1.3 School science and its problems with scientific literacy

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From 1983 to the present day, 'Science for All', or a variant of it, has been officially espoused as the intention for school science in country after country. The Ministers of Education in the Asia Region of Unesco (from Pakistan and India to Japan and New Zealand and a dozen countries in between) determined that this goal was an urgent priority for their educational systems (Unesco 1983). In the same year, the National Science Foundation (1983) was presented with a high-level report that called for *Science for All Americans*. In 1984 in Canada, *Science for Every Student* appeared and, soon after, the Royal Society (Bodmer 1985) in Britain argued persuasively that *Science is for Everybody*.

The substance of all these reports is very similar; they can be summarized by the set of goals for school science that the report of the Science Council of Canada (1984) recommended following the most searching of these reviews.

A science education appropriate to individual needs and designed to enable students to:

- participate fully in a technological society as informed citizens
- pursue further studies in science and technology
- enter the world of work
- develop intellectually and morally.

The traditional role of school science is present in the second of these goals, but only as part of it since it (like the other three) is concerned with all students, not just the small minority (less than 20 per cent of any age cohort) who will take up science-based careers of any sort.

With such expert and official agreement about the need for school science to contribute to the scientific and technological literacy of all future citizens, one would expect to find by now that new curricula consistent with these goals would be in place and that appropriate pedagogies and assessment procedures would be practised in many classrooms. In fact, remarkably slow progress has been made; in a number of countries, promising initiatives in the later 1980s now seem less likely to be implemented or they have been stifled.

In this chapter, some of the factors that make it so difficult for school science to contribute to general scientific literacy are considered. To do this a brief account is provided of school science that pre-dated these goals and second, the circumstances in which these new goals were set.

The legacy of the 1960s

In the 1960s and early 1970s many countries reconstituted the curriculum for science in their schools. The models for these changes were a number of curriculum projects established by the National Science Foundation in the USA and in Britain by the Nuffield Foundation. In both cases these initiatives were supported by hitherto unheard-of amounts of funding. They were a response to well-justified claims that school science was hopelessly out-of-date because of the neglect of its curriculum during the world depression, the Second World War and its aftermath.

The priority for these reforms was clear when the first projects to be established were all concerned with science at the upper levels of secondary schooling which, in the 1960s, involved only that small minority of each age cohort who were aiming for university studies in science-based courses. With leadership and involvement from enthusiastic academic scientists, experienced science teachers with strong scientific backgrounds developed materials for chemistry, physics and biology. Bringing school science up to date turned out to be presenting abstract concepts that are of basic importance in each science as the primary content of significance for their study in school. It did not mean new topics that reflected the many advances, such as polymers, semiconductivity and biosynthesis, that had been made in these sciences in the previous thirty years.

This change in content discarded two social dimensions of science – the applications of science in society and the individual and cooperative processes in the scientific community that lead to these abstract concepts. As a consequence, there was no basis in school science on which to develop a critique of the role science plays in society or an appreciation of its strengths and limitations (Fensham 1973). The change did, however, mean that in the years immediately before students moved into its study at university, school science was coherent with, and a logical preparation for, such further studies.

Other projects followed that took up the issue of science at the lower levels of schooling. Their direction and character were, however, very much influenced by the conception of school science as the beginnings of an induction into science that was to be completed by studies of the disciplines in higher education. Although a few projects which originated in the USA did develop materials that could enable school science to serve other purposes, such as an understanding of technology (Engineering Concepts Curriculum Project) and creativity about the natural world (Environmental Studies Project), nowhere were these adopted as the mainstream curriculum. By the mid-1970s, the legacy of these exciting reforms was well established as the curriculum of what school science should be in most of the industrialized countries and a number of developing ones.

For the lower secondary years, there was a belief that an introduction to these specialized languages, models and processes of the sciences was good for everyone, paving the way for the accelerated treatment of this conceptual approach in the upper secondary years. For the primary years, where science had not hitherto had a significant place, the most commonly encouraged content for learning was the so-called 'processes of science' like classifying, measuring, controlling variables, and so on; practical and intellectual procedures that stemmed from a positivist and utilitarian view of what scientists do.

Roberts (1982) identified seven emphases or purposes that curriculum materials for school science had, or could have served, over time. The curriculum legacy just described had given clear priority to three of these emphases:

1 *Solid foundation* knowledge that prepared for the scientific topics that came in the succeeding years of schooling
2 *Correct explanation* a representation at the school level of a topic of its current description in science
3 *Scientific skill development* practice in the laboratory of some standard scientific procedures involving technical equipment.

The other four were discarded or quite under-used as sources for content or pedagogy: *the nature of science* (philosophical and historical aspects of science) and *Self as explainer* (active involvement of the students in scientific reasoning) are interesting among these discards because a number of the scientist architects of the 1960s reforms, like Zacharias and Rogers in physics, Schwab in biology, Halliwell and Campbell in chemistry and Bruner had argued that both of these were important. *Everyday coping* (local and wider applications of science) was eliminated to make room for the new conceptual content and *science, technology decisions* (being informed and equipped to make informed judgements about socio-scientific issues) was not itself considered an issue for school science in 1960.

Unpredicted social changes

During the 1960s and 1970s, a number of changes occurred in the industrialised societies that were not apparent when the definition of school science that this curriculum legacy represented, was laid down in the late 1950s. The nuclear threat of the Cold War following the Cuban missile crisis in 1962, and the increasing recognition of the serious damage that unbridled technology causes in the biosphere, regularly gave science a bad image in the media.

The rebuilding of the totally devastated German and Japanese industries enabled these countries to incorporate the latest technologies, and hence to threaten, economically, the traditional means of production in other countries that had not had their industries destroyed. The new technologies did away with many of the less-skilled workers and required different skills from those who remained. From the middle of the 1970s, higher levels of unemployment than had been known since the 1930s became a chronic feature in many societies. In response to these pressures, students were encouraged or required to stay for more and more schooling and secondary education began to change from an elite to a mass phenomenon.

Two other social movements highlighted other inadequacies in school science. The women's movement raised questions about the participation of girls in schooling and about their access to certain professions and occupations after school. These questions of access focused attention on the participation of girls in the physical sciences which, everywhere, had become gateway subjects biased in favour of boys. The second societal change stemmed from the growth of multi-culturalism, as immigration brought in many new citizens with a variety of new ethnic backgrounds. The participation of their children in the education system was of great importance to the social mobility of these immigrants and, once again, they were often disadvantaged by the elite position that science had in the curriculum.

It was thus not surprising that evaluators of the new science curricula repeatedly found that these were not being implemented in the manner that was intended and that a decreasing proportion of the student body was being attracted to, and was benefiting from, their school science. Whatever the curriculum achieved for those who went on to further science-related studies, it was not enthusing the great bulk of students, nor providing them with a scientific basis to participate with confidence in societies that were increasingly influenced by science and technology. It was the recognition of these failures that prompted the reviews and reports referred to at the beginning of this chapter, with their urgent calls for alternative approaches to school science.

Search for alternatives

The difficulties in making school science more meaningful for all students as future citizens are not due to a lack of alternative approaches to the induction and preparatory ones that I have described as the legacy from the 1960s. Indeed, the 1980s proved to be an extremely fruitful period, both in terms of research into the problems of better and more widespread science learning and of the development of ideas and novel materials for school science. Rather, the difficulties lie in the hegemony of school systems and science's role in them, in the place of choice of science in senior secondary schooling. These reflect the conceptions of school science that prevail in educational systems and they are reinforced by the attitudes and behaviour of some key players in the school science scene. Academic scientists, science teachers and science educators are the main groups of players, with the first group usually maintaining the legacy and the third group contesting it, while the members of the second group are divided between the two positions.

How these structural, corporate and personal features of this curriculum scene act as barriers to 'Science for All' will become apparent as the development of some of these alternatives is described.

Uncovering alternatives

With the considerable resources that the national reviews once again released for school science, a number of projects and research studies began in many countries. These processes were greatly assisted by the fact that science education, by the early 1980s, had become an established and active field of scholarly research. This meant that the projects in the 1980s had a much sounder base for their development than the ideas from general psychological learning theory that had been almost the only theoretical underpinning for learning science in the 1960s.

Many of the new projects did not, in the first instance, set out to develop materials as the earlier ones had all done. The Learning in Science Project in New Zealand spent most of its first phase exploring children's conceptions or understanding of a wide range of natural phenomena and science concepts. Among these were the widely and strongly held ideas that motion is associated with the force *in* the moving body, that things get lighter when they burn, and that what *life* or *animal* mean is often quite different from their sense in biology. The shift of focus that Osborne and Freyberg (1985) achieved in this project, from the teacher and teaching to the learner and learning, reverberated around the world in a quite remarkable fashion. A better understanding of the needs and characteristics of young science learners and how their conception of learning science became recognized as precursor conditions for the sensible development of new materials and new curricula. The Secondary Science Curriculum Review in England and Wales brought groups of teachers together to share their experience of the problems of teaching science to the demographically different school populations of the 1980s.

Some of the projects focused on the knowledge content that could make science more relevant to students in the different stages of schooling. Others concentrated on how science learning could be a deeper, more active process than the shallow short-term learning of unconnected facts, concepts and algorithmic rules that school science was for so many. This sense of 'active learning' was quite different from the emphasis on laboratory activity that many of the 1960s projects had advocated. Now 'active' referred to the learners being active in mind, personally constructing and reconstructing meaning from their experiences of phenomena in the laboratory and from their teacher's inputs.

Yet another area of exploration related to the purposes for science at different stages of schooling and the aspects of science that could contribute most effectively to these different purposes. Roberts' (1982) work on broad categories of purpose has already been mentioned. Aikenhead (1986) and Solomon (1988) spelt out how the relationships between science, technology and society could be related to school science. Hodson (1988) did a parallel job for the philosophy of science and Fensham and May (1979) provided an epistemology for a science education that set out to make students environmentally aware and responsible.

A number of projects did produce materials, many of which claimed a place within Science-Technology-Society (STS), a slogan that became shorthand for moves to extend school science to purposes such as Roberts's *nature of science*, *everyday coping* and *science, technology decisions* and to *science in applications* and *science in making*, two other categories of purpose that are needed to cover some of the new materials from the 1980s.

Salters' Chemistry and Salters' Science, two British projects based at York, set as a guiding principle that the science concepts (required for course approval in England and Wales in the mid-1980s) would be introduced only when the need for them could be rooted in material and phenomena familiar to 13–16-year-olds from their own experiences or from television and books (N. Smith 1988). This principle called for radical new foci and reordering of traditional content in school science. It can be contrasted with the earlier and very popular Science and Technology in Society (SATIS) project, which produces short modules about applications of science that can be added, if a teacher wishes, to topics in the existing science curriculum.

In the Netherlands, the PLON Physics project evolved materials slowly through the 1980s, learning from the classroom trials of one unit the aspects to strengthen and delete in subsequent units (Eijkelhof and Kortland 1988). One of these, 'Ionizing Radiation', included some topics and concepts in pure physics such as the characteristics and measurements of short-wave forms of electromagnetic radiation that are not part of traditional school physics in many countries. While academic physicists are attracted to this advanced physics in the PLON materials, they are not, however, comfortable with the biology that is included to make sense of the interactions between these radiations and human beings, or with the socio-scientific concepts like 'radiation damage' and 'social risk' that this unit introduces as society's ways of quantifying and regulating such phenomena.

These selections of STS materials and a number of others from Germany, the USA, Australia and Canada are examples of Concepts in Contexts – an approach to curriculum that is strongly supported by research on how students learn and are attracted to learn science. It uses familiar and motivating contexts from the students' world outside school to provide meaning and interconnectedness for the science concepts, and the concepts, in turn, provide the students with powerful new insights of the contexts (Lijnse 1990).

While the materials mentioned so far do not avoid 'decision-making' about socio-scientific issues, they do not emphasize it. This educational objective for school science is, however, quite prominent in the rhetoric of national reports, for example 'the scientific knowledge necessary to fulfill civic responsibilities' (National Science Foundation 1983: 44) and of politicians, 'to grapple with environmental issues' (Gillian Shephard, UK Secretary of State for Education, February 1995). Chemicals in Public Places (Thier and Hill 1988) and *Logical Reasoning in Science and Technology* (Aikenhead 1991) are two examples of curriculum materials that have made such decision-making a quite explicit learning outcome.

The issue of girls and science led on to comparative studies of the interests of boys and girls. Smail (1987), for example, found an interest in nurturing more strongly, but not exclusively, in girls. However, a number of studies found that the differences in interest of topics for study were less than had been thought. In many countries there are differences in participation and in achievement in the physical sciences in senior secondary schooling. These may be more due, in that attenuated remainder of the original cohort, to the subgroup of boys who, for extrinsic and intrinsic reasons choose to continue with these subjects, than to evidence that boys as a whole are more interested in them than girls.

'COMETS: career orientated modules to explore technology and science' (W. Smith 1987), *Girls into Science and Technology* (Kelly *et al.* 1984) and Chemistry from Issues (Harding and Donaldson 1986) are examples of materials that were developed to incorporate the nurturing interest in various ways. It may be reasonable to include as also expressing this interest the many materials that have been developed with an environmental concern. Together they would then fall in yet another purpose for school science, namely Science for Nurturing, in which care for people, society or the environment is explicitly present.

There is thus no shortage of alternatives to meet the official calls for Science for All: new purposes for school science have been spelt out and new content and new pedagogies devised and invented to serve them. As yet, however, there has been very little decisive will at the educational system level.

Contradictions in intentions

In discussing why it is so difficult for school science to make serious contributions to general scientific literacy, I will draw on a number of specific examples from the debates and efforts that have occurred in Australia (and especially in the State of Victoria). I do this partly because of my knowledge of these scenes and because there are now enough similar reports from other countries that suggest these are, indeed, examples of factors and conditions that have very widespread currency.

Education systems in general are well known for their in-built properties of benefiting the children of rich and well-educated parents more than disadvantaged children from poor backgrounds. Despite repeated attempts to compensate disadvantage, the basic hegemonic effects of these systems and their curriculum of schooling are rarely disturbed (see Bourdieu and Passeron 1973; Lundgren 1981; Connell *et al.* 1982).

Earlier in the twentieth century, science (with advanced mathematics as a concomitant partner) began to take over the hegemonic role that the classical languages had played for so long. This accelerated with the coherence reforms of the 1960s brought about between the content of the science disciplines in schooling and their counterpart parent disciplines in the universities. The study of the sciences, particularly the physical sciences, became the most powerful factor in sustaining the differentiating function of schooling (see Fensham 1980; Scriven 1987).

Science (plus mathematics) was well placed to assume this mantle. Its history in schooling is quite different from that of mathematics itself. Until very recently – the 1960s – it had no place in primary schooling, whereas elementary mathematics has always had a central and expected role from the earliest levels of schooling. David Layton (1973) described the failure of an attempt in the middle of the nineteenth century to introduce science in the primary schooling of rural children before it was established in elite schooling in England. In the USA, a similar suggestion from the philosopher, Spencer, failed and it was late in the nineteenth century when science began to appear in the US upper secondary years as part of the selection process for university entrance.

Parents, secondary teachers, school authorities, employers and society quite generally expect pupils to learn elementary mathematics. No such consensus exists about an elementary science. The current pressure for it comes much more from the compelling logic confronting educational and societal leaders, that it would be irresponsible in late twentieth century technological society if science was not part of all levels of schooling.

So, science entered the school curriculum in the form of senior secondary subjects associated with the separate disciplines of science in the universities. Indeed, until as late as the 1970s, it was not uncommon to find botany, zoology and physiology as subjects in the school curriculum, rather than biology. The combination of their content to form a single subject was made possible by the shifts in emphasis in universities from the whole organism to the micro-biological level of cells, biochemicals and genes and to the macro-level of ecology and hence to the reorganization, in the 1960s, of first-year teaching in universities to a common year of biology.

A number of university courses that led to prestigious and financially rewarding professions like medicine, engineering, dentistry, veterinary science and, to a lesser extent, science itself, expected or required entering students to have high achievement in the physical sciences (with mathematics) at school. Many of these professional fields also involve biological sciences, but if science faculties in the universities, and even biological science departments themselves, have to choose between the physical sciences and biology as a prerequisite study, they usually choose the former. This purchasing power of the physical sciences for university entry is further strengthened by the fact that, in many countries, students with high achievement in these subjects are also looked on favourably for highly selective courses like law and economics, which have little need of specific prerequisite knowledge.

The expansion of higher education everywhere since the 1960s has done nothing to lessen the discriminating power of these science subjects. Rather, it has served to heighten the competition (fundamental to hegemony) to gain a place on the exclusive courses at the higher-status universities that lead to the greatest social rewards. Universities increasingly draw their status from the research success of their scientific and technological academics and the academic quality of their entering students. Identification of its name and content with a university discipline that is recognized as important is a major factor for gaining status. It is not, however, a sufficient condition, as the differential status between school chemistry/physics and biology indicates. With status comes constraint and chemistry and physics were more constrained to include only preparatory content in the 1960s than was biology, into which more frontier topics were allowed (Fensham 1980).

When Araos (1995) asked secondary school teachers in Victoria to list the subjects in the final years of schooling in order of academic status and difficulty, physics, chemistry and advanced mathematics invariably occupied the top positions, followed usually by literature and economics. At the low-status end were found the interdisciplinary subjects, like home economics, physical education, environmental studies, and the integrated forms of science that have been developed and adopted in the last few years in some systems. By academic status, teachers mean quite simply the purchasing power that a subject has, vis-à-vis university selection. To maintain their own reputation, schools tend to encourage only students with high achievements in middle-school mathematics and science (separate or combined) to undertake the 'difficult' physical sciences. Students with lower achievement levels will be discouraged from taking these subjects or encouraged to study the 'less demanding' interdisciplinary science subjects, if these are available. It is this sort of hegemonic pattern that leads teachers to the contradictory position of agreeing that environmental science ought to have a very high priority but not insisting on it being in the school's curriculum or, if it is, ascribing only the weakest students to it.

Van Berkel (1995), in a study of the structure of school chemistry, has been concerned with a subject's maintenance of status as well as gaining it. One of the conditions his international set of respondents emphasized is demarcation. Three demarcations are reported – from common everyday thinking about substances, from technological applications and from treatment in other sciences. The problem with many of the alternative approaches to Science for All outlined above is that they deliberately set out to blur these demarcations. Van Berkel's categories correspond almost directly with Society, Technology and Science – the STS movement's favoured bases for scientific literacy. If school science is to be about real-world situations and issues it will inevitably involve content from a number of sciences. Furthermore, these situations also involve technological or science knowledge for 'practical action' (Layton 1991), that is as much of society's making as it is of the academic scientific community. [...]

Conceptions of school science

I have argued that the dominant conception of school science in the 1960s reforms and in the curriculum legacy that still prevails in most countries, is one of induction into the scientific disciplines – a process that can, at best, be achieved only to a limited extent in schooling. The fact that so few science teachers, even with a tertiary degree in science, think of themselves as scientists, testifies to the extended nature of this induction process.

As part of a national review of the education of mathematics and science teachers in Australia, Speedy *et al.* (1989) asked the staff in the science departments of universities and institutes of technology – the two types of tertiary institutions involved – what image of a graduate scientist determined their curriculum. A future secondary teacher spends three years in science studies and one year in education.

The replies from the institutes were readily forthcoming as 'an applied chemist or an applied physicist, etc.', usually to fit specific niches in the Australian industrial scene. These institutes have evolved since the 1960s from senior technical colleges, with close links to industry, to degree-granting bodies, rather like polytechnics in a number of other countries. The staff in the universities, the origins of which will be familiar, have long been very explicit about their research role. At first they suggested that the question was meaningless because a chemistry (physics, etc.) course was simply self-defining, but discussion of the content included in the various years soon led to the answer, 'an academic research chemist, physicist, etc.' Since only the university staff exert a large influence on school science, it is thus not surprising that induction into this long process, stretching from school through a degree to a PhD, remains the dominant conception for school science.

Science, Technology and Society (STS) – with the addition of Personal Development (PD) – was adopted in the mid-1980s as the official curriculum framework of school science for seventh to tenth grades (ages 12–13 to 15–16) in Victoria (Malcolm 1987). The prevailing high degree of school-based curriculum development and the strangeness of these ways of conceiving of school science meant that Chan (1993), for her studies a few years later, could find only a handful of teachers who claimed strong identification with this STS-PD approach to science. When a brave attempt was made to extend the STS alternative concept to the final two years in Victoria, Fensham and Corrigan (1994) found that even the more innovative teachers had reinterpreted the STS use of contexts into pedagogical procedures that enabled them to teach the traditional concepts more effectively, rather than to see them as opportunities for new content and learning outcomes.

When some of the alternative conceptions of school science were included in draft proposals for a possible national curriculum for first to tenth grades (ages 5–6 to 15–16) in Australia in 1993, they were strongly attacked by a number of leading academic scientists and by their spokespersons in the professional institutes of chemistry and physics. 'Subjective revisionism', 'a mess shrouded under the mantles of feminism and aboriginal culture', 'hand waving descriptions of natural phenomena', 'the impact of science and technology on society is simply not science', 'a takeover of true scientific teaching by a socially motivated, pseudoscientific approach' and 'undermines the Western scientific tradition' are but some of the scornful or angry epithets that were heaped in a number of reports in the mass media on what was, in fact, a very compromised version of what some science educators and teachers had hoped for when this project began in 1989. Paul Davies, winner of the 1995 Templeton Prize for his own very popular but highly speculative writings on the religious meaning of modern physics, was a leading member of one of these groups of hard-liners. At one point in his group's article, they did seem to acknowledge that schools should cater for the majority who need some acquaintance with scientific ideas without advanced mathematical skills. They immediately, however, went on to confirm their need to maintain the *solid foundation* purpose for school science that marks the induction conception: 'one cannot start teaching real science in grades 11 and 12 (ages 16–18) – students simply would not be able to cope without prior grounding'.

A comparative analysis of science curriculum developments in Australia, England and Wales, New Zealand and Canada from 1985 to 1995 (Fensham

1995a) has revealed that educational bureaucrats have played quite decisive roles in preventing or delaying the adoption of alternative conceptions of school science. Very often, these persons have been innovative in their own, different, areas of the school curriculum but, for science, they prove to be identified with the induction conception. Whether this is because they view science (like the primary teacher students above) in terms of what they did not study when they were at school or because they assess where the power lies between the advocacy groups proposing what school science should be will require more detailed case studies to determine (see Blades 1994; Hart 1995).

The power players

The difficulties that schools face in teaching scientific literacy discussed so far arise from relative power-plays between different advocacy groups, or between individuals who can call on institutional or other supports for their case. In this last section, I describe the positions and powers of the three main groups.

Academic scientists

The most powerful and persistent of these groups is to be found among academic scientists. Traditionally, academic scientists and their acolytes among the science teaching ranks have completely controlled what counted as school science (see e.g. Fawns 1987; Layton 1984). In general, they welcomed the reforms of the 1960s and some of them played leadership roles. As has been indicated, these changes to a conceptual content for school science meant that students entering universities to study the sciences were prepared at school and selected in terms of the same type of content as university science.

Since then, a few scientists (see e.g. Gillespie 1976 in Canada; Bucat and Cole 1988 in Australia) have been concerned about the lack of experience of new students with many of the phenomena they seem able to define and handle in conceptual and algorithmic terms. However, the main complaints from academic scientists about school science stem from quantitative features of the current scene. Not enough of the high-school achievers are taking science subjects at school and too few of those who do are choosing science courses in higher education. This leads to students with weak backgrounds in physical sciences and mathematics entering science courses, to the dismay of the academics who have to teach them. This has not led many academic scientists to question the appropriateness of the curricula of the legacy type. For example, there is currently a particularly widespread concern about the shortage of students interested in physics, but academic physicists often continue to be the main opponents of any attempts to introduce alternative approaches to school science and to school physics itself that could make this subject more appealing (see Rowell and Gaskell 1986; Hart 1995; Fensham 1995b).

Another case of this support of the legacy-type content is typified by the concern that has been expressed by some academic scientists in England at the various suggestions to widen the number of subjects to be studied for the A Level examinations that precede university entry. This could be to the advantage of science students, giving them the opportunity to be more broadly educated, but it would be at the expense of studying proportionately less of the traditional content of the prerequisite physical sciences and mathematics. An even more radical move for many countries would be general acceptance by the universities that, at least for some able students from school, studies in physics and chemistry could begin from scratch at university (as is now commonly the case with the biological or earth sciences). This approach has been tried in some universities with considerable success, provided the students have a strong mathematical base.

Although some scientists were part of the reviews in the 1980s (referred to earlier) that recommended that new approaches be developed, the academic scientists, in general, have been relatively uninvolved in, or negative about, the development of the alternatives being suggested. When these alternatives reach the point when they might be implemented, there has usually been strong opposition from leading scientists, especially if changes are suggested to science in the final years of schooling. They have, of course, much to lose in these changes, namely the narrow, but concentrated, conceptual preparedness of their first-year students in the physical sciences. They may, however, gain a much broader base of able students interested in further studies in science and, overall, future citizens who are more able to differentiate those programmes of scientific work that are in the long-term interests of society, and hence be a base of support for them. At the moment, most academic scientists seem to have chosen to stay with the preparedness potential they see in the curricula of the narrow conceptual legacy (if only more of their students had succeeded in it) and they fight hard to retain it.

From the collection of quotes above, it is evident that academic scientists are vehemently against the suggestions that school science should acknowledge that the subjective, the irrational, or social construction play a part in science. Although, in their own circles, and, as Marton *et al.* (1994) found among Nobel laureates, features such as the subjectivity of much scientific work, the role of intuition in it and the importance of the various disciplinary communities are accepted and often shared, they are not to be shared with neonate science students or with non-science audiences. It is as if this would undermine an authority about their scientific knowledge that these academics need to keep and, indeed, are responsible for guarding. Bingle and Gaskell (1994) have discussed how this power and authority of science is threatened by the complexity of real-life environmental situations for which a total scientific analysis is impossible.

School science teachers

Although a growing number of science teachers are now regularly confronted by the open boredom of their students (Baird *et al.* 1991) and their inability or unwillingness to learn school science, the general response of science teachers to the new approaches has been conservative and unenthusiastic. In England and Wales, relatively few science teachers participated in the curriculum innovations made possible by the substantial funds in the Technical and Vocational Educational Initiative (TVEI) programme. In Canada and Sweden, subject groups of teachers have used their union affiliations and other means to resist changes to their science curricula. In Australia, science teachers were found to be very inarticulate about why students should study science compared with the way other teachers argued for their subjects. They were more inclined to rest with the strength of position the eliteness of their subjects gave them than to be concerned with the mass of students' education in science.

Reference has already been made to the socialization that most of today's science teachers have been through in their own education in science. Few of them experienced the very different, more concrete and social curricula that existed before the legacy of the 1960s took over. They have all been socialized in its induction approach in their schooling and in their university studies in science. Furthermore, at school they were among the most successful students in that they continued in tertiary scientific studies for a long way, albeit not far enough to feel like scientists. It is no wonder so many of them also have a stake in its maintenance and a reluctance to teach students whose academic interests are so different from their own. There are, however, growing reports in a number of countries of groups of science teachers who are working together to use as many of these alternatives as their formal curriculum will allow.

The formal professional associations of science teachers and their umbrella organization, International Council of Associations for Science Education (ICASE), have generally been more progressive and open to the exploration of alternative approaches. A number of these bodies have provided status, publicity and, in some cases, financial support, for developing or distributing material that embodies these options. There is a growing number of reports of teachers in many countries working together on alternative approaches and, indeed, using them in their classrooms.

Academic science educators

One of the lasting and more interesting outcomes of the 1960s' projects has been the emergence of a second group of academics with interests in the nature of school science. Many of the outstanding teachers who were recruited as writers and team members of these projects did not return to their classrooms when the projects ended. Rather, they took up positions in the expanding higher education scene as teacher educators. Informed by the extensive and intensive experience in the large-scale projects, they shared not only their own experience of teaching but also the range of approaches and ideas that had been learnt in the project. They also had many questions about science teaching that needed answers; quite quickly science education became established as a field of lively research and scholarly discourse that could inform and influence school science.

With the renewal of official interest and support for school science in the 1980s, a number of these science educators became very active in promoting and developing the alternative approaches that have been outlined earlier. With the responsibilities and opportunities they have in the pre-service and in-service education of science teachers, they are well placed to explain the new conceptions of school science and to contribute to teachers' ability to accept and act on them in their teaching (see Fensham *et al.* 1994; Solomon and Aikenhead 1994). Accounts are also now appearing of the way in which these science educators have also played important roles in the debates and decision-making about whether the new approaches will be implemented (see for instance several papers in the theme issue on Policy and Science Education, *International Journal of Science Education* 17(4) 1995).

The role played by science educators in the proposed changes has, however, been much more ambiguous than has so far been suggested. This stems from the results of what is their most successful area of research since the mid-1980s, and from the limitations that their positions in higher education impose.

The shift of focus from teaching to learning and some easy-to-use methodologies (see White and Gunstone 1993) unleashed what has become a flood of more than 3,000 research studies of students, alternative conceptions of natural phenomena and of basic scientific conceptions (Pfundt and Duit 1994). Almost all of these studies have been of science concepts and topics associated with the legacy science curriculum, for the obvious reason that this was what students were supposed to be learning in school. The research has been fruitful in laying bare the extent of the problem of poor science-learning and in leading to the invention of many new pedagogies that have been shown to enhance this learning. Together, these findings provide a very solid research base for the renewal and resurrection of the legacy curriculum and the induction conception of school science. 'Things are bad but we now know how to do it better' is one reasonable interpretation of this decade of research, whether this is what these science educators with their curriculum hats intend or not. If any of us had bothered to conduct the same sort of research into students' conceptions of socio-scientific issues (like the historical nature of science) or of technological and environmental concepts (like 'social risk', 'product shelf life' and 'radiation damage', etc.) we would, I am sure, have found a similarly amazing range of alternative views and misinformation, and of useful pedagogies. A parallel research base to support the social constructivist and STS alternative approaches would then exist and the reforming science educators' hands would have been much stronger. [...]

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