

Designing a science curriculum fit for purpose

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ABSTRACT The science curriculum to age 16 should be judged on how well it meets the needs of students who progress to A-level science courses and those (a larger number) who do not. To address the diversity of students' interests and aspirations, we need a clear view of the purposes of science education rooted in a view of the purposes of education itself. This article argues that a flexible curriculum structure for science is essential at key stage 4, offering a variety of pathways that can be better matched to the needs and interests of students.

Science for all

The principal concerns that have driven the 2011–2013 review of the National Curriculum for Science in England and of GCSE subject content are a perceived need to set more challenging learning targets that raise expectations of what students should accomplish – in line with the curricular goals of countries and regions that achieve the top rankings in international comparative studies such as PISA and TIMSS. Matching the performance of these 'high-performing jurisdictions' is deemed essential for the UK to be competitive in the STEM subjects that are seen as the key to future economic success and prosperity. The White Paper that launched the coalition government's review of education begins its discussion of qualifications by saying that '*we must make sure that the standards set by our qualifications match up to the best internationally in providing a good basis for future education and employment*' (DfE, 2010, para. 4.4).

Of course, we should aspire to provide a science education that is, in international terms, second to none. But on what criteria should the science curriculum to age 16 and the qualification that is based on it be judged? Often, the primary requirement seems to be that it is a good preparation for progressing to AS- and A-level (post-16) courses in the sciences. Those who criticised the 2006 changes to science GCSE specifications (for ages 14–16) did so, first and foremost, on the grounds they were a less

adequate preparation for AS- and A-level sciences than the specifications they replaced. And this appears to be the dominant criterion in the current review. While it is certainly one criterion on which we should judge science provision to GCSE level, however, it is not the only one. Fewer than 20% of the students who complete GCSE science (or sciences) and receive a grade do in fact go on to study one or more of the sciences at AS-level. The remaining 80% do not. The science curriculum to age 16 should be judged on how well it meets the educational goals we have in mind for *all* students, not just the 20% who choose to take more advanced academic courses in science.

This point is not a new one. The Higginson Committee (DES/WO, 1988), invited to review and advise on A-levels, argued that: '*The most fundamental error in the traditional GCE/A level system was that each stage was designed to be suited to those who were going on to the next*' (para. 8). Going back further still, the Thomson Committee (or, to give it its full name, the 'committee appointed by the Prime Minister to enquire into the position of natural science in the educational system of Great Britain'), in 1918, argued that: '*In framing a course in science . . . up to the age of 16, it should be recognised that for many this will be the main, for some the only, opportunity of obtaining a knowledge of science, and that the course should therefore be self-contained*' (para. 48).

Concerns about the diversity of the school population at key stage 4 (ages 14–16) in terms

of interest, aptitude and ability were central to the previous National Curriculum review in 2005. The aim was to offer a more flexible curriculum in science at key stage 4 that could be better matched to the needs and interests of students. The existing double-award science curriculum was seen as insufficiently challenging for academically more-able students, but also insufficiently engaging for many others. The latter concern has not been prominent in the 2011–2013 review. But the issues raised by student diversity, and difference of aspiration and interest, have not gone away. Unless they are recognised and addressed, dissatisfaction with the science curriculum and its outcomes is likely to persist.

The first step in addressing them is to ask what it would mean in practice to develop a science course that was ‘self-contained’ (in the Thomson Committee’s words) – designed to be suited to those students who were not going on to the next stage (in those of the Higginson Committee). To answer this, we need to ask why we want to teach science to all students. What are the aims of school science for all students, including those (the majority) who end their formal study of academic science at age 16? When we have answered this, we can then ask how we can best structure the science curriculum to provide a worthwhile educational experience for those who aspire to study science to A-level and perhaps beyond, those who might study the kind of science that can lead to a range of technical jobs, and those who will study no more science at all. These are not simple questions with easy or obvious answers. If they were, we might have made more progress in the century since the Thomson Committee’s recommendations. Nor are there ready answers to be found by looking at practice in other countries; while the tension between ‘science for all’ and ‘science for future scientists’ is widely recognised, there have been few attempts to implement and evaluate potential solutions, and none (that I know of) at national level. Also, there are influential bodies in many countries, including the UK, whose interests lead them in practice (whatever their rhetoric) to prioritise the science education of the 20% who go on to study more advanced academic science, and to see changes designed to address the goals of ‘science for all’ as a threat. In fact, higher levels of public engagement with science, arising from a more positive experience of science at school,

and more students following more vocationally oriented science courses, might serve their interests better.

Science as education

What is school science for? What does it contribute to a person’s education? These are very large questions. Any answer we might give has to be set in the context of a view of the purpose (or purposes) of education in general. Pollard and James (2007) suggest that:

Within contemporary Western democracies, three major strands of philosophical and political thinking on educational purposes are well established. The first concerns teaching and learning linked to economic productivity – and has taken various forms historically as labour market needs have evolved. The second concerns social cohesion and the inclusion (or control) of different groups within society – and this remains important within our unequal and diverse societies today. The third concerns personal development, fulfilment and expression – with a contemporary manifestation perhaps in the term ‘wellbeing’. The three are, of course, deeply interconnected. (p. 2, emphases added)

The arguments most commonly put forward for teaching and learning science map on to these three purposes quite readily. They are summarised in Box 1. The economic argument relates directly to the first of Pollard and James’s purposes. The democratic and cultural arguments express different aspects of the aim of social cohesion; all four arguments link in different ways to aims associated with personal development, fulfilment and expression. But what should be the balance between them?

The economic argument is a strong reason for teaching science to some students. But it is only an argument for ‘science for all’ insofar as we are willing to see school science to age 16 essentially as a means of identifying those who could successfully pursue a career in science if they so choose. The other three arguments make the case for teaching science to all students. The core curriculum – the entitlement of all students – should be based on these three arguments. It is important to stress that giving greater weight to these arguments does not mean moving away from teaching ‘real science’ towards teaching ‘science studies’ or ‘science appreciation’. All

BOX 1 Arguments for teaching and learning science

- **The economic argument:** A steady supply of people with science qualifications (both academic and technical) is essential to maintain and develop the kind of society we value. Science is central to the innovation on which our future economic success as a nation depends. School science provides the foundations of the knowledge required for a wide range of careers in science and engineering.
- **The utility (or usefulness) argument:** It is useful in everyday life to know some science, in order to use artefacts skilfully and safely, and to make better-informed choices on matters of diet, health and lifestyle. Science also develops practical capabilities and habits of mind that are useful in many domestic, workplace and leisure situations.
- **The democratic argument:** In their daily lives, and via the news media, people encounter issues that have a scientific dimension. Some understanding of science, and of both the importance and the limitations of empirical evidence, are needed to reach a more informed view on such issues and engage more effectively in discussion and debate.
- **The cultural argument:** Science (seen as both product and process) is one of the major cultural achievements of humankind. It shapes our material and intellectual environment. Practical applications of scientific understanding (for example, in electrical devices and medical treatments) have transformed our lives materially, and accepted scientific ideas (for example, about the scale and structure of the universe and the Earth's place in it, the age of the Earth, and the evolution of species by natural selection) have profoundly altered our view of ourselves and of the universe we inhabit. Everyone should be given an opportunity to appreciate the elegance and power of scientific ideas and the cultural significance of science.

four arguments in Box 1 make a case for teaching and learning science but they have different implications for the choice of curriculum content and learning outcomes, and hence for methods of teaching and assessment.

Decisions about what science to teach, and to what depth, cannot be avoided. The scientific canon is simply too large to teach more than a tiny amount of it at school level. So what guides the choices that have to be made? Science courses designed with the curriculum emphasis that Roberts (1988) has called 'Solid Foundation' are invariably based on the perceived structure of knowledge in the science disciplines. The historian of science, T. S. Kuhn (1962), described a 'training in science' as an immersion in the paradigms (the concrete examples of accepted solutions and approaches to problems of specific types) that embody and communicate scientific practice, through practice and repetition, until these become second nature. In the words of a leading sociologist of science, Harry Collins (2000), *'it is romantic nonsense to imagine that potential science specialists can learn all the science they need without a lot of routine learning and practice along with indoctrination into traditional ways of thinking'* (p. 171).

Courses of this sort, that focus on communicating an understanding of disciplinary science, have, however, been criticised on several grounds. Critics (for example, Linder, Östman and Wickman, 2007: 7–8) argue that they do not adequately develop students' understanding of the processes of scientific enquiry, of the historical development of ideas and understandings, of science as a human enterprise, of the importance of creativity, ingenuity and persistence in generating knowledge, or of the role of science in understanding and addressing major global issues such as food and water supply, the eradication of disease, and climate change. Many students also point to the characteristics of such courses as features of school science that they find unattractive. Lyons (2006), for example, reports that school students in three separate studies carried out in Australia, Sweden and the UK were critical of science lessons that they saw as *'teacher-centred content transmission'* (p. 595) and of curriculum content that they felt was disconnected from their lives and concerns.

One way to tackle these criticisms is to select course content on the basis of the utility, democratic and cultural arguments. Courses that give priority to these arguments for teaching science are likely to give more time to case-studies of the application of scientific ideas, of unresolved or contested issues that involve

science, and of the historical development of ideas. Hence they offer more opportunities to make science lessons less teacher-centred and ‘transmission’ dominated. To repeat the point made earlier, the change involved is not from teaching science to teaching ‘about science’; it is about the ‘driver’ (Fensham, 2002) that is used to select the curriculum content.

Curriculum structure

The substantial differences between the kind of course that might raise the understanding and appreciation of science of all school students, as described above, and the kind of course that is most effective for providing a ‘sound foundation’ for more advanced study pose a real challenge for curriculum design. A single course that tries to fulfil both aims inevitably comes to feel like an uneasy compromise that achieves neither aim very well. Over time, successive revisions give less emphasis to abstract ideas that cannot easily be related to everyday situations in which more students are interested. Students are not asked to spend as much time practising and rehearsing standard methods and approaches in the laboratory and on problem solving. The course becomes a less satisfactory preparation for more advanced study but does not become more appealing to those students who do not plan to study science further anyway. This, in a nutshell, was what happened to double-award science over the 20 years of its existence.

How can this dilemma best be resolved? How can we provide a school science programme that stretches and challenges students who aspire to study a science or science-related subject to degree level, caters for students with a possible interest in science-related work of a more technical sort, and also provides a worthwhile educational experience for those (the majority) who have goals and interests that do not require the study of science post-16? This question was at the heart of the deliberations of the *Beyond 2000* seminar group in the late 1990s. Their answer, based primarily on the numbers involved, was that ‘*The science curriculum from 5 to 16 should be seen primarily as a course to enhance general scientific literacy*’ (Millar and Osborne, 1998: 2009), but that this should be augmented by ‘*a wide choice of science options, including modules of a more academic and of a more vocational kind, which could be taken by pupils in a variety of combinations*’ (p. 2010).

The *Twenty First Century Science* project was an attempt to test these ideas by developing a suite of courses that could provide this kind of flexibility (for a discussion of its rationale and design, and the outcomes of pilot trials, see Millar, 2006). It had a core course, GCSE Science, whose content was chosen on the basis of the cultural, democratic and utility arguments. Alongside this were two options, GCSE Additional Science and GCSE Additional Applied Science, whose contents were chosen primarily on the basis of the economic argument, to provide a sound foundation for later courses that could lead to careers and jobs of different sorts in science and technology. These were innovative courses and it would be astonishing if they solved all of the problems they addressed and worked perfectly. The core course did well enough, however, during the pilot trials for many teachers to tell us that, for the first time in their recollection, none of their students had asked them ‘*Why do we have to study this?*’

The changes to GCSE science in 2006, which made a ‘core + additional’ course structure mandatory, were rushed in before the pilot had run its course, let alone been evaluated. Perhaps as a result, the *Twenty First Century Science* suite was not implemented as the developers intended, with many schools opting to treat the GCSE Science course as their year 10 (age 14–15) programme and GCSE Additional Science as their year 11 (age 15–16) programme. This had the highly undesirable consequence that some students who aspired to continue to academic post-16 science felt short-changed by the lack of concept-led science in their early year 10 course. An even bigger problem was the assessment model adopted by the awarding body, OCR, and the use of many selected-response and short-response questions, which made it almost impossible to assess ‘ideas about science’ in the depth or manner that was intended.

Despite these difficulties and weaknesses, a survey of *Twenty First Century Science* centres in Autumn 2008 reported increases of between 25% and 35% across the three sciences in the numbers of students choosing to begin AS-level courses (Millar, 2010). Not surprisingly, helping more students to connect school science to things they hear about outside school led to more thinking it worth continuing the study of science.

Instead of using an innovative pilot to provide evidence of what works and what does

not, however, attention seems to have moved to different issues. Rather than a concern about flexibility, to address different student needs and interests, the focus is now on more-demanding academic goals for all students. The push for triple science is one manifestation of this; the revised National Curriculum and GCSE subject content documents are another. But for the reasons outlined above, these courses and qualifications will inevitably adjust over time to fit the population that takes them. If the proportion of the cohort taking separate sciences increases significantly, the nature of the teaching and the assessment of these will inevitably evolve. Questions will have to be included to discriminate across the ability range taking a given paper, and the examinations as a whole will be designed to generate marks that are normally distributed with a mean that is not so high or so low as to skew the distribution unduly. Rather than triple science for as many as possible, a more effective strategy would be triple science for those who are best suited to that kind of science course.

The findings of a recent study of the factors associated with above-average uptake of science subjects at post-16 level corroborate the view that diversity is more successful than a monoculture. Bennett, Hampden-Thompson and Lubben (2011) found that:

The nature of the science curriculum offered at Key Stage 4 exerted an influence [on uptake of science post-GCSE]. In high-uptake schools, the

curriculum provided alternative GCSE science subjects for pupils with a non-science interest, or with a vocational aptitude, such as GCSE Applied Science in parallel with double award and triple science. The provision of alternative curricula permitted more homogeneous GCSE double award and triple science teaching groups, and this, in turn, appeared to influence pupils positively towards choosing chemistry or physics. It should be noted that the provision of a triple science option did not, in itself, appear to have a universally positive effect. (pp. 54–55)

The central message is a simple one. Young people are different. They are interested in different things, have different aspirations for their lives, learn in different ways. They are also growing up within a society that needs to be grounded in some common understandings and ideals. The science curriculum needs to address both the things that make us different and the things that we need to hold in common. Reconciling the demands of diversity and cohesion will always be a challenge for educators. The issues explored by the *Beyond 2000* group and the *Twenty First Century Science* project have not gone away. Only by recognising the tensions, and exploring ways to reduce and remove them, can we hope to make lasting progress. These issues have not been a priority for the 2011–13 National Curriculum review. Currently they seem to be off the policy agenda. But be sure they will be back.

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