# Science Education for the 21st Century

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There are concerns about the quality and effectiveness of school science education in the UK, and in almost every developed industrialised country. These are of two main kinds. First, in many countries the proportion of young people who choose to continue to study science beyond the point where it is compulsory is falling, particularly in physics and chemistry. Second, public understanding of science – and trust in science – often appear to be low. So people's views on important issues, such as genetically modified (GM) organisms and global climate change, are often not well-informed – with potentially significant consequences for the public response.

School science has an important role in addressing both of these concerns: Science in schools must maintain its traditional and vital focus on preparing the most interested and talented pupils for science courses at university. At the same time, it must equip *all* students for what has been called 'scientific literacy' or 'science for citizenship'.[1]

This 'dual mandate' poses a very real challenge for school science. On the one hand, it has to provide all young people with a sufficient grasp of the scientific account of the physical universe – and of the methods of enquiry and the commitment to careful reasoning from evidence which are central to science – to allow them to take an active and informed role in making the decisions and choices that face us as individuals and as a society. It should give all students a positive experience of science, a sense of why science is valuable to them, even if they do not intend to pursue a career that requires more advanced study of science. At the same time, school science must also provide a sound foundation for further study of science for those who may want to follow this route, either out of personal interest or as a possible career direction – and it must do so in a manner that stimulates and retains the enthusiasm of students who have a particular interest in and aptitude for science.

If we only wanted to do one of these two jobs, the task of designing a science curriculum would be considerably easier. Indeed, we have in the past had science courses that were widely seen as a suitable preparation for more advanced study, when offered to the highest achieving 20% of the student cohort. But these have proved very much less satisfactory as a form of school science for the whole cohort – and the changes that have been made to broaden access have steadily diminished their suitability and effectiveness for the higher attaining group. There is much less experience, either in the UK or elsewhere, of school science courses to develop the kind of understanding of science that is of value to people who do not aspire to careers that require more advanced science. But there is very general recognition that this is crucially important in developing the social and political climate within which science and technology can thrive in an open society. We urgently need to develop expertise in designing science courses that can do this job well.

The fundamental reason why the dual mandate poses a challenge for school science is that science courses designed for each of these two purposes would be quite different in content, depth of treatment, and emphasis. A science curriculum for citizens would aim to help all students understand enough science, and enough about scientific methods of enquiry, to make better-informed choices and hold better-informed views on issues that affect them directly – like whether or not to have a child vaccinated, or to eat food produced from GM crops, or to support measures to reduce carbon emissions. It would teach some basic scientific knowledge, but would also highlight the importance of basing claims on careful reasoning from evidence and of peer review in checking and scrutinising claims that are made. The science education of future scientists, on the other hand, is an induction into an accepted set of explanations for the behaviour of the natural world. It begins from the foundations, and proceeds in slow logical steps. It involves extensive practice in applying standard methods and in carrying out standard procedures. Students have little opportunity for independent thinking or for genuinely open enquiry until they reach an advanced stage. They learn little that they can apply practically in everyday situations. Not surprisingly, many students see little reward for the effort of trying to understand it: "A lot of the stuff is irrelevant. You're just going to go away from school and you're never going to think about it again."[2]

Studies in other developed countries report similar views.[3] Teaching 'academic' science to the whole school population results in fewer students wanting to continue to study science – and to negative views of science and science education in general. One particularly telling piece of evidence comes from the Third International Mathematics and Science Study (TIMSS). In this study, random samples of 15-year-olds in over 40 countries took a test of school science knowledge and completed a questionnaire designed to assess their attitude towards science. If we plot the average score for each country against the percentage of students in that country with a high positive attitude towards science, the graph shows a strong negative correlation between the two variables.[4] A high average score goes along with a low proportion of 15-year-old students with a positive attitude towards science. In other words, those countries which teach science in a way that results in high average scores on a rather traditional science test have the smallest proportion of students with positive attitudes towards science and school science.

The problems we, and many other countries, currently face are a consequence of thinking that one science curriculum, if suitably designed, can achieve both of the aims of the school science curriculum – the 'dual mandate'. Instead this leads to an unsatisfactory compromise – a course which does neither of the jobs of the science curriculum well. The first step towards a solution is to acknowledge the need for different kinds of science courses for different purposes, and for different students – depending on their interests and their future aspirations. We need to move away from a failed 'one size fits all' model of the science curriculum towards a more flexible set of options, each of which can be designed more effectively for purpose.

This is what I and my colleagues have been trying to do over the past 8 years in the work that has led to the *Twenty First Century Science* GCSE specification – one of four available to schools from September 2006. In developing it, we wanted to improve significantly on its predecessor, Double Award Science, in two main ways. We wanted to find a way to teach some stimulating and conceptually challenging science to students with an interest in science – something which had been gradually eroded over the previous 20 years. And we also wanted to design a course that could provide **all** students at this age with the kind of understanding of science that would help them engage more thoughtfully and critically with science as they meet it in their everyday lives – in particular, to develop their skills in looking thoughtfully and critically at the evidence that supports the kinds of claims that are made and to develop their ability and confidence to discuss and evaluate these. I emphasise 'all students' here, because this kind of understanding of science is also essential for those who wish to pursue the study of science further. So we developed a Science course to develop the 'scientific literacy' of all students – and a more formal and abstract Additional Science course for those who chose it. We quickly realised the importance of also offering an Additional Applied Science course – for students with a more practical interest in science as it is used in some real workplace situations.

If we want to address both aspects of the 'dual mandate' for the school science curriculum, we need to accept that no single course, however well-designed, will do both jobs well. We need a variety of provision, for students with different interests and aspirations. And we need a continuing effort – involving everyone with an interest in school science – to review, revise and improve the science courses we offer both to those who may go on to work with science, and those who will not.

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# The Importance of Good Teachers

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The Devonshire Royal Commission of 1875 claimed that 'the present state of scientific instruction in our schools is extremely unsatisfactory'[1] reminding us that this is not the first time science education has come under scrutiny. More recently, a wide range of bodies across government, business, industry and the scientific and engineering communities have also expressed their views on why students should be taught science.

There is widespread acceptance that all students should have access to the study of science throughout their years of compulsory education. The Association for Science Education (ASE) has for many years championed the cause of 'Science for All' and, since its origin in 1901, has worked to improve teaching and learning in science through its members working together to share good practice and to express views on science education. ASE argues[2] that all pupils should experience, and have access to, a broad, relevant science curriculum, which puts the understanding of science and its applications in a social context. Furthermore pupils should experience a variety of teaching and learning approaches, including practical work, in order to extend, develop and adapt their knowledge, understanding, skills and attitudes in science. Regardless of whether it is in primary or secondary school, the role of teachers, who are enthusiastic, have good subject knowledge, a clear philosophy of science education and high quality expertise in teaching, is a key element in meeting these aspirations. As Osborne and Collins[3] concluded,

"In essence, school science's most valuable resource is not its equipment or its laboratories but a cadre of *well-qualified, enthusiastic teachers* who are justly remunerated for their skills."

These teachers would be the first to acknowledge they could not do it without the support of their colleagues, technicians and teaching assistants who make up the wider science team.

The challenge for science education in the 21st Century is translating such aspirations into practice. The answers are not straight forward but it is worth reminding ourselves why most of us went into teaching in the first place. In part it is to do with our interest in our subject but for many it is because we wanted to share it with young people, getting them engaged, experiencing something different or coming to understand something that started as a 'mystery'. To do this all teachers have to juggle a wide range of demands, principally, the curriculum, the assessment requirements, the facilities and resources available and their own pedagogical skills in order to engage their students. Each of these elements obviously relates to, and impacts on, the others thus emphasising the complexity of the task and the level of expertise required by a highly accomplished teacher.

Thus if we want high quality science education in and for the 21st Century we need to ensure that teachers and other members of the science team are well prepared and have access to high quality CPD in order to keep up to date, maintain their own enthusiasm and are able to adapt to changing circumstances. This of course is easier said than done but below I have attempted to illustrate some of the implications for teachers that arise from different aspects of providing science education which is appropriate for young people. Although the main focus here is on secondary education, the issues identified also relate to primary science.

It is important to stress that there are many positive claims that can be made about science education in the UK: the performance of the UK in international comparisons, Ofsted Inspection reports showing improvements in the quality of teaching, the success of primary science and the fact that there are many pupils who do enjoy science. Such positive aspects are all too easily forgotten in the debates that take place yet these are strengths on which we can build and make progress.

## Facilities and resources

In some schools the science laboratories have not changed for many years but science has moved on. The sophistication of the equipment that is available for carrying out practical work has also moved on. The potential of ICT and other technologies provides a myriad of opportunities to improve the quality and excitement of teaching and learning. Science education in the 21st Century must embrace these developments, not just because they are new but because they provide greater insights into, and ways of investigating and learning about, the natural world.

Apart from the obvious fact that provision of new facilities and equipment needs careful planning and the funding to go with it, teachers and technicians need to be comfortable working in the new environments and with using the equipment. This in turn requires time not only in training but also to follow up the training and try things out.

## Curriculum

Debates about the curriculum seem to be endless but, whatever the curriculum specification, we must have appropriately qualified teachers to teach it. Simply to argue that teachers should have a degree in a particular subject does not guarantee that they can teach what they know to young people nor that they have the breadth of knowledge from their degree course to cover that required by the curriculum. This problem is generally acknowledged and individual teachers take it on themselves to ensure that they do know what it is they have to teach. However at a system-wide level it is not so straight forward. A report in 2006[4] set out concerns that in maths and science (principally physics and chemistry) there are not enough qualified teachers to teach the curriculum required. Some steps are being taken to address this issue in the short term but ultimately it means that more individuals trained in the scientific disciplines need to be attracted into teaching and those in the profession need to engage in subject-specific CPD.

## Assessment

Closely tied up with the curriculum is the issue of assessment which in turn drives what is actually taught and what students are asked to 'learn' for tests and examinations. We delude ourselves if we think it was different in the past. As teachers we have all tried to improve our students' chances of success by doing 'revision' and highlighting particular aspects of the topic that 'are likely to come up in the exam'. So what has changed? The frequency of external tests and examinations and the culture of 'league tables' have certainly contributed to creating an environment in which the assessment regime has, at the very least, restricted opportunities for exploring the subject beyond the scheme of work.

Paradoxically, assessment used in a formative manner, rather than for summative purposes, is an integral part of the learning process. The potential impact of formative assessment on the achievements of students was summed up by Black and Wiliam[5] saying,

"There is a body of firm evidence that formative assessment is an essential feature of classroom work and that development of it can raise standards."

However for teachers to maximise the benefits of formative assessment requires changes in their practice.

## Engaging Students

Getting pupils engaged with the science can be done in different ways but not every approach will engage all students. Grabbing interest with a 'spectacular or intriguing demonstration' can be effective as is finding a way of making it 'relevant' to them. This will differ from student to student, for some 'relevant' means the work should be 'applied'. For others it is the need for some 'personal link', discussion of 'ethical issues', hearing about a scientific discovery or investigating something they personally find fascinating. Sparking some kind of interest is an important first step in pupils' learning.

## Pedagogy

Whichever way you consider science education for 21st Century there are implications for the teachers both individually and collectively. The importance of their teaching skills, their knowledge of the subject, their understanding of children's learning, amongst other things, cannot be denied. Yet too often in the debates about curriculum, assessment and resources the implications for teachers have not been made explicit. Recent developments which have raised the profile of subject-specific CPD, have started to address the situation. I would argue that in looking ahead we need to reconsider how we manage the introduction of changes at national and school level. Teachers implementing the changes need to be well prepared but, importantly, there should be enough time, support and flexibility for teachers and schools to be able to decide how best they meet the needs of their students.

Science education has come a long way in the last 100 years and will, without doubt, move on in the 21st Century but the interactions between teachers and pupils will remain at its heart. It is through highly accomplished teachers skilfully managing the, often competing, demands that we will enthuse the next generations in science.

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# Science for Science's Sake

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When I wrote my essay *"What is science education for?"* I was asking a seemingly uncontroversial question. However, the response to the essay proved this is not a question we feel confident we can answer with any degree of certainty. In response to the introduction of the new Science GCSE last September, based on the Twenty First Century Science (TFCS) GCSE pilot, I wrote a critique of the direction educational reform was taking. In essence, I was asking for a pause to take stock before we committed ourselves to a course of action from which it will be very hard to extract ourselves in the future. The furore surrounding the publication of my essay proved there is real concern about the rush to reform school science. Famously Baroness Warnock was quoted on the front page of *The Times* calling the new Science GCSE "fit for the pub" rather than the basis for a sound science education.

On the other hand, almost everyone thinks that "something must be done" to improve science education. The decline in numbers taking science at A-level and university, especially the hard science sciences – physics and chemistry – has now reached the status of a national disaster. Despite advertising campaigns, the lure of pop stars like Myleene Klass and out-and-out bribery to attract new science teachers into the profession we still face a dire shortage of qualified physics teachers in our classrooms. The closure of university departments seems to have reached the proportions of near collapse in the physical sciences. But this is not the only driver towards the reform of science education.

The position of science in society has suffered a dramatic decline with the response to BSE, MMR and GM foods just to name a few crises that have faced the government over the last couple of decades. Scientists are now tainted by their relationship to industry and government. We just don't trust them like we once did. For government the issue of trust has become a direct target of educational reform. Robin Millar and Jonathan Osborne made it clear in *Beyond 2000* (http://www.kcl.ac.uk/education/publications/bey2000.pdf) that science education had to educate the citizen to "have sufficient knowledge and understanding to follow science and scientific debates with interest, and to engage with the issues science and technology poses – both for them individually, and for our society as a whole". That is science education should be about creating the scientifically literate citizen.

The problem is that all this asks too much of the GCSE science curriculum. The conflicting demands of creating future scientists and producing scientifically literate citizens do not sit easily at the heart of science education. They pull science education in two totally different and at times contradictory directions.

I believe neither perspective is right. Science education can only work if we believe science is worth knowing about in its own terms. Trying to claim what amounts to crude political imperatives as the rationale for science education can only serve to undermine further the value we give to science. It is our failure of nerve when it comes to explaining what we are doing in the school science laboratory which encourages us to look for other widely disparate justifications for science education. Science education will not work if we don't believe that it is worth educating young people with knowledge and understanding of science for its own sake. And by science I mean academic science, a proper foundation in the disciplines necessary to study science to a higher level. Science for science's sake is the only option if we want young people to believe that learning science has something to offer them all. The trouble is that few adults believe that this is either possible or worthwhile.

But just because something is difficult that is no reason to give up. One of the most disheartening things about the debate about science education is the assumption that traditional science education is boring. From politicians to the authors of *Beyond 2000*, there is a common assumption that science taught as an academic subject is irrelevant to young peoples' lives and so inherently dull. Even more insidious is the implication that science is just too hard for most young people. All of this is just a reflection of our lowering of expectations of what young people can achieve. It is all too easy to produce findings in attitudinal surveys that young people are turned off by their science lessons. But the banally obvious point is that if we don't think science is interesting as politicians and educators then children have little chance of finding it important. Children have a habit of reflecting back our own concerns to us – with a pinch of disinterest just for good measure.

But even if we take the reforms on their own terms, they just don't add up. The TFCS GCSE pilot which has now become the flagship specification for the OCR examining board and the driving force behind the QCAs new programme of study for key stage 4 (14-16 year olds) is worth interrogating in its own terms. The centre piece of this new GCSE is the emphasis on scientific literacy or as the QCA calls it "how science works". This marks a dramatic shift away from academic science towards an appreciation of how science affects the consumer of science. The problems with this approach are threefold: it neither seems capable of encouraging a broader uptake of the sciences post GCSE; nor will it provide the basis for a greater trust of science for consumers of science; and lastly it just isn't science.

The clearest demonstration of the flaws of this approach is to look at how it deals with issues in science. The "science in the news" aspect of the TFCS GCSE replaces experimental coursework. This was trialled at Graveney School with year 9. The task selected asked pupils to consider "Should Britain replace it's ageing nuclear power stations?" The material provided by the exam board consisted of information in the form of press cuttings about energy production and consumption. I added my own press cuttings as this issue was very much in the news at the time. The response of pupils to this task was interesting. They asked me questions like "What is nuclear power?" "Is radioactivity dangerous?" "What is a nucleus?" etc. They wanted to know about the science and were to put it bluntly not interested in playing politics with nuclear power. Asking fourteen year olds to deal with a question posed in this way is asking them to deal with an issue the Government finds itself struggling to answer to its critics.

This approach fails on many levels. It fails to recognise how young people learn. Instead of being offered ethical choices to decide upon fourteen year olds want to be told what they should know and learn. Expecting teachers to have a clear enough perspective on such questions is asking too much of them. They will reflect wider concerns in the public arena about science, amplifying pupils' own doubts about the use of science rather than clarifying issues. Science teachers are not experts in ethics any more than they are experts in the Government's political priorities. As a result, controversial issues within the classroom very quickly become reduced to a matter of ethics based on a lack of information. This was one of the conclusions I drew from an earlier project I was involved in with the Wellcome Trust on sex selection - http://www.wellcome.ac.uk/node5962.html .

So turning science lessons into media studies classes by mimicking the worst aspects of breakfast time TV is not going to encourage pupils to trust science. Nor is it going to foster their interest in studying what amounts to a demanding choice at A-level and beyond. In fact, just these points were raised by my colleague Tony Gilland at The Institute of Ideas when he looked at the publication of research following up the pilot TFCS GCSE. Pupils following the course were if anything less likely to trust scientists and less likely to want to pursue science to a higher level ("New science GCSE: A failed experiment?" Tony Gilland, http://www.instituteofideas.com/sciedproject.html).

When pupils arrive at secondary school, science is one of the most exciting subjects on offer. Seeing their eyes light up when they first get to use a Bunsen burner never fails to enthral me. I have never found it hard to capture pupil's interest in science. They all want to know how to do science. Turning their natural enthusiasm into the hard work necessary to master the scientific disciplines is the job of the science teacher. I fail to see how replacing Bunsen burners with cuttings from the *Daily Mail* is going to help us to do this.

***In discussion the following points were made:***

One of the slides appeared to indicate that if you want more science, teach less of it! However social science data are always messy and possibly not reliable. An early choice is required between Science and Humanities at age 14.

The low carbon economy will require applied scientists in the future. Presently foreign nationals fill nine of every ten posts due to the lack of national graduates.

The view that science will not be required after leaving school is widely held. Hence much more effort is required at Primary Schools.

If science is boring, it is not well taught. Exciting subjects are those that are well taught. Kids are fascinated by science, but there is hard work to do as well and this needs pointing out. Science for Science Sake was endorsed and is important in its own right.

There are not enough practicals at schools. These require resources and competent teachers. Teaching can with advantage be linked to real life challenges (such as military experience, for example) with beneficial results.