Children's Science and Its Consequences for Teaching

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Many research studies in recent years have shown that children have beliefs about how things happen and expectations which enable them to predict future events (Driver & Easley, 1978). Evidence is accumulating from a wide variety of sources (Clement, 1977; Nussbaum & Novak, 1976; Leboutet-Barrell, 1976; Stead & Osborne, 1980) to show that children, on the basis of their everyday experiences of the world, hold these beliefs and expectations very strongly. Moreover, children have clear meanings for words which are used both in everyday language and also in formal science (Gilbert & Osborne, 1980; Osborne & Gilbert, 1980a). Such views of the world, and meanings for words, held by children are not simply isolated ideas (Champagne, Klopfer, & Anderson, 1979) but rather they are part of conceptual structures which provide a sensible and coherent understanding of the world from the child's point of view. These structures may be termed children's science.

In the development of science curricula the existence of children's science has usually either been ignored or inadequately considered (Fensham, 1980). The two different assumptions on which science teaching has been based, and one on which it could be based, can be readily identified.

The "Blank-Minded" or "Tabula Rasa" Assumption

This approach, which by implication underlies many modern curricula (Fensham, 1980), assumes that the learner has no knowledge of a topic before being formally taught it. The assumption is that the learner's 'blank mind' can be 'filled' with teacher's science (S_T). This is diagrammatically shown in Figure 1.

The "Teacher Dominance" Assumption

The assumption here is that, although learners may have some conceptual view of a new science topic before being taught it, this understanding has little significance for learning and can be directly and easily replaced. Thus, even if children's science views (S_{Ch}) exist, they are not strongly held in the face of science teaching. This is diagrammatically shown in Figure 2.

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Figure 1. Science teaching in which it is assumed the learners have no theoretical views of the topic or phenomena under study.

Figure 2. Science teaching in which it is assumed that learners may have theoretical views but that these are easily displaced by the views presented by teachers.

Figure 3. Science teaching which recognizes that learners often do hold strongly entrenched theoretical views that persist in the face of teaching.

The "Student Dominance" Assumption

This assumption recognizes children's science views as sufficiently strong that they will persist and interact with science teaching. The interaction is diagrammatically shown in Figure 3.

There is growing evidence that the learned amalgam $\{S_{CH} \setminus S_T\}$ of children's science and teachers' science can co-exist in varying proportions. 'Successful' learners use teachers' science when required in tests and examinations, but still retain children's science in dealing with many every day situations.

If science curricula and teaching are to be based on the third assumption, rather than on either of the first two, it will be necessary for us to learn much more about children's science: to know how to explore it, to know about its nature, and to consider the various ways in which children's science may, or may not, be modified by learning experiences.

The Exploration of Children's Science

A variety of methods have recently been developed for use in investigating children's science. White (1979) has analyzed the similarities and differences of some of these methods. Most involve in-depth interviews with children (see, for example; Pines et al., 1978; Brumby, 1979; Tiberghien, 1980). This study used two such methods which we have called the Interview-about-Instances approach and the Interview-about-Events approach. The Interview-about-Instances approach (Osborne & Gilbert, 1980b; Gilbert, Watts, & Osborne, 1981) explores children's meanings for words by means of taped individual interviews. For a particular word, e.g., work, force, living, up to 20 familiar situations, depicted by line drawings on cards, are presented to the child. Some of the situations present an instance of the scientific concept embodied in the word and some do not. Children are asked, for each situation in turn, whether they consider it an instance or not. The children's reason for the choice is then elicited. The interview situation allows children to ask questions, to clarify perceived or actual ambiguities before answering, and also gives flexibility in discussing reasons or lack of reasons, for a particular answer. The method has been used to explore children's meanings for many words: for example; 'work' (Osborne & Gilbert, 1979); 'electric current' (Osborne & Gilbert, 1979; Osborne, 1981); 'force' (Osborne & Gilbert, 1980a; Watts, 1980), 'light' (Stead & Osborne, 1980), 'living' (Stead, 1980), 'friction' (Stead & Osborne, 1981a), 'gravity' (Stead & Osborne, 1981b), and 'animal' (Bell, 1981).

The Interview-about-Events approach (Osborne, 1980) places more emphasis on eliciting children's views of the world within the overall framework of children's science. It involves an individual discussion with an interviewee about an articulated series of demonstrations. This discussion is tape recorded, transcribed, and subsequently analyzed. The interview is built around a scientific concept, e.g., 'physical change.' The events are practical demonstrations of situations to which the concept may be applied. The demonstrations, performed by the interviewee with minimum assistance, are articulated to produce a smoothly linked conversation. The method has been used to explore children's views on 'physical change' (Cosgrove & Osborne, 1981), 'chemical change' (Schollum, 1981), and the 'particle nature of matter' (Happs, 1981). In Appendix A a sequence of steps used to investigate children's views on physical change is provided.

Patterns in Children's Science

On the basis of the findings from research which has been carried out using the two investigatory techniques, referenced above, at least five different patterns of children's science can be described (Osborne & Gilbert, 1980a). These patterns will be illustrated from the sequence of discussions on physical change (Appendix A). These illustrations arise from interviews with 43 New Zealand school children spread evenly over the 10–17 year age range. (The 10–15 year olds were studying general science, the 16–17 year olds were studying physical science). The pupils were selected by their teachers as being of average attainment in science (Cosgrove & Osborne, 1981). Each quote given will be followed by the step in the discussion sequence to which it applied, and the age of the interviewee.

Everyday Language

Many words in science are used in an alternative way in everyday language. Often a student can listen to, or read a statement in science and *make sense* of it by using the everyday interpretation of the word. The interpretation is not the one intended by the teacher or textbook writer. For example:

> The air is made up of small particles (is anything else made up of small particles?) glass . . . they are made out of small particles of sand which have been turned hot . . . turned clear and then sort of take them out . . . and put them between two pieces of metal when they have been hardened and when they take it off they find that they have a clear surface called glass.
>
> (Step 7; age 11)

The word 'particle' is commonly used in science classes to mean atom, molecule or ion. In everyday use it refers to a small, but visible, piece of solid substance. The everyday meaning has been applied to air. The interviewee has apparently presumed that the 'particle' size in sand is retained in glass. A parallel has been drawn between glass and air based on appearance.

Self-Centered and Human-Centered Viewpoint

Many very young children have very egocentric views of the world. By age nine or ten most children no longer adopt this strictly egocentric view but they still interpret and consider things in terms of human experiences and commonly held values. For example:

Ice is just frozen water (what's the difference between frozen water and ordinary water?) You can't drink it very good.

(Step 7; age 10)

Properties as a drink govern the evaluation made by this child of ice and water. A second example is:

I think I said it was oxygen in the bubbles . . . but if you put your face over (the steam) and breathe in . . . it doesn't seem you can breathe too well . . . so I don't think there is much oxygen . . . it be more hydrogen.

(Step 2; age 17)

Steam has been evaluated here by its capacity to support breathing, oxygen being known to be effective. In both cases, simple human concerns have governed the interpretation made of phenomena.

This different focus on how and why things behave as they do can result in children viewing situations in quite a different way to the more analytical, and impersonal, view of science. Answers given by children in science classrooms are sometimes apparently 'off the track' hoped for by the teacher because of this difference in perspective of science teacher and student. The anthropocentric view often takes the form of some widely held beliefs—heavier objects do fall faster, things do get lighter when they are burnt, animals are things you take to the vet—and these human-centered views are reinforced by everyday language to some extent.

Nonobservables Do Not Exist

To a number of children, and some learners despite formal teaching, a physical quantity is not present in a given situation unless the effects of that quantity or the quantity itself is observable. Some examples are: "If you cannot feel an electric current it is not present" (Osborne & Gilbert, 1979); "if the effects of the presence of light, for example, flickering on a wall, are not observable the light is not present" (Stead & Osborne, 1980).

Oh, it has evaporated. (what does that mean?). Well it has not gone into the steam form because it doesn't look as if it has gone up in the water state . . . it must have split up because you couldn't sort of see steam or anything rising. (what do you mean split up?) The hydrogen and the oxygen molecules.

(Step 5; age 16)

The student has presumed that, on all occasions, the visibility of water is maintained on the transition from the liquid state to the vapor state. When this visibility is not maintained, an explanation is presented in terms of elements known to be invisible and constituents of water, i.e., hydrogen and oxygen, commonly encountered in their gaseous form.

Endowing Objects With the Characteristics of Humans and Animals

Children often endow objects with a feeling, a will, or a purpose. This is partly related to children's view of living things being much broader than the biologists' viewpoint (Stead, 1980), but it is also reinforced by the use of metaphor in both common language and even in the teaching of science. Teachers' make statements like "the electric current chooses the path of least resistance," "the positive ion looks out for a negative ion." However, it would appear that, not surprisingly, children do not always consider such statements to be metaphoric. For example:

It's cold in there and the chill's coming to the outside . . . the coldness just . . . um . . . oh, it's cold in there and it's just trying to get out . . . and it's somehow got out.

(Step 6; age 13)

'Cold' is thought to move towards the outside of the jar under the effect of an implied will.

Endowing Objects With a Certain Amount of a Physical Quantity

It is not uncommon for children to endow an object with a certain amount of a physical quantity and for this quantity (e.g., force, momentum, energy) to be given an unwarranted physical reality. For some physical quantities (e.g., force, coldness, etc.) this tendency of children leads to considerable difficulties in learning, particularly in appreciating the abstract nature of these quantities and their relationship to other quantities. For example:

The heat makes the air bubble come out of the element.

(Step 2; age 12)

The implication here is that heat is a physical entity. It is thought to physically force the air bubble to come out of the heating element in the kettle. Both the nature of heat and the source of air bubbles have been unconventionally understood. A second example is:

The coldness of the ice could have brought the water . . . but that's a bit funny.

(Step 7; age 12)

Here 'coldness' is thought to have a physical identity.

Teachers' Views of Science

Just as by *children's science* we mean those views of the natural world and the meanings for scientific words held by children before formal science teaching, so *scientists' science* (S_S) means the consensual scientific view of the world and meaning for words. Ideally the view of science presented to children by teachers, or directly through curriculum material, will closely relate to scientist's science. However this may not always be so. Teachers undoubtedly have a wide variety of viewpoints, S_{T_i}, ranging from almost children's science to scientists' science, but often different from both these in distin-

Figure 4. Strongly held teachers' views of science may persist or interact with the views in science curricula.

guishing less clearly between the objects of science and the concepts that relate to them (Fensham, 1979). This teacher's view of science interacts with the science curriculum and its materials as he/she prepares for teaching. This may or may not modify this view in the direction of scientists' science as shown in Figure 4. The resultant is the *viewpoint presented* by the teacher to the pupils. It is the interaction of children's science and their teacher's science that will have profound implications for the outcomes of teaching.

The Consequences of Children's Science for Teaching

A further consideration of the data collected using the Interview-about-Instances and Interview-about-Events techniques suggests that for children who have been taught science there are at least five patterns of outcomes from these interactions. The five outcome patterns will again be illustrated from protocols using the same Interview-about-Events sequence in Appendix A (Cosgrove and Osborne, 1981).

The Undisturbed Children's Science Outcome

Some children have an undisturbed viewpoint despite formal teaching. Reasonably common among this pattern of learners are those who now incorporate some language of science to describe the viewpoint, but whose viewpoint is essentially unaltered. The following is an example of undisturbed children's science despite teaching:

(Where have you used the word particle?) In the science lab. (Are there particles in the jar of ice water?) Yes, I suppose so. (Which are the particles to you?) The ice blocks. (Has the water got anything to do with particles?) Oh, they melted into the water.

(Step 7; age 13)

The children's science view was that a visible piece of ice is a particle. The language of science, using 'particle' to mean molecule of water, has had little impact on this view. This type of interaction is presented in Figure 5. Similarly:

The water has melted it . . . it has become part of the water . . . but there are parts of it left that you can't see . . . the taste of sugar.

(Step 4; age 11)

The children's science view, that taste is separate from material substance, has not been modified by contact with the phenomenon of dissolving.

Figure 5. A prelearning or children's view of science can persist unchanged by science teaching.

Figure 6. Science teaching can result in a second view being acquired for use in school but the original children's view persists elsewhere.

The Two Perspectives Outcome

It is possible for the student to basically reject the teacher's science as something that can be accepted in terms of how to view the world, but to consider it as something that must be learned, e.g., for examination purposes. The student, therefore, has two views, but the learned science viewpoint is not one that has been adopted for use outside the formal learning situation. For example:

It is dry . . . the water has evaporated . . . the water has gone (where to?) well . . . the teachers tell me that it has gone you know . . . that it makes up the clouds, you know in the sky and that sort of thing. (I see, it has gone up to the sky?) it is meant to have (where do you think the water that was on the saucer has gone?) I don't know . . . I don't think about it (it is not still on the plate dried up is it?) no, I don't think so . . . (how does it get from here to the clouds?) I don't know (magic?) no . . . it's sort of a gas there . . . not magic (where did you learn about clouds and evaporation?) in about fourth grade (9–10 years) . . . around there somewhere (oh, well they wouldn't have talked about it in much detail at that sort of level would they?) no (and all that you can sort of remember is that when water evaporates it goes into the clouds?) yet (but you don't have a picture of how that goes on?) no, except for little arrows that point up (I see, what were those arrows do you think?) can't remember (so you have got this sort of picture of water, arrows and clouds?) yes, and it sort of comes down as rain.

(Step 3; age 14)

This student has the view that water disappears from a place into the air. However, the standard explanation, concerning evaporation and using diagrams, has proved less than believable to the student. Nevertheless, it has been learned but is not used willingly to explain phenomena. This type of interaction is presented in Figure 6.

The Reinforced Outcome

The dominance of the students' prior understandings and meanings for words can, as suggested earlier, often lead to quite unintended uses of what is being taught. One common example of the outcomes of this is the confusion between physical quantities. Quantities defined in science in a particular way can be misinterpreted to mean something quite different. In Figure 7, the children's science viewpoint is being maintained following

Figure 7. The original children's view is strengthened by science teaching which now is misapplied to support it.

Figure 8. Science teaching resulting in a mixed outcome where children's science and teachers' science now co-exist together.

Figure 9. Science teaching which extends children's science and teachers' science to a more unified science view.

teaching but now scientific concepts are put forward to explain or underpin a particular viewpoint. For example, the statement by a younger student:

It would come through glass

(Step 6; age 10)

becomes, for an older student

Through the glass . . . like diffusion through air and that . . . well it hasn't got there any other way (a lot of people I have talked to have been worried about this water . . . it troubles them) yes, because they haven't studied the things like we have studied (what have you studied which helps?) things that pass through air, and concentrations, and how things diffuse.

(Step 6; age 15)

The notion of diffusion, learnt in connection with movement through air and water, has been applied to explain movement through glass. The children's science idea of 'movement through air' has been transformed into 'diffusion through glass.'

The Mixed Outcome

In many cases, scientific ideas are learned, understood, and appreciated by learners. However, the interrelationships of these ideas are manifold and at any one time only a limited amount can be learned. Often this results in students holding ideas that are not integrated and may be self-contradictory. In this outcome the learners' views are a mixture of amalgam of children's science views and teachers' views, Figure 8. For example:

I think it is the same atoms in the ice before and now they are unfrozen in the water (what else is in there besides the atoms? the stuff that freezes?) no . . . I don't know . . . yes . . . no . . . it's all atoms but the atoms are just frozen.

(Step 7; age 14)

The idea of the conservation of matter between physical phases has been learned. However, the microscopic change in structure is being interpreted as a general change in the properties of microscopic components, i.e., atoms (sic).

The Unified Scientific Outcome

The aim of all science education is that a learner should obtain a coherent scientific perspective (S_S) which he understands, appreciated, and can relate to the environment in which he lives and works. Students can be found who have this view in relation to specific words and viewpoints that we have investigated. In some of these cases, the learned viewpoint is in fact more closely aligned to scientists' science than to the teacher's views of the science. This outcome is represented in Figure 9. A typical example of the coherent scientific perspective:

It is wet on the outside . . . 'cos the jar's cold . . . 'cos the ice is inside it and therefore the water molecules that are in the air moving around . . . although we can't see them . . . when they hit the cold jar . . . that makes them cold . . . and therefore they group together again in their groups of molecules and then they become water again because they've been cooled down.

(Step 6; age 15)

It is the outcome that all teachers would wish to arise from their interaction with students.

Conclusion

This paper suggests, by argument and example, that the view which children bring with them to science lessons are, to them, logical and coherent and that these views have a considerable influence on how and what children learn from their classroom experiences. Our conclusions from a variety of studies support the view of Wittrock (1977) that people tend to generated perceptions and meanings that are consistent with prior learning. Learning can be anticipated and understood in terms of what the learners bring to the learning situation, how they relate the stimuli to their memories, and what they generate from their previous experiences.

We have also attempted to suggest, by argument and example, that the aim of science teaching and learning can be viewed as the development of children's science. Traditionally, the goal of the development is scientists' science. This has proved to be an immense task that is often very incomplete even among so-called successful learners. As happens in many present science classes, we may have to be satisfied with largely undisturbed children's science as our outcome. A more modest and manageable goal in these cases would be to make these learners aware that there *is* another viewpoint, the scientists' viewpoint, which is useful to scientists and may have more general use also. Only by adapting our teaching to make these two views explicit is this new goal likely to be achieved. This approach may also facilitate the development process on its way. Such a development will only occur in a genuine and nonsuperficial way if the scientific perspective appears to students to be at least as logical, coherent, useful, and versatile way of viewing the world than their present viewpoint.

Whatever the goal, it would seem that teachers need to be aware of children's science and to encourage students to express their views. We all need, as teachers, to listen to, be interested in, understand and value the views that children bring with them to science lessons. It is only against that background of sensitivity and perception that we can decide what to do, and how to do it. This is a major challenge for science teaching.

Appendix

Interview-about-Events Outline Schedule for Physical Change

Step 1 The interviewee is presented with a screw-top jar containing ice and is invited to dry the jar thoroughly. The jar is then set aside.

Step 2 The interviewee is invited to observe the water coming up to, and boiling, in an electric kettle. Preliminary questions are 'What is happening?' and 'What are the bubbles made of?'

Step 3 The interviewee holds a saucer in the steam and is invited to comment on what is observed and why it has happened. After these questions, it is put, inverted, to one side.

Step 4 Some of the hot water (from step 2) is put in a cup. The interviewee puts some sugar in it and stirs the mixture. The preliminary question is again 'What is happening?.'

Step 5 The inverted saucer (see Step 3) is now reconsidered. The dryness is discussed through 'What has happened to it?' and 'Why is that?'

Step 6 The jar (see Step 1) is now reconsidered. It now has water on the outside. The interviewee is asked 'Is that different to when you had it before?' and 'Can you tell me about that?'

Step 7 The lid of the jar (see Step 6) is removed, and some water and ice extracted on a spoon. The questions begin with 'What is happening here?'

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