CHAPTER 1

Children's Ideas and the Learning of Science

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Two 11-year-old boys, Tim and Ricky, are studying the way a spring extends as they add ball-bearings to a polystyrene cup which is hanging from it. Ricky is intent on adding ball-bearings one at a time and measuring the new length of the spring after each addition. Tim is watching him, then interrupts: 'Wait. What happens if we lift it up?'

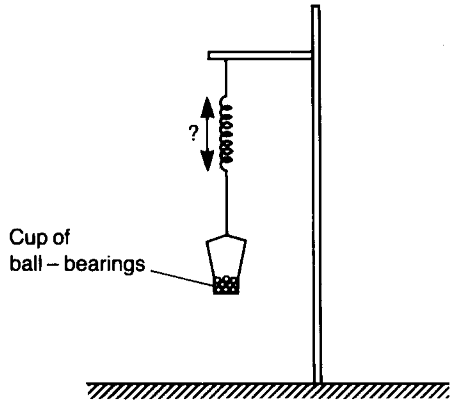

Figure 1.1

He unclamps the spring, raises it higher up the stand, and measures its length again. Apparently satisfied that the length is the same as before he continues with the experiment. Later, when he is asked the reason for doing this, Tim picks up two marbles, holds one up higher than the other and explains:

> this is farther up and gravity is pulling it down harder the farther away. The higher it gets the more effect gravity will have on it because if you just stood over there and someone dropped a pebble on him, it would just sting him, it wouldn't hurt him. But if I dropped it from an

aeroplane it would be accelerating faster and faster and when it hit someone on the head it would kill him.

Tim's idea about weight increasing as objects are lifted higher from the Earth's surface is not an irrational one as his argument indicates (although from a scientist's point of view he seems to be referring here to gravitational potential energy).

Like Tim, many children come to science classes with ideas and interpretations concerning the phenomena that they are studying even when they have received no systematic instruction in these subjects whatsoever. Children form these ideas and interpretations as a result of everyday experiences in all aspects of their lives: through practical physical activities, talking with other people around them and through the media.

This book documents the conceptions that have been uncovered in children aged 10-16, in different physical domains, and indicates the importance of these for teachers and others concerned with science education.

What can be said about these ideas?

Do the ideas that children possess represent coherent models of the phenomena that are frequently presented in classroom settings? Experienced teachers realize that students do have their own ideas about phenomena, even if at times these 'ideas' may seem incoherent at least from the teacher's point of view. It is also recognized that such ideas often persist even when they are not consistent with the experimental results or the explanation of a teacher. In other words, they may be stable ideas. These characteristics of childrens' ideas—their personal nature, their coherence and their stability—will now be discussed in more detail.

These ideas are personal

When children in a class write about the same experiment they can give various diverse interpretations of it. Each one has 'seen' and interpreted the experiment in his or her own way. Our own behaviour is similar; when we read a text or discuss a topic with another person, we may or may not modify our own point of view. The extent to which we do modify our thinking depends at least as much on the ideas we have to start with as on what is written or said. A number of people attending the same lecture or reading the same book, even a scientific text, will not necessarily get from it and retain the same points.

Individuals internalize their experience in a way which is at least partially their own; they construct their own meanings. These personal 'ideas' influence the manner in which information is acquired. This personal manner of approaching phenomena is also found in the way in which scientific knowledge is generated. Most philosophers of science accept that hypotneses or theories do not represent so-called 'objective' data but that they are constructions or products of the human imagination. In this way of thinking, observations of events are influenced by the theoretical frameworks of the observer. The observations children make and their interpretations of them are also influenced by their ideas and expectations.[1*]

The fact that these ideas, whether of a child or a scientist, are personal does not necessarily mean that they may not be shared by many people (just as in the history of the sciences, it has happened that different scientists have independently developed and used the same theoretical framework). The following chapters will show that students, even those in different countries, may have the same ideas, or the same interpretations of similar events.

A child's individual ideas may seem incoherent

What teacher has not been struck by the different and at times contradictory interpretations of phenomena that have been proposed by individuals in a class. Even if students are confronted with what appear to be contradictions to the teacher, they will not necessarily recognize them. In addition, we will see that the same child may have different conceptions of a particular type of phenomenon, sometimes using different arguments leading to opposite predictions in situations which are equivalent from a scientist's point of view, and even switching from one sort of explanation to another for the same phenomenon. We will see many examples during the course of this book of such contradictions in students' thinking. Why these contradictions? The need for coherence, and the criteria for coherence, as perceived by a student are not the same as those of the scientist: the student does not possess any unique model unifying a range of phenomena that the scientist considers as equivalent. Nor does the student necessarily see the need for a coherent view, since *ad hoc* interpretations and predictions about natural events may appear to work quite well in practice.

These ideas are stable

It is often noticed that even after being taught, students have not modified their ideas in spite of attempts by a teacher to challenge them by offering counter-evidence. There are a number of examples in the chapters which follow which illustrate this issue: students may ignore counter-evidence, or interpret it in terms of their prior ideas. Although students' notions may be persistent, as we have already argued, this does not mean that the student has a completely coherent

*Superscript numerals refer to numbered references at the end of each chapter.

model of the phenomena presented, at least in the scientist's sense of the word coherent. The students' interpretations and conceptions are often contradictory, but none the less stable.

How do these ideas affect the learning process? A possible model

Students' minds are not blank slates able to receive instruction in a neutral way; on the contrary, students approach experiences presented in science classes with previously acquired notions and these influence what is learnt from new experiences in a number of ways. These include the observations made of events, the interpretations offered for such observations and the strategies students use to acquire new information, including reading from texts and experimentation.

The child, even when very young, has ideas about things, and these ideas play a role in the learning experience. Many different authors such as Ausubel, Piaget and Wallon, have incorporated this notion as an integral part of their theory. What children are capable of learning depends, at least in part, on 'what they have in their heads', as well as on the learning context in which they find themselves.

A model introduced by cognitive scientists fits well with what we now know of the interaction between the child's different ideas and the manner in which these ideas evolve with teaching. This model is based on the hypothesis that information is stored in memory in various forms and that everything we say and do depends on the elements or groups of elements of this stored information. Such elements or groups of elements have been called 'schemes'.* A scheme may concern an individual's knowledge about a specific phenomenon (for example, the sensation of cold elicited by a metallic object), or a more complex reasoning structure (for example, the association of one variable with another that leads some children to anticipate that 'the brighter the light bulb, the larger the shadow will be'). Thus, the term 'scheme' denotes the diverse things that are stored and interrelated in memory. These 'schemes' also influence the way a person may behave and interact with the environment, and in turn may be influenced by feedback from the environment.

We will illustrate the idea of 'scheme' using as an example a person's notion of a high school.[2] This scheme may incorporate relationships between events or situations that comprise it and which are themselves schemes. Some of these represent physical features, e.g. one or more buildings, stairways, corridors, rooms, a playing field; or people, including a large number of students, teachers, technicians, cleaners and a principal or head.

*Here the word 'scheme' does not have the meaning attributed to it by Piaget but rather the meaning derived from studies of memory and information processing.

Other aspects of the person's general scheme may include the types of relationships or attitudes between the people involved, such as friendship, submission and power, and the activities of these people including, going up or down the stairs, writing, talking, playing musical instruments and teaching.

Thus this relatively simple 'scheme' of the high school contains different elements organized among themselves to form a structure. This structure may be linked to schemes in other structures (for example, teachers, students, education, etc.).

In scientific theory there are some very elaborate 'schemes' representing knowledge in a particular domain such as mechanics, light, or chemical reactions. Such scientific 'schemes', integrated as they are into structures, are composed similarly of elements and relationships between them. However, they differ from the example just used of a high school in that some elements in the structure of a scientific theory do not correspond to direct perceptions.

This model of the organization of schemes integrated into structures can be used to describe learning or the acquisition of a new piece of knowledge. First we will consider an analogy with the grouping of students in a class. Students relate with one another and form groups for different activities such as sports, drama and science lessons. These groups are not static but change as friendships and interests change; some students may not relate to others at all but remain isolates. Consider what may happen when a new boy arrives in the class. When he arrives, there are various possibilities for what might happen: he might not relate with the other students at all and remain isolated; he might join a group that already exists; or his presence might provoke a reorganization of friendship groups of the class as a whole. The same student could also be integrated differently depending on the class that receives him.

The analogy with learning is clear; the way a new piece of information is assimilated depends both on the nature of the information and the structure of the learner's 'schemes'. Thus the same experience provided for students in their science lessons may be assimilated differently by each individual.

These images of the organization of schemes and the acquisition of new schemes may account for the existence of these personal, contradictory and stable ideas. Each one of us has a characteristic organization of schemes. Acquired information is linked to other information and even if this new information is the same for several people, the link established between this acquired information and already stored information has little chance of being the same from one person to the next.

When a student states several contradictory ideas, different schemes are brought into play; these ideas may all be stable in so far as the schemes leading to them are integrated into structures, and to change any one of them may require the modification of a structure, not merely of an element of that structure.

In learning science, a pupil may note an event that is contrary to his or her expectations, that does not fit in with his or her schemes. Simply noting such a discrepant event however is not necessarily followed by a restructuring of that student's ideas—such restructuring takes time and favourable circumstances. To help students to accomplish such reorganization in their thinking about natural phenomena, science teaching can play an important role in giving children a wide range of experiences relating to certain key ideas. This is illustrated in later chapters, particularly those relating to children's ideas about heat transfer (Chapter 4) and about gases (Chapter 6). In both cases examples are presented and discussed which illustrate the conceptual 'schemes' used by students in lessons indicating that changes in some of these ideas do not take place readily despite the practical activities the children have undertaken.

What purposes are served by understanding students' ideas?

Taking account of students' prior ideas is one of the strategies, though certainly not the only one, which enables teaching to be better adapted to students. This can occur in a number of ways:

(1) *The choice of concepts to teach.* In some teaching schemes used with secondary school pupils, some concepts have been considered to be obvious and have been taken for granted in planning a course. Yet, as the findings in Chapters 4 and 8 indicate, studies of children's ideas suggest that even some apparently simple notions such as the conservation of matter or the intensive nature of temperature may not be appreciated by many secondary school students. Failure to appreciate such basic ideas then leads to further and more serious learning problems.

(2) *The choice of learning experiences.* If students' prior ideas are known then these can be challenged directly by experiences which conflict with expectations, so provoking students to reconsider their ideas. However, challenging students' current ideas is not by itself enough to promote change; alternative ideas have to be offered and these need to be seen by students not only as necessary but also reasonable and plausible. Knowledge of students' ideas enables us to choose teaching activities which are more likely to be interpreted by students in the way intended. The case of the reflection of light by objects, described in Chapter 2, is an example of this. Most children aged 13-14 recognize that a mirror has the property of reflecting light, even though they think that the light remains on other objects. To support this idea, they refer to the fact that with a mirror one can

light up an object or flash a light at someone. One can introduce similar experiences to convince them that light is reflected by ordinary objects. At noon in midsummer, a piece of white paper will glare when struck by the light from the sun. In a dark room, one can easily perceive a light-coloured object being lit by light reflected by a sheet of white paper. We also see that, on the other hand, knowledge of children's conceptions allows us to reject certain classical teaching experiments, which are not interpreted by the child in the way we expect them to be.

(3) *The presentation of the purposes of proposed activities.* In formulating the purposes of learning tasks it is important to bear in mind that pupils may reinterpret the intentions of the teacher in terms of their own understandings. This is illustrated in the following example where secondary pupils were programmed through a series of activities on work-cards. One group of girls carried out an experiment in which an immersion heater was placed in blocks of equal weight but made of different metals (Figure 1.2). The function of the experiment was to demonstrate variation in heat capacity. The pupils had been instructed to draw a temperature-time graph as each block was heated. Towards the end of the lesson the girls were instructed to look at the graphs they had produced and compare them, suggesting an explanation. The teacher (T) enters their discussion:

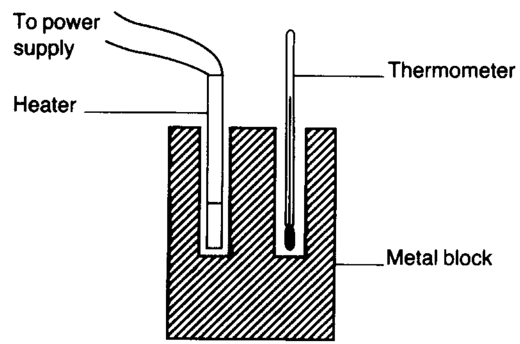

Figure 1.2

T: What has your experiment shown you?
P2: That different... um... that different materials and that... see how heat could travel through them.
T: What did you find out?
P1: Well... er... that heat went through the... the... iron more easier than it did through the er...
P2: Aluminium.

The pupils had had first-hand experience—they had collected their data, but these had been assimilated into a scheme concerned with conductivity, rather than in the way intended.

While it is necessary to bear students' ideas in mind while teaching, it certainly is not easy to put this into practice. The teacher has responsibility for the class as a whole and may consider it quite unrealistic to take the varied ideas of each student into account.

One of the recurring themes in the studies which are reviewed in the following chapters is that, although there is variety in the ideas children use to interpret phenomena, there are clearly some general patterns in the types of ideas that children of different ages tend to use. Studies of childrens' conceptions relating to a number of scientific topics have been undertaken in different parts of the world with children whose experience of formal science teaching has varied considerably. Despite this, quite independent research studies have reported similar patterns of ideas held by young people. For example, studies in the area of students' conceptions of dynamics (Chapter 5), their views of the Earth (Chapter 9), and their ideas about heat (Chapter 4) have been undertaken in a number of countries and the findings paint a consistent picture with students' early experiences of phenomena dominating their thinking. Studies reported on the particulate theory of matter in Chapters 7 and 8 indicate how difficult it is for many students to assimilate aspects of that model despite carefully designed teaching sequences. The report on children's ideas about electricity in Chapter 3 gives a rather disturbing finding; the proportion of students using an incorrect 'sequence' model for electric current remains dominant as students go through secondary school.

Studies of this kind suggest that despite the apparent variety of ideas suggested in science classrooms, there may be some value in attempting to take account of general trends in childrens' thinking, both in planning learning activities and in order to improve communication in the classroom itself.

In this chapter we have given an outline of a particular view of learning; a view in which learning is seen to take place through the interaction between, on the one hand, a learner's experiences and, on the other, the 'mental entities', the 'ideas' or 'schemes', used to interpret and give meaning to those experiences.

Throughout the following chapters various terms are used to describe these 'mental entities' and each has a slightly different connotation. Some terms, such as 'intuitive notion' or 'intuition' are suggestive of the origins of the ideas; some, such as 'conception', 'rule' or 'prototypic view', hint at the generality of use of the ideas. In some cases the organization of ideas and the relationship between them is emphasized in the use of such terms as 'cognitive structure',

'frameworks' or 'childrens' models'. In other cases the term used is qualified with the word 'alternative' (e.g. 'alternative conception', 'alternative framework'), thus emphasizing the difference between childrens' ideas and accepted scientific theory.

In our view, this plurality of terms reflects both the multifaceted nature and the variability which characterizes childrens' ideas; a variability which exists from one type of phenomenon to another, between contexts and between children themselves.

We have not, therefore, attempted to impose a common terminology throughout the following chapters. As in the story of the blind men describing an elephant, each of the various terms used reflects some aspects of the central concern of this book: the description of childrens' thinking about phenomena in the natural world.

References

[1]Driver, R. (1983). *The Pupil as Scientist?* Open University Press: Milton Keynes.

[2]Tiberghien, A. (1980). Quel rapport y a-t-il entre ce que les éleves "ont dans la tête" et ce qu'ils font ou disent? In *Sciences Physiques*, pp. 197–202. Livre du Professeur 3ème coll Libres Parcours, Hachette, Paris.