1 WHAT IS SCIENCE TEACHING? WHO ARE SCIENCE TEACHERS?

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This chapter:

- considers the nature of science and the implications to science teaching
- attempts to justify science as a core subject in the National Curriculum
- examines the changing roles of science education and science teachers in England and explores the drivers for this change
- examines the typical motivations of science trainee teachers at the start of their career and describes some the challenges to science teachers
- discuses the strategies that novice teachers use to acquire subject knowledge competence in a multidisciplinary subject
- reflects on what is perceived as good practice in science teaching.

WHAT IS SCIENCE AND HOW DOES SCIENCE WORK?

I think its fair to say that up till the introduction of the National Curriculum for England and Wales (1989) many practising 11–16 teachers of science did not feel the necessity to reflect too long over the nature of science, that is, 'what science is' and 'how scientists work'. Some school teachers will have worked in the wider scientific community in previous careers and would have had a subjective awareness of a scientist's role. This absence of reflection changed in 1989 with the introduction of the statutory National Curriculum (1989) when in the 17 sections labelled 'Attainment Targets' (ATs) was enshrined a commitment to allow children to 'explore science'. They were to use the vehicle of scientific investigations to develop their knowledge and understanding of the 'ways in which scientific ideas change over time' and the 'social, moral spiritual and cultural contexts in which they are developed'. The science teacher was now responsible for addressing issues other than the straightforward teaching of the body of knowledge that has been classed as science.

Even when the National Curriculum was revised in 1991 and again in 1996 most 11–16 science teachers tended to be too busy teaching the key scientific facts and key concepts to spend long hours exploring the link between the 'real' science that has been happening, I would argue since the appearance of her mankind, and the activities that teachers were asking pupils to do in the classroom.

The National Curriculum for science (DfES, 2004b) placed greater emphasis on the way scientists work and how the body of knowledge the can loosely be labelled as 'science' moves forward. And by 2007 in the revised national curriculum for key stage 3 (QCA 2007b) you can see that attainment target 1 on p214 is titled 'How Science Works'. This has targets for pupils that include amongst others the development of the key concept of the fair test. Also the QCA suggest that pupils need to develop the skills and attributes of a scientist. These include observational and measuring skills. Also the abilities to select and use resources analyse data, spot patterns if they exist and then communicate their finding to others effectively. Described on p208 are the Key Concepts that straddle science and are linked to How Science Works. For example in the scientific community theories are generated to explain phenomena. There is also the idea that the scientific community 'shares developments and common understanding across disciplines and boundaries. In short it is as if the knowledge and understanding broadly described on pages 210 and 211 are the vehicle to deliver the skills of the scientist and an insight into how the scientific community works.

At Key Stages 1, 2 and 3 in the 2004 National Curriculum science document we see the latest 'scientific enquiry' strand forming what has been commonly known to science teachers since the implementation of a National Curriculum for science as 'Sc1'. It consists of two interrelated sections that are found in all Sc1 sections in all key stages.

In one section there are descriptions of the practical and investigational skills that you are generally led to believe are intrinsic to scientists and as science teachers we need to develop. At Key Stage 4 these are the ability to

- plan a testable idea
- observing and collecting data
- work safely autonomously or with others
- evaluate methodology.

Some science educationalists, Millar (1989) point out that, firstly, these skills are not unique to science and, secondly, that they are extremely difficult to learn. Like all skills they have to be practised to get any better and are in fact linked to what is now being called higher-level thinking skills. How many times do you think science teachers go into lessons with their primary objectives skill based? Consider 'today children I am going to give you the opportunity to develop your planning skills'. As an outcome of this 'you will be slightly better at planning testable ideas'.

If we consider the first section we see the instruction that 'teachers should ensure that the knowledge, skills and understanding of how science works are integrated into the teaching'. So pupils should be taught (and I paraphrase):

- how scientific data can be collected and analysed
- how data can be creatively interpreted and how it can provide the evidence to test ideas and develop theories
- how scientific ideas and models can explain phenomena
- that there are some questions that science cannot currently answer and some that science cannot address.

Later on we see that pupils should also be taught about the applications and implications of science (and I am careful not to paraphrase here!)

> a. About the use of contemporary scientific and technological developments and there benefits, drawbacks and risks
> b. To consider how and why decisions are about science and technology are made including those that raise ethical issues, and about the social, economic and environmental effect of such decisions.
> c. How uncertainties in scientific knowledge and scientific ideas change over time and about the role of scientific community in validating these changes. (DfES, 2004b: 37)

The science content in the latest version of the National Curriculum (2007) shows wholesale revisions to the Key Stage 3 programme of study and attainment targets (QCA, 2007a). We see that Mick Waters's curriculum development team (Mick's role at the Qualifications and Curriculum Authority is Director of Curriculum) have cut content substantially. Their aim is 'to develop a modern, world-class curriculum that will inspire and challenge all learners and prepare them for the future' and in doing so they have reduced the content from 94 statements of learning to 14 (http://www.qca.org.uk/qca8665aspx). The themes are constant but the specificity is gone. The team see this content as being relevant and the driver underpinning the key concepts that all pupils have to understand. These key concepts are,

1. Scientific thinking (developing models to test phenomena and theories).
2. Applications and implications of science (link between science and technology).
3. Cultural understanding (science is rooted in all societies and draws on a variety of approaches).
4. Collaboration (developments are shared across the scientific community).

Gone are the old divisions that labelled the knowledge as chemistry, biology and physics. Now we see the breadth of subject that teachers should draw on as very loosely defined. Just one example 'energy, electricity and forces' has three broad statements of what might be taught. The first states 'energy can be transferred usefully, stored or dissipated but cannot be created or destroyed'. The second statement leads us to teach about 'Forces are interactions between objects and can affect their shape or motion'. Finally, we see that 'electric current in circuits can produce a variety of effects'.

Also at Key Stage 3 the pupils have to develop the 'skills and processes in science that pupils need to make progress'. Section 2 (2.1, 2.2, 2.3) is a reworking of the 2004 National Curriculum, and indeed previous incarnations, as it recognizes the skills intrinsic to the scientists but throws an increasing emphasis on risk assessment, group working and using secondary sources, and asks pupils to communicate by way of presentations and discussions, again mirroring how scientists work. In Chapter 2 we see the Every Child Matters (ECM) agenda hard at work. Pupils should be allowed to develop skills of discussion, research, creativity, enterprise and communication, as well as a recognition that science occurs in the work place.

In short the National Curriculum for Key Stage 3 for implementation in 2008 seeks to use a science education to develop a well-informed, globally aware, confident, critical audience. They need good communication skills to express this awareness and criticality. They also need an appreciation of how scientists work and the limitations of what science can do. There is an implicit belief that the development of the higher-level skills that science can hopefully develop in children can be used in the wider work place. That is the challenge to you as new science teachers in the coming decade and beyond.

So this 'how science works' strand in the National Curriculum describes a way of working that is indicative of the way that scientists work and it invites pupils to become scientists in school science and mirror the way that real scientists work. As a consequence they might gain an insight into the scientific way of working and the consensual way the scientific community collectively operates.

Perhaps at this point it is worthwhile very briefly reflecting on the observations of two twentieth-century scientists who are acknowledge as insightful and analytical observers of the way scientists and the scientific community works.

Karl Popper was an Austrian who later became a British national. He was born at the turn of the century and died in 1994. Popper argued that the theories and explanations of observable phenomena undergo over time a sort of evolutionary process similar to natural selection. A 'best fit' model exists at any one time (Popper, 1959).

Are there implications for you as a science teacher teaching Year 8 set six 'the things plants need to grow' or at Key Stage 5 'the functions of the Golgi apparatus' of Popper's ideas about science? Certainly if you are doing a class practical with Year 7 or Year 10 and eight of your groups find that their resistors fit ohms law but two groups find that their data does not fit in with the rest, then is this not an ideal opportunity to explore a 'best fit' approach – the consensus? Might you then explore how the scientific community works? How do they deal with this type of data? Might you ask 'Shall we do it again and see if we get same, similar or different results'? Can you see Popper's 'take' on how science collects theories and models is found in the 'applications and implications of science, section c'?

Thomas Kuhn was a physicist who became Professor of the History of Science in 1961 at the University of California. He later went onto the Massachusetts Institute of Technology. In 1962 he published *The Structure of Scientific Revolutions* (Kuhn, 1970). Kuhn proposed that most scientists work within an accepted 'paradigm'. A paradigm is a generally accepted set of shared 'beliefs' about a particular model that can be used to explain phenomena. Most scientists busy themselves with simply enlarging the data bank that supports this accepted model. Kuhn points out that eventually anomalies will begin to show then slowly accrue – they will build over time. What is vital to Kuhn's analysis is that with *every* model, theory or explanation this inevitably happens. As the anomalies begin to stack up, the scientific community will reach a crisis and accept a new set of beliefs – a new paradigm emerges. This may seem pretty obvious but again it is built into 'how science works' and you have to teach it in some shape or form.

If you consider the current case of carbon dioxide-led global temperature rise, we are looking at a classic case of a legion of environmental scientists beavering away inside a commonly held model that attempts to explain an apparent climate change. Yes I would agree that there is data linking rising carbon dioxide levels with a rise in global temperature but is it conclusive? Have we assessed the phenomena over a timeframe that allows a degree of certainty? If a scientist provides data that suggests an alternative model (for example, solar cycles, changing cloud distribution and pH changes in oceans) that disagrees with the broad consensus of scientists that blame carbon dioxide, then the community tends to dismiss such evidence as unreliable – almost heretical. What happens if other data also seems to suggest a new model? Might we eventually have a paradigm shift? I have to say that personally I have always been aghast at the First World's massive reliance on fossil fuels to provide energy – after all, fossil fuels will eventually run out and are far to precious to burn on making electricity when we have other ways to generate it. Can you also see that as we begin to move away from reliance on fossil fuels then the Third World will begin to crank up the fossil fuel engine even more. It is becoming obvious that China and India want what we have had in terms of material benefits, and oil, coal and gas are a big part of the package. Is there a political driver fuelling research into climate change? Might you explore aspects of funding issues here? Is there a political agenda in how scientific research is funded? These are all issues that you can explore in the classroom with pupils, and they are all highly relevant.

Now although you would probably agree with me that Key Stage 3 and four pupils do not require an in-depth consideration of Popper and Kuhns' philosophies of science, it would seem that the National Curriculum demands some insight by pupils. You might also agree that only a small proportion of the population really need an in-depth bank of scientific knowledge and understanding for their future work. You would certainly agree with the sentiment that every adult should be able to look critically and analytically at scientific claims in the media. For example, 'scientists have evidence in recent years suggested there is a link between a factory pushing out a heavy metal into a river and mutations in fish'. Locally in the north-west of England we find issues such as 'Is there a link between the Sellafied site and leukaemia'. Similarly claims that 'cell phones can cause brain damage' or 'there are only 200 Bengal tigers left in the world' cause immediate issues that require reflection and criticality. The public domain is awash with such scientific claims but very few people every read the original paper that forms the basis of the claim. Even when they do it is often inconclusive. Let me describe an activity I did with a large group of trainee teachers.

Some years ago the scientific community got extremely excited with the discovery and subsequent analysis of a meteorite that was found in ice at the north pole. Scientists Everett Gibson and David Mc Kay, from NASA, were convinced with a high degree of certainty that meteorite ALH 8001 came from Mars and it appeared to have nodules in the rock that appeared to be fossilized bacteria. The scientific paper on the rock was presented in the media as certain evidence that bacterial life had existed on Mars and that Earth had been seeded by such contamination from outer space. Scientists and religious clerics all passed comments on the claims. What were we to believe? We are not alone, or at least at some point were not alone! I gave the original paper to 100 trainee teachers and they spent an hour contemplating the evidence in the paper. About 10 thought it was clear evidence of life on Mars at some stage, 10 thought it proved nothing and 80 sat on the fence stating 'not enough evidence to make a decision'. If you read the paper, it presented a series of points about the rock that suggested they could have been made by the fossilization of microbes but each point in isolation was not enough. It was rather like a court case where the evidence builds bit by bit and you have to give a verdict on the sum of the bits. Science is like that and it is important that young people realize this. You can go back to Karl Popper on this one. Science works by eliminating hypothesis that is seen to be false. It is impossible to prove anything absolutely in science – scientists do not deal in 'truths'. Part of the problem is that scientific journalists and writers hover around the scientific community and pick up on papers. They then talk to the publishers and derive their own slant on things, and out it comes.

Now this may be difficult for children to come to terms with but the earlier you start the more chance they have of understand how science works. If you look at the single page of learning objectives in the National Curriculum (DfES, 2004b) that relates to Key Stage 4 you will see that some objectives readily lend themselves to an exploration of 'how science works'.

- Human health is affected by a range of environmental and inherited factors.
- New materials are made from natural resources by chemical reaction.
- Radiations in the form of waves can be used to transfer energy and be used for communications.

This final section that allows teachers to explore the environment, the earth and the universe is potential a goldmine for exploring issues about the way scientists work, the nature of the scientific community and how ideas and evidence evolve. Recently published commercial schemes of work with their incredible range of resources such as 21st Century Science and suggested activities, have moved into the market to assist teachers in delivering the less content-orientated and more process-driven learning on offer (http://www.21stcenturyscience.org).

Similarly science is a valid vehicle for delivering health and safety awareness in pupils. Some years ago now the Consortia of Local Education Authorities for the Provision of Science (CLEAPS) published a pack of risk assessment forms for pupils to consider and fill in prior to doing investigations with hazards involved. Great idea to involve Year 10 and above being actively involved in the health and safety aspects prior to doing it. I have never seen them in use! I would like to think that a scientific education would develop in pupils the skills to assess risk and know where to go for hazard information. After all, it is an important life skill.

If the main aim of the ideas and evidence section is to force science teachers into being frank about the very nature of science and the ways in which science works and feeds into society through technology, then surely it is a good thing. It should allow children to develop a better understanding of how individuals enquire. Everyone makes observations, everyone thinks about why that is the way it is, everyone questions, everyone tests out his or her explanation and everyone comes to some sort of conclusion which is often very personal. This is the way scientists work and it is also indicative of the human condition. In the mean time it will hopefully also allow science teachers to address issues which have recently been a primetime news such as 'should the Japanese kill humpback whales for scientific reasons'? Hopefully it will make human the face of the scientists. It also gives science teachers an opportunity to make science teaching more interesting.

PUPILS' PERCEPTIONS OF SCIENTISTS

Lots of research has been done into pupil's image of science (for example, Driver et al., 1996). Many children think scientists are people that know loads of facts can explain everything and are mostly men and grey people in white coats, all 'Dr Spock'-type logical thinkers with the capacity to explain all events. A research scientist once said to me 'all my imagination and creativity has been binned by 20 years of doing science research'. Surely this is a depressing view, and it is backed by the pupils in school who are choosing to go into marketing, banking, media and sports rather than science. Pupils should realize that all scientific explanations are models and models are the product of the mind. In some science laboratories you are surrounded by physical models made by hand. This should be made clear. Science teachers are 'pedlars' of creative models and imagination, and creatively are part and parcel of the nature of science and how science works. Does it help or hinder the image of scientists when, on the basis of Professor Roy Meadows's evidence in court, a number of women were jailed because of 'scientific evidence'? They were subsequently released because of flaws in the scientific evidence. In one way it is good in that it proves that working scientists are fallible and that even respected experienced scientists can get it 'wrong' and see correlations in data when none exist. In other ways it puts a human face on the scientist. As science teachers we can use these cases to inform observers and pupils that science is not about 'truth' but, rather, about the collection of data and the statistical interpretation of it.

Nevertheless the scientist working inside the academic scientific community offers the 'best' answers we have to many questions. The community seeks to regulate itself by peer appraisal through publishing and discussion. Data that is non-reproducible, not valid or is unreliable goes down a cul-de-sac in the same way that the sabre-toothed tiger did. Yes there are questions, phenomena we do not understand, dark matter, and now dark energy is a good example, and we sometimes feel that we are 'making it up as we go along' but the science community offers the best most reliable way we have of making any sense of the incredibly complex universe we live in.

Point for reflection

Point for reflection

Think about your own views on science. What do you think is most important for children to learn, the facts and bits of knowledge that science offers or an appreciation of how science works. Think about the influence of your view of science on how you might teach science. Develop a teaching resource that might be useful in the classroom to illustrate to children how scientists work.

SHOULD EVERY LEARNER STUDY SOME SCIENCE?

One thing you should be able to do is argue a watertight case for the inclusion of science as a core subject in any staffroom. Certainly every mathematics and English teacher would find it obvious and not have too much difficulty in building a case. Since the implementation of the National Curriculum in 1987, science has been core alongside English and mathematics. The teachers who sit nervously in the classroom include linguists, technologists and many of the humanities department. Science teachers are 'safe' in the role since the committee that put together the original National Curriculum (1989) made us indispensable by arguing the case for science in the core curriculum.

Certainly one of the answers that scientists offer when asked at interviews 'Why is science important?' is that 'science gives you answers to things that go on all about you'. They expand on this; statements like 'You know how the trees make food or even how a car works'! This is fine and shows an appreciation of one aspect of science education. It shows at least that the person is inquisitive, curious and seems to have thought about the wide-ranging question.

In fact, in 1989 when the prescriptive National Curriculum was introduced, there were 10 subjects. It has of course been modified four times since then and has undergone further modification in 2007 for implementation within Key Stage 3 in 2008.

Science was and is a core subject right through from age 5 to 16 – everybody gets science. Why is this? Originally the arguments for its inclusion were:

- A need for scientists (economic argument).
- A scientifically literate population in a scientific and technical society (utilitarian argument).
- Pupils should learn about how science and scientists work.
- Science is part of a global culture and needs preserving and passing on.
- Science is an important vehicle for driving a young person's intellectual (cognitive) development in a wide range of aspects.

These reasons cannot be dismissed easily by politicians and curriculum developers but I do think we are now in a position nearly 20 years down the line to explore them again with a fresh perspective. If a pupil says to you 'I don't like science. I never asked to do it. I was forced into it but I don't see the point in it. I want to do plumbing like my Dad and earn £1000 per week', what do you say to him or her?

Your answer has got to be rooted in the wider sense of what the pupil may learn and develop. It is not just about the acquisition of scientific knowledge and understanding – although it is obviously important in order to make sense of the real world and use scientific models to explain what is going on around them. I am sure you realize that it is also important to pass formal examinations as well!

First, let us explore the aspects of learning not strictly to do with knowledge and understanding. Patrick O'Brien (2003) offers an insight into how higher-level 'thinking skills' can be developed in children through problem-based learning that is rooted in scientific enquiry. The book gives many examples of tasks to do with 'gifted pupils' at Key Stage 3 but, of course, the ability to 'think' beyond the simple absorption of facts is something that all pupils need to develop. Children can, through a science education, develop all the 'thinking' that will equip them to function as autonomous learners for the rest of their lives. So, for example, pupils need practice to develop creative thinking to synthesize facts in a new or original way. They also need to be able to use thinking that is reflective and centres on how well the synthesis fits the purpose. Although O'Brien points out that these skills are hard to define, surely as a science teacher you can develop in pupils creative thinking – how might the information be redesigned for another use?.

You might also develop in pupils the skills of analysis. These might contain grouping and classifying, spotting patterns and modelling. Also the ability to evaluate might be developed where issues such validity reliability, and an appraisal of the strengths and the weaknesses of a performance might develop higher-level thinking. These are all aspects of learning that the good science teacher can develop and, moreover, feels the duty to develop. Now I agree that it is not that easy to explain this to the potential plumber but as a science teacher it is important to recognize this and for your reluctant learner to appreciate it. Science can help him or her take a 'thinking skills tool kit' out to his or her adult job.

Similarly on page 8 of the National Curriculum (DfES, 2004b) we see defined the role science has in developing key skills. They are linked to the notion of thinking skills and we see seven listed in black and white:

- Communication: Scientific writing and presentations perhaps?
- Application of number: Collecting and analysing data?
- IT: spreadsheets, databases, word processing, on line research etc.
- Working with others: Is group work in Science done because we don't have enough kit?

- Improving own learning and performance: Thinking about what they have just done and highlighting the strengths and weaknesses of the data and the procedure
- Problem solving: finding ways to answer the questions with creative solutions. So that pond is covered with algae but the other isn't. Why is this? Have I any ideas? How will I test them? What do I think I will find?

Alongside these key skills being developed you are also going to tell the student that he or she will gain an awareness of how science works and so develop a critical eye to scientific claims. He or she will also pick up an awareness of health and safety and risk assessment through practical work. The student might also develop his or her motor skills as a result. I once heard a Year 8 pupil muttering mutinously about why he did not see the need for science and, more specifically, practical work. I asked him to put 30 cm^3 of water into a nearby measuring 100 cm^3 cylinder. He opened the tap and in rushed 60 cm^3. He then tried to empty 30 cm^3 out and ended up down to 20 cm^3. He then went back to the tap and put some water in again – back up to 70 cm^3! I think he could have spent all day measuring out water. He had a huge grin on his face and laughed all the way out the door but I guess there was some recognition that fiddling around in the laboratory might develop in him some useful science techniques and perhaps even develop his 'touch' about the house and work place.

Although I think it is fair to say that many children will never see another bunsen burner after they leave school, there are some scientific techniques they can acquire and if they have lots of practice fiddling about with the kit in the preparation room they may well get better at such skills as observation – noticing changes that may be fine and subtle. Again this is an aspect of learning that is going to be valuable after formal schooling is over. Give them lots of observational tasks. For example,

- What happens to copper sulphate as you heat it and then add water?
- What can you see under your microscope?
- What's growing on the school's field?

The list available to you as a science teacher is endless and can be generated by the pupil him or herself. As science teachers we are developing all these aspects of learning and it is crucial the good science teacher conveys these learning aspects to the children. This is why you are doing science. It is not just to pass an examination or even get then to recognize that an insect has six legs, wings and three body segments. I can hear you now: 'Today Year 9 you are going to incrementally, by practice, develop your observational skills'. That would be tough but you need to emphasize that today your lesson is primarily about 'practising working as a team player' or the 'sharpness of your observation' or 'considering the merits and demerits of your performance'. You are developing their skills and they need to know that.

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Paul in lesson two takes the pupils down a path that mirrors the role of scientists. He gives them a hypothesis to test – are all metals the same reactivity? Might the pupils suggest there own hypothesis? He asks them to plan jointly and then offer suggestions as to the game plan. They measure, observe and collect data. They are involved in group work and health and safety aspects. I would like you to consider the benefits of getting 10 sets of observations on data reliability. How does this reflect how a scientist works in practice?

Finally I think it is worth mentioning that one of the main reasons for doing science is that it is fun and most children can enjoy science. What 12-year-old does not enjoy looking down the barrel of a microscope at a water flea or using a bunsen burner to burn metals and observe the colour of the flame. Who dislikes field trips? I once taught a particularly 'challenging' Year 8 group. I took them on a day trip to a science museum and among the rocks and insect specimens they were perfectly happy. One pupil who was always in trouble really appreciated the visit – he had never seen anything like it! He told me he was going to ask his dad to take him next week. Some months later I asked him if he had ever gone back to the museum. He said he had asked his dad but the dismissive look on his dad's face meant he would only ever go back on his own – in fact probably never. Is there a message for you as a teacher?

HOW HAS THE ROLE OF A SCIENCE TEACHER CHANGED OVER THE PAST 20 YEARS?

A teacher's role has evolved radically over the past 20 years, really since 1989 when the National Curriculum and its statutory framework was conceived. The social changes in England have put a greater emphasis on the teacher as a solution to many of society's problems. For example the rapid influx in recent years of pupils with English as a second language (ESL) has meant that all teachers have had to try to come to terms with more and more pupils in the classroom with low literacy and oracy. Progressive governments and departments have pushed for the inclusion of all but the most severely disabled pupils into mainstream schools. The current Every Child Matters agenda, precipitated by the recognition that schools, home and other support agencies were sometimes not working in unison has led to a more integrated approach to pupils' needs. Every teacher is now required to take a holistic approach to every child and have a full working knowledge of all the agencies that might provide a spoke in a pupils support network. We can see this development reflected in the Professional Standards for Qualified Teachers (2008, TDA, 2007c) where Standard Q20, Q21a, Q21b all emphasize the need for trainees to recognize, be aware, know the players involved in issues of support and inclusion and the Every Child Matters agenda. It is a theme that runs through the document and is a challenge to every teacher or trainee as well as tutors in initial teacher training.

The revised National Curriculum states as its overarching aims (and the aims are tied in with the Every Child Matters agenda).

- Successful learners who enjoy learning, make progress and achieve.
- Confident individuals who are able to live healthy and fulfilling lives.
- Responsible citizens who make a contribution to society.

Again teachers have had to find ways to include all in the classroom often with enormous challenges, and I feel it safe to say that many were not trained to cope with. It's not in the scope of this book, and certainly not in this chapter, to examine in a wider context the professional role of the teacher. Clearly the role of all teachers is changing.

WHAT ARE THE CHALLENGES SPECIFIC TO THE SCIENCE TEACHER?

You have seen that a major challenge to teaching pedagogy, the methods we adopt to teach, has been raised by the slimming down of the heavily content-laden National Curriculum over the past 20 years. The 2004 version of the National Curriculum cut the statutory content detailed in the 1999 version (DfEE, 1999) from 158 items of learning to just 16 at Key Stage 4 (they conveniently fit all on one page). The emphasis is now on teaching how science works and scientific enquiry through the study of four key themes. This is an incredibly difficult transition for many practising teachers to make and for trainee teachers to engage with and build into their teaching. Yes, it has allowed scope for additional science courses to proliferate and give freedom of choice to all pupils at school, but clearly an understanding of how science works is vital if you are to teach it.

In this section I examine specifically the changing role of the science teacher and draw on the experience of others who have had the task of coming to terms with the changes that happened as a consequence of the reorganization of the statutory content of the National Curriculum in 2004 and its implementation in 2005 resulting in core and additional science, new assessment modes and a proliferation of courses by all the awarding bodies.

The major challenge emerges on two interlinked fronts. The first I explored in some degree of detail in an earlier section – you will have to move away from the traditional role of the science teacher, with its emphasis on content, knowledge and understanding, to a role focused on skill development and developing in pupils an understanding of the nature of science.

The second aspect that will present massive problems is a natural consequence of the changes to the science National Curriculum at Key Stage 4 in 2006. Most children are studying the core science as defined as the statutory science that has to be taught. This is normally delivered in Year 10. In Year 11 there are a whole plethora of options for teachers to decide route which individual pupils will follow. The awarding bodies publish a range of syllabi that schools can follow, all accredited by the Qualifications and Curriculum Authority. Some are traditional, some are vocationally linked and some purely vocational. Choosing these options, then familiarizing yourself with the multitude of assessment modes for the chosen courses and then adapting to the new content is mind boggling for many science teachers. The curriculum is rapidly being opened up so small groups of pupils and even individuals can mix and match the courses on offer to suit their individual needs. Personalized learning is upon us.

At this stage I consider the options open to the pupils in a large 11–16 school in the north of England. Remember the Assessment and Qualifications Alliance (AQA) and Oxford, Cambridge and the RSA (OCR) are both awarding bodies and that core science is the statutory science in the National Curriculum.

It is also worth while pointing out that a single award is worth one General Certificate of Secondary Education (GCSE) and a double award is worth two passes if successful. In this context most pupils in England will expect to achieve two GCSEs with core and additional.

The quote below is from a local science teacher and gives a fascinating insight into the differentiated curriculum that now exists (see acknowledgements):

> AQA Separate Sciences: This is a course for the pupils with a proven track record in science who would be capable of studying science at a higher level. At the end of the two year course pupils have a separate GCSE for biology, chemistry and physics.
>
> AQA Core: This is a one year course worth one GCSE, usually taken in Y10.
>
> For the pupils that do very well in the year nine SATs it is a combination of two biology, two chemistry and two physics modules plus coursework. The type of pupil that would usually take this course will have performed reasonable well in science over the previous key stage. It is the first part of two GCSE's and some of the pupils would be expected to study advanced level science. A small minority of pupils with a past performance profile that is not so strong in science will also take this course but over two years and therefore will only get one GCSE in science.
>
> AQA Additional Science: This is a 1 year course studied in Y11 and combines with AQA Core to give the most pupils a double GCSE.
>
> OCR Gateway Science B: This is a 1 year course studied by Y10s for pupils who have not performed particularly well in science over the previous key stage.
>
> It is quite a different course to AQA but the same types of pupils could still do it. Also it is a suitable course for pupils to move on to Advanced level with if they have got high enough grades. This is to be combined with the equivalent year 11 course from OCR but we have not started to deliver this yet as we are only in the pilot stage with the first cohort of year ten.
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> OCR Double Award Applied Science: This is a double award GCSE for pupils who have low past performance in science but pupils who work hard and have good attendance. The best pupils have high CATs and low SATs scores due to their poor performance during tests.

Clearly the logistics of implementing such diverse options is a huge challenge. Selecting and sorting children into diverse courses that will decide their future employability is a daunting responsibility. Becoming familiar with the differing content and changing pedagogy inherent in each course will be time-consuming and require extending your repertoire. The individual modes of assessment are, case studies, individual skills assessment, module examinations and, in some cases, terminal examinations. This is all being thrown at teachers by a government responding to the needs of a diverse and evolving pupil clientele.

The major challenge to all science teachers involved in delivering the demands of the revised National Curriculum is summed up quite succinctly by a work colleague of mine and an assistant head teacher of a north-west 11–18 comprehensive (see acknowledgements) who astutely and with some insight sees the future of your role and its changing nature.

> The stiffest challenge science teachers face is coping and adapting to change. All teachers must understand that the profession is never static and a permanent state of change is normal. In fact the only constant thing is that we are always changing. Sometimes change is trivial and transient, at other times it is more fundamental. The changes in the science curriculum at the moment are more fundamental. With far greater attention being placed on how science and society interact rather than pure science for science sake, the science teacher needs new skills. There are many science lessons these days that could be taught well, (perhaps better), by English or Humanities teachers because the classroom skills necessary include group work, discussion, opinion, critical analysis etc. Certainly science teachers will need to have a greater repertoire of classroom techniques than they have had before.

Point for reflection

Point for reflection

Consider your own experience at school. Did you do traditional chemistry, physics and biology at GCSE? Do you think everybody should study this type of traditional course? Go to the websites of the three main awarding bodies (EdExcel, OCT and AQA). Compare and contrast the traditional science, vocationally linked and vocational science courses. Can you fit a person profile and perhaps career to the particular course?

GETTING STARTED: FROM NOVICE TO EXPERT

In your teacher training course, certainly if you were training via a Postgraduate Certificate of Education (PGCE), I am sure you noticed a wide variety of science degrees. Trainees bring to the course a huge variety of qualifications and experiences. This is one of the reasons why the year is incredibly stimulating and rewarding both for trainees and tutors.

There will be the trainee that is 22 and straight out of university not having exited the educational system at all. There will be the career changers, who, having worked for 10 years and are dissatisfied with a job that does not excite them. There will be a fair share who have worked a sizeable part of their working careers in a variety of professions and who want a fresh challenge, in many cases expressing a wish to do something that they had 'always wanted to do but got sidetracked by life'. The split between male and female at secondary is roughly 60:40 in favour of females. That is not a problem for the Teacher Development Agency. What is a problem is that the cohort each year on postgraduate initial teacher training (ITT) courses breaks down to about about 80 per cent biology, 15 per cent chemistry and about 5 per cent physics as their subject specialism. This reflects the intake and output at undergraduate level for the science disciplines.

All trainees start with two fundamental anxieties.

- Will I be able to manage the pupils?
- Will I be able absorb all the knowledge and understanding that is in the National Curriculum? A fear of not knowing all the facts and having a lack of understanding of basic scientific ideas.

This second anxiety is a particular fear for the scientists because they have such a wide breadth of knowledge to work with. Science is a multidisciplinary theme. Science teachers are often expected to teach all three disciplines in school, and most scientists have only one specialist subject area. Many studies of trainee teachers (Deng, 2004) have suggested that subject knowledge is fragmented and in some areas week. If you want to explore the almost limitless misconceptions and alternative conceptions that exist both in children and adults, and I include science teachers in the adults' category, then look no further than Driver et al. (2002). What is comforting is that all specialist scientists are in the 'same boat'. It's been this way since science became broad and balanced in the National Curriculum in 1989.

Nevertheless on an 11–16 ITT science course you will be expected to know enough science to be able to teach at Key Stage 3 across all disciplines and at Key Stage 4 in your specialism. I think its realistic to say that the more confident and competent you are in all the disciplines the more it will give you a boost in the job market where flexibility in an era of broad science across the key stages is required. Biologists appreciate that many schools will not have many specialist chemists and physicists and will need to step into the breach were required and teach both aspects of the physical sciences.

Schulman (1986; 1987) emphasizes the importance of teachers' subject knowledge in effective teaching. If you think about it, it is reasonable to suggest that the more knowledge and understanding of a science topic you have then the more adept and effective you will be at teaching it. He also suggested three components make up a teachers holistic knowledge:

- Content knowledge – a knowledge of the underpinning scientific principles.
- Pedagogical content knowledge. This is knowledge of how to represent and transmit the science knowledge.
- Knowledge of the curriculum. What do the pupils need to be taught?.

I would suggest that the second strand that includes what activities, strategies and 'kit' I use to deliver my knowledge to the pupils, is the most demanding and can only be acquired over a period of years. Both experienced science teachers and trainee teachers learn many new ways to deliver the key concepts that are on offer every day. The first and third strands are more readily acquired but again take time. I think it is safe to say that the 'best' way to learn something is to be asked to teach it! All novice science teachers will buy science textbooks and revision guides to quickly acquire subject knowledge. You will make sure you are very quickly au fait with the key concepts, facts and ways in which pupils are tested. Apart from the textbooks you are working with, how else will you slowly acquire Schulman's 'three aspects' of you knowledge? McCarthy and Youens (2005), working at the University of Nottingham, provide an insight into both the ways you can develop your subject knowledge and trainee teachers' perceptions of the usefulness of the method of building subject knowledge on a postgraduate ITT secondary science course.

Trainee science teachers were asked, at the end of the ITT course, the question: 'What strategies did you use to develop your subject knowledge and how do you perceive the usefulness of the different strategies?' The results are shown in Table 1.1.

I include Table 1.1 for a number of reasons, not least because it illustrates that all trainees use a variety of strategies to develop knowledge were there is a gap and enhance existing knowledge and understanding when it is present. It must be said that I do think that the question focuses largely on what I have referred to earlier as Schulman's 'first strand', that is, what I call 'straight' subject knowledge of science. You will not get advice on how to teach something from a revision guide, although there are books that give advice and I have listed three such books at the end of the chapter in the further reading list. Knowledge of the 'art and craft' of the science teacher will be build up by interaction with experienced teachers, tutors at your training institution, who are often specialists with a wealth of hard-earned experience, and workshops with specialists such as Chris King and Peter Kennett from the Earth Science Unit at Keele will build all aspects of your science teaching. My message is read around science education, join the Association of Science Education (ASE), join the Institute of Physics

Table 1.1 Frequency of use and usefulness of methods for development of subject knowledge, each in rank order.

Frequency of use		Usefulness	
Method	**Mean**	**Mean**	**Method**
Revision guides	1.16	1.19	School textbooks
School textbooks	1.20	1.20	Revision guides
Method workshops	1.46	1.47	PGCE colleagues
Websites	1.50	1.49	Lesson bservations
Lesson observations	1.54	1.50	Reference books
Reference books	1.76	1.52	Websites
PGCE colleagues	1.84	1.57	Mentors/teachers
Mentors/teachers	1.88	1.68	Method workshops
Tutors	2.36	1.86	Tutors
Television/videos	2.38	2.07	Television/videos

(IOP) or the Institute of Biology (IOB). If you are a chemist then join the Royal Society of Chemistry (RSC). All have websites that channel materials and courses for the practising teacher. Keep your eyes open for subject knowledge-based courses organized by universities, educational agencies and local authorities. Geology, astronomy, plant science, information technology (IT) in science and now an array of courses aimed at teaching you how to teach how science works – they exist and will act as a driver for your professional development if you want to develop as a teacher.

CONTINUING PROFESSIONAL DEVELOPMENT (CPD): SUBJECT KNOWLEDGE IS IMPORTANT

In 2000 a piece of research (Dillon et al., 2000) found that at Key Stage 4 the percentage of topics taught by teachers without a degree in the subject was 39 per cent in biology, 51 per cent in chemistry and 66 per cent in physics. Alarmed at such research, which clearly indicated a shortage of teachers with specialist qualifications in the physical sciences, the Teacher Development Agency (then the Teacher Training Agency) went into overdrive on plugging this gap in expert qualifications and funded a number of higher education institutions to organize a range of taught courses for prospective PGCE trainees. These ongoing courses include short subject knowledge booster courses for ITT trainees and lengthy six months' long chemistry and physics enhancement courses. These have involved a large number of prospective science teachers, largely postgraduate scientists with an offer of a place on a PGCE course, enhancing their knowledge of the physical sciences. There is a move to place much of the materials generated by these courses in an online, interactive, blended learning environment in the next two years. These courses have been extremely useful in filling gaps in both subject and pedagogical knowledge. You could call them method workshops where prior to the start of your ITT course you can both enhance your subject knowledge and begin to acquire knowledge of pedagogy and the National Curriculum. The TDA also fund two-year PGCEs where the first year is subject knowledge enhancement and the second year is subject application (pedagogical and educational studies). Most lately we have extended PGCEs were applicants for PGCE science courses with a blend of science modules and non-science modules in their degree, for example, psychology, study a selection of physical science undergraduate modules to strengthen their subject knowledge and enhance their academic profile in science. These courses are organized by the local ITT provider and are bursaried.

For in-service teachers a number of higher education institutions have been funded by the TDA to deliver physics and chemistry subject knowledge/ pedagogy courses to practising teachers that are primarily biologists but find themshelves teaching physics and/or chemistry in schools. These courses have the support of the IOP and the RSC and a regional network of school- and university-based mentors to support teachers in school and assess the success of the schemes on the quality of teaching in the classroom. The 'additional specialism' courses have a bursary attached and many have master's-level credit awarded by the organizing institution. Booster courses, enhancement courses and additional specialism courses can all be accessed on the TDA website. Again as in the pre-ITT courses there is an ongoing development programme to get them online in the next two years.

A problem in some schools is the lack of enthusiasm sometimes shown by head teachers to fund subject teachers to refresh or enhance subject knowledge and pedagogical knowledge in 'work time'. This is understandable for a number of reasons. First, the children will have their regular teacher absent for a day or half a day, with possible supply cover – this breaks the continuity in terms of teaching. Secondly, it might not fit in with the school's developmental plan and this is crucial in terms of funding by school governors who are aware of budgetary constraints. It is worth mentioning here that I taught in three secondary schools from 1985 to 2000 and I cannot remember once were the management team invited in a subject specialist tutor/teacher to deliver science subject knowledge and application to any of the science departments I worked in. The attitude was that it was 'up to you' to keep your subject knowledge and knowledge of the craft of delivering it up to date. I think this is a shame as it lowers the status of subject knowledge below, for example, classroom management or teaching children with special educational needs. I seem to remember that I was frequently addressed by guest speakers and regularly popping into local professional development courses themed around these practical and relevant aspects of teaching – but not so many subject knowledge-based events were evident. Of course, the best CPD is organized by yourself and for yourself. Read around your subject. If all you know is what is in the curriculum you are teaching then you are at a severe disadvantage. Grab hold each week of non-expert publications like the *New Scientist* or *Nature*. Keep you university library card active and talk to other scientists about developments. If you do not adopt this constant engagement your teaching will suffer – if you do not progress you will regress. Join the ASE and visit regional and national conferences. In five years' time you will be presenting at one.

Point for reflection

Point for reflection

Get hold of the content, that is, the knowledge and understanding, contained in the Key Stage 4 GCSE separate sciences from the AQA. For your specialist science discipline make a broad list of the learning objectives specified in the booklet and try to identify your individual gaps in your own subject knowledge. Do this with the A2 and AS content in your specialism. Reflect on how secure you are. Consider the use of an audit like this with children. Is it useful as a teaching and learning tool?

WHAT IS PERCEIVED AS GOOD PRACTICE IN SCIENCE TEACHING? THE NOTION OF A GOOD SCIENCE LESSON

All of us are aware that there are science teachers out there who are enthusiastic, making the science relevant to the children, teaching with clear objectives and outcomes, and using a variety of different strategies in the classroom. Working in ITT and seeing both trainees and experienced teachers teach science, I know with some degree of certainty that this is the case. The Key Stage 3 strategy, now the secondary strategy, has had a massive impact on science teachers. They now know what a tripartite lesson is. They also know that assessment must be integral if it is to be useful. The knowledge of what constitutes an Office for Standards in Education (Ofsted) 'good' lesson is common knowledge. What about the 'good' science lesson?

Recently the Science Advisory team for Sefton Local Education Authority (LEA) in Merseyside produced a poster for science teachers to reflect on. It is a large glossy pin-up for your preparation room or classroom and attempts to define the characteristics of a good science lesson. I paraphrase and rework the English but essentially it suggests that you:

First set the scene – Show me what you've got
Find out what ideas they have on the concept. Don't knock any of their ideas if they are incorrect. Share the learning objectives with them without giving away any 'answers'. Then, tell them what activities they are going to do and with the timings. Check they know what to do. Explain why they are doing the activities.

Second – Let's do something
Get them working as groups to promote constructive discussion. Intervene only if you have to. Intervention should be directed at getting them to think – if you've given clear instructions then you shouldn't have to give task support.

Third – What have we got? Is it different?
Pull together the data, analysis and results and find out what they have learnt. Share the learning around the group by considering the evidence. Have any of their ideas changed? Have they gained any new knowledge or skill? Again get them to talk about what the task(s) have led them to alter or discover.

Fourth – Can we join it up?
Link the learning to relevant, everyday situations that will allow them to transfer the new knowledge into different situations. Give them homework that reinforces or extends the learning. It doesn't have to be test tubes and 'practical' work but if the hands are engaged then there is a better chance of the 'brain' being engaged as well. Can you see that this sequence, which is very prescriptive, links with many positive aspects of teaching and learning science.

- Observation
- Group collaboration
- Discussion
- Building on what knowledge the pupils have already
- Intervention only when necessary
- Making it relevant
- Having fun
- Engaged in finding things out that are not evident
- Using scientific pieces of kit
- Using what is learnt in a wider context
- Pupil reflection on their own learning
- Shared and clear learning
- Data collection
- Data handling
- Pattern spotting.

I explore more fully some of these aspects in Chapter 5 but I do think the poster is a thought-provoking piece of advice and sets a clear vision of the pupils as scientists and researchers. It goes without saying that a lesson like this is not possible without structured planning and a working knowledge of were the individuals in the class are at. The three-part sandwich proposed in the secondary strategy is a format that can be built around a lesson that encompasses these aspects.

What the research says

There has been plenty of recent research into children's views of scientists. Many such research investigations into childrens ideas about scientists use DAST (Draw-A-Scientist – Test).

Buldu, M. (2006) 'Young children's perceptions of scientists; a preliminary study', *Educational Research*, 48(1): 121–32.
Quita, I.N. (2003) 'What is a scientist? Perspectives of teachers of colour', *Multicultural Education*, 11(1): 29–31.

Both provide accounts of the nature of young children's views of scientists. They typically show that they hold stereotypical images of white, middles-class, ageing figures with glasses. Many children have no real notion of the way scientists work and the scientific process that is essentially observation, data collection and analysis to gain understanding. These images and ideas about scientists show no real signs of being revised. You might try a DAST test in you own classroom.

Further reading

Driver, R., Leach, J., Millar, R. and Scott, P. (1996) *Young Peoples Images of Science*. Buckingham: Open University Press.
How pupils perceived scientists and science 12 years ago. Any change?

Kuhn, T.S. (1970) *The Structure of Scientific Revolutions*. Chicago, IL: University of Chicago Press.
Thoughts from a pivotal philosopher of science on how science works.

McDuell, R. (ed.) (2000) *Teaching Secondary Chemistry*. London: John Murray for ASE.
Ideas on how you might teach 11–16 chemistry.

Millar, R. and Osborne, J.F. (eds) (1998) *Beyond 2000: Science Education for the Future*. London: King's College London. Definitive suggestions for a new direction in science education You can see the beginnings of core science.

Monk, M. (2006) 'How science works; what do we do now?', *School Science Review*, 88(322): 119–21.
Monk suggests that we need to develop our own views of how science works to effectively teach such a curriculum.

O'Brien, P. (2003) *Using Science to Develop Thinking Skills at Key Stage 3*. Materials for Gifted Children. London: David Fulton.
Useful ideas on developing pupils higher level cognitive processes.

Osborne, J., Duschle, R. and Fairbrother, R. (2002) *Breaking the Mould? Teaching Science for Public Understanding*. A report commissioned by the Nuffield Foundation, London: Nuffield. Downloadable from www.kcl.ac.uk
Evaluation and commentary on the AS science for public understanding course. A course which attempts to develop at Key Stage 5 an appreciation of how science works, treatment in the media of science and how science impacts on peoples lives globally.

Popper, K. (1959) *The Logic of Scientific Discovery*. London: Routledge.
Heavy reading but outlines how science moves on and up.

Reiss, M. (ed.) (2000) *Teaching Secondary Biology*. London: John Murray, for the ASE.
Ideas on how you might teach 11–16 biology.

Sang, D. (ed.) (2000) *Teaching Secondary Physics*. London: John Murray, for the ASE.
Ideas on how you might teach 11–16 physics.

Sang, D. and Wood-Robinson, V. (eds) (2002) *Teaching Secondary Scientific Enquiry*. London: John Murray for ASE.
Ways to develop pupils' skills of enquiry.

Useful websites

www.qca.org.uk

Documents relating to the National Curriculum and even obsolete previous versions of the National Curriculum can be found via the QCA website.

www.teachers.tv/video/22844

Lots of ideas to deliver How Science Works shown in moving images.

www.nuffieldcurriculumcentre.org/go/minisite/OtherScienceProjects/Page_148.html

Project on How Science Works from the Nuffield curriculum team.

www.sciencelearningcentres.org.uk

Any of the regional science learning centres will offer training courses to practising teachers giving ideas on how to teach how science works effectively.