TEACHING SCIENCE

DEVELOPING AS A REFLECTIVE SECONDARY TEACHER

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Teaching Science

Reflective Teaching and Learning: A guide to professional issues for beginning secondary teachers

Edited by Sue Dymoke and Jennifer Harrison

Reflective practice is at the heart of effective teaching. This core text is an introduction for beginning secondary teachers on developing the art of critical reflective teaching throughout their professional work. Designed as a flexible resource, the book combines theoretical background with practical reflective activities.

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HOW TO USE THIS BOOK

As you start your training to become a teacher, you will be faced with a bewildering array of information and requests for your personal details. A lot of the information will come from your training provider, and will give details about the course that you are starting. Your personal details will be required in order to compile a curriculum vitae (CV) that can be sent out to your placement schools; they will also be needed so that you can receive clearance from the Criminal Records Bureau (CRB) to work with children. Very early on, you will learn that your success on the training course depends on your ability to demonstrate competence in the Professional Standards for Qualified Teacher Status (QTS) that are laid down by the Training and Development Agency for Schools (TDA).

This book is designed to help you make a success of your training course. It shows you how to plan lessons, how to make good use of resources and how to assess pupils' progress effectively. But its main aim is to help you learn how to improve your classroom performance. In order to improve, you need to have skills of analysis and self-evaluation, and you need to know what you are trying to achieve and why. You also need examples of how experienced teachers deliver successful lessons, and how even the best teachers continually strive to become even better.

The book has a practical focus. It will help you to feel more comfortable about what is expected from you on teaching practice, through demonstrating good practice into a whole-school and a national context. You will, for example, find suggestions about how science lessons can contribute to whole-school initiatives such as developing pupils' thinking skills.

A key feature of this book is the accompanying website (www.sagepub.co.uk/secondary). The icon shown in the margin will appear throughout the text where additional material is available. The website contains simple links to sites that provide useful support for your science teaching. The book (in particular Chapter 4) makes extensive references to two science lessons. On the website you will find documents that give you a breakdown of the teaching and learning sequences for each lesson. Commentary in the text will refer to an incident or detail by the time; for example, you might be asked to view a teaching sequence which runs from 2:10/8:20, i.e. from 2 mins 10 secs to 8 mins 20 secs. The filmed lessons demonstrate key aspects of planning, teaching and student learning but the commentary will also draw your attention to particular aspects of a teacher–student dialogue or perhaps to the techniques being used to put the topics across to the pupils. The video clips are in Windows media video file format (.wmv), and give the best quality visuals if viewed with Windows Media Player. (Players that support this file type are Windows Media Player 7, Windows Media Player for

Windows XP, Windows Media Player 9 series, Windows Media Player 10 and Windows Media Player 11.)

Although the focus throughout is on improving your professional skills, there is no attempt to provide a 'tick list' of how to achieve each of the individual Professional Standards for QTS. We believe that a more holistic approach is better suited to this type of publication. The book addresses professional attributes, professional knowledge and understanding, and professional skills in a more holistic way than the way they are presented in the Standards. You will, however, find frequent reference to the Standards, and it is hoped that through using the book reflectively, you will acquire the general skills required to gather and present your evidence against each of the Standards statements. A rough guide to where the book addresses individual Standards is given in the following chart.

Table H.1 Professional Standards for Qualified Teacher Status

	Standard	Opportunities to learn more (chapter)
Professional attributes. Those recommended for the award of QTS should: Relationships with children and young people		
Q1	Have high expectations of children and young people including a commitment to ensuring that they can achieve their full educational potential and to establishing fair, respectful, trusting, supportive and constructive relationships with them	3. Planning to teach a science lesson 5. Managing learning in science 6. Managing learning; measuring learning
Q2	Demonstrate the positive values, attitudes and behaviour they expect from children and young people	3. Planning to teach a science lesson 5. Managing learning in science 6. Managing learning; measuring learning
Frameworks		
Q3a	Be aware of the professional duties of teachers and the statutory framework within which they work	2. What are you expected to teach in a science lesson? 7. Teaching different abilities; teaching different pupils
Q3b	Be aware of the policies and practices of the workplace and share in collective responsibility for their implementation	12. Refelctive practice and professional development 1. What is science teaching? Who are science teachers? curriculum: a public perspective' 2. What are you expected to teach in a science lesson?
Communicating and working with others		
Q4	Communicate effectively with children, young people, colleagues, parents and carers	2. What are you expected to teach in a science lesson? 4. Elements of a science lesson

Q5	Recognize and respect the contribution that colleagues, parents and carers can make to the development and well-being of children and young people and to raising their levels of attainment	3. Planning to teach a science lesson 6. Managing learning; measuring learning 11. Science outside the classroom 12. Reflective practice and professional development
Q6	Have a commitment to collaboration and co-operative working	3. Planning to teach a science lesson 5. Managing learning in science 6. Managing learning; measuring learning 11. Science outside the classroom 12. Reflective practice and professional development
Personal professional development		
Q7a	Reflect on and improve their practice, and take responsibility for identifying and meeting their developing professional needs	1. What is science teaching? Who are science teachers? 6. Managing learning; measuring learning 12. Reflective practice and professional development
Q7b	Identify priorities for their early professional development in the context of induction	
Q8	Have a creative and constructively critical approach towards innovation, being prepared to adapt their practice where benefits and improvements are identified	3. Planning to teach a science lesson 10. Creativity and innovation in science teaching and learning
Q9	Act upon advice and feedback and be open to coaching and mentoring	1. What is science teaching? Who are science teachers? 12. Reflective practice and professional development
Professional knowledge and understanding. Those recommended for the award of QTS should:		
Teaching and learning		
Q10	Have a knowledge and understanding of a range of teaching, learning and behaviour management strategies and know how to use and adapt them, including how to personalize learning and provide opportunities for all learners to achieve their potential	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson 5. Managing learning in science 6. Managing learning; measuring learning
Assessment and monitoring		
Q11	Know the assessment requirements and arrangements for the subjects/curriculum areas in the age ranges they are trained to	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson

	teach, including those relating to public examinations and qualifications	4. Elements of a science lesson 6. Managing learning; measuring learning
Q12	Know a range of approaches to assessment, including the importance of formative assessment	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson 6. Managing learning; measuring learning
Q13	Know how to use local and national statistical information to evaluate the effectiveness of their teaching, to monitor the progress of those they teach and to raise levels of attainment	6. Managing learning; measuring learning 12. Reflective practice and professional development
Subjects and curriculum		
Q14	Have a secure knowledge and understanding of their subjects/ curriculum areas and related pedagogy to enable them to teach effectively across the age and ability range for which they are trained	1. What is science teaching? Who are science teachers? 2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson
Q15	Know and understand the relevant statutory and non-statutory curricula, frameworks, including those provided through the National Strategies, for their subjects/curriculum areas, and other relevant initiatives applicable to the age and ability range for which they are trained	1. What is science teaching? Who are science teachers? 5. Managing learning in science 7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16
Literacy, numeracy and ICT		
Q16	Have passed the professional skills tests in numeracy, literacy and information and communication technology (ICT)	
Q17	Know how to use skills in literacy, numeracy and ICT to support their teaching and wider professional activities	3. Planning to teach a science lesson 6. Managing learning; measuring learning 10. Creativity and innovation in science teaching and learning
Achievement and diversity		
Q18	Understand how children and young people develop and that the progress and well-being of learners are affected by a range of developmental, social, religious, ethnic, cultural and linguistic influences	6. Managing learning; measuring learning 7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16

Q19	Know how to make effective personalized provision for those they teach, including those for whom English is an additional language or who have special educational needs or disabilities, and how to take practical account of diversity and promote equality and inclusion in their teaching	6. Managing learning; measuring learning 7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16
Q20	Know and understand the roles of colleagues with specific responsibilities, including those with responsibility for learners with special educational needs and disabilities and other individual learning needs	5. Managing learning in science lesson 7. Teaching different abilities; teaching different pupils
Health and well-being		
Q21a	Be aware of current legal requirements, national policies and guidance on the safeguarding and promotion of the well-being of children and young people	2. What are you expected to teach in a science lesson? 5. Managing learning in science lesson 7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16
Q21b	Know how to identify and support children and young people whose, progress development or well-being is affected by changes or difficulties in their personal circumstances, and when to refer them to colleagues for specialist support	
Professional skills. Those recommended for the award of QTS should:		
Planning		
Q22	Plan for progression across the age and ability range for which they are trained, designing effective learning sequences within lessons and across series of lessons and demonstrating secure subject/curriculum knowledge	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson 7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16
Q23	Design opportunities for learners to develop their literacy, numeracy and ICT skills	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson
Q24	Plan homework or other out-of-class work to sustain learners' progress and to extend and consolidate their learning	10. Creativity and innovation in science teaching and learning 11. Science outside the classroom

Teaching		
Teach lessons and sequences of lessons across the age and ability range for which they are trained in which they:		
Q25a	use a range of teaching strategies and resources, including e-learning, taking practical account of diversity and promoting equality and inclusion;	3. Planning to teach a science lesson 4. Elements of a science lesson 5. Managing learning in science 10. Creativity and innovation in science teaching and learning
Q25b	build on prior knowledge, develop concepts and processes, enable learners to apply new knowledge, understanding and skills and meet learning objectives;	3. Planning to teach a science lesson 4. Elements of a science lesson 5. Managing learning in science 10. Creativity and innovation in science teaching and learning
Q25c	adapt their language to suit the learners they teach, introducing new ideas and concepts clearly, and using explanations, questions, discussions and plenaries effectively;	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson 7. Teaching different abilities; teaching different pupils
Q25d	manage the learning of individuals, groups and whole classes, modifying their teaching to suit the stage of the lesson	8. Teaching different ages: Key Stage 3 to post-16 10. Creativity and innovation in science teaching and learning
Assessing, monitoring and giving feedback		
Q26a	Make effective use of a range of assessment, monitoring and recording strategies	4. Elements of a science lesson 6. Managing learning; measuring learning
Q26b	Assess the learning needs of those they teach in order to set challenging learning objectives	6. Managing learning; measuring learning 7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16
Q27	Provide timely, accurate and constructive feedback on learners' attainment, progress and areas for development	6. Managing learning; measuring learning
Q28	Support and guide learners to reflect on their learning, identify the progress they have made and identify their emerging learning needs	6. Managing learning; measuring learning
Reviewing teaching and learning		
Q29	Evaluate the impact of their teaching on the progress of all learners, and modify their planning and classroom practice where necessary	12. Reflective practice and professional development

Learning environment		
Q30	Establish a purposeful and safe learning environment conducive to learning and identify opportunities for learners to learn in out-of-school contexts	2. What are you expected to teach in a science lesson? 3. Planning to teach a science lesson 4. Elements of a science lesson 5. Managing learning in science 11. Science outside the classroom
Q31	Establish a clear framework for classroom discipline to manage learners' behaviour constructively and promote their self-control and independence	4. Elements of a science lesson 5. Managing learning in science
Team-working and collaboration		
Q32	Work as a team member and identify opportunities for working with colleagues, sharing the development of effective practice with them	7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16 10. Reflective practice and professional development
Q33	Ensure that colleagues working with them are appropriately involved in supporting learning and understand the roles they are expected to fulfil	7. Teaching different abilities; teaching different pupils 8. Teaching different ages: Key Stage 3 to post-16

As the title of the series suggests, this book aims to help you to develop into a reflective practitioner. Each chapter contains several points for reflection. These encourage you to break off from your reading and consider the issue being discussed. Sometimes you are asked to compare the information in the text with your own experience; sometimes you are asked to complete a small task. It is hoped that you will not be in a hurry to read through the whole book; take your time, reflect on the issues presented and, if possible discuss the issues with other trainees.

The main focus of the book is on practical advice, but there is another area of your course where we hope that you will find the book useful. If you are undertaking an award-bearing course (for example, leading to a PGCE or a degree with QTS), then you will have to do some assignments, and this book will help you with that too.

1 WHAT IS SCIENCE TEACHING? WHO ARE SCIENCE TEACHERS?

Bernie Kerfoot

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
- discusses 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 it is fair to say that up until 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 would 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 humankind, 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 that 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 findings 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
- observe and collect data
- work safely autonomously or with others
- evaluate methodology.

Some science educationalists, for example, Millar, 1989) point out that, first, 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 their benefits, drawbacks and risks.
b. To consider how and why decisions about science and technology are made including those that raise ethical issues, and about the social, economic and environmental effects of such decisions.
c. How uncertainties in scientific knowledge and scientific ideas change over time and about the role of the 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 acknowledged 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 post-16 '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 that 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 on to work in 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 blames 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 too precious to burn to make 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 Stages 3 and 4 pupils do not require an in-depth consideration of Popper's and Kuhn's 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 suggesting that 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 Sellafield 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 ever read the original paper that forms the basis of the claim. Even when they do their conclusions are 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 about the discovery and subsequent analysis of a meteorite that was found in ice at the North Pole. Scientists Everett Gibson and David McKay, from NASA, were convinced with a high degree of certainty that meteorite ALH 8001 came from Mars and that 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 the nodules 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 hypotheses that are 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 it is published.

Now this may be difficult for children to come to terms with but the earlier you start the more chance they have of understanding 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 potentially 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 the Consortium for Local Education Authority for the Provision of Science Services (CLEAPSS) published a pack of risk assessment forms for pupils to consider and fill in prior to doing investigations with hazards involved – seemingly a 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 meantime it will hopefully also allow science teachers to address issues which have recently been 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 images 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 ‘Mr 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

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 in any staffroom a watertight case for the inclusion of science as a core subject. Certainly every mathematics and English teacher would find it obvious and not have too much difficulty in building a case for their own subject. Since the implementation of the National Curriculum in 1989, 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 made us indispensable by arguing the case for science in the core curriculum.

Certainly one of the answers that scientists offer when asked 'Why is science important?' is that 'science gives you answers to things that go on all about you'. They expand on this with 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 and for implementation within Key Stage 3 in 2008.

Science was and is a core subject right through from ages 5 to 16 – everybody has science lessons. 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 £1,000 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 as 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?