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Chapter 4

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*The Construction of Scientific  
Knowledge in School Classrooms*

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... at the heart of any good teaching and learning experience is a critical relationship, that is, a relationship in which teachers and learners alike seek to question each other's ideas, to reinterpret them, to adapt them and even to reject them, but not to discount them. To be critical in this sense, we need to know something of the origins of those ideas, their roots, the frameworks in which they are embedded (Rowland 1984: 1).

This chapter presents a constructivist perspective on learning in science and discusses the implications of this perspective for teaching and learning in classrooms.

**Epistemological Issues**

*Children's Knowledge Schemes*

From the earliest days of their lives children have developed ideas or schemes about the natural world around them. They have experiences of what happens when they drop, push, pull and throw objects, and in this way they build up ideas and expectations relating to the way objects feel and move. Similarly ideas about other aspects of the world around them develop through experiences, for example, with animals, plants, water play, light and shadows, fires and toys. A 9-year-old boy noticed that it took a few seconds after a record player was turned off for the sound to die away. 'There must be miles and miles of wire in there,' he said, 'for the electricity to go through for the sound to take so long to stop.' This boy had received no formal teaching in science and yet had developed the notion that electricity was involved in making the sound, that it flows through wires and it flows very fast!

There is now an extensive literature which documents the ideas children develop about the natural world (Driver, Guesne and Tiberghien, 1985; Osborne and Freyberg, 1985; Gentner and Stevens, 1983) and the way these progress through childhood (Carey, 1985; Strauss and Stavy, 1982). Work in this field has drawn attention to the fact that when they come to science lessons, pupils already have knowledge schemes which can be drawn on in a learning situation. What pupils learn from lesson activities, whether these involve talk, written text or practical work, depends not only on the nature of the tasks set but on the knowledge schemes that pupils bring to these tasks (Driver and Bell, 1986); learning thus involves an interaction between the schemes in pupils' heads and the experiences provided. The experiences may fit with pupils' expectations in which case little change is required in the pupils' schemes. On the other hand, the experience may be novel and pupils may change or adapt their knowledge schemes as a result. This process of using and testing current ideas in new situations requires active involvement of learners in drawing on their present schemes, relating them to new tasks and perhaps reorganizing them. In this way learning science is seen to entail the progressive development and restructuring of learners' knowledge schemes.

#### *Social Factors in Learning*

Learning about the world does not take place in a social vacuum. Children have available to them through language and culture ways of thinking and imaging. Phrases such as, 'shut the door and keep the cold out', or 'dew is falling', provide, through metaphor, ways of representing aspects of the physical world. This dynamic relationship between children's personal knowledge schemes and the schemes available through the culture has been commented on and explored by science educators (Sutton, 1980), psychologists and anthropologists (Rogoff and Lave, 1984). Drawing on the work of Schutz and Luckmann, Solomon presents a theory of the social construction of meaning in which it is argued that 'objects of common sense' only exist through social communication whereby ideas are exchanged, explored and reinforced.

In what Schutz and Luckmann refer to as 'life world knowing' the essential criterion is no longer the internal logic of the explanation but that it should be recognised and shared with others. We take it for granted that those who are close to us see the world as we do, but, through social exchanges, we seek always to have this re-confirmed. This continual reaffirmation of social notions makes them very durable and resistant to change (Solomon, 1987: 67).

Whether an individual's ideas are affirmed and shared by others in class-

room exchanges has a part to play in shaping the knowledge construction process.

#### *Science as Socially Constructed*

The perspective presented here, whereby individuals through their own mental activity, experience with the environment and social interactions progressively build up and restructure their schemes of the world around them, has been broadly termed *constructivist*.

So far I have sketched how such a perspective portrays the development of children's knowledge about the natural world. However, science as public knowledge is also personally and socially constructed. Scientific ideas and theories not only result from the interaction of individuals with phenomena but also pass through a complex process involving communication and checking through major social institutions of science before being validated by the scientific community. This social dimension to the construction of scientific knowledge has resulted in the scientific community sharing a view of the world involving concepts, models, conventions and procedures. This world is inhabited by entities such as atoms, electrons, ions, fields and fluxes, genes and chromosomes; it is helpfully organized by ideas such as evolution and procedures of measurement and experimentation. These ideas, which are constructed and transmitted through the culture and social institutions of science, will not be discovered by individuals through their own empirical enquiry; learning science involves being initiated into the culture of science.

There is an important point at issue here for science education. If knowledge construction is seen solely as a personal process, then this is similar to what has traditionally been identified as discovery learning. If, however, learners are to be given access to the knowledge systems of science, the process of knowledge construction must go beyond personal empirical enquiry. Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. The challenge lies in helping learners to construct these models for themselves, to appreciate their domains of applicability and, within such domains, to be able to use them.

#### *Towards a Constructivist Pedagogy*

What might teaching and learning science be like if such a perspective on knowledge construction were to be adopted in classrooms? This question has been explored during the last few years by various groups of science teachers and researchers. These groups have identified a number of features of science teaching which derive from a constructivist perspective and have

explored the implications of putting them into practice in classrooms. Important features which have been identified include:

identifying and building on the knowledge schemes that learners bring to lessons;

developing and restructuring those knowledge schemes through experiences with phenomena, through exploratory talk and teacher intervention;

enabling pupils to construct for themselves and use appropriately conventional science schemes;

encouraging pupils to take responsibility for their own learning;

helping pupils develop an understanding of the nature and status of scientific knowledge itself, the claims it makes and the way these are validated and may change over time.

It has also been recognized that such approaches may require teachers to reconstruct their ideas about the teaching/learning process and to modify their teaching accordingly.

How do these ideas work in practice? This section identifies and documents aspects of pedagogy which take account of children's current understandings while encouraging the development of conventional science ideas. The examples are taken from the reports of two action research projects, the Children's Learning in Science Project based at the University of Leeds (Driver and Oldham, 1986) and the Students' Intuitions and Scientific Instruction (SI)<sup>2</sup> Project (Kuhn and Aguirre, 1987), based at the University of British Columbia and directed by Gaalen Erickson. Both projects have been working collaboratively with teachers for a number of years, exploring the implications of a constructivist approach for work in classrooms.

### *Listening to and Exploring Children's Ideas*

Opportunities for pupils to talk through their existing ideas can invite further learning as pupils clarify and compare ideas. In the following extract 13-year-old pupils were presented with a range of simple phenomena and in each case were asked to describe their observations and to explain them in their own way. In one task pupils were presented with a block of perspex and a block of granite of identical size and shape. They focused their attention on the obvious difference in weight:

**Darren:** So, what we're really saying is we think the particles are spread out in one and bunched together in another.

**Clive:** Yeah. So it's obvious, they're different weights and the only way they can be different weights is different

materials — and particles — all t'particles could be bunched up or spread out.

**Darren:** I think if they're bunched up they could be more heavy so that would be the heavier one and the lighter one . . . .

**Clive:** Yeah, well — what do you think, Daniel?

**Daniel:** Er, they both could be plastic but the darker one could be more bunched up but they don't have to be different substances, they could both just be plastic.

This notion that the difference in the weight of the two blocks is due solely to the difference in packing of the component particles, while the component particles themselves are the same, is further explored:

**Darren:** Yeah, they *could* be, but they both look like different materials.

**Daniel:** But it wouldn't make any difference if they were the same material, say like paper, paper might be all spread out, all the particles in it might be spread out but *wood* they're all bunched together.

**Darren:** Yeah, and when they make . . .

**Daniel:** They make paper from pulp and wood and that.

**Darren:** And they might be — it becomes lighter, obviously.

**Daniel:** Oh yeah. 'Cos all t'particles are spreading out. So that's what I think's happening (Johnston, 1989: 43).

Here the pupils introduced the notion that density could be explained in terms of particulate ideas. They explored the idea that the differences in the densities of the two blocks could be due to the packing of constituent particles, and they checked these ideas against other experiences such as their knowledge of wood and wood pulp. For these pupils such an initial discussion enabled them to share ideas and to make some progress in their thinking.

Such discussions also reveal to pupils where their thinking is confused. Towards the end of a topic on plant nutrition 13-year-old pupils were asked to review in small groups the part played by a number of substances in the process of photosynthesis:

**Anna:** I don't know about chlorophyll.

**Kate:** I don't know what it is.

**Dianne:** It's a green substance in plants.

**Kate:** It breathes out carbon dioxide.

**Anna:** No, it doesn't, it breathes out oxygen and breathes in carbon dioxide.

**Dianne:** It takes in carbon dioxide and breathes out oxygen.

**Kate:** But it needs oxygen at night (Oldham, 1989: 159).

The confusion about the gas exchange processes in plants is beginning to emerge and the teacher is asked to help.

Taking a little time to find out how children may think about a particular topic or problem provides indications of their initial knowledge schemes. In an exploratory discussion in small groups some 13-year-old pupils were considering what 'food' is for plants:

*I:* Do you think food for plants is similar to food for animals?

*John:* No.

*Jason:* Er, no, I don't think so.

*David:* Flies. Plant eating animals they get the same sort of things out of the plants probably.

*I:* As . . .

*David:* Well, the plants could take it in and . . .

*John:* Like with cows, when they eat the grass they get the minerals out of the grass.

*I:* I see, whereas you're saying that the plant gets the minerals . . .

*John:* From the ground.

*I:* From outside itself.

*John:* Yeah.

*I:* And what does it need food for, anyway?

*Steven:* For growth.

*Jason:* To make it grow.

*John:* And repair.

*David:* All the cells.

*I:* So, if you wanted to 'starve' a plant, could you starve a plant in some way?

*Steven:* Yeah, just take it out of the soil (Oldham, 1989: 67).

The way animals feed appears to be extended by the children to plant feeding, and hence they are identifying the substances that plants take in from their environment to support life processes as food. This notion differs substantially from the biological idea that the starch and sugars that provide energy to support life processes in plants are manufactured by the plant.

Although the children are using their present knowledge in an intelligent way and are relating this to plants, they are using a different knowledge scheme from that of conventional science. Such a difference in meaning often persists through lessons and can cause problems for children's learning unless it is identified and addressed. Experience from classrooms shows that simply pointing out such differences in meaning to pupils is not enough for them to construct alternative meanings for themselves. The process of restructuring ideas can be lengthy and can take unforeseen paths. (Scott, 1987).

## Restructuring Ideas

One of the most commonly recommended strategies for promoting change in pupils' ideas is to show pupils the limitations of their notions through a discrepant event. As part of their work on the topic of 'air' a class of 13-year-olds was considering whether or not air has weight. They were presented with a simple equal arm balance with a deflated balloon on each end and asked to predict what would happen to the balance if one of the balloons were inflated. One group of four pupils differed among themselves about the outcome:

*Daniel:* Air's heavy, right. It's heavier, isn't it?

*Joanne:* No.

*Daniel:* It is, it is.

*Ann:* It's the same, air weighs nothing.

*Daniel:* Look, it'll go down — air's heavy.

*Jaspal:* Look, listen! When we blow the balloon up it's gonna come down, isn't it, 'cos the air in the balloon's heavier and gravity pulls it down.

*Joanne:* Yes, but air's light, so how can it come down?

*Ann:* It floats so it'll stay the same.

They then inflate one of the balloons and see that the side of the balance with the inflated balloon hanging on it does go down. Although they acknowledge the event, the two girls are still not convinced that air has weight.

*Ann:* Hey, it's gone down.

*Joanne:* But what makes it go down?

*Jaspal:* Look, we're doing about air, right? It's heavier than normal air outside — gravity pulls the balloon down.

*Ann:* Air's light, it'll make the balloon float.

*Daniel:* How come it came down then?

*Ann:* I dunno. I thought it'd stay the same.

*Joanne:* If it were light it would go up wouldn't it.

*Jaspal:* Look, gravity pulls it down — it pulls the air down.

*Daniel:* Only when it is in the balloon (Brook, Driver and Johnston, 1989: 70).

As this example illustrates, observational evidence (in this case that the side of the balance with the inflated balloon went down) is not enough by itself for pupils to reconstruct their ideas. They need not only the evidence but a new theory which the discrepant event by itself does not provide. In this example about air and weight the problem appears to be in the way the girls are conceptualizing weight. Their notion that air has no weight — it floats — tells us not only about their knowledge about air but about their conception of weight. Results from further investigations (Brook and

Driver, 1989) indicate that pupils' notion of weight is that it is a property of solid objects, it is what makes them fall down when released and press down when resting on surfaces. Everyday experience of air tends to indicate that it does not have these properties. To promote change in the ideas these children hold about air one may need to recognize that the conceptual structure within which their ideas and concepts are embedded differs from that of conventional science. Learning involves children in the process of theory change, not the mere acceptance of empirical evidence.

In some cases when discrepant events are presented, children's observations are influenced by what they expect to see so as to avoid conflict with their existing ideas (Nussbaum, 1985; Gunstone and White, 1981). Sometimes discrepant events may occur in the course of conventional lessons. In a lesson on change of state and boiling points a class of 13-year-olds was undertaking the familiar activity of heating a beaker of water over a burner and taking the temperature of the water at regular intervals of time.

*T:* What are you expecting to happen to the temperature?

*P1:* To rise as it gets hotter. It should be about 100 when it evaporates.

*P2:* Water should evaporate at 100 degrees centigrade, so it might shoot off this gauge. It should be about 100 degrees centigrade for the water to evaporate.

[A little later:]

*T:* Well, what happened?

*P2:* It stayed at 103, the last er two goes (referring to two earlier trials). We haven't marked it in for them two.

*I:* Is that what you'd expect?

*P3:* I would have thought it would keep going up, but it stayed at 103. It isn't going up.

*I:* Why do you think it would still keep going up?

*P2:* 'Cos it would, the bunsen burner's still er, heating up the water but it isn't getting any hotter.

*I:* Well, how do you explain that?

*P2:* I don't know.

*P1:* I don't know. It's evaporating with steam, er.

*P2:* And that could be taking out the heat.

*P1:* 'Cos when you feel steam it is hot.

*I:* What do you mean when you say taking out the heat?

*P2:* Well, the steam there holds in er so much heat and it, and it's taking out just enough to keep it at the same constant temperature once it starts boiling (Wightman, 1986: 237).

This familiar class activity presented the pupils with what was for them a discrepant event based on their lack of distinction between temperature and

the process of heating. Discussion with an adult in this case enabled them to go beyond their surprising observation to construct a possible interpretation.

Children in secondary school classes seem to expect explanations and generalizations to be offered or at least 'orchestrated' by the teacher. It is interesting that in the above example the pupils repeated their observations three times as a check rather than stopping to consider whether the thermometer 'getting stuck' could 'make sense'. It was only when the adult invited them to consider this observation that they entertained an interpretation. If pupils are explicitly invited to consider explanations for the observations they make, then small groups are often able to make useful progress in theorizing and explaining events.

After a number of initial activities relating to change of state, a class of 13-year-olds was invited to develop their model to explain the properties of ice, water and steam. After an initial discussion in which the idea of molecules was introduced by pupils and adopted, a group started paying attention to the question of bonding.

*P1:* Water turned to ice? I think it probably strengthens the bonding.

*P2:* Yeah, that one's not too clear really.

*P1:* 'Cos we didn't really do an experiment similar to that today. We were just on about melting.

*P2:* We weren't sure, I mean we are more or less clear how things go from solids to liquids to gases, but not from gases to liquids to solids.

*P1:* The point is in the gas the bonding has totally gone.

*P2:* So how does it happen that bonding comes back?

*P1:* I suppose it works vice versa, when it's heated, it destroys the bonding, when it's cold it, you know, remakes it.

*P3:* But how does it remake it? What does it remake it with though?

[The question of where the re-made bonds come from continues to exercise the group.]

*P2:* If atoms are bonded an atom can't change into a bond to hold the other atoms together, can it?

[At this point an observer in the classroom intervenes:]

*I:* How do you imagine bonding?

*P4:* Sort of like a string between the atoms.

*P1:* No, it isn't. He [referring to the teacher] explained to us about magnetic, magnetism. Some sort of force.

*P4:* Static electricity or something like that.

*P2:* Yeah. That kept them together. And I suppose if it was hot, then it wasn't magnetised as much or something and when it was cold it — magnetised more.

The group seems to have adopted the idea of bonds being due to a kind of magnetic forces, and they return to considering how this can account for bonding apparently changing when a substance is heated.

P4: When they are hot they vibrate more, so that the static isn't as strong.

P2: Yeah, I know, but they vibrate more, and break the bonding and then they finally get to a gas and that's as far as they go... but how does it get the bonding back!? [emphatically]

P4: When it starts to cool down, they don't vibrate as much.

P1: Ah, yeah. When they cool down, the bonding will be increased so they won't be able to move around as much, that fits in doesn't it?

[Note the obvious checking for consistency here. The idea being checked appears to be that due to the greater strength of the bonding at lower temperatures the molecules will not be able to vibrate so much due to being constrained. This idea, however, still begs the issue of how the bonding becomes stronger at lower temperatures as the next pupil's comment indicates.]

P2: Yeah, but the point is, how do we get the bonding back?

P4: Slow down the vibrating....

P2: Slow down the vibrations.

[One of the pupils at this point has a different insight. He suggests that the force is present all the time].

P4: I suppose it's ever present *there* but... yeah it hasn't got a chance to like grip, grip them, you know and keep them together. Well, where it slows down, you know, it might get to grips with the....

P3: A bit easier to keep slower things together (Wightman, 1986: 292).

This outcome of the discussion is a considerable achievement. The pupils have brought together their knowledge that particles are in constant motion and that this motion increases with temperature with the idea of the force between particles being present all the time to explain the apparent 'making and breaking' of bonds.

This example clearly illustrates that pupils, if motivated and if given the opportunity, can bring ideas and prior experiences together to take their thinking forward. However, it would be misleading to give the impression that pupils can essentially teach themselves from experience and discussion. If the teaching is to lead pupils towards conventional science ideas, then the teacher's intervention, both through providing appropriate experiential evidence and making the theoretical ideas and conventions of the science community available to pupils, is essential. This is illustrated in the next example. A grade 10 class (16-17-year-olds) in Vancouver, Canada is study-

ing the topic of radiation and nuclear energy. The teacher has set up a Geiger counter and before bringing a radioactive source near the tube he calls students' attention to the fact that the counter was already counting.

T: Why is it counting now?

Terry: From the environment?

T: Yeah. Somewhere and from different sources, radiation is coming to us all the time. What are the sources for this radiation?

Ann: The sun, the stars.

Others: From space.

T: Is it coming from any object around us?  
[no response]

Yeah, from buildings, rocks, even your bodies. All these put together produce the so-called background radiation — and it happens everywhere. As a matter of fact North Vancouver is higher than normal.

Susan: And the clicks happen at uneven intervals. Is that supposed to happen?

T: Well, what do you think? Has anyone else noticed what Susan has heard?

[Several students agree by nodding.]

Stan: Yeah — clicks happen at random.

T: What do you mean by random?

Stan: Well, you can't predict when it's going to happen.

T: Now, I would like to measure background radiation and I'm not sure how to do it. Dave, what sort of measurement, will you do it?  
[pause] How am I going to assign a number to tell the background radiation?

Gary: Just count.

T: If we do it we can get 1000. What does it mean? [no response]

What else do we have to measure?

Student: Measure how many per second or per minute.

T: And then get the average?

Student: Yeah.

T: Well, let's do that. O.K., how long should we use?

Students: One minute!

T: Let's try that. Craig, tell me when to start — and how many in one minute [pause] nine — [most agree on 9].

T: If we take the measurement again, what is your prediction?

Students: 9.  
8.  
10.  
11.

T: Ann will time this time. Tell me when to start [pause] and what is the count? It's eleven this time. If I do it again what am I going to get?

Students: 13.  
11.  
9.

T: Let's do it again. Are you ready, Ann? [pause] Now it's twelve.

T: If we do it again, can we get twelve?  
[majority of students say no]

T: What we have been measuring is the radiation intensity. It's the number of counts per unit of time — the unit is in seconds — then — it's the number of counts per second — and this unit is called the becquerel.

[The teacher writes on the board:

$$\text{Becquerel} = \frac{\text{counts}}{\text{t in sec.}]$$

T: What was the last radiation intensity? It is twelve over sixty equals point two becquerels.

[On board:  $\frac{12}{60} = .2$  Becquerel.] (Aguirre and Kuhn, 1987)

In this sequence the teacher first gives students direct experience of counting background radiation. A student observes that it appears to be random and this observation is checked with measurements and confirmed. Finally, after students have some informal experience of measuring the rate at which the Geiger counter is recording, the teacher introduces the term 'radiation intensity' and the unit 'the becquerel'; both are conventional aspects of knowledge that pupils could not discover from experience but which needed to be introduced through an authoritative source.

In a simple way this example illustrates a common feature of science classes: the introduction of concepts, models, measurements, conventions of the scientific community. In this case these were introduced after students had gained familiarity with the phenomenon, and so the terms 'radiation intensity' and 'becquerel' were linked to the students' experience and readily adopted and used.

Ideas that teachers suggest may not always be readily adopted however. This is often the case when pupils have strongly held conceptions which differ from conventional science ideas. As the earlier example about

weighing air illustrated, it may take time, a range of experiences and opportunities to think things through for pupils to begin to adopt a different conception. The following example illustrates the subtle conceptual problems which are encountered by children when they are introduced to the idea of gravitational potential energy. The class of 12-year-olds was considering the question of energy transfer when a heavy object was pulled up using a pulley system. The class readily agreed that energy was used by the person who pulled the object up, but they were not able to make sense of the idea that this energy was transferred to the lifted object. The teacher tried to make this notion reasonable by asking them to think about what happens when the lifted object is released.

T: Why should the weight fall, then?

Matthew: Because gravity pulls it down.

T: Gravity pulls it down . . . you need energy to push up, but not fall down.

Matthew: You do. You need energy for lifting, but when you let go it's only gravity pulling it down.

Here the idea of energy being 'stored' in the lifted object is not accepted by the pupil because for him the subsequent movement of the falling object is due to the external influence of gravity and this is seen as different from the energy being 'stored' in the object.

After further activities in the lesson, the class returns to discuss the question of energy transfer in the case of raising a brick. The brick was pulled up and was secured near the ceiling of the laboratory.

Mark: Sir, it can't be getting energy, because it's not a living object.

T: So you are saying that only living objects have energy?

Matthew: No, Sir — electricity.

Andrew: Cars have energy.

T: Yes, he's got a point. Well, if a car can have energy, why can't a brick have energy?

Andrew: A car's moving, though — gets energy from petrol.

T: But you're going to tell me that that brick has got no energy.

Steven: Ah, but it's gravity what's coming down on it.

T: I'm asking about energy — not force. Does that brick [pointing to the brick near the ceiling] have energy?

Steven: No.

T: If I take that brick and I hold it high up and then I drop it, has it got energy?

Steven: Yes, it's moving (Brook, 1987: 57).

Children can reflect on experiences in and out of lessons. Ideas can be re-organized in unpredictable ways and at unpredictable times. However

carefully a teacher may plan a particular activity to introduce an idea, in the end it is the pupils who have to think through and make sense of the experiences for themselves. Sometimes this can happen quite quickly, in other cases pupils may be reorganizing their ideas and trying to make sense of a new topic over months or even years.

From early days in school, children's ways of seeing the world are being shaped by adults. Much of the interactive teaching that occurs in secondary science practical classes reflects an often patient shaping and selection by teachers of the aspects of experience which pupils need to pay attention to in order to construct the conventional scientific interpretation. This process, which has much in common with what Vygotsky refers to as 'scaffolding', can be carried out in ways which vary in their sensitivity to learners' perspectives. In some cases, as in the following example, the teaching is not negotiating the meaning of the activity with pupils. In a review of energy transfer in simple devices with a class of 13-year-olds attention turns to an electric bell.

T: Do you remember the electric bell?

Ss: Yes.

T: Did any of you notice, did any of you actually hold on to the bell after it had been working? What did you notice?

S: Vibration.

T: Well, the arm vibrated, yes. Sound. What else did you notice? Anything? — If you held on to this bit here, where the wires were, did you notice anything there?

S: There were sparks there.

T: Heat. Did you notice some heat?

S: There were sparks from there.

T: There were?

S: Sparks. I don't know about . . .

T: There were some sparks, yes. Let's just ignore the sparks a minute, but we can come back to those. Some heat. There was a little bit of heat there with that one (Brook and Driver, 1986: 48–9).

In this case it was clear that the teacher was looking for a particular observation. He did not consider the observations offered about vibrations and sparks to be relevant and in the end he introduced the answer he was looking for. This game of 'guess what the teacher has in mind' is commonly played in classes. Through it the teacher manages to keep what appears to be a clear line of reasoning leading to the point to be made. Pupils play the game to provide the answer the teacher wants. In the process the engagement necessary for knowledge construction by the pupil is short-circuited. This structuring of the discourse by teachers is not confined to secondary school classrooms. In a study of discourse in 'child-centred' primary classrooms Edwards and Mercer (1987) commented:

While maintaining a tight control over activity and discourse, the teacher nevertheless overtly espoused and attempted to act upon the educational principle of pupil-centred experiential learning, and the importance of pupils' engagement in practical activity and discovery. This led to the pupils' grasp of certain important concepts being essentially 'ritual', a matter of what to do or say, rather than 'principled' i.e. based on conceptual understanding (p. 157).

One of the features of this 'ritual' procedural knowledge which the authors identified is that of 'cued elicitation'.

This distinction between pupils' responses being based on ritual or principled understanding is of critical importance if classroom talk is to lead to meaningful knowledge on the part of pupils. Doing this successfully, however, means listening to what the pupils are contributing and assessing the degree of shared understanding. This process of collective negotiation about what pupils could see when looking down a microscope at Brownian motion in a smoke cell illustrates some features of this process.

T: Right, well, let's have somebody else come to have a look, just keep to yourself what you've seen. Have a look. Now, have a look and tell me what else you can see. You've got the circular field of view, can you see anything else?

P: Little white bits.

T: Little white bits, all right. Let's have somebody else come and have a look, come and have a look. Little white bits. I'll just sort of make some notes as we go along of some of the things that you see. White bits. Can you see anything else? Would you agree about the colour, would you call them white?

P: Yes.

T: You would, right. Can you tell me anything else about those bits? Are they doing anything? [laughter] They're moving, yes. O.K. Let's have somebody else to have a look. Come on keep coming round because I want everybody to have a look. [children chattering]

So, we've got some white bits that are moving. Would you agree about the white bits? What can you tell me about the movements?

P: Jumping.

T: Jumping. All right. Let's, come on, keep coming and having a look. . . . How would you describe the movement apart from being jumpy?

P: Sir, they look, they're all bump . . . they're all dodging. They're all dodging . . . Sir, they go along straight next minute when they get dead near to each other they shoot away from each other.

T: How would you describe the movement?

P: They are like dodges.

P: Two magnets going for each other.

P: Like if there's two magnets. But when they get near to each other they shoot away to the sides. Is that the way they charge? Like you said they charged.

Pupils have noticed that the 'white bits' are moving, that they change direction without touching each other and there is speculation about how this might happen.

T: Is there a simpler explanation? I did give you a clue . . . .

P: Are they just not attracted to each other?

[chattering]

P: Sir, is it something to do with cohesion being reversed and they are pushing each other away?

T: Right, let's have your attention again then. Now, let's try to piece together all the observations that people have made.

T: Um, perhaps we ought to ask ourselves, first of all, what it is you're actually seeing, when you see these white bits, gold bits, call them what you will, what do you think it is you're actually seeing?

P: Particles.

T: What of?

P: Smoke.

T: Alright, what is smoke?

P: Gas.

T: Alright, it's the debris, isn't it, that's left over when you burn the string.

T: How do you describe some . . . the movement of something that you can't predict where it's going to go, what sort of word?

P: Irregular.

P: Random.

T: Go on.

P: Random.

T: Yes, that's the best word, all right. It's a random movement which means you don't know quite where it's going to go next. So we've got a rapid, random motion.

Having established through feedback from pupils what they are seeing, the teacher then moves to consider how the rapid random motion of the 'white bits' is caused.

T: Now the question is, what causes it? What makes those particles of dust in the smoke move about? Now, I gave you the clue at the beginning because *you* told *me* that there was

something else in the tube. What was it?

P: Air.

T: Yes, there's air. Now suppose that we think about air as being made up of particles just the same as everything else that we've been talking about. The particles are very tiny. Much too tiny even to catch the light and reflect them up through the tube of the microscope, but they're not too tiny perhaps to do something to the smoke — what do you think they might be doing to the dust particles? Can you think of what might happen? Suppose that at half-past twelve you try to go out through that door and everybody's all turned out at the same time and you're trying to get down the corridor, and you know you want to go straight down the corridor, what path are you likely to follow?

P: Zig zag.

T: Right, a zig zag path. Why, what makes you follow a zig zag path?

P: You're bumping into them.

T: Right, you're bumping into people. Somebody pushes you from one side, somebody shoves you from the other side, and you've got a zig zag path. So what might the air particles be doing to the smoke particles?

P: A zig zag path.

P: Deflection.

T: How?

P: Well, they're . . . they're moving as well, and they're hitting them as well and bouncing off.

T: All right, the air particles might be moving about, bumping into the smoke particles and making them move completely at random, and that's the process that we think is taking place. And it's called Brownian motion, um, this chap Robert Brown first discovered, I think with pollen grains, on the surface of water and he found that *they* did exactly the same thing (Wightman, 1986: 95–100).

The direction and initiative in this sequence clearly came from the teacher. However, the questions and ready answers from the class gave continuous feedback as to the extent to which the pupils shared in the observations and interpretation. Edwards and Mercer (1987) comment on this process of negotiation as follows:

The overriding impression from our studies is that classroom discourse functions to establish joint understandings between teacher and pupils, shared frames of reference and conceptions, in which the basic process . . . is one of introducing pupils into the conceptual world of the teacher and, through her, of the educational

community. To the extent that the process of education can be observed taking place in the situated discourse of classrooms, it is on our evidence essentially a process of cognitive socialization through language (p. 157).

This seems to be a truism when we consider science classes; moreover, it is of the nature of scientific knowledge as socially constructed that this process is essential to learning science. What is problematic is to enable individual pupils to engage in the negotiation so that the socialization process enables them to develop principled understanding rather than giving ritualized responses. This requires teachers to be prepared to listen to the suggestions and ideas of pupils as a check on their understanding.

### Reviewing and Checking Understandings

Listening to pupils' contributions in a diagnostic way means going beyond an immediate judgment of whether the contribution is 'right' or 'wrong'. It means attempting to understand how the pupil comes to the answer that is given. In the grade 10 class in Vancouver the teacher gave the class a series of simple exercises to calculate the activity of different radioactive substances. He then checked the answers round the class:

- Tom: 125 Bq.  
 Tammy: 113 Bq.  
 T: What is she doing incorrectly?  
 Nancy: She is putting the time over the counting. She should put the counting over the time.  
 T: If you do that, Tammy, what do you get?  
 [no response]  
 T: The number of counts is . . . ? And the time?  
 Tammy: Oh, I see, it's 50.  
 T: I think you just misread before . . . emissions mean the same as counts (Aguirre and Kuhn, 1987: 58).

Here the teacher has not only identified the problem with Tammy's response but encouraged others as well as Tammy to do so and to correct it.

At the end of a topic on photosynthesis with 13-year-olds the teacher has given groups the chance to discuss their answers to a number of questions and these are being shared with the rest of the class. Rachael is called to explain her group's task.

- Rachael: 'You are provided with the following meal: potatoes, carrots, beef and milk. Describe how the energy you get from this meal may be traced back to the sun.' Potatoes: the sun goes into the leaves which is the chlorophyll and then makes it into sugar and

starch and the starch builds up into spuds — I mean, potatoes [laughter]. It's the same with the carrots. It goes into the leaves of the carrots and it's all built up. And the beef — it gets in through the grass which is the chlorophyll and then it goes into the cow which eats it and then the milk is done the same but it's all sort of processed.

- T: Did you all get that?  
 Class: Yes, yes. No.  
 T: Who just said no?  
 Class: Christopher.  
 T: Right, Chris. What did you miss?  
 Christopher: How is all this light getting into the leaves, then?  
 Michael: From the sun.  
 Rachael: The sun's light just gets into the leaves and it makes sugar and starch.  
 Susan: Through them holes.  
 Michael: The rays.  
 Rachael: You're just trying to complicate it all and get me muddled up.  
 Susan: He is — he does that in English.  
 T: No, I think he's asked a good question. How does the sunlight get into the leaves? How does the leaf grab hold of the sunlight? Sh! I'm asking Rachael.  
 Rachael: Through them holes?  
 T: Through the holes in the leaf?  
 Susan: Yes, it just falls upon them and it all sort of absorbs it.  
 T: Do we all agree?  
 Michael: No . . . .  
 T: Hands up if you agree. Hands up if you disagree. Hands up those who don't know. Right, who said they disagree? Right, what do you think happens?  
 Michael: The chlorophyll — it lets all the light through . . . .  
 T: Right, it's the chlorophyll which catches some of the light. Right, do you remember looking through those spectra shining through chlorophyll and there were bits missing? O.K., that's how the plant catches the light. What does go through the holes?  
 Michael: Water. I mean — yeah — rain.  
 T: Do we agree with that one?  
 Susan: No.  
 T: Any volunteers as to what does go through the holes?  
 Brendan: Brendan?  
 Brendan: Oxygen and carbon dioxide (Oldham, 1989: 211–2).

Here again the teacher is giving time to sort out a problem and to check understandings with the whole class. He also makes links to previous class activities (such as shining white light through chlorophyll extracted from leaves to show that some of it was absorbed).

### Concluding Remarks

#### *Teachers as Diagnosticians*

Classrooms are places where children are in the business of constructing and reconstructing meanings as a result of learning experiences. However, in a classroom where the teacher is adopting constructivist approaches, that teacher is also constructing meanings — identifying the sense that children are making of the learning experiences presented. The Vancouver case study makes this point clearly:

Mr. Kuhn [the teacher] mentioned how crucial it was to *listen* to what students had to say. He expanded this by saying that this 'listening' meant that the teacher must open her/his ears and mind when listening to students' ideas. He added that many teachers say that they listen to students but they really don't, for they have prepared their lessons step by step, not allowing room for possible changes; they can pretend they are listening, they can even make a remark such as 'that's interesting', but after this they will proceed as planned without considering the students' ideas. Mr. Kuhn was positive that listening is a skill that can be learned, but teachers have to be willing to do so. Part of this listening is to reflect back on what a student has said or done; one must address what lies behind a response or question (Aguirre and Kuhn, 1987: 78).

If teachers are familiar with some of the more common features of children's ideas, then this diagnostic process is more easily undertaken. In the last analysis, however, although it is possible to learn about what to expect, the analysis has to be undertaken for each class afresh.

#### *The Interactive Process of Teaching*

Some pedagogical thinking has been influenced by an oversimplistic dichotomy: either children discover things for themselves or they are told the answers by the teacher (or by some surrogate authority such as a book, worksheet or computer program). The analysis in this chapter has indicated the fallacy in this dichotomy. On the one hand, there are things which children cannot be expected to 'discover' for themselves because of the conventional nature of science. Moreover, if given the opportunities, children

will make discoveries but these will not necessarily be what was intended. On the other hand, even when pupils are told something they still have to make sense of it for themselves. Edwards and Mercer (1987) comment on this dichotomy:

... we shall not be using any critique of progressive education to argue for a return to traditional didactic methods. The progressive movement was right to argue for the importance of children's active engagement in their own education. What we shall advocate is a third step, towards a cultural-communicative model of education... The traditional ideology was all about teaching, and the progressive ideology is all about learning. What is needed is a new synthesis, in which education is seen as the development of joint understanding (p. 36).

#### *Authority and Belief*

If learning science is essentially a process of a cultururation into the ideas and models of conventional science, the danger from the point of view of learners is that they accept what they are presented with through books, teacher talk and guided experimental work because of its authoritative status. This can and does get in the way of pupils making sense of the ideas for themselves and results in the 'real world' and 'school science' being kept as distinct systems.

Within a constructivist perspective there are two aspects to the issue of authority. One is whether an idea is accepted within conventional science — that information can be obtained from external authorities. The other is whether the idea makes sense to the learner, whether it has the authority of his or her own experience and knowledge schemes behind it (in other words, whether it is believed). After a unit of work on particle theory a 14-year-old was addressing this problem:

P: I can't really explain, but there's summat where you think, well this table it's made up of particles — I think it is too, well you can't see any particles or owt, so it's just — just can't believe it. You know, that this table's made out of particles — hundreds of millions.

T: You don't believe it?

P: Well, I do in me own way, you know, but well wood's wood, I mean it grows from trees — you know more or less — well — sometimes — if a teacher tells you that it's made out of particles you think — well fair enough it's made out of particles, but it's, you can't really believe that this table's made out of particles.

T: What about the atmosphere in this room? Can you accept that that is made of particles?

P: Not really because — 'cos you can't really see 'em. I mean, for all we know there could be particles, but in another way, for all we know it could be scientists saying that there's particles in the air and making us believe it. Well it could just be normal sky you know, because there is sky coming all the way down — it could be sky — you know in t'buildings and that (Wightman, 1986: 69).

### *Learning as the Progressive Reconstruction of Conceptual Schemes*

Learning in science can involve learners in changing the knowledge schemes they use. Such changes are not trivial and can, as illustrated in the example of air and weight given earlier, involve learners in radically changing the meanings of component elements in their schemes and the way they are organized. A number of areas have been identified as requiring learners to make significant changes in their conceptual schemes; for example, moving from impetus notions of mechanics to Newtonian ideas or changing from a thermal theory in which heat and temperature are undifferentiated to one in which they are distinguished as separate entities.

Making these changes is not a trivial matter. We know that despite some carefully structured teaching, learners may continue to use their prior ideas. The question of how to design teaching approaches which promote conceptual change in learners is currently a focus of research interest. An important starting point is to recognize this as a significant problem. It requires an adequate description of the prior conceptual schemes of learners, a description which indicates how the learners' concepts are related within their way of seeing (and goes beyond a superficial identification of 'misconceptions'). Further, it requires learning tasks which specifically address the changes that learners need to make in their conceptual schemes. Lastly, such changes also require time and opportunities for revisiting the ideas in a range of contexts.

### *The Responsibility of the Learner*

Within a constructivist perspective teachers have an important role to play in diagnosing the pupils' current understandings, making decisions about what could be useful learning activities and interacting with pupils to help them interpret those activities appropriately. Pupils too have their part to play. Only they can make the links between their current knowledge schemes and presented learning experiences. There will always be the questions of judgment for teachers about how far a pupil may be helped to progress in his or her understanding, about when and how to intervene. In

suggesting a guiding principle for teachers on this matter, Osborne and Freyberg (1985) comment:

The problem, however, is to decide just when a pupil will be able to benefit from visual and verbal input which deliberately encourages the scientifically acceptable viewpoint . . . if we wish to avoid alienating many pupils from science, we must take care not to insist upon conceptual change at the expense of children's self-confidence, their enthusiasm and curiosity about the world, and their feeling for what constitutes a sensible explanation (pp. 89–90).

It is maintaining learners' confidence in themselves as capable of making sense of their experience and the will and interest to continue to do so which is essential to the learning process.

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