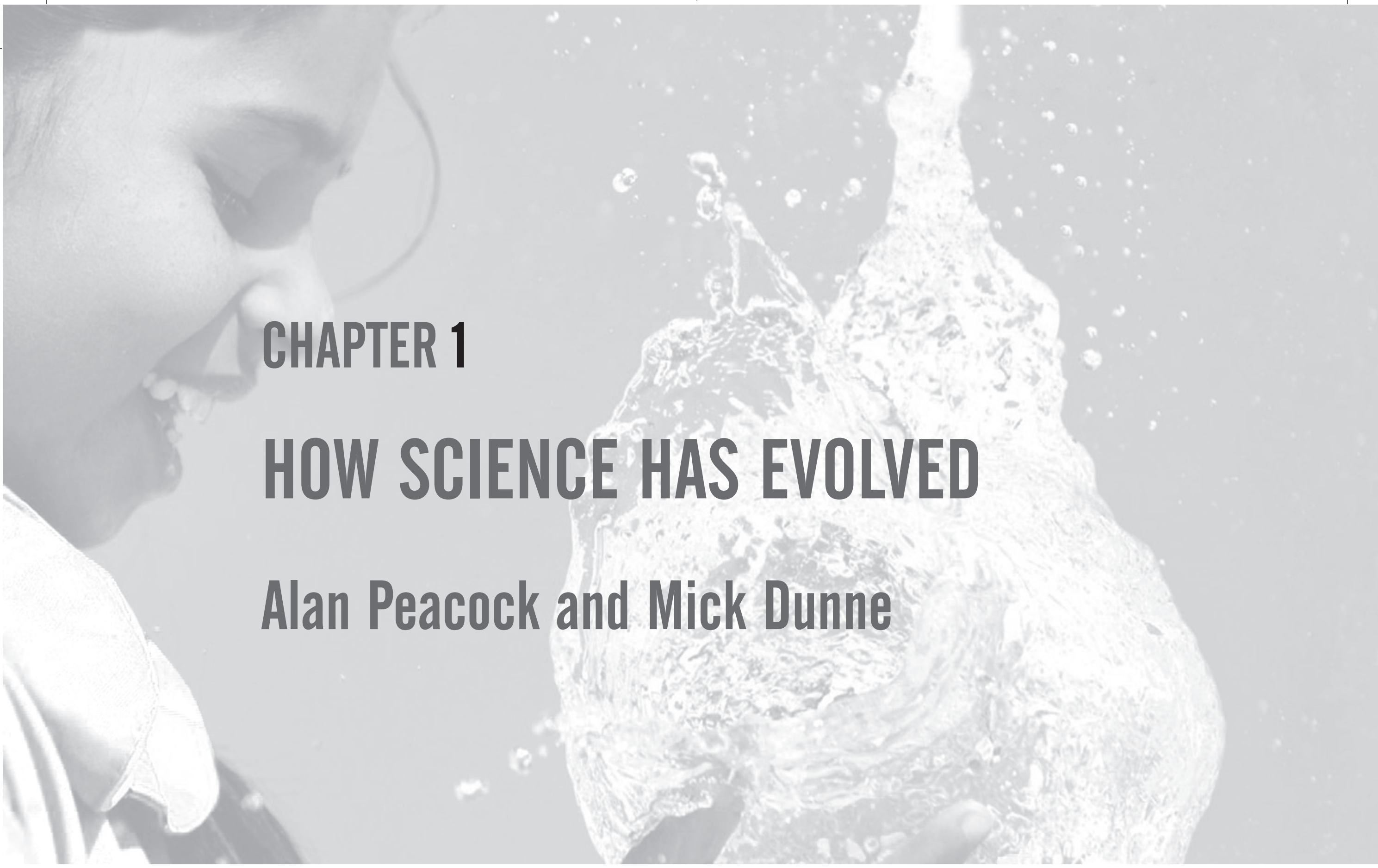

CHAPTER 1

HOW SCIENCE HAS EVOLVED

Alan Peacock and Mick Dunne

Chapter Overview

This initial chapter focuses on the relevance of an understanding of the evolution of science and science education to primary teachers, at a time of what seems like perpetual change in the curriculum, approaches to teaching it, and the training of teachers. It traces the origins of much of what we know as science back to roots in China and the Islamic world, acknowledging some of their accomplishments we now take for granted in astronomy, chemistry, medicine, papermaking, ceramics, and many other fields. It also draws attention to what we now call Inquiry-based Science Education (IBSE) which has been at the root of scientific advances for centuries, such as the importance of observation, hypothesising, and the testing of ideas against evidence. The chapter then focuses on something that lies at the heart of this book – that science acknowledges uncertainty, rather than certainty,

as its starting point. It is not about 'right answers' but about enquiring minds and the skills to handle evidence and postpone certainty. This has been the basis of work by all the great scientists, from Galileo and Newton through to Darwin, Einstein, Heisenberg, and Hawking. The only science knowledge we possess is that which emerges from such enquiry.

The chapter concludes by tracing the development of resources for primary science teaching from the 1960s onwards in the UK, including Nuffield Junior Science, Science 5–13, the SPACE research reports, and a wide range of commercial science schemes. This leads into the advent of the National Curriculum, the status of science as a core subject, and the controversial and often contradictory recent reviews that have set out to guide future developments. It concludes by asking you to consider where you stand in relation to some key questions about the future of primary science teaching.

Key Ideas

If you are a trainee, or an inexperienced primary teacher confronting science for the first time, you are probably opening this book expecting to find answers to some big questions like *'What is science?', 'Why should we teach it?'*, *'What is good science education?'* and '*How do children learn best in science?'* And so you may wonder why the focus of this first chapter is relevant: what you'll have to teach is laid down in the curriculum isn't it? How will searching back through history help?

You may feel like this because your previous experience has conditioned you to expect answers in the form of definitions – the kind that start off '*Science is …'* or *'As a teacher of science in primary schools, you should …'* – the clear-cut statements that tell you what to do to conform with official expectations. But the authors of this book, all of whom are and have been closely involved in training and developing teachers of science for primary schools, do not believe in that approach. And we have gone to great lengths to consult with 'Focus Groups' of trainees, in different parts of the country, on what exactly ought to go into 'your' book on Primary Science.

The reason for this is that science and the way it is taught have been in a constant state of flux for a very long time and remain so, as this first couple of chapters will try to show. And there are reasons why things constantly change. So the way in which you teach science will need to be adapted to the situation you find yourself in – which means to the children you teach, the environment of your school, the current concerns of society, government policy, and to technological change, to name only a few factors. To be effective as a teacher of science, therefore, you can't just trot out the tried-and-tested ideas of the past; you need to be a thinking, reflective teacher who can weigh up alternatives and makes up your mind on the basis of the best evidence, sound advice, and what suits your own personality.

The following chapters will therefore provoke discussion and debate rather than tell you what to think. Such discussion will inevitably draw on many of the key qualities of effective scientific enquiry and show how these concerns relate to classroom practice. This will start by exploring how the characteristics of science, and science enquiry, have evolved, leading in recent years to their application in a primary classroom context. We aim to balance historical perspectives with a clear focus on the present climate for primary science education. And most importantly, we will always be helping you find an appropriate balance between the characteristics of scientific activity and science as a body of knowledge.

Where did Science Start?

It's likely that science began when our ancestors first made stone tools, used fire and water to cook, or utilised skins and wood for clothing and shelter. But they certainly didn't think of themselves as scientists; in fact the term 'scientist' was only coined in 1833 by William Whewell at the request of poet and philosopher, Samuel Taylor Coleridge, who needed a word to describe the group of active experimenters who were making such huge advances in 'Natural Philosophy', as it was called, at the end of the eighteenth century. Thousands of years ago the people of the Nile valley made observations of when the river flooded so they could predict when best to plant their crops. The Mayans of South America were remarkable astronomers who made such accurate observations of the sun, moon, and planets that their calendars were virtually as accurate as ours are today. One way in which they did this was by digging deep, well-like pits in the earth and lying at the bottom; by doing so, they could observe a tiny portion of sky from which all extraneous daylight was excluded. They recorded, without any instruments, observations of stars which are now no longer visible to the naked eye!

Observe, suggest explanations, test them, expand knowledge, and then apply it – this is what people have done for millennia, a process of 'Coming to Knowing' about the world and the universe. What those very early ancestors were doing is something which is still at the heart of much science and technology, namely the search for understanding and ways to make work and life easier. Try asking children or your fellow non-science students what science is; they will probably say things like, *'how the world works'* or *'understanding the world around us'* – but they might also tell you *'physics, chemistry and biology'* because that has been their main experience, science as school subjects. And it's here that we face the first way in which science has evolved, because even these 'subjects' are quite recent inventions. For example, Humphrey Davy, the famous Cornish scientist and inventor of the miners' safety lamp (as well as investigating anaesthetics), claimed in his first book, in 1797, that *'Chemistry has arisen from the ruins of Alchemy'.* But even he didn't claim it should be taught in school! Geology and geography were new disciplines in the nineteenth century and today you will find university departments for things like socio-biology, geo-chemistry, paleo-archaeology, neurosciences, and many others. Yet all these new branches of science basically use the same underlying approach.

We have to go a long way back beyond Davy to see where science began in earnest and this happened not in the famous universities of Europe but in China and the Islamic world. In the ninth century Jabir ibn-Hayyan was preparing strong acids and alkalis using scientific methods, well before these techniques became common in the West. Jabir is believed to have written;

> The first essential … is that you should perform practical work and conduct experiments, for he who performs not practical work nor makes experiments will never attain the least degree of mastery.

This is something we are still encouraging learners to do over a thousand years on.

Such 'scientists' were capable of great scientific accomplishments in astronomy, medicine, and algebra in the Muslim 'Golden Age' of 800–1200 AD, contrary to some current ideas that Islam opposes the scientific method or the advances of scientific understanding and the application of technology. The Prophet Muhammad urged individuals to be curious and to reason about the knowledge to be found in the natural world and this amazing research and development work carried out in the Islamic world can best be seen on the '1001 Inventions' website (http://www.1001inventions.com/) which describes the invention of various things we now take for granted, like soap, shampoo, fabrics, perfumes, fountain pens, toothbrushes, carpets, clocks, coffee, and the camera.

The Chinese were active too, long before their counterparts in Europe, in creating paper, printing, porcelain, the compass, medicines, and gunpowder. In Africa the people of Benin were creating beautiful and incredibly detailed bronze castings. All these developments by skilled artisans were based on principles and procedures that resemble what we now call 'the scientific method' of observation and experimentation. Aristotle had propounded some of these ideas as early as the fourth century BC by emphasising the importance of the experience of the senses – what is sometimes called Empiricism – and these ideas lasted and were refined over many centuries by famous names like Roger Bacon, Copernicus, Galileo, Francis Bacon, Newton, Descartes, Dalton, Darwin, Davy, Faraday … the list is endless, of course. A quick 'Google' will tell you as much as you wish to know about all of these and many more.

Another more recent shift in thinking about science was Karl Popper's understanding that scientific theories could not be proved, they could only be falsified; in other words, no matter how much evidence you produce to back up an idea, it is still always possible that someone may find evidence to prove you wrong – and once you do find this falsifying evidence, the whole theory will collapse and you will have to start again. Thus science proceeds by falsifying, not by proving; even with young children science can be seen as testing their ideas against the evidence of their senses.

From a twenty-first century point of view specific ideas are not the most significant things. What matters is that frequent huge shifts in science-related thinking have taken place. Galileo and Newton changed the way we see our universe and the forces that make it work; Darwin changed our view of ourselves and our origins as a species; and in the past one hundred years, Einstein, Bohr, Heisenberg, Feynman, Hawking, and others have altered the way we think about matter, what it is, and how it can be transformed. But all these came into conflict with other, often religious, beliefs, particularly Galileo and Darwin, and even today the argument between evolutionary biologists and creationists who promote 'intelligent design' rages on in many countries.

Change and Uncertainty

Gradually, therefore, our understanding of what science is and how it works is changing. During the nineteenth and twentieth centuries, it became commonplace to believe that science and technology could control nature; we were 'harnessing' it to produce energy or grow more food. But in recent years, tsunamis, earthquakes and volcanoes have reminded us that even with the most sophisticated technology there are things we can't control. Native peoples in the Americas, Australia, and Asia have always known this and are aware of the need to live with nature and not try to control it. Yet many science professionals still do not regard their ideas (on natural remedies, for example) as being 'proper' science. David Peat in his (1995) book *Blackfoot Physics* explores these ideas at great length and other eminent scientists such as Fritjof Capra have made a huge effort to emphasise the links and similarities between the ideas of physics and ancient belief systems, such as those of eastern mysticism. Capra opens his (1975) book *The Tao of Physics* with this quote from Werner Heisenberg:

> It is probably true quite generally that in the history of human thinking the most fruitful developments frequently take place at those points where two different lines of thought meet. These lines may have their roots in quite different parts of human culture, in different times or different religious traditions: hence if they actually meet, that is, they are at least so much related to each other that a real interaction can take place, then one may hope that new and interesting developments may follow. Capra, F. 1975.

So science also progresses by making links with ideas from other disciplines and thought systems and in his other groundbreaking book, *The Hidden Connections* (2002), Capra demonstrates how we need a unifying system that can help understand the network of connections between science and such fields as economics, ecology, the mind, and social realities. In 2011 we are highly aware of the impact of global capitalism on all we do and these connections have been made forcibly by James Lovelock using his Gaia Principle, which sees our planet as a living entity in itself which will always find its own equilibrium, regardless of what we do to it (or even whether we are here or not!).

One further big change is the relatively recent realisation that our understanding of everything is beset by uncertainty, as proposed by the same Werner Heisenberg in his Uncertainty Principle. Scientists in the early twentieth century developing the quantum theory of matter realised that you could not observe very small, sub-atomic particles without changing them – a realisation that has had profound effects. We can only now talk about an electron probably being here or there, this or that; we cannot say for certain, and never will be able to. Hundreds of millions of dollars are being spent on investigations, such as that currently going on using the Large Hadron Collider (LHC) in Switzerland, in an attempt to find the 'ultimate' particle – but how will we know it is the ultimate? Probes with high-res cameras are also being sent to the edge of our solar system, but we are unlikely to be able to test the probability that, given the unimaginable number of galaxies and planets, there is life elsewhere.

At this point I can sense you are thinking, *'Hmm, maybe this book isn't for me, after all...'* but please stay with it! Uncertainty is everywhere and as teachers we have to recognise this. Nobody was certain where the volcanic ash cloud was heading in April 2010, despite the incredible technology available to the Meteorological Office, and while new species are being discovered all the time (over 100 in Borneo this year, I read) others like the tiger have an uncertain future. We are uncertain how fast the climate is actually changing, uncertain about how fast the Greenland icecap will melt, because it is impossible to have enough data to know for sure. We have to accept that our understanding is beset by inadequate data and the need to live with probabilities, as we do all the time when watching the weather forecasts on TV.

So developing young minds to think scientifically means first of all not preparing them to expect certainties, not wanting to know what the 'right answer' is, because despite the years of testing you have probably endured in school so often there will be no right answers. Of course if you jump off a building there's a high probability that you will fall and hit the ground; some probabilities are quite high! Ironically, of course, we have better 'gear' for enquiry and investigation than ever before. In school I used a Bunsen burner, test-tubes, balances, and (rarely), a microscope; now there is a huge range of digital technology at your disposal to help you do and see things that were impossible twenty years ago. And there are still a myriad things in your environment to enquire into, things probably unique to your school's surroundings.

Take the humble dandelion, a plant probably found around every school in the country, and consider how many investigations into its growth, size, seed dispersal, place in the food chain, etc. you could carry out. Simply investigating how the seeds move in the air could fascinate children for hours (what happens if ... you cut the parachute shorter, for instance?). Or take a bowl of fruit and think of the observations, predictions, and theories you could come up with by just considering the link between their size, colour, skin, and the seeds inside each fruit. We will suggest more simple activities like these in subsequent chapters.

The Emergence of Resources for Science Teaching

However, this kind of thinking about science as enquiry penetrated primary schools only recently. Until the mid-1960s, the closest that younger children got to a science activity was through nature walks and a nature table in the classroom. This might involve collecting frogspawn in spring, bringing it to the classroom and watching the eggs develop; or by collecting wild fruits and seeds in autumn and planting them in soil; or making systematic observations of the weather on a class chart. Of course much of this depended on whether your class teacher had the knowledge and understanding and even an interest in this sort of work. The physical sciences were rarely tackled. In the late 1960s, however, the Nuffield Foundation introduced *Nuffield Junior Science*, a scheme which had the deliberate intention of encouraging a practical, sensory experience of physical phenomena for children. Those who experienced this new approach clearly relished the chance to do practical activities even though there was little in the way of a clear link between this and their concept of learning.

There was at that time still no National Curriculum in Britain, so it was entirely up to individual schools and teachers to decide if and how to deal with science learning. However there was in existence an organisation called the Schools Council, an independent body which drove much curriculum change, and as each of its project teams was at least 50 per cent made up of teachers, their initiation of a programme for science was based on what teachers felt was needed. Out of this came *Science 5–13*, a project based at the University of Bristol, which had a much clearer basis in the understanding of children's learning, introducing the idea that 'science skills' were central to effective learning, as well as new ways of looking at a wide range of science content. Its publications included the ground-breaking introductory book, *With Objectives in Mind*, setting out the essential skills and concepts needed for an understanding of science. This was organised using three developmental stages and adopted Jean Piaget's ideas about intellectual development. Crucially it also tackled the physical sciences, with units on topics such as Structures and Forces, Working with Wood, Science from Toys, and Metals. The scheme also coined the now-familiar concept of Minibeasts. Happily, these excellent resources (developed, in the main, by teachers) are now becoming available again this time online.

Science 5–13 was highly influential amongst teachers and especially teacher trainers at the time. And it illustrated how, as our understanding of science changes, so too do our ideas about the way it is taught. Its impact was in some ways a precursor to the government's publication in the mid-1980s of *Science for All*, a first attempt not only to create a basis for good practice but also to insist that all primary school teachers should be teachers of science – something that had existed systematically in few classrooms up to then.

The Arrival of the National Curriculum

Sadly, however, ideas about science teaching have sometimes been steered and influenced by considerations that were quite remote from what could be called 'good science practice'. In particular when the government of the day centralised control of school education in the early 1980s, removing it from being the responsibility of local authorities, political interference in teaching led in the late 1980s to the emergence of the first National

Curriculum (NC) for Science and the standard testing of children's science knowledge, which has since become increasingly controversial. This was never the intention of those experts who devised the NC – they wished to develop a system that would balance the testing of knowledge with examining enquiry skills through practical investigations. But cost and logistics, alongside the politicians' wish to simplify, gradually led to an abolishing of practical tests and a reversion to paper and pencil exams. This in turn has led too many teachers away from science as a process and towards a narrower view of science education (as represented by *'Posh science words to know',* something I saw on one classroom wall). This was a great pity as huge strides had been made by schemes such as those mentioned above to develop science learning that was based on enquiry skills. Primary Science, in a way, was the guinea pig for subsequent NC subjects, as it was the first to be implemented, in 1989, and went through a number of disruptive revisions in the following years.

At this time also international surveys of attainment in basic subjects were being carried out with increasing frequency and the UK's failure to do well in these prompted yet more government intervention. Consequently teachers and other educators had to manage the introduction of a whole new raft of jargon into the way we talk about curriculum, including Programmes of Study (PoS), Attainment Targets (ATs) and Standard Attainment Tests (SATs), all of which arose out of the government's wish to adopt approaches that had seemed to be successful elsewhere especially in the USA and Japan.

Yet parallel to this was some important research being carried out at the universities of Leeds, Liverpool and Kings' College, London, on children's science misconceptions. Until this time it was commonly thought that children's minds, as far as science was concerned, were empty vessels into which 'correct' science ideas could be poured. Research showed powerfully that this was not so and that children on entering school already had their own ideas about science phenomena, even if many of these were at odds with those held by scientists. As a result the *Science Process and Concept Exploration Project* (SPACE), systematically explored young children's understanding of science concepts and their development in 12 areas, such as Electricity, Materials, Evaporation, Growth, etc. and built on earlier research from New Zealand and by the late Rosalind Driver in Leeds (whose (1983) book, *The Pupil as Scientist*, exemplified much of what was known about children's learning in science). The results led to the publication of eight major research reports and then to the development of a set of curriculum materials – *Nuffield Primary Science* (1994) – which quickly developed a national and international reputation. This new scheme aimed to establish and communicate the ideas which primary school children have in particular science concept areas and set out to show ways in which teachers could help children to modify their ideas as the result of relevant experiences, bringing them in line with those of the science community.

Teacher's Professional Development

In the early 1990s, therefore, and following on from these bursts of developmental activity, primary science suddenly took centre stage where the curriculum and teacher education were concerned. The amount of time devoted to science in primary teacher education, and the numbers of trainers involved, increased rapidly. Science was now deemed to be a 'core subject' of the primary curriculum and it began to be treated with greater status in schools. Government schemes of work, such as that from the Qualifications and Curriculum Authority (QCA), flooded into schools and universities and Continuing Professional Development (CPD) programmes proliferated, sponsored by local authorities, universities, and private operators. A bandwagon was thus in motion. Scotland followed its own path, deliberately avoiding the standard testing route, but otherwise all the home countries put science at the forefront of their thinking. For example, many schools were using science-based topics as ways of thematically linking subjects together.

No doubt you will have noticed that all this has now changed. The first major factor in reducing the emphasis on science was the introduction of the National Literacy Strategy (NLS) in 1998, closely followed by the National Numeracy Strategy (NNS). Literacy has always held pride of place in the concerns of many primary teachers and whilst it became increasingly difficult to attract teachers into science CPD programmes those relating to the NLS were usually oversubscribed. Literacy has continued to be the central and probably most controversial aspect of primary teaching ever since. It has been difficult at times to combat the tendency of some advocates to see science as a 'vehicle for literacy teaching', rather than the reverse!

The second major influence on primary science teaching was the change to a New Labour government in 1997. This came at a time when England's performance in international surveys of attainment was still not good and it seemed to many at the time that the education strategies which were soon to be adopted by Prime Minister Blair were directed primarily at improving this state of affairs, at whatever cost. We had to be seen to be 'raising standards', following his claim that his priorities for government were 'Education, Education, Education'. The strategy adopted to achieve this took the form of increased testing of primary age children in particular, tests which served to reverse, in many schools, the move to effective, inquiry-based science (now usually referred to internationally as IBSE). Testing – and thus teaching – continued to emphasise the learning of factual knowledge rather than the acquisition of science inquiry skills which were much harder and more time-consuming to test. Under pressure from Ofsted inspections to improve the (fairly arbitrary) standards, schools and teachers rapidly refined their strategies for 'teaching to the test' in order to improve their schools' standing in the now mandatory league tables of attainment.

Recent Changes

Research, however, stubbornly continued to indicate that early improvements soon levelled off (Royal Society, 2010) and that primary teachers, 97 per cent of which still did not have a post-school science qualification, still lacked confidence when it came to teaching science. One approach to tackling this came with the government's *Every Child Matters* initiative which required teachers, in all subjects, to demonstrate how they were reaching individual children whatever their background and level of attainment. At the same time the emphasis on digital technology and children's need for ICT skills was gaining ground. Having commissioned a new review of the primary curriculum in 2008, headed by Jim Rose, the Brown government made the decision in 2009 to adopt these proposed changes to the curriculum which would give an increased emphasis on ICT, withdraw the core status from science, and make it part of an 'area of learning' characterised as 'scientific and technological understanding' (Rose, 2008). At the same time though, the consultation process had suggested that many in primary science education were not happy with the findings, particularly as another large review headed by Robin Alexander in Cambridge had come simultaneously to quite different and (to primary science people) much more preferable conclusions that took account of teachers' concerns. For example, it highlighted a worry amongst many, after years of teaching to the test, that 'We need permission to innovate. Sometimes it even seems as if we even need permission to think' (Cambridge Primary Review, 2009).

Yet only a matter of months before the Rose Review was due to be implemented New Labour was replaced, in May 2010, by the present coalition government and plans for a revision along the lines of Rose were shelved. A hiatus thus exists at the time of writing in relation to what changes in the primary science curriculum can be expected – if any. Many would probably wish for no change in order to enable a period of consolidation, yet differences between the primary science curricula and the approaches of the four home countries have been growing, to the extent that England alone now persists with a standard testing of science at age 11 and the contents of the four curricula have considerable differences in emphasis, especially where IBSE and curriculum integration are concerned. Creativity in primary science teaching, some would suggest, has been developing more rapidly in Wales, Northern Ireland, and Scotland following their withdrawal from a narrow emphasis on testing knowledge.

We therefore need an authoritative pronouncement based on evidence and fortunately this has been provided recently by the Royal Society's *State of the Nation* report on Science and Maths Education (Royal Society, 2010) and effectively summarised by Wynne Harlen in a recent issue of *Primary Science.* This re-iterates the report's conclusions about what should be done to improve primary science education in schools, as follows:

- Provide every school with access to a science specialist.
- Increase funding for teachers' continuing professional development in science.
- Focus assessment on promoting progress rather than on measuring it.
- Ensure that national policy for science education is based on evidence from research and effective practice.

- Encourage more research into children's development of science knowledge, understanding and skills.

(Harlen, 2010)

Summary

The Royal Society's report brings us right up to date with the state of play in late 2010. It is, of course, not mandatory in any way and schools will – whilst taking note of it as helpful guidance – be reluctant to make major changes until the dust settles around government policy. But for you, as a trainee or novice teacher, or as one of the many non-science specialists wishing to engage more productively with science, it raises several important questions that you might wish to discuss before moving on to read the rest of this book. Some of these questions could be formulated as follows:

- If you were asked to initiate a discussion about the policy for science in your school, what would be on your agenda and what would your priorities be in order to bring about improvement?
- Taking account of the Royal Society's recommendations, which of these do you think are likely to be implemented under the current climate within education?
- What can you learn from the development of primary science as set out above that could help you arrive at good practice in your own classroom?

These questions will be returned to in our final chapter, in an attempt to summarise what authors from a wide range of perspectives have to say on these issues. They are also relevant in that they signal to those entering the profession, and indeed to more established colleagues, an acceptance of our need to be able to manage uncertainty and change. Primary education since the late eighties has witnessed a huge number of initiatives from the 'top down': one of the characteristics of being a good professional is the capacity to engage with change but not to do so unquestioningly. Such a person does not function cynically but with a clear sense of being able to identify what is right for the educational context in which they are located. Top-down change has focused, and is likely to continue to focus, primarily on the 'what' and perhaps concentrate less so on the 'when' but not on the 'how'. Decisions about whether or not to do practical work in science should not be determined by curriculum guidance but by the principle of educational fitness for purpose.

Change management will always exercise teachers' professionalism. This book accepts and welcomes the dynamic nature of education in general and science education in particular. We hope that by engaging with what is being shared you will see that change can be engineered effectively without a consequent loss of quality in educational provision. The authors place a strong emphasis on not providing you with a 'ready reckoner' for science education but with a resource that will encourage you to think, to not be afraid to exercise your judgements but to know what is high quality science education for our younger learners.

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Further Reading

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This small publication provides a philosophical perspective of some of the ideas introduced in this chapter. It also helps explain what science is thought to be and provides an alternative insight to the history of the development of science.