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BECOMING SCIENTIFIC

1.1 BECOMING SCIENTIFIC

This phrase is meant to convey a particular way of thinking about learning science which involves the whole person of the learner, what s/he thinks, feels and does. It acknowledges the parts played by learners' personal interests, their previous experiences and how they perceive themselves as learners. Becoming scientific involves many things, including learning about what scientists know and think, how they have come to believe in their, sometimes strange, ideas, and why they do science. Young children can best learn this by developing scientific knowledge and thinking at their own level of understanding, using increasingly complex scientific ways of finding out, following their own purposes and interests and learning about the purposes and interests of scientists. When children are becoming scientific, they playfully explore new experiences, think about previous ideas and develop new ones to develop their knowledge. They progress by focusing their curiosity more sharply and making their ideas and evidence more scientific through critical discussion and deeper investigations.

Scientific knowledge on its own is not science, any more than a collection of paintings and sculpture is art. Knowing facts and concepts in biology, chemistry and physics is not being scientifically educated, any more than knowing the names of monarchs and the dates of their reign is being historically educated. *Being scientific* is a way of knowing, doing and thinking which is distinct from being artistic or being historical. It involves thinking about one's own ideas, how they are tested against experience in scientific ways and comparing them with scientists' ideas and evidence.

1.1.1 The National Curriculum perspective

The Science National Curriculum programme of study in science has the following statement about knowledge, skills and understanding: 'Teaching should ensure that *scientific enquiry is taught* through contexts taken from the sec-

tions on life processes and living things, materials and their properties and physical processes' (emphasis added). This underlines the central importance of Attainment Target 1 (or Sc1 for short) which is then specified under two headings:

1. Ideas and evidence in science
2. Investigative skills

This means that whatever ideas we are teaching from the other Attainment Targets in the National Curriculum (Sc2, Sc3 or Sc4) whether they are to do with seeds, magnetism or rusting, then **how** we teach them should involve learners in thinking about the **ideas** in relation to **evidence**, in the investigatively skilful ways that are specified by Sc1. **This should apply to all learning of science.** The other Attainment Targets specify **what** is to be learned, while Sc1 specifies **how** the science is to be learned. This chapter is about understanding why Sc1 is so important in learning science.

The phrase 'Ideas and evidence' is meant to convey that at the heart of science itself there is an expectation that when we are thinking scientifically, the ideas we use to try to understand or explain what we experience about the world need evidence in the form of observations and measurements to enable us to decide if the ideas are valid. Equally, when observing closely or measuring carefully, we need good ideas to explain or understand or apply to our thinking. It is these kinds of interactions of ideas and evidence that we can look for in children's thinking that we call scientific.

It may be helpful to compare the relationship between Sc1 and the other Attainment Targets in the science national curriculum, with the relationship between the official curriculum and the *hidden curriculum*. The official curriculum is **what** we intend to teach. We may define this as subjects such as English, mathematics, history, etc. or as cross-curricular topics such as *The school's environment*. But, **how** we intend to teach such subjects or topics should include consideration of our *hidden curriculum*: our values and beliefs about how we want children to learn them. In science, **what** we teach in Sc2, Sc3 and Sc4, **provides the context** for **how** we help children to gain what we value in being scientific. This includes developing the skills, attitudes and ways of working that express our scientific values such as curiosity, collaboration, scepticism, imagination, questioning, tolerance to uncertainty, etc.

1.1.2 Wider educational perspectives

The Sc1 part of the Science National Curriculum also implies that a teacher needs to be aware of how their teaching of science is related to wider perspectives. This includes what we are aiming for in children's education, and what we understand about how children learn.



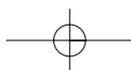
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To be clear about our aims, we need to deepen our understanding of what it means to **be scientific**. Some argue it is a quality that is fundamental to what it means to be human. Frank Smith, a Canadian professor of education says that being scientific is also a fundamental quality of how we learn.

In some areas of research it has become customary to talk of 'the child as an experimenter' or 'the child as scientist'. But I do not think that these analogies do sufficient credit to children. They suggest that children are precocious, and raise the question of where children might get the specialised skill which among adults seems to be largely restricted to scientists. I think the analogy should go the other way. When scientists are conducting experiments they are behaving like children. Scientists, in the discipline of their professional activities, do deliberately and consciously what children do naturally, instinctively and effortlessly. *The 'scientific method' is the natural way to learn displayed by us all in our early years.* The problem as we get older is that we give up the basic requirement for learning by experiment – tentativeness. As we get older we become dogmatic about what we think (I tentatively propose). But in childhood the very basis of our learning is a willingness to look for evidence that might lead us to change our minds. (Smith, 1978: 91–2, emphasis added)

We are all born with a capacity to become scientific which we can develop.

If our teaching of science is to contribute to the achievement of wider aims of education, then we need to bear in mind that science is a human endeavour that is an increasingly important part of the cultural inheritances that we are handing on to the next generation. Scientific learning is one of the most recent aspects of our civilization to develop, historically. More and more people use existing scientific knowledge and engage in scientific ways of finding out new knowledge as part of their working lives. Teachers need to have a modern image of science and its place in society and this should inform how we understand and use Sc1 in our teaching. A Victorian image of science, for example, which regarded science knowledge as fixed and certain truth, would be consistent with a didactic method of teaching, with little need for learners to engage in genuine, whole investigations of their own. But a modern image of science, as described briefly here, is consistent with constructivist approaches which involve learners in whole, real investigations. Teaching is better when it is guided by a thoughtful understanding of how children learn in different ways and how a teacher enables their best learning. Theories of learning are helpful in guiding our teaching of children's thinking abilities and attitudes that are important to their achievement of Sc1. For example, behaviourist approaches to the teaching and learning of Sc2, Sc3 and Sc4 may match the limited intentions of *teaching to the test* in a Y6 class preparing for SATs, but constructivist approaches are more helpful to a teacher who is aiming for children to develop their thinking about scientific ideas through investigative activity.



1.2 THINKING ABOUT SCIENTIFIC KNOWLEDGE AND INVESTIGATION

Science is a way of exploring and investigating our world. The aim is to learn more about and understand better, the objects, materials, living things and phenomena we experience. Science combines the ability to investigate scientifically with the growth of knowledge and understanding. They are like the opposite sides of a coin: in looking at one or the other we mustn't forget the whole thing. Science is not only a way of knowing: it is also a way of doing, and each shapes the other. Understanding the nature of science helps us as teachers to understand not only what scientists do, but also to understand and encourage children's investigations much better.

In a modern view of science, the facts, concepts and theories which make up scientific knowledge are neither permanent nor beyond dispute. They are much more like a report on progress so far, which future investigators will modify and even, maybe, contradict. Any scientific theory is, to put it simply, the best agreed explanation which scientists have produced up to the present. Theories are not final, and certainly not true with a capital T: they are provisional, and are used until something is observed which contradicts them or which they cannot explain. When that happens to an important and influential theory, something rather like a scientific revolution occurs: an old theory may be discarded and a new one is invented, tested, discussed, negotiated, refined and eventually accepted, or rejected, by the scientific community. Large-scale scientific theories such as the theory of evolution can never be proved true beyond all doubt. Older views of the nature of science held that the strength and reliability of scientific knowledge and its claim to be highly regarded were based on its certainty; on the way it had been tested and proved true. It was as if the 'scientific method' could infallibly find a way to know for sure. Newer ideas take almost exactly the reverse view. Today, the strength of science can be thought to lie in its openness to criticism and correction. Science is regarded as a powerful and influential activity precisely because the truth of scientific knowledge cannot be taken for granted and because it is always open to question. Like other human activities, science is fallible. This does not mean that science is simply guesswork or that 'anything goes'. On the contrary: whether in the research laboratory or the primary school, no observation, idea or theory should be accepted until it has been tested in as fair and as thorough a way as possible (1.10), while remembering that testing ideas and theories cannot prove that they are true. Testing may be essential, but it can do no more than help us to decide whether our answers and explanations are good enough to accept *for the time being*, until they obviously need correction or a better idea emerges. How then can there be any measure of the reliability of scientific knowledge? Because when it is used in research, technology or everyday affairs, it is constantly being tested against experience and



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what can be observed in the world. Of course all this is not necessarily *directly* applicable to our teaching in the sense that we tell children about all these ideas explicitly (although we can, in some situations) but indirectly, an appreciation of the uncertainty of science is helpful to teaching science investigatively because we can reassure ourselves, as teachers, that tolerance to uncertainty in our own and our children's learning is a feature of science itself.

1.3 THREE KINDS OF KNOWLEDGE

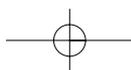
Becoming scientific includes developing three kinds of knowledge, which have been called knowledge 'that', knowledge 'why' and knowledge 'how to'.

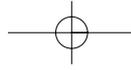
1.3.1 Knowing 'that'

Knowing 'that' is the knowing of facts, events and changes. It is the kind of knowing which grows out of, and enables us to answer, factual questions beginning with **what, where, when** and **how**. **Becoming scientific involves learning more scientific facts.** Examples of knowledge 'that' are that *muscles only pull and do not push* (3.5), that *if steam is cooled it condenses into liquid water* (6.2.2) and that *steel is a magnetic material, but brass is not* (12.3). Knowing 'that' is important because it gives us an account of how the world is thought to be, and helps to frame our expectations about what we may see or what may happen in the future. For example, if a child knows that when sugar dissolves in water, it does not disappear but mixes with the water, she is likely to expect the solution to taste sweet, whereas if she does not have this knowledge the sweetness is likely to come as a surprise. Surprises are particularly important in both scientific research and education. We feel surprise when we experience things that do not happen as we expect. What we expect has grown out of what we know and understand. A surprise may signify that the new evidence is challenging our existing personal theory. This means that **surprises should always call for investigation** both in what we know (knowledge 'that') and in our understanding of it (knowledge 'why').

1.3.2 Knowing 'why'

Knowing 'why' is concerned with identifying causes for what has been observed (1.3) by seeking explanations and by gaining understanding rather than gaining factual knowledge. It is the kind of knowing which grows out of, and enables us to answer, questions beginning with 'Why ...?', and which can be summed up in statements beginning with 'Because ...'. Knowledge 'why' is usually more complex than knowledge 'that', because it starts with the facts and seeks to explain them. **Becoming scientific involves learning explanations and under-**





standing. Most established scientific theories are highly developed and tested examples of knowledge 'why'. For example, why does the Sun seem to move across the sky during the day? It seems to move because the Earth is spinning and we are carried round with it, so the angle from which we see the Sun changes through the day. This is an explanation which grows out of the theory that the Sun is at the centre of the Solar System and the Earth is in orbit round it (14.2.1). The nature of knowledge 'why' is explored further in section 1.7, in relation to the making of hypotheses.

Scientific knowledge is commonly thought of as knowing 'that' and knowing 'why', but the third kind of knowledge, knowing 'how to', is just as important. Science is not only concerned with knowing and understanding: it is also concerned with practical investigation, and the ability to investigate effectively is particularly important in primary science, where theories of learning advise us that children's learning depends as much on personal, first-hand experience as on being told about things or reading about them.

1.3.3 Knowing 'how to'

This is an essential part of becoming scientific. There are two main kinds. One is concerned with knowing how to do investigative processes and procedures, including 'fair' tests for ideas and theories (1.10). For example, investigating scientifically whether a parachute with a small hole in the centre is better than one with no hole depends on knowing how to set up and carry out fair and thorough testing. The other kind of knowing 'how to' is about making things work practically in a controlled and predictable way. It is often on the borders of science and technology. Most testing of scientific ideas and theories involves knowing 'how to' of both kinds. For example, if children want to find out which of a collection of play-balls is the bounciest, they have to carry out a fair test. This will involve not only knowing how to conduct a fair test by identifying and controlling variables (1.10), but also the practical knowing how to devise and use a method for measuring accurately how high each ball bounces.

An important point needs to be made here about the use of Information and Communication Technology in helping children to learn science. It is increasingly easy to find visual ways of indirectly experiencing scientific ideas on a screen, some of which may give opportunities for the teacher to demonstrate cause and effect relationships. They can help children to gain 'knowing that' and 'knowing why' in science. However, children can only develop 'knowing how to' by doing their own practical investigations and gaining direct experience of the challenges of finding out for oneself. This is when they best feel that they are becoming scientific and it is where technology can be immensely helpful in making better measurements and records to strengthen the evidence base for testing ideas.

Scientific investigation makes two important contributions to primary education. First, it helps children develop the ability to perceive problems, think up





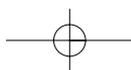
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possible answers, find out whether their ideas stand up to testing and communicate their findings clearly. Second, it develops a critical awareness of science and its influence within the community. As far as anyone can predict, the lives of children who are in primary schools today will be affected even more by science than the lives of their teachers and parents are at present. There is an obvious need for as many people as possible not only to understand something of the scientific knowledge and theory which affects their lives, but also to be critical of scientists' claims. Critical evaluation of any kind of knowledge or discovery is impossible unless one knows how the results were arrived at. This is because, **in any kind of investigation, results and ways of working depend on and shape each other.** What is discovered depends not only on what is investigated, but also on the methods used (1.5) and the ideas, knowledge and experience of the investigator. This means that first-hand investigations are relevant and valuable not only because they develop knowledge, understanding and the ability to investigate competently, but also because they help to give children a more realistic insight into how science works, its achievements and (equally importantly) its limitations.

1.4 THE TOPIC APPROACH

Becoming scientific is largely concerned with investigating through first-hand experience which helps children to understand the world around them. This presents the teacher with great opportunities, but can also raise problems. One major problem when trying to develop a science education based on first-hand experience is that it is impossible for children to investigate everything in their lives, so choices have to be made. Another is that real-life situations are usually much more complex than the artificially simplified world of the science laboratory. A third is that the experience which children bring to school, and the learning opportunities offered by each school's locality, are as varied as the localities and life itself. The topic approach used in several parts of this book offers one way to overcome such problems: to exploit local conditions and resources effectively and to help ensure the relevance of science investigations to children's lives and experience. This is consistent with the current curriculum planning advice, for schools to develop their own interpretation of the National Curriculum, contained in *Excellence and Enjoyment*.

There are two main ways of using the topic approach. The first is for planning in which the science component is focused on particular resources and opportunities. For example, if there is a building site near the school it could, with good liaison, act as a focus for work on the properties of materials, and physical and chemical change, which would fit easily with related work in most other areas of the curriculum. The second use of the topic approach is relevant to teaching about complex aspects of science such as living things and the environment where a



great variety of animals, plants, environmental conditions and climate are involved. It offers a means of reducing such complexity to manageable proportions. For example, instead of trying to investigate a range of ecosystems (5.7), a topic could be focused on one or two (preferably small and simple) habitats. Using expert help where necessary, the animals and plants can be identified, conditions measured and an understanding of each ecosystem built up, which can be related to general theories and principles. Using this approach, children are likely to gain a greater insight into, and respect for, areas which they might previously have ignored as trivial. It has the added advantage that information, understanding and expertise can be accumulated over a period of time, so that the burden of preparatory work becomes less as the quality of experience for the children increases. The topic approach is also recommended when children are learning and investigating in the context of large-scale scientific theories such as adaptation (5.5, 5.6) or chemical change (6.3.2) when the teacher chooses one or two examples as case-studies, researches these in detail and helps the children to see, through their own investigations, how these relate to the broader scientific ideas.

1.4.1 Children's questions

A teacher's planning for children to become scientific using a topic approach can draw upon a hugely powerful resource: the children's own questions and problems. The first national curriculum project in primary science stated that:

We concluded, and believe very strongly, that a child should raise his/her own scientific problems, partly because isolating a problem is an important part of scientific thinking, partly because the ever increasing body of knowledge makes it increasingly ridiculous to prescribe what any child should know, but mostly because we do not believe that anyone can ask a completely significant question for someone else. This would demand a complete appreciation of the person's ability, and the extent and quality of previous experience, and *only the individual him/herself can ask a question which takes all that into account.* (Wastnedge, 1968: 642, emphasis added)

A topic can begin with a visit to a building site or an interesting habitat near the school, or with making a classroom display or collection of interesting things that relate to the topic, e.g. shiny things that prepare for learning about reflection of light. This **experiential starting point** arouses children's curiosity, scientific thinking and discussion about what they already know and want to learn next. Then their teacher can help them to express their curiosity through questions, and help them to sort out which of their questions are investigable ones. Until this point is reached, the teaching objectives in the plan are broad ones, but now it becomes possible to define specific objectives and personalized targets for particular children and groups. This is done when the teacher elicits children's investigable questions or problems and negotiates with them over which ones



lead to appropriate practical investigations and how to seek answers or solutions. The point made in the quotation above is that a teacher cannot know with sufficient detail or accuracy everything that is crucially relevant to each child's next step in their learning, to plan what to do. However, children's own questions and problems, which are intuitively based on their own starting points for learning provide the first step in achieving the topic aims. Therefore the topic plan should elicit and respond to children's questions and problems. Children who are enabled to share control over their learning in this way become more fully learning partners with each other and with their teacher.

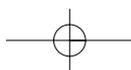
1.5 PATTERNS IN SCIENTIFIC INVESTIGATION

Another important implication of a modern view of science (1.2) is that science can, to some extent at least, be demystified. Scientific investigation and research are often seen as very complex, but it is possible to see how they are rooted in, and grow out of, the common-sense sort of investigations which people use in everyday life. Although scientists have sophisticated ways of working and testing ideas, and they use special materials, equipment and methods, there is no 'scientific method' which is right for all kinds of enquiry and which always leads to the discovery of the truth if it is properly applied. This more open and flexible view of scientific investigation is particularly important for primary education because it makes it possible for teachers to see a clear relationship and progression from children's exploratory play in the early years, through increasingly well designed investigations as they grow older.

Scientific investigation grows out of human exploratory behaviour as a whole. What makes it scientific is not a special method, but the fact that it is carried out in an agreed and thorough way. It is applied to questions and problems which scientists find interesting and significant, using existing scientific concepts and theories which are tested by being used in this way. Very similar kinds of investigation are carried out by many people – historians and archaeologists, for example – but their work is not science because their purposes are different. Children become scientific in their thinking and learning when they too apply scientific ways of investigation to the questions and problems which they find purposeful.

1.5.1 Purpose and curiosity

Children do investigations to answer a question or solve a problem about what they perceive as relevant to their personal and social interests. This is basically the same as for scientists except that personal and social interests may also serve commercial or military interests. As teachers, we need to honour children's interest as the motivational drive for their learning. We need to do all we can to stimulate their curiosity, and nurture its expression in the questions and prob-



lems they raise. All that follows in the rest of this chapter is founded on an assumption that scientific skills and processes occur in the context of whole, real investigations that link closely to questions and problems originated by the children themselves as their purpose for learning. If we think about B. F. Skinner's claim (1964: 94) that 'education is what survives, when what was learned has been forgotten', then maybe our greatest aspiration as science educators is that even if our children forget some of the science knowledge they learned, then at least, they will have been educated to be scientifically purposeful and curious, and know how to go on inquiring scientifically into new knowledge.

1.5.2 Variety and style in learning and investigation

Although scientific investigation is not governed by a rigid formula and a precisely defined method, this does not mean that there are no patterns and sequences in answering questions and solving problems. One of the most fundamental patterns in any investigative activity is the integration of two apparently opposing qualities: creative imagination and strict criticism. In science, the ability to come up with bright ideas has to be allied to the logical thinking, thoroughness and practical ability as an investigator which are needed to test both one's own ideas and those suggested by others. Strict standards and fairness are useful to understanding how scientific ideas are tested and criticized, but the process by which a person actually creates the ideas themselves cannot be described in this way. It is not that there are no patterns in the ways that ideas, knowledge and possible solutions to problems (see hypothesising 1.7) are arrived at. Quite the reverse: there are so many patterns that it is impossible even to attempt to describe them. As much as anything else, it is a matter of personal style.

Different children and adults trying to learn and solve problems are likely to look for knowledge and possible solutions in quite different ways. The two extremes of learning style can be represented by the following two models:

- *Knowledge first*: facts, concepts and theories are taught, and the learner integrates them with remembered experience and existing knowledge. Later, they are made meaningful, extended and modified by being applied to observation, interpretation and prediction of real-life situations.
- *Experience first*: hands-on experience, coupled with existing knowledge, is provided by the teacher to develop a new idea. Learners then verbalize, communicate and make it meaningful by modifying or extending their existing knowledge.

In practice, no one seems to rely solely on either of these models. Any person's learning is likely to be a complex interaction of both, but individuals may show a marked preference for one of these styles of learning and dislike the other.

Some topics in science may also lend themselves more readily to one style of learning rather than the other. For example, when learning about basic plant structure (4.2), the 'knowledge first' approach is likely to be helpful. Basic and



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partly familiar concepts such as stem, leaf and bud can be introduced and related using a diagrammatic plan (Fig. 4.1) as an 'advance organizer' before children try to identify and interpret the varied forms of real plants. In contrast, children can arrive at concepts of magnetic and non-magnetic materials and magnetic poles (12.3 and 12.4), through exploratory play. Their ideas can then be verbalized and shared in discussion, brought into line with accepted scientific terminology and consolidated by being used in further investigations.

1.5.3 Creativity and criticism

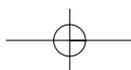
When we watch children being scientific, their ideas develop, like ours and scientists' do, from a combination of imagination and criticism. When we see children who seek safety in plodding through all the possibilities methodically we can encourage them to guess more boldly and take a bit of a risk. On the other hand, some children just make a wild guess and stick to their idea come what may, so we need to encourage them to think if it makes sense and fits all the observations. Through guessing, criticizing and testing ideas against experience, everyone can learn that ideas can be changed and improved. A really useful and testable idea is often arrived at in several stages, each one getting nearer to the final idea by eliminating what can be shown not to fit the evidence, or adding some new evidence. Once a testable hypothesis (1.7) has been arrived at, stricter rules and patterns of activity have to be followed in order to test it properly, involving the identification and manipulation of variables (1.10).

1.5.4 Investigative skills

Although there is no precisely defined scientific method, different authors identify different sets of skills, processes and 'process skills' that are used in scientific investigation. By watching and talking to children when they are being scientific, we can learn about how children use them in their investigation. In the National Curriculum, Sc1 refers not only to the importance of *ideas and evidence in science* but provides lists of *investigative skills*. The meaning of both is defined with increasing depth and detail at each Key Stage. Here, investigative skills and processes are presented in the rest of this chapter in five groups: observing, hypothesizing, predicting, experimenting and fair testing. They are the scientifically most important ones to understand and to use in teaching primary science.

1.6 OBSERVING

Scientific observation can use any of the senses, but for simplicity, and because vision is for most people by far the most important of the senses in scientific investigation, we will focus attention on observing through sight. However, as



teachers, we can encourage children to learn through experience by using all relevant senses, with the proviso that we know if there are risks, particularly in using taste and smell to investigate, and that we take appropriate action to manage such risks. Observation is a well recognized feature of very young children's scientific learning, but tends to be an undervalued part of being scientific with older primary school children.

Vision is not simply a matter of opening our eyes and allowing light into them. It is a complex process, involving the eyes and the brain, by which we carry out an exploration or investigation of the world around us (3.10). Our brain directs the scanning of our eyes in response both to the information reaching it, and what we know or remember. The result is that what we see usually depends very much on our prior knowledge, understanding and experience. A rare or unusual plant, for example, is likely to attract the attention of a knowledgeable person, whereas someone who knows little about plants may not even be aware of it, even though both are looking in the same place. As scientists use the term, however, observation implies something rather more than simple recognition: it can usefully be thought of as *seeing-with-understanding*.

I can say I have observed something in the scientific sense when I have both perceived it and realized something of its importance or significance. For example, most trees have green microscopic plants (algae) growing on their trunks and branches, but when we see the trees, only a few of us are likely to be aware of the algae, or to observe that on most trees they grow in particular patterns. (More algae grow in parts of the bark where there is shade or the sunlight is less strong and also where there is more moisture more of the time.) Also, if I say I have observed the pattern, it does not necessarily mean that I can explain it, but it does imply that I have realized that there is something to be explained. Once a pattern of this kind has been investigated and understood, it is much more likely that similar patterns will be observed elsewhere, on walls and buildings, for example. **In science, observation and understanding reinforce one another: the more we know and understand, the more we can observe, and the more we observe, the more we will learn.** In primary science, children need to learn in the same way.

Like the other processes and skills, observation rarely if ever takes place on its own, but is rather part of a purposeful activity. If I wish to observe how woodlice behave when they are given a choice between damp and dry conditions, for example, I will concentrate on the pattern of their movement and activity rather than on the details of their structure, even though those details are there to be observed and, in other circumstances, might be what I want to learn about. So observation is a very disciplined activity and for most children, learning to concentrate and observe in this purposeful way is a very gradual process, requiring patience and skill from the teacher as well!

In many scientific investigations, observation is accompanied by measurement, requiring the development of a complementary range of skills related to



numeracy and computational ability on the one hand, and manipulative skill on the other. Here again, the experience and judgement of the teacher are likely to be fully exercised to ensure that the kind of measurement, the scales used and the accuracy required match both the nature of the investigation and the understanding and skill of the pupils.

Before moving to another aspect of being scientific, it is worth bearing in mind the earlier point about the importance of children's curiosity. A teacher who was describing (a little unkindly?) how closely one of her children was observing the spiders in the tree outside the classroom said: 'Now, she watches them laying eggs and sees the eggs hatch, but before she wouldn't have seen the tree!' The teacher had not directly taught this child to observe, but had encouraged the child's curiosity for ideas and experience. As soon as curiosity appeared, the teacher fostered it by modelling close observation and asking the child questions to provoke more and better observations, such as: 'What is it like? What can you notice? Does it always do that? Does it change? How is it similar/different is it from X?'

1.7 HYPOTHESIZING

Before asking what a hypothesis is, let's begin by asking what part it plays in a scientific investigation. Like children, scientists carry out investigations in order to answer questions or solve puzzles and problems. Hypotheses are simply the guesses or tentative answers or untried solutions to these questions or problems. They are guesses which we want to test, to see if we are right. For each kind of scientific knowledge – knowing 'that', knowing 'why' and knowing 'how to' (1.3) – there are corresponding kinds of scientific hypotheses.

1.7.1 Descriptive and predictive hypotheses

These relate to knowing 'that'. They are either statements about matters of fact (descriptive hypotheses) or simple predictions about what is expected to happen (predictive hypotheses). They are a very common starting-point for children's hypothesizing.

Examples of hypothesizing may occur when children are investigating rolling cars down a ramp. They may make a descriptive hypothesis such as 'The steeper the ramp, the further the car goes across the floor' or make a predictive hypothesis, such as 'If we raise the end of the ramp, the car will go further', which is a different form of the same idea. Other examples include: 'The red car will go further than the green one', 'This ball bounces better on the floor than on the carpet' and 'This paper towel absorbs the most water'. All these are quite straightforward descriptive or predictive hypotheses. They claim to say something about a part of the world which the child has experienced and is investigating, but they



need to be tried and tested to see whether or not they are true. Unlike the more complex causal-explanatory hypotheses (see below), there is usually a simple way in which this testing might be done. Predictive hypotheses and some kinds of predictions are very similar.

Descriptive-predictive hypotheses play a valuable part as children's investigative ability develops, because they can often lead directly on to more complex learning such as causal and explanatory hypotheses. For example, quite young children may hypothesize that: 'all balls bounce better on hard surfaces than on soft ones' and children with more investigative achievement may go on to guess why.

1.7.2 Causal and explanatory hypotheses

These are guesses **why** something happens as it does. Scientists are rarely if ever content with factual knowledge (knowing 'that'): they also seek understanding (knowing 'why'). There are usually two aspects to scientific understanding. The first is to identify the **cause** for what has been observed; the second is to seek an **explanation** of it. For example, if I run fast, my pulse rate increases. The cause of this is that my heart is beating faster, but identifying the cause does not explain why it happens (see 3.9). This is usually more difficult, involving scientific knowledge, understanding and previous experience, and much of this book is devoted to providing scientific explanations for commonly observed objects, events and changes. (By the way, an explanation for my heart beating faster is to do with a complex series of causes and effects involving my muscles using up oxygen and producing carbon dioxide at faster rates than usual, changes in the concentration of these gases in my blood, and the mechanisms of control over my heart rate.)

When we seek causes and explanations, to develop our knowledge 'why', our hypotheses are different from descriptive-predictive hypotheses. For example, a child observes that when a candle is first lit, it often burns with a small flame, which becomes much bigger after a few minutes. S/he may learn to predict that this will happen routinely. Then s/he might wonder why this happens and guess that: 'The flame gets bigger because the wick gets longer'. This is a causal hypothesis: it identifies the cause of the change but does not explain it. To do that, an explanatory hypothesis is needed, which might be, 'Because the wick is longer, melted wax is vapourized and burnt at a greater rate, so the flame is bigger.' (8.3.2).

If children make a statement, whether a spontaneous guess or something more considered, which could be rephrased as: 'I think it may happen because ...' they are almost certainly making a causal or explanatory hypothesis. Once we as teachers are able to recognize this kind of statement, we can notice that most children are generating them all the time. Most of their intuitive theories about the world and themselves are ideas of this kind; for example, the idea that



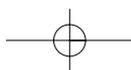
seeing consists of sending out a ray from the eye to the object which is seen (13.4). The teacher's role is to help children identify causes and think up possible explanations using their observations, their prior experience and their existing scientific knowledge and understanding. Learning to do this is likely to be a long, gradual process, so we need to support its development patiently.

Sometimes explanatory hypotheses can be generated easily. For example, children watching woodlice disappear into damp leaves are likely (among other, less testable ideas) to hypothesize that they do it 'Because they don't like light' and 'Because they like damp places'. Often, however, causal and explanatory hypotheses have to be arrived at by longer and less direct thinking involving ideas and evidence. When trying to find out why some seedlings grow more than others, for example, or why an electric lamp is dimly lit, it may be necessary to identify causes by eliminating possibilities: 'It can't be the water because we watered them all the same', or 'It's not the battery because we tested it with another lamp'. This kind of thinking is allied to the scientific meaning of fair comparison or fair testing (see below). Perhaps the greatest challenge facing teachers of science is to help children to develop this way of thinking without stifling their spontaneity and creativity.

1.7.3 Procedural hypotheses

These are guessed ways of how to find out and how to make things work better, using and developing knowing 'how to' that is concerned with the procedures and practicalities of experimenting and fair testing. Procedural hypotheses are concerned with setting up fair tests (1.10). For example, if we want to test the (descriptive) hypothesis that the weight of a person affects how easily a trainer shoe slips on the floor, we need to test it in ways that are scientifically fair. If we are not sure how to carry out a fair test, we may have to imagine an untried method of testing. This is the procedural hypothesis. We may try out a procedure in which we put different metal weights on to a trainer shoe and measure how much force is needed to make it slip. Any possible solution such as this to the procedural problem of how to test the original idea, may have to be modified if it is found to be unfair. Our knowing 'how to' is developed through repeated practical investigations in which we realize that there is a factor which has not been properly controlled or our observations or measurements are not reliable. Talking and planning are no substitute for practical experience in gaining the know-how and ingenuity to make things work and take reliable measurements, neither is a computer generated simulation or demonstration.

Children who are testing the 'strength' of magnets by attraction, or comparing the tearing strengths of different papers, have to invent some device to carry out the test. It is most unlikely that they will achieve this without a process of testing and modifying. During the development process



the children are likely to go far beyond what they have expressed or could express in words or drawings, through what they actually make and test and the intuitive know-how that they gain. Also, their quality of understanding will be way beyond what they could gain from passively watching a computer presentation of the same ideas. It is practical experience of the devices themselves which are the trial solutions to the problem; the procedural hypotheses. Like other hypotheses that have to be tested. Do they satisfy the requirements of fair testing and do they work reliably?

Here is a summary of the three ways of scientific knowing and the related kinds of hypothesizing.

Kind of knowing	Examples of each kind of knowledge	The related kind of hypothesizing	Examples of each kind of hypothesis
Knowing that: Facts, events, changes	Muscles only pull and do not push. If steam cools it turns into liquid water. Steel is a magnetic material, but brass is not.	Gussed description or prediction of what will happen.	The red car will go further than the green one. The ball bounces better on the floor than on the carpet. The paper towel absorbs more water than the piece of plastic sheet.
Knowing why: Identifying causes, explanations, understanding	The reason why the Sun seems to move across the sky during the day is because the Earth is spinning, and so the angle from which we see the Sun changes throughout the day.	Gussed cause of what happens or a gussed explanation of what happens.	The red car may go further because its wheels have less friction and turn more easily than the wheels on the green car. The ball may bounce better on the floor because the floor is harder than the carpet. The paper towel may absorb more because it has tiny spaces in it where the water goes, that the plastic sheet doesn't have.
Knowing how to: Carry out scientifically investigative processes and procedures, making things work	How to test the idea that a parachute with a hole in the centre is better than one with no hole, means changing the independent variable, measuring the dependent variable and keeping all the other variables the same each time.	Gussed procedure for how to find out or a gussed method of testing.	If I put different weights on the same training shoe and measure how big a force is needed to make it slide across the same surface at the same speed, then I may be able to find out if a heavier weight on the shoe makes it slide more easily or less easily. If I slowly move a magnet closer to a paper clip and measure the distance between them just as the clip jumps on to the magnet, I may be able to do this with several magnets, to find out which one is the strongest.



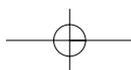
1.8 PREDICTING

Predictions are statements about what we expect to happen in the future. They are used in scientific investigation in two ways.

The first form of prediction is the predictive hypothesis (1.7.1), which young children especially are likely to make in the form of a simple guess, such as 'If you load the trolley with Plasticine it will go further'. The ability and willingness to predict in this way (and risk being wrong) is of great importance in developing an awareness and understanding of the links between causes and effects. Children can develop this awareness if we encourage them to look for patterns emerging from their observations and measurements and predict future observations and measurements. For example, children who are investigating the effect of hanging weights on rubber bands may observe a pattern that if the weights increase, then the bands get longer. We could ask them to record this by drawing and we could ask them to write down measurements of the length of the elastic band for one weight, and predict what the length will be when a different weight is added. Maybe adding a weight that is twice as heavy will make the increase in the length of the elastic band twice as big. The ability to predict in this way can be used to sharpen observation and help in the search for explanations wherever predictable patterns are to be found.

The second form of prediction is more complex. It becomes important when a causal or explanatory hypothesis is being tested. We need to make a prediction based on our hypothesis and find out, by observing or experimenting, whether it is true or false. For example, if children hypothesize that the bending of plants towards a window is caused by light coming from one side, it could be predicted that if the plants are turned through 180° they will straighten up, then bend towards the light again, and this prediction could be tested.

Although strict logic requires us to make a prediction when a causal or explanatory hypothesis is being tested, both children and adults often do not state the prediction explicitly because we tend to go intuitively from hypothesis to testing by observation or experiment. Children who hypothesize that woodlice do not like light, for example, will usually set about devising some kind of choice-chamber to test their idea. This does not mean that they have no clear idea of what they predict will happen, but that they have not made their prediction explicit. If things go as the children expect and their hypothesis is upheld, this does not matter, but if their implicit prediction is wrong and the unexpected happens, it may be necessary for the teacher to backtrack and tease it out with some questions such as, 'What did you expect to happen?' and 'Why did you think that would happen?'



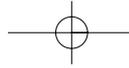
1.9 EXPERIMENTING

'Experiment' is a much misunderstood and misused word. It may be used popularly to refer to any practical experience that is perceived to be scientific in some way, including playful exploration. It may be used to refer to a practical way of showing a scientific principle or idea. Although this is a valuable way of teaching, it is a demonstration, not an experiment. The term 'experiment' is also used quite often when what is really meant is investigation by trial and error. For example, children making, testing and modifying parachutes to find out which designs and materials work best, could be described by many people as 'experimenting', whereas they are doing something much wider and more varied. Experimentation is only one part of an investigation. To confuse the two is to risk failing to notice all the other skills and processes (such as hypothesizing and predicting) which are being used as part of the overall activity.

The strict scientific meaning of **experiment**, is to devise a practical test of a hypothesis. If I hypothesize that the amount of water used to mix concrete has an effect on its strength when set, I have to set up a special test situation, under strictly controlled conditions (1.10) in order to find out whether the idea is true or false. It is this special test situation which is the experiment. Many hypotheses cannot be tested by setting up experiments. For example, if I hypothesize that the pattern of green micro-plants on a tree is related to water supply, I have to test that idea by controlled observation, interfering with the natural situation as little as possible.

Young children may switch from a broad investigation (How to make the best parachute) to a much more focused enquiry involving systematic experiments (How does a hole in the middle change how a parachute works?). It is useful to be able to identify this switch, because children may begin experimenting without being entirely clear as to what idea it is they are testing; in other words, with an unstated hypothesis. As with unstated predictions (1.8), this may raise no problems, but if the experimental procedure becomes too complex to manage or the children find it difficult to communicate their findings, it may be necessary for the teacher to go back and help them make clear to themselves exactly what idea it was they were testing, and what they expected to happen.

Effective experiments rely on a wide range of knowledge, understanding and skill. Most fundamental, perhaps, is the ability to decide what evidence is needed to uphold or reject a hypothesis: can the experiment really be a good test of the idea? Then the experimenter needs the ability to identify all the variables which need to be controlled (1.10) and the ingenuity to invent ways of controlling them, as well as the practical skill to think up a valid, workable experimental procedure and carry it out. This apparently complex process is possible at primary level only because, like other science skills,



experimentation in a well managed science programme is an extension of children's natural exploratory and investigative play: a more refined, reasoned and disciplined version of what they do spontaneously. Children do not need to be taught the capacity to be scientific because they have it already. They need to be taught how to become more scientific.

1.10 'FAIR TESTING' AND THE CONTROL OF VARIABLES

Although the idea of a single scientific method cannot be upheld, the scientific community expects that hypotheses will be tested thoroughly and fairly before they are published in research papers or books. Children can and should begin at primary level to develop both an understanding of the principles behind this kind of testing and the practical ability to carry it out. The practical arrangement of the toy car experiment is used to illustrate this.

Identifying variables. The first stage in scientific testing is to identify clearly what the focus of investigative interest is. This may not be simple. For example, if children are investigating how far a toy car will move when pushed by releasing a stretched rubber band, there are many factors which could be changed and which would affect the outcome if they were. Every factor that we can observe and/or measure is called a variable. In the toy car investigation, the variables include: the kind or number of elastic bands used, how thick and how long they are, what quality of rubber they are made of, how far they are stretched, how the toy car is released, how large a load it carries and the surface it runs on. Our first step is to list as many of these variables in the situation as possible.

The independent variable. After we have identified the variables, we decide which of them is relevant to the hypothesis we want to test. This may require children to state their hypothesis and predictions in a much more precise way than they had done up to that time. For example, if the hypothesis is that 'Using two elastic bands makes the toy car go further than one', then the focus of interest is the number of bands used. This is the variable which the tester is going to change in order to see what happens, and it is known as the independent variable. It is part of the hypothesis which guesses what is the **cause**, and the guessed **effect** is how far the toy car moves.

The dependent variable. The next stage of the testing procedure is to identify what outcome is to be observed or measured in order to find out the effect of changing the independent variable. This is called the dependent variable, and in our example it would be the distance travelled by the toy car. The dependent variable is the guessed **effect** of the cause-effect relationship expressed or implied in the hypothesis.



Control variables. Once the independent and dependent variables have been identified, the next stage of the testing procedure is to identify all other variables which could affect the outcome. For the test to be fair, these must be controlled, which means that they must be kept the same throughout the test procedure. These are known as control variables and in our example these are all those originally noted, except the number of bands used. If these variables are not controlled, the test cannot produce a valid result. For example, if the number of bands was varied, but the amount by which they were stretched was not kept exactly the same each time, it would be impossible to say which of the two variables had produced any differences observed, so the hypothesis would not have been fairly tested.

Summarizing a fair test procedure. This can be made easier by following a simple sequence of questions:

1. What should be changed in the test? (Identify the independent variable.)
2. What should be observed to see the effect of changing the independent variable? (Identify the dependent variable.)
3. What should be kept the same to make sure the test is fair? (Identify the control variables.)
4. How will the results be used to decide if the hypothesis can be upheld? (Work out what would be concluded by the different outcomes.)

Although children often like to rush into carrying out tests, they gradually need to learn that it is good scientific practice to adopt a disciplined approach and make sure that these questions have been clearly thought about before the practical work begins. If not, a great deal of time and ingenuity may be wasted on what turns out to be an invalid or badly devised test procedure. Despite our best efforts, however, it is sometimes necessary for children to have a frustrating or disappointing experience of presenting their evidence to the class, and facing the criticism that it does not test the hypothesis in a way that persuades others is really fair. In our example, it may be necessary for the children to realize that they cannot say for sure that two elastic bands make the toy car go further, because they did not take enough care to stretch them to exactly the same extent, before they fully realize the importance of following this method. Until this point, they may have been using the idea of fair testing in a ritualistic, uncomprehending way, because 'the teacher told us to do it like this' or because of a vague sense of social fairness: 'we keep them all the same, just to be fair'. We want them to be able to claim that they **know that** two elastic bands make a toy car go further than one, having used their **know how**: they have tested their idea rigorously and they have evidence that the effect (of the toy car going further) was not due to a different cause (a different amount of stretching).

1.11 THE ROLE OF SCIENTIFIC CONCEPTS AND LANGUAGE IN SCIENCE EDUCATION

1.11.1 Language

In science, as in any other human activity, the need to communicate clearly and efficiently has led to the development of a specialized language, which can become a jargon if it is used insensitively or out of context. When scientific language is used correctly, a term such as 'gravity' is like the tip of the proverbial iceberg: a convenient verbal shorthand for a complex set of concepts which the speaker shares with the remainder of the group, and which contribute both to understanding and the ability to use scientific ideas to investigate further.

A problem with using specialized language in primary science occurs when mere use of a technical term is taken, either by the teacher or by the children, as evidence of understanding. When trying to describe or explain what has been observed, both children and adults may assume that the correct use of a word in an appropriate context is all that is required. Instead of being the tip of an iceberg of shared understanding, the word has become a thin layer of ice over a void of ignorance.

For example, if I hold up a ball, then release it so that it falls, and ask what happened, even quite young children are likely to answer 'Gravity pulled it down!' and sit back, convinced that this pleases the teacher because it answers all possible scientific questions about what they have just seen. But this raises two professional questions for the teacher. First, am I sure the child really does understand the full implications of what has happened and what s/he just said? Second, if I accept this reply, will it short-circuit all the observation, reasoning, discussion and growth of understanding to which even a simple event can give rise? Here is a way of coping with this teaching problem.

1.11.2 The 'describe-explain' strategy

The premature use of scientific language is unproductive, even when it is appropriate to the context, because it leads away from focusing on the experience which is of paramount importance if children are to develop their knowledge and understanding. A very simple strategy which can overcome this problem is to make as sharp a separation as possible between describing what has been observed and explaining why it happened or came to be that way: **first describe carefully, then explain.**

In the example of the dropped ball, a description might be: 'While it was being held, the ball was not moving. When it was released, it started to fall. It fell straight down and seemed to get faster as it fell, until it hit the floor. It bounced four times, getting lower each time, then rolled across the floor and stopped.'

After that it didn't move any more.' What is noticeable about this detailed description is that it does not involve any specialized scientific language or concepts, and this is true of most events, situations and changes that children at primary level will observe and investigate.

In most situations, a teacher can discourage a premature explanation of what children have observed until they have thoroughly described it, with all relevant details noted. Until this has been done, it is often not possible to assess exactly what needs to be explained. In the case of the falling ball, the teacher can focus on two separate sets of events: what happened before the ball hit the floor, and what happened afterwards. We observe that before the ball hit the floor, it began by not moving and then moved when it was released. We can describe the way it was moving as something that changed. Then we can explain that forces which were out of balance were acting on it (11.5) (see Figure 11.9d). Our description of the ball as seeming to carry on moving faster, can then be explained by saying that there was a force which was making it fall and it must have been acting on the ball all the time it was falling. At this point, the nature and identity of the force can be explored by asking a directed sequence of questions, such as:

'In what direction did the force act?' (Straight downwards, i.e. vertically.)

'Does the force always seem to act that way?' (Yes.)

'Is it acting all the time?' (It seems to.)

'Do you know a name for this force which tends to make things fall, always acts straight down and acts all the time?' (Gravity!)

Unlike description, scientific explanation does require the use of special concepts and language (in this case, forces out of balance, see 11.3), but technical terms should be used only after the explanation has been developed, to communicate what has been found out. Technical terms are important, because as scientists we need to communicate effectively, but their use can be deceptive if the user does not fully understand what they signify.

1.11.3 The role of scientific concepts

The 'describe-explain' strategy is useful because it not only helps to prevent short-circuiting of investigation by premature use of scientific language, but also it shows clearly the role of concepts in science and science education. At primary level and in most everyday situations, scientific concepts are not needed to describe the world. Their role is in identifying causes and developing scientific explanations for what has been observed, in helping people to make sense of their experience in scientific terms and to make accurate predictions. Separating description and explanation can make it much easier for teachers and children to understand both the nature of scientific concepts and the proper use of the specialized language to which they have given rise.



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Note that the 'describe-explain' strategy does use a somewhat artificial distinction. Particularly as children grow older, descriptions may require specialized language if they are not to become over-long and wordy, and explanations often lead back to fresh observations and the attempt to make a better description. If the children reach this stage, however, it is unlikely that the premature use of scientific language will be a problem: it is far more likely that the investigation itself will have assumed its proper role as the driving force behind the children's activity.



Refer to the CD-ROM for summaries of Progression in learning SCIENTIFIC ENQUIRY.

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