

## SCIENCE FOR CITIZENSHIP

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### *Science Education and its problems*

It is Collins (2000) who most aptly points to the horns of a trilemma on which science education sits. That is that science education attempts to wrestle with three mutually contradictory requirements. On the one hand it wants to demonstrate the tremendous liberatory power that science offers – a combination of the excitement and thrill that comes from the ability to discover new knowledge, and the tremendous insights and understanding of the material world that it provides. Yet its mechanism for achieving this aim is to rely on a dogmatic, authoritarian and extended science education where students must accept what they are told as unequivocal, uncontested and unquestioned. Only when they finally begin practising as scientists and enter the inner sanctum will the workings of science become more transparent. Moreover, its foundationalist emphasis on basic concepts rather than the grand ideas of science means that any sense of its cultural achievement is simply forgotten. The consequence, as argued in the report *Beyond 2000: Science Education for the Future* (Millar and Osborne, 1998), was that:

We have lost sight of the major ideas that science has to tell. To borrow an architectural metaphor, it is impossible to see the whole building if we focus too closely on the individual bricks. Yet, without a change of focus, it is impossible to see whether you are looking at St Paul's Cathedral or a pile of – bricks, or to appreciate what it is that makes St Paul's one the world's great churches. In the same way, an over concentration on the detailed content of science may prevent students appreciating why Dalton's ideas about atoms, or Darwin's ideas about natural selection, are among the most power-

ful and significant pieces of knowledge we possess (Millar & Osborne, 1998, p. 13).

The outcome is that science education is, in a non-too trivial sense, science's worst enemy leaving far too many pupils with a confused sense of the significance of what they have learnt and, more seriously, an enduring negative attitude to the subject itself (Osborne & Collins, 2000; Osborne, Driver, & Simon, 1996). None of this matters for the traditional education of the scientist which demands a lot of routine and rote learning to acquire the basics of the domain.

The result, however, is that such an education ignores or neglects the third horn of its trilemma, the requirement to provide its students with some picture of the inner workings of science. Knowledge, that is, of science-in-the-making (Latour, 1985) – knowledge which is essential for the future citizen who must make some judgement of reports about new scientific discoveries and applications. Contemporary society, it is argued (American Association for the Advancement of Science, 1989; Jenkins, 1997; Jenkins, 1998; Millar, 1996. Millar & Osborne, 1998), requires a populace who have a better understanding of the workings of science enabling them to engage in a critical dialogue about such issues and arrive at considered decisions about the political and moral dilemmas posed by science. New developments in science will, for instance, require the ability to distinguish whether an argument is sound: to differentiate evidence from hypotheses, conclusions from observations and correlations from causes.

Another aspect of concern is the gulf between science-as-it-is-practised and science-as-it-is-taught in schools. The growing gulf between these two is well-illustrated by our recent research (Osborne & Collins, 2000). Many pupils expressed antipathy to topics such as the periodic table. Not only did they experience difficulty in memorizing the constituents of the table, but they also failed to perceive its relevance to their everyday lives at present or in the future for instance:

Edward: It doesn't mean anything to me. I'm never going to use that, It's never going to come into anything, it's just boring.

Similar sentiments were expressed about the inclusion of the blast furnace in school science:

Roshni: The blast furnace, so when are you going to use a blast furnace? I mean, why do you need to know about it? You're not going to come across it ever. I mean look at the technology today, we've gone onto cloning, I mean it', a bit away off from the blast furnace now, so why do you need to know it?

The lack of perceived relevance to pupils' lives of such topics was a recurring theme throughout these discussions in all groups, either for continuing education in science and/or career aspirations. For instance, it was argued by a boy not continuing with science post 16 that 'I won't need to know all the equations or the chemicals. Without the essential ingredient of relevance, sustaining interest is difficult, if not impossible.

The emphasis of school science on consensual, well-established science, means that there is no space for any consideration the science that dominates contemporary society—the science and technology of informatics, CD-ROMs, mobile phones, lasers, health and disease, modern cosmology, modern imaging systems using computerized techniques, advances in materials technology and polymers, and last but not least, advances in medical genetics. This is the science that interests adolescents and would be included if the curriculum was, instead, organized around the question 'what makes young people want to learn science?' Yet there is as much chance of finding any contemporary science on the curriculum as there is water in a desert. This is not to argue for a curriculum based totally on contemporary science but simply for some aspects to be included as a vital point of engagement.

More fundamentally, the question needs to be asked how this gulf between school science and contemporary science has emerged. My analysis is that, as currently practised, science education rests on a set of arcane cultural norms which inhibit change and adaptation. These are 'values that emanate from practice and become sanctified with time. The more they recede into the background, the more taken for granted they become' (Willard. 1985). A closer examination, and the insights of contemporary scholarship, expose these norms to be nowhere near the self-evident truths that we may think—what I might choose to call the eight *deadly sins* of science education. For in contemporary society, research would indicate that trust in science is dependent on developing knowledge not only of its basic concepts and ideas of science, but also *how* it relates to other events, *why* it is important, and *how* this particular view of the world came to be. Any science education which focuses predominantly on the intellectual products of our scientific labour – the facts of science – simply misses the point. Science education should rest, therefore, on a triumvirate of a knowledge and understanding of:

- a) the scientific content;
- b) the scientific approach to enquiry;
- c) science as a social enterprise – that is the social practices of the community.

Evidence would suggest that in many countries, normative practice regards school science education as a selection mechanism for the few who will become the future scientists of contemporary society. Consequently, the predominant emphasis is on the content of science and consensual well-established knowledge. Contemporary science – the science that interests adolescents – is notable by its absence. The result is a curriculum with only marginal relevance and extrinsic instrumental value for a limited set of career aspirations rather than a discipline valued for its intrinsic interest. Western societies can ill afford the consequent alienation and disengagement with science that such courses generate. First on the economic front, the lack of recruits into science and technology is in danger of undermining economies which are highly dependent of the skills and knowledge of these disciplines. Second, the ensuing lack of engagement and ambivalence to science threatens science's relationship with its public. Indeed, and the growing distrust of scientific expertise is in danger of placing unwarranted restrictions on future research and technological development. Moreover, fear of the worst is leading the public to demand a naïve application of the precautionary principle to research potentially limiting the advancements that science offers for solving the plethora of problems that face contemporary society. In the UK, for instance, significant pressure groups have argued that all research on genetically modified food should be halted using highly questionable ethical arguments.

What then are the norms that hinder the development of current practice in science education obstructing the development an appropriate understanding of science, a more positive engagement with the fruits of scientific labour, and a critical but constructive, understanding of its strengths and limitations? The argument here is that the practice of science teaching rests on eight fallacious assumptions which are as follows.

### *The fallacy of miscellaneous information*

All too many science courses have attempted to make students memorize a series of dry facts which no practising scientist knows, such as the boiling point of water, the density of various substances, the atomic weight of different chemical elements, conversion factors from one system of units to another, the distance in light years from the earth to various stars (and so on). However, an increasing body of work now shows that knowledge is only one component of the many competencies required of adults in their professional life and, unless it is constantly used, is rapidly forgotten (Coles, 1998; Eraut, 1994).

*The foundational fallacy*

This is the fallacy that because scientific knowledge itself is difficult and hard won, learning and understanding science requires a similar process where the student's knowledge and understanding are assembled brick by brick, or fact by fact. As a consequence, only those that reach the end ever get to comprehend the wonder and beauty of the edifice that has been constructed. Current practice, therefore, is rather like introducing a young child to jigsaws by giving them bits of a one thousand piece puzzle and hoping that they have enough to get the whole picture, rather than providing the simplified 100 piece version. In effect, although the pupils can see the microscopic detail, the sense of the whole, its relevance and its value—the things that matter to the pupil (Rowe, 1983) are lost. Chown (1998) offers a good example of a tale which the foundationalist approach offers only to undergraduates or postgraduates taking courses in stellar nucleosynthesis – the grand ideas of science which are reserved only for those who complete the course.

But if all these examples of our cosmic connectedness fail to impress you, hold up your hand. You are looking at stardust made flesh. The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath – all were baked in the fiery ovens deep within stars and blown into space when those stars grew old and perished. Every one of us was, quite literally, made in heaven (Chown, 1998, p. 62).

Yet there is nothing about such a story which is intrinsically difficult. The failure to communicate such ideas in compulsory science education simply reinforces Claude Bernard's, the famous 19th century philosopher, view that science is a 'superb and dazzling hall, but one which may be reached only by passing through a long and ghastly kitchen'.

*The fallacy of coverage*

School science is suffering from a delusion that the science we offer must be both broad and balanced. The result is an attempt to offer a smattering of all sciences and to cram more and more into an oft-diminishing pot. Quite clearly, as the bounds of scientific knowledge expand from evolutionary biology to modern cosmology, more and more knowledge vies for a place on the curriculum. However, just as those teaching literature would never dream of attempting to cover the whole body of

extant literature, choosing rather a range of examples to illustrate the different ways in which good literature can be produced, has the time not come to recognise that it is our responsibility to select a few of the major *explanatory* stories that the sciences offer? And surely it is the *quality* of the experience, rather than the quantity, which is the determining measure of a good science education?

### *The fallacy of a detached science*

Science education persists with presenting an idealized view of science as objective, detached and value free. This is wrong on three counts. First the public, and particularly young people, do not distinguish between science and technology. Second, science is a socially-situated product and the language and metaphors it draws on are rooted in the culture and lives of the scientists who produce new knowledge. Thirdly, those that engage in science are not the dispassionate, sceptical and disinterested community that Merton (1973) portrays. Science is a social practice, engaged in by individuals who share a 'matrix of disciplinary commitments, values and research exemplars' (Delia, 1977). Within the contemporary context, where scientists are employed by industrial companies with vested interests, it is hard to advance a case that science is simply the *pursuit of truth* untainted by professional aspirations or ideological commitments. For these days scientists are:

judged as much by the company they keep as the data they may gather (Durant & Bauer, 1997).

Finally, the separation of science from technology eliminates all consideration of the societal implications for society. For, as Ziman (1994) argues, if science education fails to make the small step from science to its technological applications, how can it take the much larger step to the implications for the society in which it is embedded?

### *The fallacy of critical thinking*

This is an assumption that the study of science teaches students reflective, critical thinking or logical analysis which may then be applied by them to other subjects of study. It is based on the fallacious assumption that mere contact with science will imbue a sense of critical rationality by some unseen process of osmosis. It is also an assumption questioned by the Wason 4 card problem and the Wason 2, 4, 6 problem

(Wason & Johnson-Laird, 1972) both of which require a standard scientific strategy of falsification to determine the correct answer and, which very few, including scientists, use.

Secondly, the notion that science develops generalizable, transferable skills is also an assumption questioned by the body of research which suggests that people's use of knowledge and reasoning is situated within a context (Carraher, Carraher, & Schliemann, 1985, Lave, 1988; Seely Brown, Collins, & Duiguid, 1989) and that detached knowledge is of little use to individuals until it has been reworked into a form which is understood by the user. More fundamentally, the dogmatic and authoritarian training required for future scientists only permits original and critical thought once its noviciates begin to engage with original research. Prior to this point, there is little to incentive to engage in critical enquiry.

### *The fallacy of the scientific method*

This is the myth that there exists a singular scientific method whereas the record of those who have made the important discoveries of the past shows not only that scientists rarely attempt any such logical procedure, but that the methods vary considerably between the sciences. The methods deployed by the palaeontologist working out in the field are about as similar to those used by the theoretical physicist as chalk and cheese.

Yet the science that increasingly confronts the individual in the media, with its focus on environmental or biological issues, is predominantly based on correlational evidence and uses methodological devices such as clinical trials with blind and double-blind controls. Yet where, and when, is there any treatment of the strengths and limitations of such evidence (Bencze, 1996)? Is it not time to give up any notion that there is such a singular entity and turn instead to presenting a range of ideas about science and its working. Moreover, when so much of the science reported in the media is based on epidemiological research and associative findings – probability and likelihood rather than causal relationships and certainty – is it not time to teach about such data, its interpretation and evaluation?

### *The fallacy of utility*

This is the myth that scientific knowledge has personal utility—that it is essential to the mastery of the technology; to remedy its defects; and to live at ease in the culture of technology that surrounds us. For as machines

become more intelligent they require less care and thought for their effective use. Even its economic utility is questionable as current employment trends, at least in the UK and USA, suggest that, although we will need to sustain the present supply of scientists, there is no indication that there is any need to significantly improve the number going into science, which remains, as ever, a small minority of the school cohort of around 10-15% (Coles, 1998; Shamos, 1995).

### *The homogeneous fallacy*

Increasingly, in many countries, science education labours under the fallacy that its clientele are an entity who, whilst they might differ in aptitude and ability, nevertheless are best served by one homogeneous curriculum. With their devotion to pure science, a foundationalist approach, and a high-stakes assessment system, the result is a pedagogy based on transmission (Hacker & Rowe, 1997). By the onset of adolescence, the imperative of relevance increasingly challenges the delayed gratification on which such a curriculum rests leading to a lack of motivation and interest (Osborne, Driver, & Simon, 1996). Pupils, therefore, need to be offered a diversity of science courses to meet their disparate needs.

What then are the methods, practices and components of a new vision of science education that might meet these concerns? The broad framework of such a vision has been developed in the report *Beyond 2000: Science Education for the Future* (Millar & Osborne, 1998). In this report, we argued for 10 recommendations, which we saw would address many of the aforementioned criticisms. These were:

- 1) Science education should be for the majority and should be for scientific literacy.
- 2) An element of choice should be allowed at age 14.
- 3) The curriculum needs aims to ensure that its primary purpose is well understood and shared by all.
- 4) Scientific knowledge can best be presented as a set of explanatory *stories* that would provide a holistic overview of the great ideas of science.
- 5) Technology can no longer be separated from science as the former is what interests pupils.
- 6) The science curriculum must give more emphasis to key ideas-about science.



7) Science should be taught using a wide variety of teaching methods and approaches.

8) Assessment needs to measure pupils' ability to understand and interpret scientific information.

9) Change in the short term should be limited as radical change is undermined by teachers.

10) A formal procedure needs to be established for the testing and trialling of innovative approaches.

This report has been read widely and positively received influencing some of the changes in the new version of the English and Welsh science national curriculum and requiring greater exploration within school science of the relationship that exists between ideas and evidence (Department for Education and Employment, 1999). It has also led to the development and piloting of a new course for 14-16 year olds which will have a specific focus on science for citizenship. Perhaps, more significantly, the report has the support of the UK Deans of science committee who stated recently that:

'Broadly we agree the analysis presented in the report Beyond 2000: Science Education for the Future ... We are acutely aware that the style of specialist school science curriculum has not changed for many years. We thus have to recognise that an approach that worked satisfactorily in the past as a preparation for higher education no longer does so in the changed social and communications environment of today ... From a higher education science perspective, therefore, we would happily see the general approach advocated in the Beyond 2000 report applied to the entire secondary science curriculum'.

For this report to gain acceptance from the representatives of the academic scientific community is a major achievement for it is this community that are the major stakeholders in the science curriculum. That they too seek change is an important recognition of the failings and inadequacies of the current system.

However, reforming the science curriculum to meet the challenges of the contemporary society faces a number of obstacles that must be addressed and met. These are the limitations of the qualifications and abilities of the science teaching force; the problems with developing appropriate modes of assessment; the resistance of well-established stakeholders, and the culture of science teaching.

*Curriculum Reform*

Any new curriculum which gave more emphasis to developing an understanding of the nature and processes of science, would require teachers themselves to have some understanding of these dimension of science. Yet science teachers are the products of an education which has paid scant regard to history, or any examination of its social practices. And for good reason-the dominant ideology within science is one of dogmatism and authority where the tentative nature of the roots of scientific knowledge is excised to present science as a body of certain knowledge which has been the successful, linear progression of the work of isolated great men, devoid of any cultural context. The outcome of such an education is a body of science teachers who have naive views of the nature of science-seeing it as an empirical process where scientific theories are inductively proven (Koulaidis & Ogborn, 1995; Lakin & Wellington, 1994).

Similarly, Donnelly (1999) has shown how science teachers see their work as one which is dominated by content rather than process, as opposed to the contemporary treatment of history where the history teachers seek to develop an understanding of what it is to do history. The significance of empirical work to science, and in the teacher's practice, is such that teachers are endowed with distinctive status by the provision of specialized laboratories. Laboratories in their turn become rhetorical artefacts where the scientific world-view can be used to illustrate the predictability of nature and inspire confidence in the scientific world view (Donnelly, 1998). Asking teachers to teach more about the nature of a subject which they themselves only have a limited understanding of will inevitably be problematic.

Attempts to introduce change under the umbrella of the National Curriculum – particularly when those changes were later shown to be based on fallacious models of science – have met with substantive resistance and modification. The 1991 version of the English and Welsh science curriculum introduced a model of practical based investigatory work which was unfamiliar and resented by teachers who failed to share or understand its intentions. The result was a long period of adaptation whilst teachers reworked the curriculum to put into practice work which was a distorted representation of the intentions of the national curriculum document. Many teachers were alienated or disaffected by the process (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996).

The lesson of these problems is one that was clear from previous research on educational change (Fullan, 1991; Joyce, 1990). First, teachers

must he dissatisfied with the existing curriculum if the arguments for change are to be heard. Second, if change is to occur, teachers must be supported in developing new practices, new bodies of knowledge and new pedagogic methods. At the very least, that requires the rewriting of curriculum support materials which should seek to provide exemplary illustrations of the ideas to be taught and suggestions for how it can be taught. More substantive support would require a programme of professional development delivered by individuals who are themselves competent and effective teachers who have a good grasp of any new initiative. At the very best, there would be *in-situ* training provided for all teachers who required it.

### *Assessment*

The second problem lies with reform lies in the role of assessment within existing national and international frameworks. Within the past twenty years, political imperatives have led to the necessity to measure the performance of the educational system. The consequence has been the rise of national systems of assessment based on testing at certain key ages – in the UK these are age 7, 11, and 14. Internationally, we have also seen the rise of comparative assessment between countries which have been used as a measure of the overall quality of education (Beaton et al., 1996). Thus rather than assessment serving as a tool to benefit the child, providing either a formative or summative judgement of their capabilities, it has become a servant of a bureaucratic mentality that seeks to monitor the performance of the system. Whilst, it could be argued that these two aims are not incommensurable, the reality is different.

Similar problems have beset attempts to provide performance indicators in the Health Service, in the privatized railway companies, and in a host of other public services. In each, a variety of indicators are selected for their ability to represent the quality of the service, but when used as the sole index of quality, the manipulability of these indicators destroys the relationship between the indicator and the indicated. Directing more and more attention onto particular indicators of performance may manage to increase the scores on the indicator, but the score on what it indicates are, in reality, relatively unaffected. Thus whilst measures of children's achievement show year on year improvement, the actual quality of their education remains much the same.

The lesson of history then is that in seeking to make the *important measurable*, only the *measurable* has become *important*. The second problem is that within school science, assessment items are commonly devised

by those that have been, or still are, practising science teachers. Just as it is often said that you teach only that that you can teach, so assessment is often based on the normative values of what it is considered possible to assess. Hence the assessment of students' understanding of the processes of science, or its social practices, are not considered because there is no established body of knowledge of how to assess such items. At worst, assessment experts will simply assert that it is too difficult, time-consuming or expensive to assess such understandings and, at best, that they do not know how to do so. Thus, within such a context generated by the importance of measuring performance of students, teachers and schools, the clear message to teachers is that the lack of any assessment of a given topic implies that it is an extraneous item of no significance.

The single most important message that emerges from this analysis is that curriculum reform without a commensurate change in the assessment will be ineffective. Change must be attempted holistically and not in a piecemeal fashion for the intended curriculum is read as much, if not more from the assessment as much *as* it is from the curriculum. In conclusion, what *is* evident, is that *science* for all requires a curriculum for all. The current flight from science by contemporary youth would suggest that anything else would be a price that neither science or society can afford to pay.

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