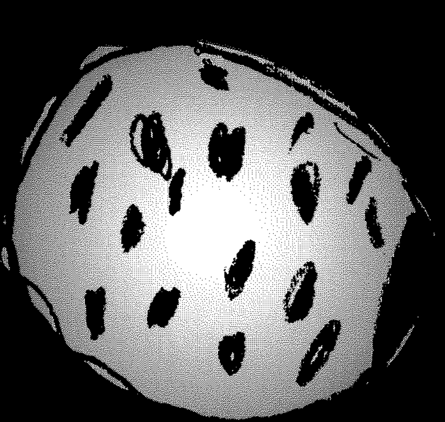
INTRODUCING SCIENTIFIC CONCEPTS TO CHILDREN



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INVESTOR IN PEOPLE

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1
INTRODUCTION

Science is most often an ***extension*** *of common sense, not an esoteric alternative to it*

(Jay Lemke, 1990, p.144).

Some background

If research into science education in the 1970s and 1980s has shown anything at all, then it is that pupils hold persistent misconceptions about numerous areas of scientific understanding. This realisation has gone hand-in-hand with the emergence of a whole perspective on learning known as 'constructivism'. For constructivists, learners' pre-existing beliefs determine how they make sense of experience, and therefore are a key determinant of what is learned from that experience. From this perspective, the presence of misconceptions hinders the development of scientific understanding, and mistakes made by children therefore take on special significance as indicators of pre-existing alternative beliefs about the world. Studies revealing the existence of these misconceptions are legion (Pfundt and Duit, 1994). There have also been attempts to guide teachers in ways of overcoming them, some of which involve adopting new teaching strategies and sequences under a constructivist banner (notably by the Children's Learning in Science group, CLIS, at Leeds University: see, for example, Driver *et al.*, 1985; Needham, 1987). Such perspectives and approaches now form an essential element in the preparation of new teachers of science and in specialist courses for primary teachers. However, in British primary schools, where the national curricula have science as a compulsory component, it is common for most or all the teaching staff to be involved in science education. What are the implications of the 'alternative conceptions' research for the non-specialist majority of primary teachers? Before addressing this question, it is worth reviewing the circumstances under which the move towards constructivist teaching approaches in science took place.

Because the mere handing over of information cannot take account of pupils' pre-existing ideas, constructivist theorists argue, it cannot always be effective. The great majority of studies of alternative conceptions have been carried out internationally in educational establishments at secondary or higher levels, and it is against the methods used in those classrooms (or perhaps against generalisations or assumptions about those methods) that constructivist approaches have been compared. Constructivist teaching approaches have been tried in primary schools on an experimental basis, notably by the SPACE project based in King's College, London, and Liverpool University. They are also advocated in publications by the National Curriculum Council (NCC, 1993). However, there has been little examination of the effectiveness of existing teaching approaches used to introduce scientific ideas by class teachers in primary schools, who reputedly have adopted more 'child-centred' methods than their secondary colleagues. Dagher (1995) makes an observation that we could well take as the motto for this research:

> *Developing a better understanding of what teachers naturally do is necessary to prevent the formulation of unfounded assumptions that lead to directives for action that ignore the richness of teacher practice.*
>
> (p.259)

The research reported in the following chapters began by examining a range of existing practice in typical primary classrooms. From these observations, the intention was to identify what teachers were achieving through their approaches to introducing scientific ideas. Often, the reasons why certain decisions were made and certain actions taken would not necessarily be explicit; teachers would work on the basis of implicit theories. The aim of the research was to provide a theoretical framework that would allow approaches to introducing scientific concepts to be analysed, and which would then be of use to teachers wanting to refine their methods and to others concerned with the processes involved in primary science teaching. It was also intended to use the framework to identify strengths in existing practice, and areas where that practice could be built upon to increase its effectiveness.

Our title for the project, and of this report, is *Introducing Scientific Concepts to Children*. We chose to focus on lessons in which particular scientific ideas were first introduced because the way in which teaching engages with children's existing understanding has been considered so crucial in establishing scientific ways of thinking. We recognise, though, that each lesson observed formed part of a longer sequence of work that would allow teachers to address aspects in more detail, or to build on the introduction by bringing in further concepts. However, unless it builds on a secure foundation, such further work must surely be imperilled. Hence this specific focus.

In the remainder of this chapter, the theoretical background to the research is discussed. Those anxious to press on and find out what the research is doing and what it is saying can afford to go straight on to the second chapter, which describes the research project and how it was conducted. The subsequent chapters bring out various aspects of the results, with the final chapter devoted to a discussion of the implications of these findings.

Some theory

What counts as effective introduction of a scientific idea? This is a question that has many dimensions. Some are quite general: a good lesson captures the interest of the children and holds their attention. Others are more specific to introducing *scientific* ideas, as opposed to introducing ideas from art or rules of spelling. It is these that are at the heart of this study. A key theme that has been maintained throughout previous work on the area of children's understanding of science is that teaching must 'start from where the child is'. But just what does it mean to do this in a science lesson? It is important that the research should offer some general insights, and not be confined to specific areas of scientific content. In the following sections of this chapter, some general principles are laid out that will underpin the research design and analysis.

Science — What is it?

The purpose of science is to develop ways of conceptualising how the world 'works' that enable people to understand it better and (often) to control aspects of how it works. There are three key elements in this process, as it is envisaged here.

The *world* itself, or 'reality', is assumed to be relatively stable and amenable to descriptions that capture something of the kinds of entities and processes that comprise it. This in itself is controversial, as some radical 'constructivist' theories of scientific knowledge deny that there can be any knowledge of an independent reality (von Glasersfeld, 1989). However, such individualistic epistemological theories cannot give an adequate account of how scientific theories may be evaluated or of how the relativist view that 'anything goes' can be avoided, and they therefore do not give an adequate account of what we call science (see Harré, 1986; Matthews, 1992; Olssen, 1996; Osborne, 1996). The idea that science addresses, albeit provisionally, real aspects of the external world is one that we will cling to closely in what follows.

Scientific knowledge takes the form of systems of concepts and theories. It is, in effect, a *language* for describing and explaining what reality consists of and how it operates. It is in the nature of scientific theories (as it is of any language) that meanings are determined in relation to the theoretical system as a whole — what Kuhn (1970) referred to as the 'disciplinary matrix'. As such, becoming a scientist is as much about learning and using a language as it is about carrying out experiments, and it is also necessary to conceive of children learning science in terms of their learning the language of science (Lemke, 1990). Like any language, the language of science constrains what we can say about the world and what we cannot, and also what we are inclined to look for in the world and what we are not. This is the opposite face of our commitment to realism. It means that it is not possible to get outside of language and see how well it corresponds with the world, independent of any conceptualisation of it (Wittgenstein, 1967; Putnam, 1981). It also means, significantly, that scientifically correct concepts and theories are not simply discovered through observing the world:

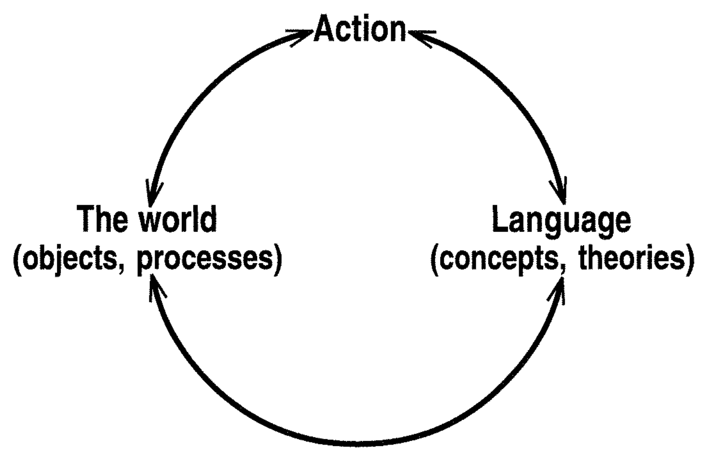
> *Learning science concepts involves the introduction of new ways of knowing through the social process of teaching, rather than making sense of the natural world through personal observation and thought.*
>
> (Leach and Scott, 1995, pp.50-51)

Observing the world also allows children to develop theories of their own that have a poor match to those of the scientist, and this is clearly no solution to the problem identified in the introduction.

Talk of learning science as a 'language', however, creates the impression of having to master a new set of words and linguistic constructions based upon them. It is, but it is much more than that. A native English speaker learning French has few problems working out what the language is 'for': problems such as how to get from one place to another or how to obtain food and pay for it are common experience to speakers of both languages. The purposes for which the language of science is used are quite distinctive from those of everyday living. As with any language, the link between the language of science and language-independent reality is forged through human *action*. It is in the context of activities of a particular kind that specific language uses become meaningful (Wittgenstein, 1967) and specific features of the world become significant; knowing *how* terms are used, and not just which are used, is important. Action in this sense is purposive. The purposes of science are based around cataloguing and characterising the kinds of things and processes inhabiting the world (Harré, 1986) in order to account for as wide a range of empirical content as possible. At first, many of these objects and processes are theoretical. However, through careful programmes of tests and experiments, a range of empirical content is built up which is interpreted as either evidence supporting current conceptualisations or else as grounds for re-examining the theory and the other assumptions behind the experiments (see Lakatos, 1970).

The interaction between these three elements may be portrayed as in Figure 1.1.

Figure 1.1: The construction of scientific knowledge



In the diagram, theories predict (or forbid) particular events, which then become the objects of empirical research. This research involves action on the world which provides the evidence required: either the predicted events occur as conceived, or they do not. This, as a result, may produce changes in the theoretical language or in the kinds of action demanded. The interaction is complex — more complex than this short account has been able to explore. However, it will suffice to move the discussion on.

If, as has been argued here, development of scientific knowledge arises in the interaction of existing theory, scientific patterns of activity and the material world, then a full appreciation of scientific knowledge must respect this interaction. To learn only a body of facts, for example, would not count as learning *science* because neither the evidential basis nor the theoretical rationale for admitting them as facts would be clear. Hence, in the National Curriculum for science in England and Wales, the three elements and their interaction can be discerned. In the programme of study for key stage 2, it is required that pupils be given opportunities to:

- use focused exploration and investigation to acquire scientific knowledge, understanding and skills
- use their knowledge and understanding of science to explain and interpret a range of familiar phenomena
- recognise that science provides explanations for many phenomena
- obtain evidence to test scientific ideas.

(GB. DFE and WO, 1995, p.7)

Nevertheless, because of the interdependence of scientific purposes, processes and concepts, gaining access to the world of scientific theory is not straightforward. The problem teachers face has two closely related aspects. Firstly, there is the question of how to provide a way into the circle for children who do not have at their disposal the full range of evidence and techniques available to the scientist. Secondly, there is the task of convincing children that scientific ideas are different from their own and that they are better for some purposes. The problem may be summarised as that of appreciating and acquiring the power of scientific ideas. This is no short-term aim, but an inroad needs to be made for each scientific topic in each classroom.

Models and analogies

The feature of scientific theorising that links language, actions and the world is the use of models. According to Halloun (1996):

> *Galileo (1564-1642) set the foundations for a modern epistemology of science whereby real-world systems are studied indirectly through abstract models. He showed us how to build* ***reduced, idealised*** *models (such as particle models) of physical systems, conduct* ***thought experiments*** *with such models, and consequently infer valid descriptions, explanations and predictions about physical systems. Science has since evolved more and more through model development.* (p. 1021)

The construction of a scientific model consists in drawing out the features of the physical real-world system that are considered (for the scientists' purposes) to be primary, and in linking these conceptually, and sometimes physically, so that inferences may be drawn about that system and its workings (ibid.). As Galileo's example testifies, the model typically incorporates simplifications and idealisations such as 'point masses' and 'inelastic threads'. Yet these impossible objects help the scientist to clarify how the real physical system might function. If, as Sir Karl Popper (1982) remarked, science is the art of systematic oversimplification, then models are the organising and simplifying tools.

Rom Harré (1986) describes how science progresses, in one respect, by providing an account of entities that become further and further removed from actual or potential observation. One important move in this chain is from what Harré calls *Realm 1*, the everyday world of directly observable objects like tables and billiard balls, to *Realm 2,* which comprises postulated entities that can only be observed with an advance in instrumentation — for example, viruses. Beyond that is a third realm of entities which could not, in principle, be observed, such as individual photons. Nevertheless, although it is not possible to observe the theoretical entities of science, we can refer to them through theories and also by means of events in the observable realm. For example, the appearance of a track in a cloud chamber may be accompanied by the declaration: '*That* is an alpha particle.'

The main means of moving beyond Realm 1 in the construction of scientific theories is the use of **analogical processes** grounded in our understanding of Realm 1: a physical model is projected on to the hypothesised entities and the supposed relationships between them. In this way, experience of the behaviour of billiard balls striking cushions on a table edge can lead to a model of the behaviour of light. Famous examples from the history of science include how the behaviour of a water pump inspired Harvey to consider the human heart as its analogue in the body, and Kekulé's dream of a snake biting its own tail which led to his model of the benzene molecule. The observable world of Realm 1 also provides the means of checking theories back against reality to ensure that they do not consist solely in flights of fancy.

Harré and Gillet (1994) emphasise the significance of the structure and content of the scientific model in how it is used. A successful model needs to represent the configuration thought to characterise the unobservable world; it is not just a logical construction. So in the particulate theory of gases, for example, the vibrating molecules are not merely a convenient feature that allows accurate predictions to be made. They are considered actually to exist. Once this is grasped, then the observer is equipped with a new way of seeing the world that structures future observations and, importantly, provides coherence to beliefs about how the world 'works'. It is in this coherence that much of the power of science to explain and control reality resides.

Children learning science

In many ways, the task for children learning science is similar to that of the scientist: they need to progress from a directly experienced realm of things and events towards more theoretical explanations which, because of their power of explanation, take children into the realm of objects and processes that they cannot observe for themselves. Clive Sutton (1996) is a leading advocate of the value of 'seeing as': helping learners to appreciate how the analogies in scientific models enable people to know the physical world in a new and empowering way. However, there are some important differences between the world of the scientist and that of the primary school pupil. Firstly, children do not have access to the sophisticated instrumentation of the scientist (or for other reasons cannot, for example, cut open human cadavers), and for them the dividing line between Realms 1 and 2 is drawn differently. The children need, somehow, to acquire or construct a way to represent or model the domain of objects and processes they are studying but which they cannot fully observe. It is here that a worthwhile link with constructivist approaches to learning may be made. The process of moving forward, both in scientific theorising and in personal understanding, consists in building on something already known in order to understand something as yet unfamiliar.

Understanding depends on fitting what is to be understood into an existing conceptual structure. Shuell (1986) explains:

> *Learning is cumulative in nature; nothing has meaning or is learned in isolation ... Only information that is structured or organized can be thought of as being meaningful and can serve as an object of understanding.* (pp. 416 & 419)

But if to understand is to fit new information into an existing theory, then where does the theory come from? How can anyone understand or acquire a new and different theory? It is now something of a cliché to assert that teachers should 'start from where the children are'. But if 'where the children are' means that they already have deep misunderstandings about scientific domains, then fitting new learning into this framework is not going to be particularly helpful. There are in the literature a number of perspectives on the matter of conceptual change. Vosniadou and Brewer (1987) divide these into

- weak restructuring
- radical restructuring through 'Socratic' dialogue
- radical restructuring through analogy, metaphor or physical models.

In weak restructuring, children's existing ideas are compatible with new learning. New learning is therefore accommodated by their pre-conceptions, and their existing theories are thereby 'filled out', as it were. For convenience, we refer to this in subsequent chapters as the 'add-on' approach. Within the radical restructuring approaches, preconceptions are not compatible with the new theories to be introduced, and the appropriate role for existing knowledge is therefore less clear. In Socratic dialogue, students are first made aware of anomalies in their existing views, and then extensive work is done by the teacher to guide them to construct new schemas that fit the evidence better. This is portrayed as implying a demanding role for the teacher, who must be 'interested in understanding the students' point of view, proposing alternate frameworks, creating conceptual conflict, and leading students into constructing conceptually consistent theories of the domains' (p. 61). It is also essentially a reactive method, which may therefore present difficulties in planning a coherent introduction to a topic.

We refer to this below as the 'confrontational' approach. However, as Boulter and Gilbert (1996) point out, the dialogue patterns characteristic of Socratic modes of argument are common in teaching episodes generally, and not just in confrontational situations. These patterns issue from the related principles that the learners should discover the correct conceptions themselves, and that it is the teacher's role to draw them out of the learners.

The third alternative proposed by Vosniadou and Brewer is to use analogies, metaphors and physical models:

> *One way old knowledge can be brought to bear on the construction of a new schema or the restructuring of an existing one is by using analogies and metaphors from a different domain.* (p61)

The latter, which we refer to as the 'model-building' approach, has clear similarities with progress in science, as discussed in the preceding section. One major difference, however, is that children are not expected to construct an entirely new model of the scientific domain; a scientists' model already exists, and it is this that must be addressed in teaching. The children have to construct a model of a model.

What methods do teachers use in practice, and how do they relate to these theoretical notions? How teachers actually go about making scientific models both accessible and attractive to children is the central concern of this research, and it is these twin themes that are taken up in subsequent chapters.

2
THE RESEARCH PROJECT

The aims

The aims specified for the research were:

- to examine how scientific concepts are first introduced to children in primary classrooms
- to develop a means of categorising these methods
- to gather information on how children's understanding of the concepts might be related to the ways they are introduced.

These aims, though simply stated, turn out in practice to be highly complex. The National Curriculum covers many scientific topics, but there is no indication of how, when or in what combinations particular topics should be approached. Such decisions are left to schools, who may, for example, decide to include the study of how the Earth moves in relation to the sun as a separate astronomy project, or as part of thematic work on ancient Egypt (as in one of the schools in the sample). Inevitably, this means that the focus of the research needed to be narrowed, resulting in compromises at various points. Our intention was to ensure that the conclusions could be of universal use despite this narrowing.

The concept areas

In the discussion of scientific models in the introductory chapter, the point was made that significant growth in scientific knowledge occurs when the events and entities that theory accounts for encompass those that are not directly observable. The point was also made that what is observable for the scientist is not necessarily observable for the primary school child. The research was therefore designed to cover areas of the science National Curriculum that include non-observable entities and events. There are several such areas in the key stage 2 programme of study, but few in key stage 1. Another constraint was that it should be possible for schools to identify clearly when these topics were to be covered, which implied that coherent but isolable units of the programme of study should be involved.

The aspects selected for study were from key stage 2:

Life Processes and Living Things

2. Humans as organisms
(circulation)

Pupils should be taught:

- a simple model of the structure of the heart and how it acts as a pump;
- how blood circulates in the body through arteries and veins.

Physical Processes

4. The Earth and beyond
(periodic changes)

Pupils should be taught:

- that the Earth spins around its own axis, and how day and night are related to this spin;
- that the Earth orbits the Sun once each year, and that the Moon takes approximately 28 days to orbit the Earth.

(GB. DFE and WO), 1995)

In the first case, the main objects in the domain, the heart and associated blood vessels, as well as the events in which these are involved, are inaccessible to children. In the second case, the main entities are observable, although not always from the most helpful perspectives, and the relationships and events connecting them are inaccessible in any useful form.

The sample

It was originally proposed to include in the research a minimum of four schools from each of four local education authorities. Accordingly, representatives of four authorities, chosen to provide a wide range of school types, were asked to nominate schools to take part. These schools were to represent typical schools for the area, and were not expected to be exemplary in any way. Only three of the four authorities were able to comply and, following contacts with schools, some of those nominated in the three areas elected not to participate. Although the sample of schools that provided data were of varied types and locations, the possibility of selective drop-out cannot, therefore, be ruled out. Schools were told that anonymity would be preserved, and so they are referred to through the use of code names in this report. The code names are from a phonetic alphabet, and have no other significance.

One of the two concept areas was the focus of the research in each school, except in one case where both topics were observed. The choice of topic was determined in part by the pattern of coverage of the programme of study within the individual schools, but also with a view to maintaining a balance between the schools. The schools had allocated the topics differently to different year groups, so circulation could, for example, be introduced in anything from Year 4 to Year 6.

Brief descriptions of the schools follow.

Area 1

	Topic	Year
Alpha Combined School A first and middle school in a large town, with high proportions of children receiving free school meals and with a high proportion of children from non-English speaking backgrounds.	Earth & beyond	6
St Bravo Primary School A voluntary aided inner-city school, with a very mixed intake. This includes both children receiving free school meals and children of visiting overseas lecturers at the university.	Earth & beyond	mixed 5-6
Charlie Junior School The school is in a large residential area on the edge of a city. A large proportion of the children receive free school meals.	Heart & circulation	6
Delta Primary School A small rural primary school with a mixed intake.	Heart & circulation	5

Area 2

School	Topic	Year
Echo Middle School A medium sized school situated in a small town which itself is situated on the edge of a new city. The school takes children from a variety of backgrounds.	Heart & circulation	6
Foxtrot Combined School A large primary school in a rural setting. The school has high proportions of pupils who are children of armed services personnel.	Earth & beyond	5
St Golf Combined School A medium sized school situated in a large village. The majority of the children live in the village and a large majority are from professional families. A minority are from agricultural backgrounds.	Earth & beyond	6

Area 3

School	Topic	Year
Hotel Primary School A city primary school in the outer reaches of London, with a mixed intake, including children of professional parents and those receiving free school meals.	Heart & circulation	5/6
Juliet Junior School A primary school in a town, with a mixed intake, including some children from non-English backgrounds.	Heart & circulation	6
Kilo Primary School A primary school in a large urban area, with a mixed intake, including a high proportion of children with non-English speaking backgrounds.	Earth & beyond Heart & circulation	4

In some schools, the children worked in groups and undertook a different sequence of activities, or occasionally different activities, depending on which group they were in. In other cases, the teacher worked with one group on each of several days, covering essentially the same activity on more than one occasion. In these cases, it was not always possible to gather data on the experience of all the children in the class, and the focus therefore switched to how the topic was introduced to one of the groups, which was always the group that was working most closely with the teacher at the time.

Data collection

Observation of the lessons

In each school, one lesson was observed which was identified by the teacher as the introductory lesson to the topic. Generally, the time available for the lesson was between 45 minutes and one hour. The main means used to observe the lessons was video recording. In some of the classes, a practice session was arranged, so that the children could get used to the idea of being recorded, although this was not possible in every case. Video records are, however, limited in some respects, particularly in having a restrictive field of view, and they were therefore supplemented by other data. Audio recordings were also made at the main focus of activity whenever possible, and field notes were compiled at the time of the observations.

Teachers were asked to write up a logbook to provide additional background data. This included information on:

- how the lesson fitted into a series and into a wider scheme of work
- aims of the lesson, resources used and a summary of the content
- a review of how the lesson went
- overall reflections on the series of lessons, where appropriate.

Since the logbooks needed to be completed after the time of the observed lesson, teachers were asked to forward these to the researchers. All except two logbooks were received.

Together, these sources of information were intended to allow close analysis of the approaches taken in the introductory lessons, as well as giving a brief indication of the context of the lesson in terms of a wider scheme of work.

Pupils' responses

Judging the effectiveness of a teaching approach is particularly problematic in this context. Because schools sequence their approaches to curriculum topics in science differently, it is not easy to make comparisons between schools, as the different ages and past experiences of the children would be expected to have an effect on what they learn. There is no established 'baseline' of understanding which all the children would share, and in addition, the teaching covered slightly different areas of the topics. However, it was considered important to have some information on what the children had gained from the lessons observed.

The approach used was to interview individually a small sample of up to six children in each class. The interviews made use of certain fixed tasks as a basis for probing children's understanding, but they were also asked what they thought they had been learning about; how well they understood; and whether they knew the answers to the tasks as a result of the lesson or by some other means.

The interview tasks were:

Heart and circulation

About the lesson

Tell me about what you have just been doing.

Did you find out anything new?

Did you understand everything? (probe)

About the heart

Point to where your heart is.

What is it for?

How did you find this out?

About blood

What is blood for?

What does it do?

Where is it in your body? (probe)

Earth and beyond

About the lesson

Tell me about what you have just been doing.

Did you find out anything new?

Did you understand everything? (probe)

About the Earth (Give the pupil a supply of modelling material)

Make a model of the Earth, the Sun, the Moon.

How does the Earth move? (probe for periods)

How does the Moon move? (probe for period)

Analysis procedures

The nature of the questions to be addressed in the research required a qualitative approach to analysis of the lessons. The categorisation of these lessons had to be grounded in the empirical data, which, broadly, is what is known as the 'grounded theory' approach (Strauss and Corbin, 1990). However, in contrast to how grounded theory is usually described, we acknowledge the influence of preconceptions on the final category scheme. It was initially expected that teachers would use some combination of:

- discussion of children's personal experience
- children's engagement with practical activities, such as investigations
- practical demonstrations by the teacher
- presentation of verbal definitions.

It was with these categories in mind that the lesson tapes were viewed by the researchers. The analysis was also underpinned by prior assumptions about the nature and use of analogies in science, as discussed above in Chapter 1. Following initial viewing, the usefulness of the preliminary categories was discussed, and points of fit and mismatch with the data were identified. This led to the refined category scheme, presented in Chapter 5, which both fitted the data and allowed interesting themes to be drawn out.

Scope for generalisations about the effect of the teaching approaches on children's understanding was limited, for reasons that have been discussed above. Rather than make judgements across the lessons, the data from pupil interviews were used to shed further light on each approach individually. For example, where children consistently confused the period of rotation of the Earth with that of its orbit, this could focus attention on possible sources of the confusion. On the other hand, if the children were unanimous in saying that the teacher's exposition was clear, then this would suggest a successful approach.

3
AN OVERVIEW OF THE LESSONS

In this chapter, a brief description of each of the lessons observed is given, by way of an overview. Various aspects of the lessons are explored in greater detail in the following chapters.

Heart and circulation

Charlie Junior School

The starting point of the lesson was a class discussion of the notion of a system as a set of things that work together for a purpose. This was exemplified by referring to various systems, such as hi-fi, electrical and railway systems. The children then gathered round a computer in the classroom, on which was displayed an animated diagram of the blood and lymph system. The heart and the blood vessels were pointed out. A reproduction of the diagram and another showing the structure of the heart were given to the children, and were talked through with the children. They then located their hearts in their chests, and engaged in an activity in which they stepped up and down from their chairs and felt the change in their pulse rate. One child was used to demonstrate this effect to the class, with another child listening to his heartbeat using a stethoscope and counting the beats. The children were then given a highly schematic diagram of the heart and its connections to the remainder of the circulatory system. The progress of blood through this system was then explained by the teacher, including the role of the four chambers and valves, the lungs and the absorption of air. The children labelled the diagram and wrote a short piece summarising the working of the circulatory system.

Delta Primary School

The lesson began with a short item of drama, in which one boy lay on the floor 'injured' as the other children arrived. The teacher drew out the importance of checking the pulse of the boy, to find out if he was alive, and describing the path of oxygen from the lungs to the body via the blood. The children were then divided into two groups, with half involved in an introductory activity and the remainder doing independent research on the topic using books and CD-ROM. The focus for the research was on the group carrying out the introductory activity. The children discussed and investigated the effect of exercise on pulse rate by measuring their pulse before and after exercise, and after a period of relaxation. The results of this were discussed afterwards by the teacher with the children and the relationship between heart rate and exercise stressed.

Echo Middle School

The teacher worked with a small group of children while the rest of the class was supervised elsewhere. She began by discussing the position of the heart in the chest, and then showing its position in an anatomical model of the body. The teacher then introduced a large diagram of the heart, its internal structure and its connections to the lungs and other parts of the body. The heart was relatively realistic in its representation, while the remainder of the system was highly schematised. The valves were represented as working components by means of cardboard flaps. This diagram/model was used to demonstrate the passage of blood by means of plastic cubes passed around the system. The movement of oxygen and carbon dioxide was explained, with red and blue cubes being exchanged at appropriate points. The movement of blood was related to children's experience of their own pulse. A worksheet was then used, covering the workings of the heart. The effect of exercise on the pulse was discussed, and related to the body's need for oxygen. Some of the children then conducted an experiment on the effect of exercise and relaxation on pulse rate, while the remainder looked up information using a CD-ROM.

Hotel Primary School

The teacher withdrew small groups one by one from the class. They discussed the pulse (which they located in their necks) as the 'pump of the heart' and as caused by blood 'pushing through veins'. The children were asked to predict what would happen to their pulse during and after exercise. They then engaged in an experiment to investigate this effect, measuring their pulse rates firstly at rest, then immediately after step-ups on a bench, and again after five minutes' rest. In reviewing the results, the relationship of pulse rate to exercise was emphasised.

Juliet Junior School

The lesson began with the class being asked to recall recent work on circulation in plants. Reference was then made to the human circulatory system, in which blood goes around the body carrying food and oxygen to the different parts. The heart was compared to a pump, with various kinds of pump mentioned as examples, and with a syringe and water used to demonstrate a pumping action. The teacher then laid out a circuit on the floor in the middle of the room, consisting of a cardboard box containing red plastic cubes, representing the heart and oxygen, and a set of labels representing major organs including the lungs. The children took turns to walk around the circuit, moving the red cubes around and depositing them at the organs. The teacher provided a commentary on what these actions represented. The children then divided into groups to complete two different activities. While some children drew a diagram of the heart and circulatory system and wrote about circulation, small groups carried out an experiment on the effect of exercise on pulse rate. This involved the children in measuring their pulse rate at rest, then immediately after exercise, and then after a rest period.

Kilo Primary School

The class were divided into groups, and the groups undertook a circus of four activities, each in a different order. The observed group discussed (under the direction of the teacher) what the heart is, what it does, and where it is located in the body. They were shown a model of the heart. During this discussion, the heart was described as something that pumps oxygen. The children located their pulse in different parts of the body, and listened to it using a stethoscope. They were asked whether they thought that their pulse rate changed, and then investigated whether it changed in relation to exercise. For this, the children measured their pulse rate at rest, immediately after exercise, and again after a rest period. In the following discussion, the teacher brought out that the pulse was due to the movement of blood through the body, squeezed by the heart, and that fitness was reflected in how much the pulse changed.

The other three activities were: (i) comparison between the heart's pumping action and that of a syringe with water passing through a tube; (ii) research from books on where the heart is located in the body, the composition of blood and where it goes to in the body; and (iii) tracing and marking a diagram to show the internal structure of the heart and how it is divided to deal with oxygenated and deoxygenated blood.

Earth and beyond

Alpha Combined School

For the first part of the lesson, the teacher asked the children in the class to complete a worksheet/questionnaire assessing their prior understanding of such things as the shape of the Earth, Sun and Moon, their size and movement. She then showed the children a model orrery, which demonstrated the relative movements of the Earth, Sun and Moon. The longest part of the lesson was spent with children working in groups to construct their own orreries from components and instructions provided for them. The teacher talked the children through how the elements of the finished model moved in relation to one another, and the children then added to the questionnaires they had begun at the beginning of the lesson.

St Bravo Primary School

An initial class discussion recalled recent work on the position of the Sun in the sky and the times at which it set, its position and movement in relation to the school, and how distant objects appear smaller than nearer objects of the same size. This was followed by a question-and-answer series in which individual children offered preliminary statements about the movement of the Earth. The teacher then explained two practical activities to the children, in which all classroom groups subsequently engaged. In the first of these, a torch was shone on the surface of a globe, on which the position of England was marked. The children noted changes to the illumination on the surface as the globe was rotated. For the second activity, the children were given a shoe box with a 'window' in the lid and a peephole in one end. A toy car was placed inside the box and a torch shone through the window in the lid. The children observed the effect on the car's shadow of changing the angle of the torch beam. The children gathered together at the end of the lesson for follow-up questions on what they had been doing, which brought out the role of the Sun and its movement in the phenomena of day and night.

Foxtrot Combined School

The work took place in a class dance lesson, which began, following warming-up activities, with the children responding to a piece of music in terms of what it suggested to them and how it made them feel. The teacher explained that their work for the term was going to be on 'Space', and that she wanted the children to create a dance with a space theme. Work then proceeded on making up the dance sequence, with discussion and a running commentary by the teacher used to elaborate on the movements and what they represented. For the dance, each child acted as a planet or star. This involved them in adopting an anticlockwise spinning movement. The dance was built up from children moving individually, then in relation to each other as pairs and finally as groups of eight.

St Golf Combined School

The lesson began with a class question-and-answer session, in which the teacher determined children's initial knowledge of the movement of the Earth. They moved on to consider the shape and size of the Earth, and its distance from the Sun. These ideas were demonstrated by having a child take a football (representing the Sun) to a particular location outside the classroom while the teacher held up a small piece of tacky material to represent the Earth. Attention then turned to an overhead projector and a globe, which were used to demonstrate the spin of the Earth, and how this affects the parts of the Earth that are in the light from the Sun and the apparent position of the Sun in the sky at different times of day. England's position was marked on the globe's surface. To follow up this activity, the children worked collaboratively on worksheets that represented similar information in diagrammatic form. When the children had finished, the answers were discussed as a class activity.

Kilo Primary School

The children worked as a small group with the teacher, while the rest of the class worked independently on other tasks. They were shown NASA photographs of the Earth taken from the Moon and from a spacecraft. The water and land areas were identified, and the children were then asked to relate these to the features on a globe. The next part of the activity focused on using the globe to represent the Earth and a desk lamp to represent the Sun. Differences in the characteristics of the Sun and the desk lamp as light sources were discussed. The teacher related the changes to where light fell on the surface of the globe as it rotated to the phenomena of night and day, and to the apparent position of the Sun in the sky. They then moved on to the movement of the Earth around the Sun, which was demonstrated by the teacher using the globe. The significance of this was brought out in relation to the length of a year and (briefly) to the seasons. The group then focused once more on the rotation of the Earth, and how this related to experience of day and night in two locations — England and Egypt (the theme for the term's work). This aspect was also followed up by the children working together on a worksheet and making use of the globe and lamp.

Discussion

The lesson outlines show not only a variety of approaches to the same topics, but also some points of considerable similarity. The idea of a physical model of the relationship between the Earth, Moon and Sun appears in each of the schools addressing that topic, but the model appears in several different forms: a light shone on a globe; a dance in which children represent objects in space; an orrery in which the three bodies are physically joined. In the work on the heart and circulation, several different approaches emerged: the use of diagrams to represent the system; the use of physical models; the comparison between the heart and pumps of various kinds. However, common to each of these lessons was an investigation of the effect of exercise and of relaxation on pulse rate. This latter is in fact a reflection of the programme of study for Life Processes and Living Things, which, although it was not an explicit focus of the research, was nevertheless linked by the teachers to the aspects of the programme of study that were chosen to be central to this study.

In the next two chapters, the content and approach of these lessons are reanalysed according to certain recurring themes.

4
CREATING THE NEED TO LEARN

Cognitive conceptions of learning characterise it as a purposive, active, constructive process (Shuell, 1986). For meaningful learning to take place, there must, at some level, be a need for that learning. In this section, the ways in which teachers created a 'need for learning' in their classrooms will be examined. It is not, however, about general aspects of motivation, about how teachers instil enthusiasm in pupils, important though such matters are. It is about creating the need to learn *specific things* in a specific area of science.

Ogborn *et al.* (1996) refer to one important aspect of explaining scientific ideas as 'opening up differences'. They say:

> *Explanation works by opening up a gap in understanding needing to be filled — a feeling of difference of view needing to be resolved.* (p.4)

> *One essential difference is that between what the student knows and what the student 'ought' to know. It is assumed that the teacher can bridge this difference. But there is a second difference: that between what the student ought to know and what the student wants to know. So the teacher may need to provoke, stimulate, demand or coax students into wanting it.* (p.12)

How do teachers go about this process of bringing children to recognise the difference between their own knowledge and the explanations provided by science, and of provoking children into wanting what they 'ought' to know?

The constructivist research programme has shown that the preconceptions children hold in several areas of science are, in many everyday circumstances, quite viable (Osborne and Wittrock, 1983). Given this, it would be understandable if children saw no need to trade in their own ideas in favour of scientific explanations. Hence constructivist teaching sequences typically attach considerable importance, firstly to discovering what ideas children hold, and then to confronting those conceptions with counter examples or 'discrepant events' (Driver *et al.*, 1985; Needham, 1987). This confrontational approach is one way of creating a 'need to learn', but not the only one. It requires teachers to be responsive to whatever ideas children raise, with the possible problem that children may vary considerably in their beliefs. In fact, none of the teachers involved in the research appeared to be using this approach in anything like the form proposed by Ros Driver and the Leeds CLIS group; all of them had clearly planned in advance how they would introduce the topic in question. Although some of them did invite children's ideas, there was no facility for adapting their approach in any major way to challenge specific ideas that were raised. This is not to say that they could not, on later occasions, devote time to examining specific conceptions. However, it does imply that the *introduction* to the topic, the focus of this research, was fixed in advance.

Some approaches

The approaches used by the teachers in this study to promote a 'need to learn' can be categorised as *monitoring understanding*, *introducing problems* and *making the familiar strange*.

Monitoring understanding

Although monitoring of children's understanding is an important aspect of the teacher's role, this is not something that in itself imparts to learners the need to construct new ideas in line with those of canonical science. On the other hand, reflective awareness and evaluation of one's own understanding (often subsumed under the term 'metacognition') have been identified as important determinants of the need to engage with learning (Garner, 1990). Children may not be fully aware that they lack knowledge, or of what they have learned from an activity, without specific tasks that promote reflection. Setting out what is known in a form that can be communicated, usually through verbalising, is recognised as an important step in achieving such reflection (Prawat, 1989).

Two examples from the research (Boxes 4.1 and 4.2) serve to illustrate different approaches to encouraging children to reflect on their own understanding. In the first example, the children's responses are available primarily to themselves and to their teacher. Aside from the teacher's responsibility to ensure that the expected learning happens, this is an essentially private monitoring process, linked to personal learning. The areas to be explored are relatively prescribed by the teacher, based on what the children are expected to learn, but the format of the questions is fairly open, allowing a range of responses.

Box 4.1: Monitoring understanding, *Alpha Combined School*

At the begining of the lesson, the children were presented with a questionnaire on what they knew about the topic. This had separate columns for them to complete at the start of the lesson, at the end of the lesson and at the end of their study of the topic:

What I know about:	Before the lesson	After the lesson	At the end
The shape of the Earth			
The shape of the Sun			
The shape of the Moon			
Ordering the Earth, Sun and Moon, with the biggest first			
[etc]			

(Redrawn)

The second example is different in that it is a much more public activity. There is a sense in which the class are working together to construct shared understanding of an area of science. It is also much more open as to what kinds of statement are admissible. Hence the statements introduced by the children cover a wide range of content and fit into quite varied discourses. This not only suggests that it would prove difficult to achieve completely a shared understanding, but also illustrates some of the problems that would be inherent in relying on elicitation and active confrontation of children's ideas as the approach to instilling new scientific knowledge. It is not clear, for example, whether some of these statements are deep misconceptions or simply irrelevancies in the scientific context. There are also propositions that could only be addressed using secondary evidence, which defeats the notion of active testing implicit in the confrontational project.

What is common to the two examples is the intention to return to the statements made at a later point in time to review what has changed.

Box 4.2: Monitoring understanding, *Kilo Primary School*

On a separate occasion, prior to the introductory lesson, the teacher asked the children to state what they knew about the Sun, Earth and Moon. She wrote up a list of statements that the children made. A wide range of propositions emerged from this open discussion, including:

- the planets get smaller nearer the Sun
- the Moon has a face
- the sun will die in 18,000,000 years
- the stars are part of the Sun
- the Earth spins round
- the Sun and Moon are sisters
- the core of the Sun is burning hot
- the Sun goes behind the Moon at night.

She then asked the whole group to pick out statements that they agreed with or disagreed with. It was the teacher's intention that children would become, over the course of the topic, more sure of whether or not they agreed with at least some of these statements.

Introducing problems

Monitoring understanding may be viewed as a relatively passive affair. There is no sure guarantee that children will identify gaps or changes in their ideas, or indeed that their own ideas will prove inadequate. Introducing real-life problem tasks that children are required to engage with personally and actively is an alternative, or complementary, approach. These real-life tasks should therefore be ones which result in some product, and this should be a solution that embodies relevant scientific models. Several examples arose across the schools studied, but the more interesting ones featured problems in which success was built into the structure of the task. Three examples will be used to illustrate this (Boxes 4.3 to 4.5).

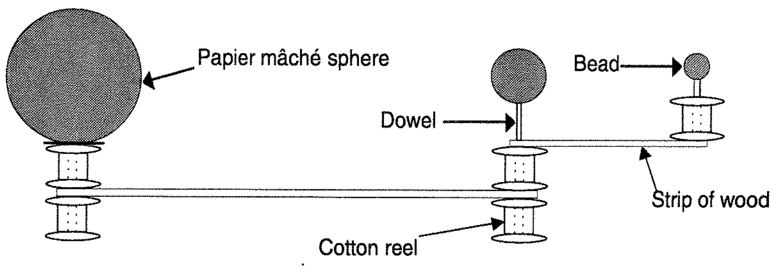
In the first (Box 4.3), the children construct a physical model. This follows on from the completion of a questionnaire on their understanding (see Box 4.1).

Their task is to come up with a product (the orrery) that embodies scientific theories about the relative size, position and movement of the Earth, Sun and Moon. The model orrery is structured so that these features are incorporated into the design via the instructions; the Moon cannot stray off and move around the Sun independently, although there is still some scope for confusion over which elements rotate about their axes and over the direction of the orbits and rotations.

Box 4.3: Introducing problems, *Alpha Combined School*

Having completed a questionnaire on their understanding of the size and movement of the Earth, Sun and Moon, the children went on to build model orreries. The teacher announced that on completion of their models, she hoped that they would all know the relative sizes of these objects, which orbited which, and which ones rotated.

The children worked in groups to complete their models, and a tray of necessary materials and a set of instructions was supplied to each group. Within each group, individual children were allocated specific tasks in the construction process. The teacher went amongst the groups clarifying and assisting where appropriate.



A different approach, but with a number of parallels, consists in producing a dance that incorporates the relative movements of the heavenly bodies (Box 4.4). This is structured by the teacher's directions and commentary, so that each movement is established as the dance develops.

The third example, this time on the topic of circulation, parallels the previous example in that it is the movements of children that go to make up the product and that embody the structures in the scientific domain. Again, the teacher's commentary ensures that each step is described in terms of what it represents (Box 4.5).

Box 4.4: Introducing problems, *Foxtrot Combined School*

As part of a lesson on the movement of the Earth, Sun and Moon, the children engaged in a piece of dance. As the dance developed, the teacher emphasised the need to present accurate information to the audience if the dance were to be performed in assembly.

The children began by curling into a ball, and then uncurling and spinning slowly, anticlockwise, in time to music. They then moved into pairs and, maintaining their direction of rotation, one began to move around the other in a circular path. It was established (by identifying who was playing which part) that this represented the movement of the Earth around the Sun.

The children were then put into groups of eight, all orbiting a single child in the centre, but weaving in and out of one another in opposite directions of orbit. This part of the lesson was rushed and was therefore to be continued in a future lesson.

Box 4.5: Introducing problems, *Juliet Junior School*

The children were given the job of acting out the circulation of blood around the human body. They sat on chairs in a large circle, from where they could observe the activity taking place in the central space. In this space, the teacher set out in a large circuit:

- a cardboard box containing red cubes
- paper labels for varous major organs.

The children took turns to act out the circulation of the blood, under the direction of the teacher, who also gave a commentary of what was being represented at each stage. They took red cubes ('blood') from the box ('heart'), and walked around the circuit, depositing a cube at each organ label. Left-over cubes were returned to the box.

As in each of these cases, the approach involves asking the children to model aspects of the scientific domain for themselves. The emphasis is strongly on points of similarity between, on the one hand, the actions carried out by the children and the objects used and, on the other, what these are supposed to represent. In this sense, it differs from the next category, although there are ways in which the two approaches overlap considerably.

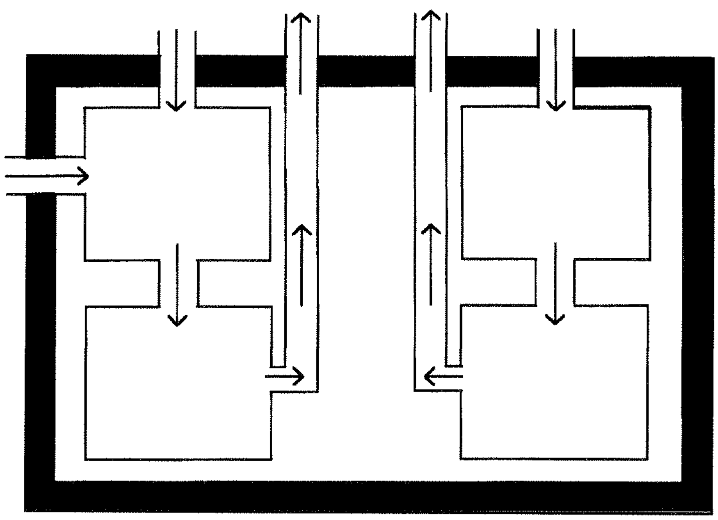
Making the familiar strange

Activities that fall into this category are also intended to highlight points of similarity between the scientific domain and its representation. Where they differ is that children are essentially recipients rather than participants, and that differences between representation and represented are very apparent. It is through this emphasis on difference that the approach achieves its leverage, by forcing the recipient to distinguish the relevant features from the irrelevant.

In many scientific texts, and in some of the diagrams and other representations used by the teachers in this study, there are clear attempts to reproduce reality as closely as possible. However, no representation can be accurate in every respect. The use of sometimes bizarre pictures of familiar objects and events has been noted by Ogborn *et al.* (1996). They report an example of a teacher who drew a diagram of an earthworm stripped to its essence as a straight-sided tube. Such highly stylised diagrams were also seen in some of the lessons observed in this present study (Boxes 4.6 to 4.7).

Box 4.6: Making the familiar strange, *Charlie Junior School*

The teacher presented children with a diagram showing the heart as four rectangular chambers, linked to each other and to the rest of the body by straight pipes with right-angle bends. The sheet was entitled 'a very unrealistic diagram of the heart'.

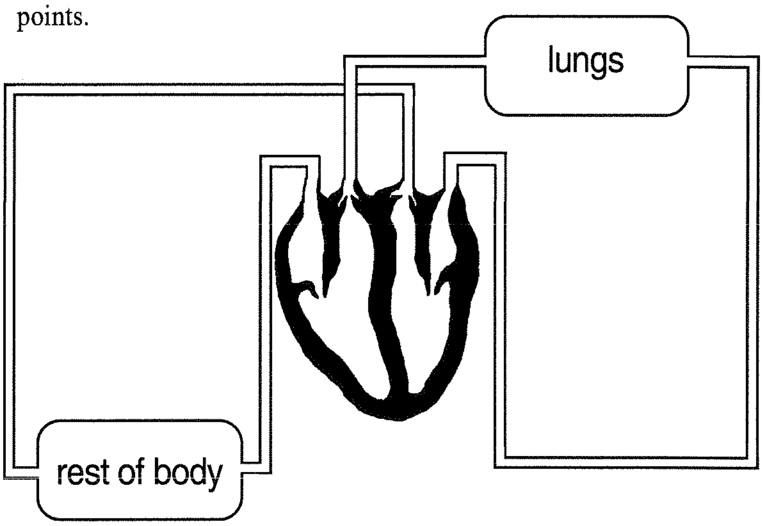


(Redrawn)

Box 4.7: Making the familiar strange, *Echo Middle School*

The teacher showed the children a large diagram. This portrayed the heart cross-sectioned, but in a relatively realistic way. However, the lungs and the remainder of the body were shown as essentially separate entities connected by a vein and an artery. The sections were coloured red or blue to emphasise oxygenated and deoxygenated blood.

The diagram had a three-dimensional element, as the valves in the heart were represented by cardboard flaps. The teacher demonstrated the flow of blood around the system by moving red and blue plastic cubes around the circuit, exchanging cubes for those of a different colour at appropriate points.



(Redrawn)

In these examples, the diagrams used by the teachers have the effect of focusing attention on the structural properties of the circulatory system by removing whatever is not essential to this purpose. By portraying *only* this structure (and even then only salient aspects of it), this is what the children are forced to consider. Both, in different ways, emphasise the internal structure of the heart, and also the destination and source of blood in the heart. In addition, the example in Box 4.7 emphasises the manner in which blood circulates through the whole system in the body.

Making predictions

In addition to the three approaches identified in the preceding paragraphs, there were instances in which children were asked to predict the outcome from an experimental manipulation, and then to observe the actual result of the manipulation. For example, in several lessons, children predicted the effect of exercise and relaxation on pulse rate and then carried out an investigation to determine the actual effect. In some senses this relates to the theory-testing approach advocated by Driver *et al.* (1985), but in other senses it is very different. Firstly, children could apply a range of models to provide successful predictions, including prior experience of their heart beating faster after exercise. Therefore the approach did not necessarily challenge children's existing ideas or discriminate between successful and unsuccessful. Confrontational approaches are intended to be more rigorous in deducing consequences from particular theoretical positions that would allow those positions to be overthrown. Secondly, in the lessons observed, the investigation tended to follow input by the teacher and not to develop from children's ideas, and was therefore better seen as a means of filling out or illustrating the scientific model than as a test of alternative conceptions, as a confirmation rather than a refutation. Consequently, we would not identify any of the approaches used by teachers in the present study to create a need to learn as 'confrontational'. Nevertheless, the potential exists for such an approach.

A common thread

The above examples of problems introduced and of familiar things made strange are interesting, not least because they raise questions about the effectiveness of different ways of representing scientific ideas. In each case, the scientific ideas are represented in a form that corresponds in some respects with how things are in the 'real world', but that differs in other respects. What teachers were doing was taking some device with certain structures and properties and using it to stand for a very different set of entities which were the real focus of the teaching. This theme is taken up and explored further in the next chapter.

5
INTRODUCING THE SCIENTIFIC VIEW

As explained in Chapter 2, the scientific domains that the children participating in this research were learning about included objects, processes and relationships that are, in practice if not in principle, not observable for young children. How did teachers in the study go about making these entities 'real' to their pupils? Also, how did they make use of children's existing knowledge in doing so?

In Chapter 1, three different ways of relating new knowledge to existing knowledge were distinguished. These were termed the 'add-on' approach, the 'confrontational' approach and the 'model-building' approach. The add-on method assumes that all the necessary prior understanding is in place for children to accommodate the new material to be presented. Whilst the restructuring at which this approach aims may be classified as 'weak', it makes strong assumptions about the suitability of children's existing conceptual structures. As in any one class it may not be the case that the children have sufficiently uniform understanding, it also therefore carries a degree of risk. It did not, however, appear that the teachers in this study were making such strong assumptions. The only possible exception was in Hotel Primary School, where there was no evidence of either of the other restructuring orientations, although these may well have come to the fore in subsequent lessons in the series. Similarly (as reported in the preceding chapter), there was little evidence that teachers were confronting children's misconceptions directly, although, again, this may have taken place in later sessions, based on information gained in the introductory lesson. The description that best fits what the teachers were doing in their classrooms was model-building: using children's knowledge of familiar domains to represent the new scientific conceptions they were presenting.

The 'already understood' components that may be used in representing the objects and processes in scientific domains are various, including: words; physical objects; personal activity; pictures and diagrams; and (for the scientist more than for the child) mathematical expressions. The task for the teacher is to assemble some combination of these components that will enable children to theorise about the domain in question — to marshal the resources in children's existing knowledge and integrate them with scientific activity in such a way as to provide an understanding of the new, scientific ideas about what exists in the world. As was noted in Chapter 1, the vehicles for restructuring children's ideas are analogy, metaphor and physical models. These are very closely related. A physical model may, on one plane, be thought of as merely replicating the scientific domain that is the target of teaching, and therefore as being quite different in kind from an analogy. However, no model is identical to what it represents in every respect (otherwise it would not be a model). Models differ in the material of which they are made, and often in terms of scale and in various other ways. Similarly, no use of a term is identical in every respect to other uses of the same word. Language itself is deeply metaphorical (Lakoff, 1987), and what we think of as literal meaning 'consists in forgotten metaphor' (Weinsheimer, 1985, p. 239). Thus the processes by which people use familiar ideas to understand new events are at the same time complex, but often largely unconscious. However, when the task is difficult, these processes become more amenable to analysis. Hence in delving into the means by which teachers seek to make scientific domains accessible to children, we also have found it useful to 'make the familiar strange'. This is done by fitting a category system to the data. The categories described below act as *directions in which to look* when examining classroom practice.

In what follows, it is necessary to distinguish between 'analogue' and 'target' domains. The target domain is the real-world set of entities and their interaction that are addressed by the scientific concepts the children are intended to learn about, and the scientific model is a 'way of seeing' the target domain that attempts to represent its significant features. The analogue is the set of entities that (it is assumed) is already familiar to the children and that is used to represent the target domain in a manner compatible with the scientific model. Using an example from outside of this study, a collection of ball-bearings shaken in a tray (the analogue domain) might be used to represent the behaviour of invisible molecules (the target domain) when giving an explanation of the behaviour of fluids based on the particulate model of the composition of matter.

This example conveniently illustrates one of the problems with analogies. An analogue domain is not the same as its real-world partner. This means that there will be points at which features or relationships in the analogue do not map on to those in the real world. In the preceding illustration, the ball-bearings fall to the ground if they escape from the tray, whereas gas molecules disperse in different directions. Also, whilst the teacher will (mostly) be aware of how the different elements in the representation map on to the unobservable real-world domain, the children will not. The important relationships between the analogue and target domains therefore need to be made clear to them, whilst at the same time recognising that it may well be impossible to make explicit *all* the correspondences. At this point, it should also be noted that the aspects of the scientific model that the teacher intends to approach through analogy will inevitably be selected from among a much larger number. The approach is therefore not without its hazards. A principal focus of the present study is on how, and what, links are established between the model constructed in the classroom, for the children's benefit, and the real-world target.

Analysing how teachers build models

The category scheme that follows was built up through the interaction of prior assumptions (outlined in Chapter 2) with the video-taped data. The categories provide a framework for identifying and describing what was going on in the lessons that goes beyond surface features (such as 'teacher asks question', 'teacher draws diagram'). Each category is given a brief definition, followed by guiding questions that indicate what to look for in the data, and then an explanation of how the category applies to the lessons observed.

Teacher exposition

♦ The teacher regulates verbally what ideas are used to build the model and how they are incorporated.

Who is doing the talking?

Who controls the flow of ideas?

Language forms the major link between the different aspects of model-building, and exposition is therefore a theme that runs through much of the material collected. This occurs when the teacher controls the information that is under consideration and the direction of the discussion in the class or group, whether or not the information is actually supplied by the teacher. This notion of exposition applied through *all* the lessons we observed. At no time were the children in substantial control of the flow of ideas under discussion. To be sure, teachers invited children to comment, to suggest ideas and to answer questions. However, this always took the form of exchanges within a sequence regulated by the teacher, and the children's comments were appropriated by the teacher in order to advance the unfolding narrative. The process was therefore evidently subordinated to the purpose of maintaining the teacher's planned unfolding of the lesson.

The modes of dialogue holding together the various elements of teacher exposition were principally of two kinds. The simplest was teacher monologue, which Boulter and Gilbert (1996) term 'didactic argument'.

This puts the teacher in the role of persuader and pupils in the role of passive recipients. The extent to which this mode was used by teachers varied along with the pattern of activities in the lesson. The other predominant mode consisted in the three-move teaching exchange pattern that has been noted in numerous studies of classroom interaction. The three essential moves in such exchanges are *teacher question, pupil answer* and *teacher evaluation* (Lemke, 1990), though other writers refer to these differently (Sinclair and Coulthard, 1975). The exchange is a subset of a more general initiation – response – feedback pattern underlying social interaction (Stubbs, 1983). What sets it apart from interaction more generally is the use of questions to draw out from pupils things that the teacher already knows and wants to convey to the children but does not want to state directly (Edwards and Mercer, 1987). Boulter and Gilbert refer to this as 'Socratic argument'.

It is not that there are no alternatives to this kind of direction. Group tasks in which children are free to discuss their own ideas and to raise substantive questions would not be classified as teacher exposition. It is quite possible that such activities were part of the teaching repertoire of those participating in this study. However, they were not, it seems, considered appropriate for these specific introductory sessions. The fact that these were expository lessons and not exploratory lessons also had a bearing on how the processes of investigative science were employed, and this point is taken up further below.

Secondary source research

- Pupils locate information from secondary sources, such as reference books or CD-ROMs.

  Other than the teacher, what authoritative sources of information are drawn upon?

  Whose questions are addressed in the research?

The main alternative means of mediating information to be acquired by the children was the use of secondary sources, which occurred in a small number of the lessons observed. Usually, this was not an activity which the focus group was engaged in, although in Charlie Junior School a computer program was used with the whole class to illustrate the circulatory system.

The pattern of usage of secondary material that we observed indicated that it was the teacher who directed the children to it, and that what information the children were expected to obtain by this means was decided in advance as part of the planned introduction of the topic. There were no instances in which children had decided to turn to secondary sources to answer questions of their own that arose in their work. This strongly suggests that, in these introductory lessons, secondary source research should be seen as a component of teacher exposition, although again, this may not be indicative of the teachers' approaches more generally.

As with teacher exposition itself, this category crosses over subsequent categories, as secondary sources typically feature pictures and diagrams.

Observation of target domain

- Pupils make observations of phenomena that form part of the target domain, or that provide evidence pointing to the target domain.

  What phenomena do children observe for themselves?

  How are links from the evidence to the real-world target established?

Reference may be established with respect to the actual entities in the real world by two subtly different means. Either one 'points' directly at the entity in question ('that thing there in the sky is the Sun') or one identifies certain indirect pointers ('that throbbing in your wrist is the blood pushing through your veins').

Where it is possible to make direct observations of objects that form part of the target domain, this is one way of making the domain 'real' to the children. However, the nature of the topics chosen for the focus of this study was, deliberately, such that much of the domain would be inaccessible. Observations could be (and were) made of the Sun and the Moon, although this was never as part of the introductory lesson observed, and mostly had formed part of previous work. In all cases, such observations were to some extent assumed as forming the background to the lesson.

The other way in which observations of 'Realm 1' can be brought into play is, as suggested in Chapter 1, in providing evidence of unobservable events. In each of the lessons on the heart and circulation, children observed their pulse by feeling either their wrist or their neck. It was not palpitations of the surface of the body that were of interest in these lessons, but the events taking place below the surface — the pulsating movement of blood being pushed through blood vessels. It was as a symptom of these unseen events that the observations acquired significance. Another instance of observations as evidence of underlying processes concerns the Sun's apparent movement across the sky. This was sometimes referenced, in lessons on the Earth and beyond, to the rotation of the Earth. However, it is a notoriously ambiguous piece of evidence, being equally compatible with a naive theory in which the Sun orbits the Earth. Consequently, observation in the target domain rarely could stand alone, and often needed to be combined with manipulation of either the target domain directly or its analogue.

Observation of analogue domain: picturing

♦ Pupils observe a picture, model or other non-verbal representation conveying information about the content or structure of the target domain.

How are the features and the relationships in the unseen domain represented (and how are they ***mis****represented)?*

How are these representations referenced to the real-world target?

For reasons that are discussed above, pictures and other representations are never exact reproductions and therefore are all considered as analogues of the real-world entities they stood for. It was possible to distinguish several varieties:

- 2D picture/diagram
- 3D picture/imitation
- drama.

These stood in various relationships to the target, and so whether and how these links were established is of significant interest.

Pictures and diagrams frequently appeared in teachers' presentations. Examples ranged from the highly realistic (such as photographs of objects, like the Earth from space, that would otherwise not be accessible in the appropriate form) to the highly schematic (such as the 'very unrealistic diagram' of the heart reproduced in Box 4.6.). Three-dimensional models featured in some lessons, including human torsos, globes, and orreries. An interesting variation was the use of the children themselves as part of the representation. In Foxtrot Combined School, the children danced the part of planets, embodying in their own actions the movement of the Earth orbiting the Sun. The model of the circulatory system used by the teacher in Juliet Junior School incorporated the action of children carrying representations of oxygen around a circuit laid out on the floor. Teachers often made explicit what the elements in the picture represented, typically using phrases such as '*this* [globe] is the Earth and *this* [torch] is the Sun'. However, this could not be maintained over all aspects of the analogue, and some of the links were invariably implicit. Often these tacit elements concerned the relationships and processes linking the objects. An example of this is provided by the lesson in St Bravo Primary School. In one of the analogies used in that lesson, a torch was shone through the lid of a shoe box and moved from side to side so that the children could observe how shadows changed inside the box. Whilst it was explicit that the torch represented the Sun and the shoe box the surface of the Earth, the fact that the lateral movement of the *torch* represented the rotation of the *Earth* about its axis was not discussed.

With some representations, aspects of the structure of the target domain were inseparable from the structure of the analogue. In the case of a globe, for example, the angle of the axis is fixed relative to the base, and this only permits rotation in a specific plane. Thus the movements that may be represented are constrained. In other cases, such as the 'dance of the planets' in Foxtrot Combined School, the constraints have to be applied by the teacher: there was nothing intrinsic to the actions involved that would prevent children dancing the path of the planets in any way they chose. Such considerations governed the possibility of carrying out manipulation of variables in the model to observe the effects. As with observation in the target domain, therefore, this category did not necessarily stand alone.

Manipulation of variables

♦ A variable is manipulated, either in the target or the analogue domain, and its effect on another variable within the same domain is observed.

In what ways do the teacher or children intervene in the real or the analogue world?

How do these interventions relate to the developing model?

With this category, further elements of 'scientific method' come into use. Although much work in science consists in observation, it is *intervening* in the functioning of nature that is characteristic of the physical sciences (Hacking, 1983). The success of this method depends on a causal link between one (independent) variable and another (dependent) variable. According to the scientific approach, if the link hypothesised is correct, then certain changes to the independent variable will instigate predictable changes in the dependent variable, predictions that can be tested. However, the emphasis in the introductory lessons observed was often quite different from that of the scientist.

In these lessons, the manipulation of variables was used as a means of filling out the developing scientific model by bringing into play new information or by illustrating a point that was being made. Although sharing in several cases the form of experiments, these manipulations were essentially used for demonstrating the effects of processes in the real-world domain, sometimes by direct intervention in that domain, and sometimes by analogy. They were not attempts to test a theory by producing disconfirming evidence, but were intended to add information in accordance with the theory. There were, though, subtle differences in how these manipulations were related to the developing model.

The oft-encountered measurement of the effect of manipulating the level of bodily activity on the pulse rate was one example of manipulation carried out in the target domain. Sometimes, but by no means invariably, the link was made to the transport of oxygen in the blood. In other cases, the emphasis was different, for example, to underline the point that the heart regulates itself involuntarily. The teachers seemed typically to be using this task to establish an item of knowledge, such as the relationship between pulse rate and exercise, or simply to make a point more vividly. Turning to manipulation of variables in the analogue domain, a common activity was for children to spin a globe in relation to a light source and to note how different parts of the surface were illuminated, and how a shadow cast on the surface of the globe by a small lump of tacky material changed as a result. The purpose of this manipulation is best seen as demonstrating how everyday experience of night and day and of the change in position of shadows relate to a 'spinning-Earth' model. It could not, however, serve to distinguish between that model and an alternative in which the Sun orbits the Earth.

Teachers did not state to pupils their purpose for introducing an experimental manipulation. Part of the rationale for using these experiments was surely to give children a more active role in their learning, to illustrate specific points and help the children to 'see for themselves'. But these aims were not generally explained to the children. In practice, the introduction of an experiment was often accompanied by 'boundary signals' of both a verbal and non-verbal nature (Sinclair and Coulthard, 1975; Lemke, 1990). For example, the kind of talk taking place could change from the typical teacher question – pupil answer – teacher evaluation sequence of class discussion to instructions issued in the form of teacher monologue and often prefaced by a verbal marker such as 'Now ...', 'Right ...' and so on. Such signals are experienced by an observer as creating a disjunction between one activity and another, and so would mark an experiment as a separate episode within the learning sequence.

Teachers' development of models in the classroom

Although the purpose of models is to aid interpretation of reality, the way in which a model is built up in the classroom is often far from simple. The manner in which the above themes interrelated in any individual instance was complex. In this section, we present a more detailed commentary on how the topics were introduced, drawing on further analysis of some of the lessons to exemplify how the different aspects were worked out in the classroom, and how this influenced children's understanding. This is done with a view to drawing out further general issues. In singling out examples, we are in no sense holding them up for special praise or criticism; they are neither seen as *the* way to teach the topic, nor as how *not* to teach.

Heart and circulation

We begin with the lesson seen in Charlie Junior School. The orientation of the teacher's approach was firmly towards seeing the heart in conjunction with other elements as part of a *system*. The lesson was part of a series in which several body systems were covered, and in the week before the lesson observed, the children had studied the digestive system. The idea of a system was not, as a consequence, a new one. Nevertheless, the teacher spent a substantial period reviewing the children's understanding of the notion, and drawing out a wide variety of examples. These then served as pictures of the target domain. The children were later reminded of this central idea of 'system' at several junctures.

When attention turned to the circulatory system as such, the teacher referred to it variously as the 'blood system', the 'blood and heart system' and the 'blood and lymph system' (accompanied, in the latter case, by a promissory note that the meaning of 'lymph' would be explained on another occasion). Thus was the interconnectedness of the entities in the domain stressed before the individual components were identified and examined in more detail. When the blood vessels were first introduced into discussion as a result of viewing the animated diagram on the computer, they were likened to the roads, wires and railways in analogue systems, thereby linking analogue and target. That these vessels go everywhere in the body and are connected to the heart was emphasised.

When the focus of the lesson turned to the functioning of the heart, the main theme of the discussion was on the heart as a muscle, which worked involuntarily and did not tire. A comparison was made with an analogue in the form of the children's biceps, which contracted and relaxed in the same way, but which contrasted in that they tired with continued use. The children engaged in an activity in which the effect of exercise on pulse rate was explored. This was effectively a qualitative exploration; measurement was not required, and the children were told that they would be making measurements at a later date. However, two children were used to demonstrate how these measurements could be made. Following this activity, the children were given the schematic analogue of the heart shown previously in Box 4.6. Stripped of unnecessary detail, this picture emphasised the features of the heart that relate to its part in the whole system, although much of the rest of that system was not included in the diagram.

Table 5.1: Development of model of heart and circulation in *Charlie Junior School*

Analogy 1

Real-world Target	Analogue Domain	Form	Elaboration
Circulatory system	Various other systems	Verbal description	A system is a set of things that work together, e.g. hi-fi, computer, motorway, railway, electrical systems
Blood vessels	Components of other systems	Verbal description	Blood vessels 'are like' roads, wires, rails

Analogy 2

Real-world Target	Analogue Domain	Form	Elaboration
Circulatory system	Computer graphic/ graphic on information sheet	Physical entity	Diagram 'is' the blood and lymph system
Heart	Area on diagram	Physical entity	Heart is made of muscle It does not tire and works involuntarily Compared with muscle in arm, which can be felt contracting
Veins and arteries	Area on diagram	Physical entity	Veins are tubes that go 'everywhere' in the body Veins can be seen as blue lines on wrist, and arteries as less blue They are pipes (like radiator pipes) connected to the heart

Analogy 3

Real-world Target	Analogue Domain	Form	Elaboration
Heart	Diagram on worksheet/ chalkboard	Physical entity	'A very unrealistic diagram of the heart' Heart comprises four chambers
Left & right atrium	Area on diagram	Physical entity	
Left & right ventricle	Area on diagram	Physical entity	
Valves	Not shown on diagram	Verbal description	Position pointed out Valves are sphincters or trapdoors between chambers that make the system a one-way system
Lungs	Area off diagram	Verbal description	Blood sent to lungs from heart Lungs used for breathing Air enters lungs and oxygen, which is part of air, enters blood
Blood flow	Arrows on diagram	Physical entity	Description of flow from body, through right atrium and ventricle to lungs, to left atrium and ventricle to body

Table 5.1 sets out in summary form the way in which aspects of the target domain were represented in the various analogies that were used to build up a model of the circulatory system. It shows how the overall notion of a system, and then each of the elements within the target system, was introduced. The first two columns show what was represented and what it was represented by. The third column shows the form in which the analogy was presented to the children. This indicates that mostly there was a concrete referent, but that in a few instances the analogue was referred to by description only; there was, for example, no railway system present in the classroom. The final column summarises how the teacher elaborated on the nature of the entities involved, and on their role, and includes any references linking the domains. How, then, did the children respond to this teaching?

During interviews with the children, the one theme that came through most strongly was that the heart is a muscle that works involuntarily, that does not get tired, and that speeds up under certain conditions such as exercise and fear. This knowledge was directly attributed by the children to the lesson. The heart was seen primarily as something that 'keeps us alive', though on probing most of the children had some idea about the link between the heart and the movement of blood in the body. In general, the children tended not to have a clear understanding of the role of blood vessels as part of the system. The majority view was that blood is loose in the body, held in by the skin. Only one child used the word *system*. Given the primary focus of the lesson, it is curious that this did not come to the fore in children's interviews. It is therefore worth identifying some possible reasons for this. One of the children commented that the computer diagram had not been very clear. This, together with the virtual absence of blood vessels from the schematic diagram, may have lessened the clarity of the link between the analogies presented and the target domain. On the other hand, the observations and manipulations in the target domain itself were particularly memorable for the children. The episode in which children explored changes in pulse rate was, as discussed above, focused on the nature of the heart, rather than specifically on its place in a system. It was this vivid episode that was reflected in the children's comments.

It is instructive to contrast the above interviews with those carried out in Echo Middle School. The children there were also shown a diagram that was highly stylised, but which did feature a representation of the blood vessels. There was in addition a very visible analogue of the blood moving through the system in the form of plastic cubes passed along the blood vessels, and the children were actively involved in making the system 'work' by moving the cubes themselves. The interview responses showed that the children at Echo Middle had dispensed with the vague notion of the heart as something that 'keeps you alive', and had all substituted a model in which the role of the heart was viewed as pumping blood around the body. They also demonstrated a clear view of the systemic nature of the heart and blood vessels, and of the movement of blood and transportation of oxygen and carbon dioxide through the body. The simplified picture of the circulatory system and its workings seems therefore to have been successful in making the scientific model clear to the children. Interestingly, and in contrast to the children at Charlie Junior, the investigation of the relationship between pulse rate and level of activity did not feature prominently in the answers given by the children, even though they had all carried out the task. This suggests that this teacher's chosen emphasis came through more clearly to these children. Comparison between the two classes is hazardous, however. The children at Echo Middle worked in a small group, with the rest of the class supervised by another adult, whereas the children at Charlie Junior were taught as a whole class. The children's backgrounds differed between the schools, and it appeared that children's prior understanding was more advanced at Echo Middle. Any apparent differences in what was learned are therefore likely to have had multiple causes.

In some ways, the approach used at Juliet Junior School was very similar to that at Echo Middle. The teacher's emphasis was on *circulation*. She began with this theme by asking the children to recall previous work on circulation in plants, implicitly comparing the circulation of water in plants with that of blood in humans, and of 'food' in both systems. Making the transition to the human circulatory system, she stated that this was a 'circular' system in which blood circulates around the body. The children described a circle in the air with their hand to reinforce the point.

The teacher then spent some time exploring the idea of pumps, allowing the children to offer numerous examples of different kinds of pump. She drew these together using the idea that a pump is something that pushes things. She then linked this analogy to the heart, which she described as having a pumping action. The children were each then given experience of a pumping action by drawing water into a syringe and ejecting it again.

In the next phase of the lesson, an analogy was built up in which the heart was located in a circuit. The heart itself was represented by a cardboard box, and in the centre of the classroom, a circuit was laid out in which major body organs, the muscles, kidneys, liver and lungs, were represented by paper labels. Plastic cubes were used to represent oxygen, and these were collected from the lungs by a person (representing the blood), carried to the heart and then transported around the organ circuit in a box (representing the tubes or 'veins' in which blood circulates). Some of the oxygen was deposited at each of the organs. The movement was carried out by the children in turns, accompanied and directed by a commentary from the teacher. The teacher introduced the term 'arteries', and explained that blood high in oxygen content is called 'oxygenated' and flows in arteries away from the heart,

Table 5.2: Development of model heart and circulation in *Juliet Junior School*

Analogy 1

Real-world Target	Analogue Domain	Form	Elaboration
Human circulatory system	Plant circulatory system	Verbal description	(Implicit link)
Blood	Water	Verbal description	Blood circulates around body (Implicit link)
Human food	Plant food	Verbal description	Food circulates around body in blood (Implicit link)

Analogy 2

Real-world Target	Analogue Domain	Form	Elaboration
Circulatory system	Circle drawn in air with hand	Verbal description + physical movement	Circular system in which blood circulates around body
Heart	Pump/syringe (Various kinds of pump cited as examples)	Verbal description + physical movement	The heart has a pumping action A pump is an object that pushes things
Heart	Cardboard box (containing cubes)	Physical entity	Box 'is' the heart
Muscles, kidney, liver, lungs	Paper labels	Physical entity	
Food		Verbal description	Circulates in blood
Oxygen	Plastic cubes	Physical entity	Oxygen is something we breathe in Oxygen circulates in blood to all body parts Blood with oxygen is called oxygenated blood, blood without oxygen is called deoxygentated blood
Blood	Person (carrying cubes)	Physical entity	The person 'is' the blood
Veins	Box (for carrying cubes)	Physical entity	Boxes 'are' veins Veins are tubes in which blood travels around body. Veins return blood to heart (arteries take blood away from heart; capillaries – examples in eye – are tiny veins)
Circulation	Movement of cubes/box	Physical movement	
Auricle/ ventricle		Verbal description	Parts of heart (not stressed)

while blood low in oxygen is 'deoxygenated' and returns to the heart in veins. She also asked them to observe the tiny veins called capillaries in their eyes, thereby making a link to the target domain. The parts of the heart were mentioned but not stressed in this lesson. Table 5.2 summarises how aspects of the target domain were represented in the teacher's use of analogies.

Following some time spent exploring this model, the teacher asked the children why blood might sometimes move more quickly through the body. The children focused on the *circumstances* under which this happened, that is, when exercising, rather than the underlying reasons. The lesson then moved to a phase in which some of the children carried out an experiment in which they manipulated their level of activity and observed the effect on the pulse rate, work which was carried out in the target domain, locating their pulse in their neck. This followed the common pattern of measuring pulse rate at rest, after exercise and after relaxation. Questioning the children as they carried out the work, the teacher encouraged the children to think through the reasons behind the effects they were observing. Children responded in terms such as: the blood moves more quickly to 'give more energy', the energy comes from 'oxygen' and 'food' in the blood. The remainder of the children copied a diagram from the board and wrote about the circulatory system and its workings. The diagram was identical in form to that seen in Echo Middle.

The children interviewed were those who had carried out the experimental manipulation. In every case, the children had found the lesson clear and interesting, and were able to describe the workings of the circulatory system and function of heart correctly. In particular, they understood that the blood flowed in a complete circuit including major organs. The main emphasis in their answers was on oxygen passing around the system from the lungs to the organs, and this was something that they claimed they had learned as a result of the lesson. Most of the children linked this to the body's need for energy. It appears that these children had constructed a sound model of the circulatory system. None of the children made reference to the experiment they had done, although this aspect of the lesson may have been reflected in the emphasis on energy.

Again, in this example, the continuous 'circular' nature of the circulatory system had been emphasised early on and reinforced through the lesson. This feature was embodied in the analogy of a circuit on the floor. The movement of oxygen was an integral part of the model constructed, and although the teacher did not specify that this lay behind the experiment the children undertook, they nevertheless appeared to make the connection and they readily related their interview responses to this idea. The heart's pumping action was something that all the children were clear about, but this action was seen as contributing to the overall system.

Earth and beyond

We begin the focus on this area of science by examining a lesson that made use of the common approach to this topic of using a globe and a light source as analogues for the Earth and the Sun. The lesson was observed in Kilo Primary School, and took place with six children working in a group with their teacher. In the early part of the lesson, some time was spent building a model of the Earth as a spherical body in space. The first type of analogue presented consisted of photographs of the Earth from space. One showed the Earth fully illuminated, and the other showed it with part of the surface in darkness. Reference was quickly established: 'This is the Earth.' The land and water masses were pointed out as brown and blue patches, and similar patches in green and blue were identified on a different analogue — a globe. This enabled the teacher to relate the colour symbolism on the globe to the real features of the Earth's surface.

At this point, attention turned to the Sun. The teacher asked the children what the Sun 'gives out', with the children replying that it gave out light and heat. The teacher then related these features of the target domain to its analogue in the form of a desk lamp. She asked them to consider how the features of the lamp mapped on to the target: 'Is the lamp like our Sun?' It was quickly established that the light from the lamp was directional, while the Sun gave out light in all directions. The children were referred to a diagram on a wall chart depicting the Sun to reinforce this point. They were asked, however, to 'pretend' that the lamp was the Sun, thus making the link between representation and represented very explicit, and the equivalent link was also underlined for the globe: 'This is the Earth.'

With these major components of the model established, the processes at work in the domain were explored. The lamp was shone on to the surface of the globe and the resulting light patch was pointed out by the teacher and contrasted with the shadow on the side facing away from the lamp. These phenomena were linked to day and night on Earth. There then followed a phase in which one variable in the analogue domain was manipulated and its effect noted: the globe was rotated on its axis and the change in where light fell on its surface was emphasised. The teacher spent some time discussing with the children what this represented in terms of their experience. The light patches were linked to their experience of daytime, and the dark to night. Early morning and late evening were described by one of the children in answer to a question from the teacher as 'a bit of both'. On further questioning, children explained that this was when the Sun was rising or setting. The teacher then posed the crucial question of whether it was the Sun that was moving. There was some disagreement among the children over this. Some said that the Sun did move, some that it was because the Earth moved round the Sun, and some because the Earth rotated. The teacher emphasised that it was indeed the rotation of the Earth that was the cause of day and night, demonstrating on the globe and stressing that the movement of the Earth round the Sun was not connected with this.

The teacher then demonstrated how the Earth orbited the Sun, using the globe. On questioning, one of the children said that this took one year, and the teacher continued by explaining that the seasons were parts of the year that were associated with this movement, but that they were not going to say any more about that during the current lesson. The teacher then questioned the children about how long the Earth took to spin round once on its axis, and at this stage it was evident that some confusion had set in, with some children replying that this took one year. This confusion remained amongst some of the children interviewed afterwards. One of the six children, for example, still thought that the Sun moved around the Earth and that it took 24 hours to do so. The others all demonstrated the Earth moving around the Sun, but three of them said that this took 24 hours. Only half of the group correctly explained how day and night occurred. It seems, therefore, that the cause of day and night was not fully established with the children by the time the movement of the Earth around the Sun was introduced into the model, and that at this juncture some of the children lost the main focus of the activity.

In the final phase of the lesson, the teacher modelled for the children the experience of night and day for people in Egypt and in England, helping the children locate the appropriate places on the globe. She showed them the direction in which the Earth turns, and gave a commentary which explained how the movement of the light patch over the surface of the globe corresponded with the rising of the Sun to the East. During this explanation, however, she reversed the direction of rotation, thereby dissipating some of the impact of the demonstration.

Table 5.3 summarises the development of the model in this class.

Similar demonstrations were witnessed in other classes. Two teachers, however, had used rather different approaches to modelling the movement of the Earth in space. The approach that differed most radically was that in Foxtrot Combined School. There, the teacher's approach was focused closely on the ideas of spin and of orbit, and the phenomena of day and night were not covered by the model during this introductory stage.

Following initial warm-up movements, the children were played a piece of music, and asked how it made them feel. The children responded by associating the music with a variety of subjects. When asked to make up titles, amongst the diverse themes mentioned, one of the children responded

Table 5.3: Development of model of Earth and beyond in *Kilo Primary School*

Analogy 1

Real-world Target	Analogue Domain	Form	Elaboration
Earth	Area on photograph	Physical entity	The photograph 'is' the Earth
Land masses	Brown areas on photograph	Physical entity	The brown areas 'are' land
Water masses	Blue areas on photograph	Physical entity	The blue areas 'are' water

Analogy 2

Real-world Target	Analogue Domain	Form	Elaboration
Sun	Desk lamp	Physical entity	Sun gives out light and heat Lamp gives out light and heat For lamp, this is directional, whereas sun gives out in all directions Appearance/non-directionality of Sun represented in wall chart of solar system
Earth	Globe	Physical entity	Globe 'is' the Earth
Daytime	Area on globe illuminated by lamp	Physical entity	Side of [Earth/globe] facing Sun is illuminated, other is not . Corresponds to day and night Early morning and evening in between day and night, when Sun just appearing in sky (link to personal experience of these times)
Earth takes 1 year to orbit sun	Globe moved around lamp	Physical movement	
Earth takes 24 hours to rotate	Globe spinning on axle	Physical movement	24 hours is one day 'One day' includes day and night
England	Area on globe	Physical entity	
Egypt	Area on globe	Physical entity	
North, south, east, west	Area on globe	Physical entity	
Sun rises in the east	Area on globe	Physical entity	

'The Planets'. The teacher picked up on this reference, and elaborated further on what it made her think of before explaining that she wanted the children to make up a space scene.

The resulting dance was built up in stages. In the first, the idea of feeling weightless in space was explored, and the children moved around with a floating motion, which they were going to maintain throughout the dance. The lesson moved on to construct an opening sequence for the dance, in which the children were each going to play the part of a star or planet. For this, they curled into a ball, and then uncurled using a spinning movement. This movement was, through a question and answer sequence, compared to the movement of planets, and other comparisons were made to spinning tops and wheels. It was established that the planets spin anti-clockwise, and this movement was demonstrated by the teacher before the children practised it, accompanied by the teacher's commentary. In the course of this commentary, she placed repeated emphasis on the slowness of the required movement.

During the next phase, the children put together under the teacher's direction a series of moves in which they approached a partner and then one of each pair danced a circular path around the other whilst both maintained a spinning movement. The teacher initiated a discussion in which it was established that this movement could represent the Earth moving round the Sun. Some children suggested that it could also represent the Moon going round the Earth, but the teacher neither explicitly agreed nor disagreed, commenting that they would find out in a future lesson. The teacher also introduced the term 'satellite' as something that goes around something else, but again explained that they would return to this in a future lesson.

For the final stage of the dance, the children moved into groups of eight, with one child in the centre. The seven others orbited the child in the centre whilst at the same time swinging from hand to hand with each other to create a swerving path. This was quite a complex manoeuvre, resulting in children orbiting the centre in opposite directions. It proved difficult to master, and there was insufficient time in the lesson to practice the movement further. The significance of these movements was not discussed, and instead the children practised the beginning of the sequence again.

Table 5.4 shows that the coverage of the target domain in this analogy was confined to relatively few elements.

Table 5.4: Development of model of Earth and beyond in *Foxtrot Combined School*

Analogy 1

Real-world Target	Analogue Domain	Form	Elaboration
Star	Child	Physical entity	The children 'are' stars The children/stars spin anticlockwise, like wheels or spinning tops. The movement is slow
Planet	Child	Physical entity	The children 'are' planets The children/planets spin anticlockwise, like wheels or spinning tops Earth orbits the sun The movement is slow
Satellite	Child	Physical entity	Satellite is something that moves around something else

Given this very specific focus, the children interviewed afterwards were generally secure in their understanding of how the Earth moved in relation to the Sun, and also how the Moon moved around the Earth, although this had been mentioned only briefly and never confirmed. The timescales of these movements had also not been covered in the lesson, and children's knowledge of this was varied. The activity brings out some interesting issues in relating scientific knowledge to the dance movements. Some of the demands of the dance were not entirely compatible with the underlying science (the growing up from a curled position, for example) and yet many of the points of match and mismatch between the domains were left tacit. This slight ambiguity between whether the lesson was primarily about dance or about science was reflected in the children's responses during the interview, where children's typical opening comments about what they had been doing and about things that were and were not clear to them during the lesson focused on carrying out the dance movements.

At Alpha Combined School, the children made orreries to demonstrate the relative movements of the Earth, Moon and Sun. The teacher had made the aim of the lesson, that children should come to understand how the bodies moved, explicit. Afterwards, the children tended to be secure in their knowledge of these aspects of the scientific model. As in the previous example, the lesson covered a selection of specific relationships, and did not focus on the phenomena of day and night. A limitation of the model orrery that came through in several answers was that the Moon was fixed to the arm that joined it to the Earth. This was correct in that one part of the Moon always faced the Earth as it orbited. However, this was interpreted by children as the Moon 'not moving' or 'not rotating'. On the other hand, the lesson had succeeded in dispelling one child's misconception that the Moon and the Sun stayed on opposite sides of the Earth. As in Foxtrot Combined, children's comments during interviews sometimes revealed that they were as much concerned about how to build the orrery as with their knowledge of the scientific principles embodied in the device. There is, then, a danger when the task of constructing a representation requires physical skill that the demands of the medium may mask the underlying message.

Emerging themes

Through this highly diverse collection of introductory lessons covering different topics in different ways, some continuous threads can be traced. These emerging themes are sketched out below, and form the basis of the discussion in the final chapter.

- The teachers made use of strongly directed activities accompanied by continuing exposition to introduce scientific models to their pupils. The lessons had a structure prepared in advance, and the extent to which they were reactive to children's preconceptions was limited. The 'need to learn' was generated in several different ways, but usually made little reference to children's preconceptions.
- Teachers employed analogies of various kinds to relate the scientific models to children's prior knowledge, rather than adopting add-on or confrontational approaches. Teachers could use single or multiple analogies.
- The nature of the scientific model overall was not something that teachers tended to make explicit, in their exposition, as an organiser for the children's learning. Instead, they tended to reveal the model step by step, leaving the links between the pictures, observations and manipulations tacit. Boundary moves in the teachers' talk marked these out as separate episodes in the lesson.
- Investigative or experimental work of a practical nature was used primarily to help children discover new information relevant to the model.
- Within a topic, teachers had different emphases for the model they were building. The children's understanding reflected the emphasis in the teacher's approach.

6
DISCUSSION AND CONCLUSIONS

In looking at a picture in an art gallery different people might see different things. A mathematician might enjoy the dimensions and symmetry of the picture, a speculator might consider its financial value, a scientist might reflect upon the chemical composition of the paints and the wavelength of light reflecting from it ... All of these illustrate different ways of looking at the same thing, each perspective is different and based on different forms of knowledge
(Brian Woolnough, 1996, pp.178-9).

We began this study with the aim of 'developing a better understanding of what teachers naturally do' when tackling the problem of introducing children to scientific ideas beyond the realm of immediate experience. In the course of the study, we have been privileged to observe some most interesting lessons and some skilful teaching. The data gathered have provided a fascinating snapshot of current practice, of what actually goes on in typical primary schools in the name of science teaching. Further than that, we have presented a framework to analyse that practice and that has enabled some of the features that make lessons effective to be identified. The framework has a dual purpose. It serves as a means of *describing* existing practice, and also as a tool that may be employed by reflective practitioners to *plan* and *develop* their approach to scientific concepts. Lastly, we have identified some of the ways that science teaching affects children's learning.

How typical were the lessons encountered during this research? The full effects of selective drop-out by teachers originally approached to participate in this research cannot be known. It certainly might be supposed that those who did allow us into their classrooms to observe what they did and to talk to their pupils were those who were confident in their handling of science. Probably this was to some extent the case. Some of these teachers were responsible for coordinating science teaching in their school, but several were not. No doubt the thought of being observed would also have inspired extra attention to the lesson concerned, and may have influenced some of the decisions teachers made so as to produce activities that were more interesting to watch. Otherwise, there was nothing to suggest that these teachers or their lessons were in any sense unusual. The data represent, we suggest, the work of competent key stage 2 teachers giving of their best.

The anatomy of a lesson

The lessons showed considerable diversity. There were elements of dance, drama and practical manipulation, in addition to the pervasive talk. In some classes, children worked in small groups with the teacher, while in others they operated as a whole class. In every case, children were actively involved in the lesson to some extent, although the way in which physical engagement related to the other elements of the lesson varied widely. Hence, while similar activities were to be seen in a number of classrooms, the approaches used by the teachers were not the same.

Central to all the lessons was the teacher's exposition. The talk and the activity engaged in by the children were fairly tightly controlled by the teacher, and were subordinated to the purpose of putting across certain ideas to be learned. Where voices from outside the classroom were called upon, as when secondary source research was used, this was also to answer questions focused by the teacher. Intermingled with more direct statements by the teacher, the characteristic pattern of dialogue running across all the lessons was the three-move teacher question – pupil answer – teacher evaluation sequence, which teachers commonly use as part of their strategy to draw out the appropriate answers from pupils, and usually from only a select number of pupils. This pattern of language use is firmly in what Boulter and Gilbert (1996) call the 'Socratic' argumentational mode. The central thread of didactic and Socratic argument points up a relatively directed overall approach on the part of the teachers, whatever scope children may have had at specific stages in the lesson. The centrality of a 'performance' orchestrated by the teacher has been noted in other studies of the 'narrative of introduction' of new scientific concepts (Scott, 1996).

Within the central theme of teacher exposition, teachers almost universally used some form of 'model-building' approach to developing the scientific understanding that was the focus of the teaching and to linking this to children's prior knowledge. In doing so, they made use of analogies of various kinds. Probably quite sensibly, given their circumstances, they did not in these introductory lessons make use of a 'confrontational' strategy, whereby children's ideas about a topic were elicited and misconceptions addressed directly. Few of the teachers elicited children's views in any systematic way. Whether this was an active choice or whether teachers just did not know how to use a confrontational approach is not clear.

The use of a model-building approach to developing scientific ideas in conjunction with a predominantly Socratic pattern of talk raises an important question: To what extent are these supportive of one another? The underlying principle of Socratic argument is that the desired knowledge state can be achieved by piecing together elements in the pupil's existing knowledge and experience, with judicious use of counter-evidence where necessary. The rationale for using a model is that this supplies a new and different way of interpreting experience. What happens in a Socratic sequence is that the ideas being developed are gradually revealed. Meaning is emergent, and it was quite characteristic of the approach of the teachers observed that they tended not to explain the reasons *why* children were doing particular things in a particular order. This was something the children were to discover for themselves. A scientific model, on the other hand, is a device for putting individuals in command of their own knowledge development and of organising shared meaning. In practice, the boundaries between the different patterns of 'argument' may not be as sharp as we have implied here. The point to make is therefore that how teacher exposition is used to structure the introduction of a model is something that must be considered if that model is to be optimally effective, and that some subtle changes of emphasis may reap benefits in terms of children's understanding of science. We return to this point later in the chapter.

Looking more closely at the ways used by the teachers to 'picture' the real-world domains, it became clear that not all the points of similarity and dissimilarity between analogue and target domain were set out explicitly, and neither was it stated what every entity in the analogy represented. Given the complexity of the analogies employed in some cases, it is unlikely that providing children with a full mapping of the points of correspondence between the two domains would be practicable. Nevertheless, it is important that teachers are aware of where their analogies begin to break down, and that they take steps to avoid reinforcing possible misconceptions through the pictures they use. We have in mind here pictures like a moving light source used to represent a rotating Earth, but which could equally well represent the Sun orbiting the Earth. Exactly when it is necessary to spell out the mappings between the domains is clearly a matter of judgement. Is it, for example, necessary to point out to children that planets do not weave in and out of each other's paths as they orbit the Sun (as the children did in their dance sequence)? Or to make clear that veins do not themselves move around the body (as the plastic box containing cubes did in the picture of circulation)? Without a much better understanding of how children respond to analogies, there are no fixed answers to questions such as this. However, what is important is that the question is raised.

One strategy that holds promise is what was referred to earlier as 'making the familiar strange'. By deliberately eliminating unnecessary elements from a picture, it is possible to simplify the relationship between an analogue and its target, which should assist in highlighting the relationships that are important. By introducing an element of surprise, this may also motivate learning. It may, of course, also introduce new difficulties, and, like a Picasso painting, which also distorts to achieve a particular effect, perhaps its message is not appreciated by everybody. As yet we are not in a position to know whether the disadvantages outweigh the advantages. Other strategies for creating a 'need to learn' were also noted. These included the use of problems whose solutions embodied the scientific model. When using this approach, some care is needed that the demands of the problem itself do not force attention away from the scientific aims.

The role of experiment

One of the most interesting themes to emerge from the study concerns the relationship between practical investigation and the more expository elements of the lessons. The use of activities in which children were to manipulate variables in the target domain, and the way in which they were used, suggested that teachers saw a value in children 'finding out' for themselves. Yet the clear structure to the lessons generally indicated that at least a substantial proportion of the information that the children were to obtain from the investigation was settled in advance and could, if teachers had chosen, simply have been stated. That is, whatever the children were expected to discover formed part of the overall structure of what they were supposed to learn, and finding out, in these cases, meant finding particular outcomes. Thus the activity was introduced with words such as: 'Now I want you to find out what happens when ... '

There is, it must be said, nothing wrong with this as an approach. Primary teachers have long favoured first-hand experience as a means of learning because they believe it makes learning more meaningful and more personally relevant, and because it is seen as more motivating than so-called 'didactic' methods. These seem in themselves worthy aims. But they are not the only possible rationale for employing first-hand experience. Clive Sutton makes the point:

> *Teachers value 'learning by doing' a lot — and for very good reasons, but have got trapped in an unjustified extension of that idea — the belief that the practical work is the basis of the lesson, from which pupils are bound to learn. This over-confidence in experience at the bench is linked*

> *with outdated views of science and mistaken beliefs about the independence of observation from language ... If these beliefs changed, and our model of learning were to change, we would then have a much better theoretical rationale for diversifying the lesson activities, i.e. for choosing those activities which help pupils tune in to 'foreign conversations' and to appreciate the scientific models which the 'foreigners' are using.*
>
> (Sutton, 1996, p.149)

Sutton's metaphor of a 'foreign conversation' is meant to underline the point that science is a strange language which people have to learn but which is, like any living language, fruitful for mediating interactions with the real world. Changing the emphasis in science teaching from acquiring scientific knowledge to appreciating scientific models also changes the role of practical experience. It is no longer the way to accrue facts but the means of trying out the scientific view; no longer '*let's see what we can find out*', but '*let's see how the model fits*' and '*let's see if the model can help us to understand what's happening here*'.

In the lessons where children were manipulating variables in the analogue domain, there were elements of this orientation. In these cases, children were interacting with a physical model and were observing the effects of the processes represented in that model, noting the effect, for example, of the rotation of the 'Earth' in relation to the 'Sun'. What was missing was the explicit message '*Let's see if we can understand day and night using this model*'. This may seem a trivial point, and in isolation it would be. It is, though, a reflection of a different view of the learning process, in which children are regarded as apprentices who need to be inducted into scientific ways of seeing the world. There were, in fact, tantalising glimpses of this view of learning to be found in the data, as, for example, in Charlie Junior School, where the teacher stressed the importance of *seeing as a system* the heart and the blood vessels.

Using the framework in teaching

The classification framework used to analyse the lessons for this research provides a set of headings and questions that could be used not only in further studies, but also by teachers to help plan teaching and to reflect on what their lessons might be achieving. The framework is presented here, adapted for this purpose.

Creating a need to learn

- Motivating children specifically to understand the scientific model

  What strategies will be used to induce surprise, puzzlement and so on?

Teacher exposition

- Introducing the model, regulating what ideas are used to build the model and how they are incorporated.

  Who will do the talking?

  Who will control the flow of ideas?

Secondary source research

- Use of secondary sources, such as reference books or CD-ROMs.

  Other than the teacher, what authoritative sources of information will be drawn upon?

  Whose questions will be addressed in the research?

Observation of target domain

- Pupils make observations of phenomena that form part of the target domain, or that provide evidence pointing to the target domain.

  What phenomena will children observe for themselves?

  How will links from the evidence to the real-world target be established?

Observation of analogue domain: picturing

- Pupils observe a picture, model or other non-verbal representation conveying information about the content or structure of the target domain.

  How will the features and the relationships in the unseen domain be represented (and how ***mis****represented)?*

  How will these representations be referenced to the real-world target?

Manipulation of variables

- A variable is manipulated, either in the target or the analogue domain, and its effect on another variable within the same domain observed.

  In what ways will the teacher or children intervene in the real or the analogue world?

  How will these interventions relate to the developing model?

What children learned

What children learn from a lesson depends greatly on what they knew previously and on their learning capacity and skill. Because it is almost impossible to control these factors in any realistic classroom context, it is not easy to indicate where one approach was more or less successful than an alternative. Nevertheless, there were instances where there seemed to be a difference in the teacher's expectations of the lesson and the emphases that children drew from it. We noted in particular the case where the children seemed to have been so taken by the idea, underlined by a very physical activity, that the heart keeps beating and regulating its functioning completely automatically, that they did not reflect the teacher's emphasis on the idea of a complete system. This is not an instance of failure; the point that the children did learn is an important one and was well made. But it was disappointing not to see the main theme emerging so clearly from children's answers.

We also noted that confusions persisted with some children between the length of day/night and the length of a year. This was almost certainly a sign that the underlying model of these changes was not firmly established. The conditions in many classrooms conspire with difficulties in representing the relative size and position of the Earth and Sun to make effective demonstration of the model problematic. It may be that focusing on only one relationship would reduce the incidence of this problem, but this is by no means guaranteed. It may also be that some changes to the way manipulation of variables is used could reinforce what is to be learned, and this is discussed below.

It is tempting to draw the conclusion from these difficulties that a single, simple analogy would be the most effective. However, the lesson on the heart and circulation in Juliet Junior introduced quite a range of analogies, as the analysis in the previous chapter shows. Yet despite this complexity, not only did the lesson appear to the observer to be clear and effective, the children's remarks and their answers to interview questions tended to confirm this impression. This would seem to indicate that it is not only the elements that go into the lesson that are important but the structure that integrates them. The lesson to be drawn from this would therefore be: 'Keep your main message simple, but feel free to take multiple perspectives on it.'

Some ways forward

Science, as the quotation at the beginning of this chapter underlines, is a particular way of seeing the world and of coming to know about the world. If it were no different from everyday knowledge, it could hardly be justified as a curriculum subject. This, however, presents something of a dilemma:

whether to ignore the difference (with the risk that, on noticing the difference, children will come to see science as nonsensical) or whether to stress the difference (with the risk that children will see science as defying common sense, and also therefore come to see it as nonsensical). The idea that science accumulates true facts about the world, and that mastering science proceeds in much the same way, is one that is probably widespread among children, and if it is, then it will determine what sense they make of their teacher's intentions. The conception of science as developing new, powerful ways of seeing the world is not one that children are likely to discover for themselves, and it will therefore need to be explained. The suggestion that we now make in response to this is not a dramatic one. It is that the notion of apprenticeship into an explicit scientific model is one that can serve as the organiser for lessons in which scientific concepts involving unobservable relationships are introduced (and, indeed, for a series of such lessons), as well as giving a rationale for the processes of scientific investigation. It therefore respects the interrelationship between language, action and the world that underlies science. This provides the basis for selecting classroom activities, a process which may be guided by the scheme of categories and questions set out in this book. It is also, importantly, something that should be shared openly with the children.

We can begin to sketch out how this would work. Teachers would consider how they could provoke the need in children to adopt a revised model: making predictions; making the familiar strange; introducing problems; monitoring understanding. The idea of a set of shared questions to which children wish to find answers, or a set of public statements to which they can express assent or dissent as encountered in one of the schools visited, is an appealing one, and could help maintain a purpose for the learning to take place. The teachers would then introduce the new model, and make it clear that this is what they were doing — providing a new, scientific, way of looking at these shared questions. The central idea of the model (for example, that the heart is a pump within a system; that the Earth is a sphere that rotates in the light from the Sun) would be stressed, and would be the single essential message of the teaching at this introductory stage. The teachers would consider carefully how they could picture the elements of the scientific model, paying attention to aspects of similarity to, and contrast with, the analogies they deployed. Lastly, they would, where possible, apply the model in experimental activities to allow children to see how well it worked, with this as the explicit aim of the activity. Throughout this process, children would be evaluating the new model, checking that they understood it and seeing how well it addressed the issues they had earlier identified. Because checking for understanding is both important and difficult, this aspect of the approach would need support. The notion of a shared 'working document' in the classroom by means of which children may chart their developing understanding is one that has emerged from previous research (Sizmur and Osborne, forthcoming). There it is suggested that children, in collaboration with their teacher, could build up a concept map of the area of science they were learning about and of how evidence supported the scientific view. These are suggestions that could be refined through research.

Some topics for further research

As yet, little is known about how children deal with analogies. How good are they at sorting out the aspects they should be attending to in the analogy and the aspects they should be ignoring? Although in this study we assessed children's learning as a result of the lessons, it was their understanding of the scientific ideas *per se* that was elicited, and not their understanding of the vehicle by which this was conveyed. Indeed, it was only through studying the approaches actually used by teachers in a range of schools that the pervasiveness of analogy as a teaching tool became evident. Further research into children's interpretation of analogies presented in lessons would be most valuable in highlighting ways that teaching could be made more effective. One interesting phenomenon encountered was the use of quite strange pictures as analogies. How did children react to these? Do they succeed in avoiding potential misconceptions by preventing children from making unwanted connections between analogy and target? These questions require a much more specific focus to pupil interviews.

In a similar vein, research on children's understanding of the purpose of practical work in primary science could be instructive. Do children see investigations as providing answers to questions, as proving a point or as practice in using investigative skills? Do they think investigations are different from other forms of practical work?

We have suggested some subtle changes of emphasis in teaching as being a valuable way forward. The task now is to try those approaches in real classrooms and evaluate the effects. The nature of this task strongly suggests an action research orientation. Groups of teachers could take on the ideas presented here, and see what effect they have on the children's understanding, motivation and enjoyment. Pooled findings and insights arising out of this experiment could then be fed back into the development of the approach. Above all, this must be seen as the beginning of a continuing programme, and not as the end of a study.

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Introducing Scientific Concepts to Children

Often, scientific ways of viewing the world involve objects, processes and relationships that children cannot observe at first hand. Sometimes, the scientific perspective also runs counter to the ideas that children develop for themselves. All this poses some considerable challenges for primary school teachers, many of whom have had limited science education themselves, who are faced with the task of making science accessible to children. What do these teachers actually *do* when introducing children to a new area of scientific knowledge? The *Introducing Scientific Concepts to Children* project set out to observe and analyse existing practice in Key Stage 2 classrooms, and to gather the reactions of those who were intended to benefit from this teaching: the children.

This book describes the approaches used by teachers in a range of schools to introduce two specific scientific topics. Common threads are identified through these approaches, as well as points of difference, and are related to a theoretical framework. The results show

- how teachers made use of children's existing ideas
- how they created the 'need to learn' the new scientific ideas
- how they integrated various resources and approaches, including exposition, analogies and practical tasks, to build up a scientific 'model'
- how children's understanding reflected the approaches used by their teachers.

The book provides a fascinating snapshot of current practice and gives insights into the processes at work in primary science lessons. It also offers teachers, and anyone else with an interest in promoting good science teaching, a basis for reflecting on practice, and therefore of making it more effective.

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