not alone in this concern. In the last few years I have been aware of concern being expressed in Ireland, The Netherlands, Norway and Finland, Australia, India, Germany, USA, France and England about the decline in university enrolments in science and the low interest during schooling. In my own country of Australia two leading universities have closed down their Physics and Chemistry departments in their traditional form and re-opened them in more specialised (Biological Chemistry, Environmental Chemistry) or in a subservient role (Physics as part of Materials Engineering). The Royal Society of Chemistry in Britain in reported its opposition to a further reduction by the Government of UK in the availability of Chemistry in that nation's universities.

Such quantitative measures point to the magnitude of the problem, but they are not very helpful in identifying the symptoms or the causes of the problem. Three qualitative studies of students' experience of school science in different countries have, however, been reported in the last three years. They are of great importance because of the commonness of their findings and because of the richness of their accounts of these student experiences. All three have involved adolescent students in the later compulsory years of learning science. Their authors Osborne and Collins (2001), England; Lyons ((2003), Australia; and Lindahl (2003), Sweden presented remarkably similar pictures of school science as:

(a) knowledge transmission of correct answers, (b) irrelevant and boring content, and (c) difficult in comparison with other subjects, The sciences should only to be continued with in the senior years if one is committed to a future that requires them. In Lyons' study (reported in detail in this Symposium) the students were all high performers in science, but their experience of success did not alter their assessment of it.

As far as the supply of future scientists is concerned the problem suggests that without substantial changes the supply will be from a small minority of senior students (including fewer of the brighter minds), while the majority will, to all intents, have "disowned" science. This is far from the intentions of the designers of the new curricula for scientific literacy. Their intention was for a larger proportion of students confident and interested to continue to study the sciences as a possible career and/or a life long interest.

II. How the problem was created

In the early 1980s national reports in a number of countries recognised that school science was designed to serve the interests of that minority of students who would, in due course, become science-related professionals and, accordingly, issued the challenge that school science should rather serve of many more students. The demand was for Science for All. By the later 1980s several initiatives in this direction began to be enacted – a movement referred to as Science/Technology/ Society (S/T/S). Before these had been fully explored more general curricular considerations moved to centre stage in some countries, such as England and Wales where the conservative government established a wide ranging National Curriculum project. Within it, Science was one the first projects to report, expansively in 1989 and, for implementation, in a much reduced form in 1991. In the USA, Project 2061 began in 1989 under the auspices of the American Association for the Advancement of Science and reported in 1993. In the 1990s Australia, Canada, New Zealand, Korea, Sweden, Norway, etc. launched curriculum projects for science at state or national levels and these appeared in close resemblance to the form of England and Wales. At the primary school level Denmark was a rare exception, taking quite a different form.

With hindsight it can be seen that a number of mistakes were made that can be laid at the door of the participating scientists and science educators.

1. We adopted the term scientific literacy as these curricula's goal and slogan.

This was, I believe, a serious mistake on several grounds. It was an undefined concept and the various attempts that have followed to define it have not led to a clear consensus. For some it should mean the

science counterpart of those minimal standards of language literacy that UNESCO refer to when describing a country's literacy level. For others scientific literacy is the science equivalent of "a well read or literate person".

If the use of the term was to give science a new found importance and status, particularly in the primary years when language *literacy* and number *literacy* have pre-eminent positions, it was unsuccessful. Basic language and number learning have always been central parts of the curriculum of schooling for all children regardless of how many years of elementary schooling they have. Furthermore, their role in these early years has been distinctly different from the more literary studies of language and of mathematics (as algebra, coordinate geometry, calculus, etc.) in secondary schooling.

Science, on the other hand, has had no such historically established place in the primary curriculum. Indeed, the sciences' presence in the school curriculum started in many countries with their introduction in the senior years of secondary schooling, and as such was intended only for that small percentage of students who continued to these levels of schooling and who were interested in science-based studies in universities.

2. We acquiesced in the decision in these new comprehensive curriculum projects to the establishment of a new subject area called Technology.

It was intended that this subject would give new status to a number of existing areas of study with names like Manual Arts, Craft and Design, Home Economics, Industrial Arts, Woodwork, Metal Work, Electronics. Whatever the title, Technology, might do for these subjects, it was at the expense of those early S/T/S projects that were curricular experiments to respond to the challenge of Science for All. The STS movement had begun to spawn in a number of countries new ideas and materials for teaching science that used technology as the a bridge between science and society. In this way the combined content from these interactions much more relevant to large numbers of students. The establishment of a new subject with Technology as its general title destroyed its role as the bridge to more relevant content for school science, effectively extinguishing the STS movement and its considerable promise.

3. We failed to heed warnings about the unessential character of scientific literacy as it was being discussed.

As early as 1992 Atkin & Helms in a report to the TIMSS development team about its use of the term scientific literacy. A year later these authors argued in a substantial paper that whatever scientific literacy means, it is not needed by citizens in the same essential sense that language or cultural literacy is (Atkin & Helms,1993). There are too many leading citizens in all societies who, not only have weak scientific knowledge, but actually acknowledge it without embarrassment. Later Shamos (1995) published a whole book that argued this case in considerable detail

4. We published thousand of small research studies that showed that traditional concepts and content of school science was not well understood and at best learnt in a rote or superficial manner.

The invention of some very simple tools for getting at students thinking led to an avalanche of small research studies that revealed many fascinating alternative ideas that were common among school students about the introductory phenomena and concepts that were in the established the school curriculum. Had the same tools been used in relation to the concepts and ideas in the new S/T/S courses there is little doubt that similar mis-learnings and alternative conceptions would have appeared, reinforcing the need for more and better teaching of S/T/S science. As it was this vast body of research was seen as reinforcing the content of traditional school science

5. We did not protest when a widely influential program of cross national testing, TIMSS, measured and publicised in the mid 1990s (and still continuing) science content for learning by mid-primary

and lower secondary students which is quite misleading in relation to the intentions of Science for All or of scientific literacy.

The TIMSS tests primarily consist of isolated items that are very dependent on recall as the main learning skill. They are, in a very real sense, school science knowledge trivia tests (Fensham, 2000). The fact that this project had to build tests from curriculum content that was more or less common across more 40 countries meant that it could not contain more recent examples of science curriculum content. Thus, although the original TIMSS Framework for the science content to be tested consisted of eight categories of scientific knowledge, only four, in fact were included in the test, three being the traditional disciplinary sciences of biology, chemistry and physics and one that included what was loosely called *Environment*. The publication of the TIMSS results in the mid 1990s and the publicity that is inevitably associated with international “league tables” did reinforce in a number of countries the need for this type of learning even where it was clearly 20 years out of date as the priority for science learning.

6. We ignored the great discrepancy between the capacity of designated science teachers in secondary schooling and generalist primary teachers to teach science confidently, and the parallel gulf in resources available to them.

In most countries, if not all, teachers in the primary years have weak personal backgrounds in the sciences and have little confidence about teaching science. Primary schools do not have designated science classrooms and most classrooms are not equipped with water, gas and electricity services or active science investigations. Nor do these schools have facilities for storing science equipment and personnel capable of maintaining it.

Secondary schooling usually has designated teachers of science (many of whom will have had tertiary studies in one or more of the sciences), specially equipped science rooms (laboratories) and in a number of countries ancillary staff to support the teaching of science.

7. We participated in a debate about *What does scientific literacy mean?, and What should be in the school curriculum for it?* that involved only science trained experts – interested academic scientists, science educators and science education bureaucrats.

In seeing this trio of expertise as the appropriate authority to answer these questions, we failed to remember the insight of the Nobel Laureate, Richard Feynman who said “The world looks different after learning science”. The topic of this debate was;

What are the essential learnings in science for all students?

Science is a very great and highly developed human enterprise. Its intricacies are clearly not essential for anyone other than scientists themselves. If we think of science as a space within the larger space of society then it is at the interfaces between these two spaces that citizens are involved with science. To see this interface clearly from the space of science is not the same as seeing or experiencing it from outside. “Science-tinted glasses” can obscure, as much as they represent understanding. Hence, the debate about *scientific literacy* failed to establish any clear criteria for what should be learnt in the new curriculum. The several interested partners brought their own particular interests to the fore, and found they could argue convincingly for all of them. This was true of both aspects of science that were not part of the existing curriculum, such as some of the high social relevance *new frontiers of science, history of science, the nature of science and argumentation about socio-scientific issues*, and for almost everything that was at present in the curricula for science and the sciences as separate subjects.

This totality of potential science learning was clearly impossible. Before the debate could find a way around this impasse, and in the absence of tight criteria for prioritising this array of content, the curriculum bureaucrats called a halt since the government deadlines for the new curricula were

looming. What was achieved was that *Science would now have a regular and mandated place in the primary child's week.*

That place would be occupied with further filtering down of some of the familiar (to secondary teachers) type of science knowledge content learning that had previously been the beginnings of the conceptual structure of the disciplines of biological science, chemistry, (earth science), and physics in secondary schooling. In country after country, beginning with the National Curriculum for Science in England and Wales (DES/WO, 1991) these three or four strands of science learnings, albeit slightly disguised in name, together with a further strand about *science as doing* (e.g. *Working Scientifically*) now stretched from the earliest grade to the 10th or 11th grade whenever compulsory schooling ended. This meant that for science no clear distinction had been made about what learning science was about between the primary and secondary levels of education, as existed for the learning of language and number. Moreover, this lack of distinction flew in the face of the very obvious disparities of human expertise and physical resources for science at these two levels of schooling.

The intentions for learning disciplinary conceptual science, and associated scientific facts and information, that were already established as science in secondary schooling, were extended for science as a core study in the primary curriculum, even to the earliest years. The priority given to these intended learning outcomes is very clear from the regular tests and other forms of assessment that are now in use in a number of education systems for learning science in the primary years (Fensham, 2000). The TIMSS testings in 1994, 1999 and in 2002 served to reinforce this situation rather than challenging it in any way.

Intrinsic interest in science, however much lip service may be given to it in the curriculum's aims, was not a priority learning outcome of the study of science at school. Similarly, *science as a way of knowing* (the nature of science as a social and historical human endeavour) and the interactions between science and society were casualties of the unfinished debate about scientific literacy

III. Recent developments as possible solutions

If confession of mistakes is important, the high status acknowledgement of the extent of the problem is a giant first step towards its resolving. It is this very appropriate that the country that began this 1990s wave of science curricula and influenced so many others should also be the first to acknowledge its failure.

Late in 1998 a high status report, **Beyond 2000**, was issued that pointed out, the decisions of the 1990s changed the status and position of science in schooling, making it mandatory throughout compulsory schooling, but they failed to change the content for learning. This failure was so fundamental, the editing authors (Millar & Osborne, 1998) argued, that the solution lay not in a quick patching repair of the national curriculum for science, but in starting again to rethink and develop afresh a more meaningful curriculum. The report gave a number of suggestions about this rethinking.

Among these, it is ironic to now find a call for re-establishing the relationship between science and technology, if school science is to meet the needs of most students in the 21st century, since England and Wales were the first countries to establish Technology as a separate subject!!

In this section I wish to outline five new directions that point, I believe, to ways to move science education ahead –each one involves learning science in a manner that goes beyond the knowledge learning we have hitherto concentrated on.

New Curricula for Science

Several new curriculum projects have been established in the last four years that recognize the need to prepare young people more adequately in science for contemporary life. The first was *Algemene*

Natuurwetenschappen (ANW) in The Netherlands and this was followed by *21st Century Science* in England, the first direct response to the **Beyond 2000** report. Now Hong Kong and the state of Queensland in Australia are each developing a similar curriculum. These new science curricula are all designed for students in grades that correspond with the last year(s) of compulsory schooling. The common characteristic is that these new science subjects are intended to serve quite different educational purposes from those that have hitherto underlain the disciplinary sciences at this level of schooling. Indeed, the formers' purposes are so clearly different that, in each of these cases, it is the new science subject that is mandatory for all students, with additional science studies, such as biology, chemistry and physics, and applied science being offered subjects some students may wish to pursue other curriculum purposes that science(s) can usefully serve. While none of these new science subjects have been called *Science for Public Understanding* or *Science for the Citizen* the statements of rationale for them are clearly argued on just such bases.

PISA (Science)

In 1998 the OECD decided to move from its interest in macro-indicators of the state of education in its member countries to more direct measures of their functioning. Since the IEA had not long before conducted TIMSS in more than 40 countries including many in the OECD and was planning follow up studies, it was decided to do something rather different. The idea of gathering data that would inform its members' education systems how well 15 year olds were prepared for 21st Century life in the fields of Reading, Mathematics and Science was well received. Thus the Programme for International Student Achievement (PISA) was launched. Three testings were proposed for 2000, 2003 and 2006 with Reading, Mathematics and Science, in turn, having the major role.

Freed of the necessity to be a project bound by the curricula of the participating countries and with only a minor role in 2000, the Science Expert Group quickly decided to focus on one aspect of the ways in which science impinges on citizens, namely, through reports in the media. This decision opened the way for a test to be constructed in which understanding of the science involved in the reports and four scientific procedures about science as a way of knowing and sharing knowledge were the abilities to be explored in the students. The test consisted of a number of units, each one of which began with an actual media report after which there was a cluster of items that required the students to demonstrate a number of the five abilities.

This PISA Science test was novel in two ways. It was exploring learning outcomes for science that had not previously been emphasized and as a test it was unlike the types of testing that were familiar in the countries' school systems. It pointed immediately to new possibilities for learning outcomes, to new topics, to new sources for learning and to new ways of assessment. Some doubted whether any 15 year olds would be able to manage this test and even more were skeptical about a science test that was so dependent on reading a number of words of text before a question was asked.

In the event there was a surprisingly good level of performance overall and a quite remarkable finding with respect to gender. In every country on the very extensive tests of Reading, girls outperformed boys, often very significantly. Yet in the Science test in which reading had such a large role, there was no gender difference in 26 countries. In three boys outperformed girls and in three girls outperformed boys. This is a quite unexpected result and can, I believe, only be explained by a high engagement of both boys and girls with the test's reading and unusual questions. This positive engagement with units that were, in fact, little stories about science with characters and a plot to be solved, is powerful evidence for the proposal that science curricula should be based on science as a story – hitherto, only explored in a couple of countries at selective school levels.

In 2006 Science has the major role in the PISA testings. During this year the Science Expert Group is finalizing the wider set of aspects of science learnings that will be included. It has changed its statement on scientific literacy to cover this wider set, and it has decided to include affective items

among the cluster associated with the various units. This later decision is very important. It moves affect about “science” (whatever 15 year olds may understand that term to mean) from being a personal attribute like the family’s SES status, to affect about science being an expected learning outcome of studying science for all students. It also acknowledges that affect in science will be as in other things a topic by topic issue.

Science for the Citizen

During the last four years I have had the good fortune to be part of an exploration in China of the public’s need to know science (Law and Fensham, 2000). The design of our study was influenced by the case studies by Layton et al (1995) in the early 1990s of the ‘science practical knowledge-in-action’ that small groups of citizens had had to acquire when their lives took a turn that involved an urgent need to know some science. It was a challenge to see if this idea of a need to know science could be extended to science knowledge that was commonly useful to wider sections of the public. I had also become aware, as I hinted earlier, that science expertise was not the most useful source of trying to ascertain the details of the interface between science and the lives of the general public.

In the cities of Hong Kong and Guangzhou we collect data from “social experts” (persons familiar with the lives of citizens) about common problems among citizens coping with everyday life, engaging in democratic decision making, and participating in the world of modern manufacturing. Analysis of these data enabled us to identify learnings about science that may if acquired prevent or alleviate the problems. These learnings can be related respectively to the citizens’ *personal scientific well being*, to their *democratic scientific well being* and to their *economic scientific well being*, concepts that had been part of the debate about scientific literacy.

From a curriculum perspective it is the categories of these learnings that are of particular interest (Law, Fensham, Li and Wei, 2000) and Law, 2002). We found the traditional curricular categories of *Knowledge, Skills* and *Attitudes* were insufficient. There was straightforward knowledge, but it was both *Scientific and Technological Knowledge* since in citizens’ lives the distinctions between S and T are quite blurred. Then there was *Scientific Awareness* – knowledge that scientific information exists, and is available, if and when it is needed. The ability to follow *Scientific Instructions* was another category. *Commitment about Science* was about the valuing involved in balancing science knowledge against other sorts of relevant knowledge. Finally, there was *Scientific Policy and Law-* knowledge about the many ways citizens lives are controlled by science-based regulations

Qualities for scientists

In another study in China we asked *Are there qualities about science that are important for future scientists beyond a great deal of knowledge?* This question as I will try to explain was both of direct interest to the science education for future scientists, but also indirectly for the science education for all students. To explore this question we interviewed eleven directors of Beijing’s leading research institutions about qualities, in addition to very high levels of scientific knowledge, that were inadequately present or missing among their applicants for positions, and which are important for the *well being* of the nation’s science.

Given the wide range of science fields our respondents covered, there was a surprisingly high consistency in the qualities that were identified. Ten qualities were identified by at least half of the respondents as important. Of these, *creativity* was the most common, listed by ten. *Personal interest in science, perseverance, willingness and desire to inquire*, and *the ability to communicate*, social concern and *team spirit* were all listed by half the respondents.

A small minority of students from each age cohort do become scientists as a result of social and educational processes that inform and select students about what is required to achieve this goal. Central to how these processes exert control over this selection are the explicit priorities for learning science that apply throughout the levels of schooling and during the undergraduate years of university courses. In other words, for students in the compulsory years of schooling to succeed in this selection process, they must learn very well those aspects of science that are given priority in the teaching and testing of science in those years. Both intra-nationally and internationally these have been cognitive aspects in which the recall and direct application of large amounts of rather abstract and encyclopaedic-type scientific information figures largely. After the compulsory school years cognitive aspects of text book science knowledge continue to hold priority as the requirement to enter graduate studies when experience and learning about research under direction is added.

This cognitively-based process of selection of future scientists from an original pool of all students is shown diagrammatically in Figure 1.

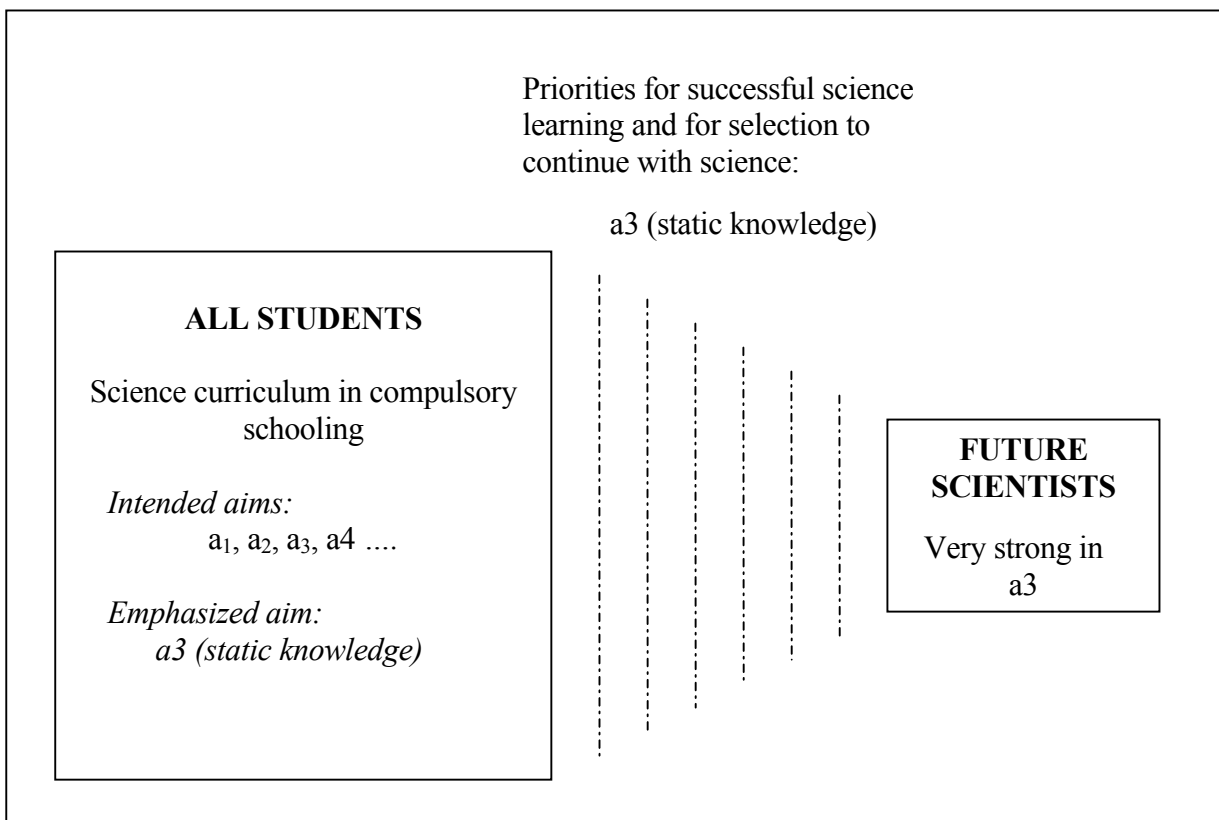


Figure 1. A representation of how cognitive knowledge of science is developed in future scientists.

This model suggests that if any of the qualities other than knowledge are really valued for future scientists, they need to be present in the science for all students at school, and be continually reinforced by attention being given to them in the “selection processes” that occur throughout formal education. This means that, if any of creativity, interest, willingness to enquire, etc. are important they must be “highlighted” in science education from its very beginnings in school. Then future scientists will be among the best achievers of whatever has been prioritised as “learning” science in the compulsory years of school science and beyond.

If these qualities were prominently encouraged in school science some students would respond to this richer sense of science by choosing to pursue it as a career. The majority would probably still choose other goals, but they would have had experiences in school science that would be very different from at present and they may well gain a lifelong interest in science and its role in society.

Curriculum Emphases

Many years ago Douglas Roberts (1982, 1988) pointed out that it was possible for science, as a study in schooling, to serve a number of different educational purposes. He described seven of these, but called them *curriculum emphases* because he argued a choice between them is necessary if the intended purpose is to be achieved, and not obscured among other intentions. When a purpose has been chosen it then becomes the basis or criterion for selecting the science content for the curriculum, the contexts for presentation, the appropriate pedagogies, and the type of assessment of learning to be employed.

The idea of curriculum emphasis has been neglected far too long by curriculum planners who, to the contrary, have essentially worked on vertical models for the science curriculum that imply that science education has the same purpose(s) throughout the years of schooling. Curriculum emphasis encourages thinking of the curriculum more horizontally. Thus, the ten or eleven grades of compulsory schooling can be thought of as four or five stages – 2 or 3 in the primary years of K-6, and 2 or 3 that cover the years 7-10/11. For each stage the question to ask is:

Which educational purposes (or curriculum emphases) are most appropriate for learners in this stage?

If agreement about this question is reached, the developers of the detailed content, pedagogy and assessment for this stage will have clear criteria for their work.

I have discussed with many groups of teachers Roberts' original seven purposes and several others that have appeared in science curricula since his work. I have asked them this question by requiring them to associate just two or three of these 10 plus purposes with the stages in a 4 or 5 staged curriculum grid of the type just described. This task makes good sense to them, and it has been remarkable to see how commonly they choose particular purposes for each given stage.

The new curricula that I introduced at the beginning of this third part of this lecture are examples that recognize the possibility that science subjects at the same level of schooling can have quite different purposes, and when developed for these purposes meet very different needs in students. What is needed now is the extension of the role of educational purposes to the lower levels of science in schooling.

I will leave you with such a possible extension that takes into account at least some of the aspects of science that I have just been sharing with you as possible ways of responding to school science's contemporary problems.

Insert Figure 2 here

In my suggested curriculum, the primary years would have as their pre-eminent emphasis the development of an interest in natural phenomena and in the ways that illustrate how science has enabled humans to interact with the natural environment. The first three years would focus on the students' sense of curiosity and be a rich exposure to the beauty, wonder and fascination of the natural world. The next three years would focus on the excitement of creative problem solving. In both these stages asking questions and exploring alternative ways of pursuing them, rather than "correctly" answering them, should be the outcome. One or two isolated lessons per week would be a very inappropriate arrangement for this curriculum. It would be better served by periodic 'science events' lasting, say a whole day, which would enable a substantial set of experiences to be completed.

In the lower secondary years the emphasis would be on investigating real life issues of personal and social relevance in which science is an important but not exclusive part. Science as powerful ideas and procedures, together with its limitations would be very much intended learning outcomes. In the 10/11 years Science for Citizenship should be the emphasis for all students, and in parallel there would be optional science studies that prepare some students for further studies in science or introduce them to the ways science in application is changing the worlds of work, leisure, and the arts.

References

- Atkin, J. M. and Helms, J. (1993). Getting Serious about Priorities in Science Education. *Studies in Science Education*, 21, 1-20.
- DES/WO (1991) *Science in the National Curriculum*. London: HMSO.
- Fensham, P.J. (2000) International success, but is it Science? - Identifying strengths and weaknesses in Australian primary school science from TIMSS and other data. *Australian Science Teachers Association Journal*, 45(2), 39-44.
- Gräber, W. and Bolte, C. (Eds.) *Scientific Literacy: An international symposium*. Kiel, Germany: I.P.N..
- Law, N. (2002) Scientific Literacy: Charting the terrains of a multi-faceted enterprise, *Canadian Journal of Science, Mathematics and Technology Education*, 2(2)151-176.
- Law, N., Fensham, P., Li, S. and Wei, B. (2000) Public understanding of science as basic literacy, *Melbourne Studies in Education*, 41(2) 145-156.
- Lindahl, B. (2003) *Lust att lära naturvetenskap och teknik? En logitudinell studie om vägen till gymnasiet. (Pupils' responses to school science and technology? A longitudinal study of pathways to upper secondary school)* (Diss., Göteborg Studies in Educational Sciences 196), Göteborg: Acta Universitatis Gothoburgensis.
- Lyons, T. (2003) *Decisions by science proficient Year 10 students about post-compulsory high school science enrolment: A sociocultural exploration*. Unpublished PhD thesis, University of New England, Armidale, NSW. Australia
- Millar, R., & Osborne, J. (Eds.). (1998). *Beyond 2000: Science education for the future*. London: School of Education, King's College.
- NCC (1989) *Science: Non-statutory Guidance*, London: National Curriculum Council.
- Ogura, Y. (2003) *Informal science education for promoting children's science learning in Japan*. Paper presented at 2003 International Seminar on Improvement of Students' Science Achievement and Attitude through Informal Science Education, Dec.5-6 2003, Seoul, Korea
- Osborne, J. and Collins, S. (2001) Pupils' views of the role and value of the science curriculum: A focus group study, *International Journal of Science Education*, 23(5), 448-467.
- Roberts, D.A. (1982) Developing the concept of "curriculum emphases" in science education, *Science Education* 66(2) 243-60.
- Roberts, D.A. (1988) What counts as science education? In P.J.Fensham (ed.) *Developments and Dilemmas in Science Education*, pp. 27-54. London: Falmer.
- Shamos, M. (1995) *The Myth of Scientific Literacy*, (New Brunswick, NJ: Rutgers University Press).