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Robertson W W and Richardson E 1975 'The Development of Some Physical Science Concepts in Secondary School Students' *J. Res. Sci. Teaching* **12** 319–329.

Solomon J 1983 'Learning About Energy: How Pupils Think In Two Domains' *Eur. J. Sci. Educ.* **5** 49–59.

Viennot L 1979 'Spontaneous Reasoning in Elementary Dynamics' *Eur. J. Sci. Educ.* **1** 205–222.

Warren J W 1982 'The Nature of Energy' *Eur. J. Sci. Educ.* **4** 295–297.

Watts D M 1983 'Some Alternative Views of Energy' *Phys. Educ.* **18** 213–217.

Secondary students' conceptions of the conduction of heat: bringing together scientific and personal views

Elizabeth Engel Clough and Rosalind Driver

In the last few years a number of studies has been made of the ideas that younger children have about phenomena involving heat. That young children should hold ideas about some objects feeling 'hotter' or 'colder' than others, or about how heat appears to get from one place to another, is not, perhaps, surprising. Since their earliest days of life children have experienced sensations of 'hot' and 'cold' in many and varied ways. Perhaps the most all-pervading experiences are those involving physical surroundings and conditions—cold hands and feet on a frosty morning, cold shivers when standing in damp clothes, the heat of the sun. Children's daily activities with adults and at play by themselves expose them to hot and cold things, to fire and flames. As a result of these experiences children make associations and develop ways of conceptualising, even tacitly, such phenomena. This ordering of experiences enables them to make predictions and act accordingly. They learn not to put their hands too close to a flame or to touch a metal pan being heated on the stove; they learn that hot water in a bath can be cooled by adding cold water, and that an ice cold drink will usually get warmer if you leave it for a while.

Events of this nature are commonplace in many children's lives, and, although there are differences in the ways individual children think about them, there are some commonly-held ideas which have been documented by a number of researchers. In this article we describe some of these main features of children's thinking about heat and temperature, which they develop as a result of interaction with the world and before they receive any formal science teaching. We also describe results from a study of secondary school students' ideas about phenomena involving heat and indicate that many of the notions used by younger children are still apparent in the thinking of older students. This is particularly obvious when we talk to students at greater length about their ideas and probe beneath the surface veneer of the 'quick fire' classroom questioning or fill-in-the-blank worksheet activities.

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Younger children's ideas

Heat as a 'substance'. In a study with children of primary school age, Albert (1978) noted that young children (four and five years of age) talked of heat in static terms as residing in objects. Slightly older children related the hotness to themselves and, for example, concluded from the fact that a 'coat makes you warm' that the coat was the warm object. At about eight years Albert found that children described heat in spatial and dynamic terms (e.g. referring to heat rising, moving away etc).

In a detailed interview study of Canadian 12-year-olds, Erickson (1979, 1980) reported a tendency to talk of heat as though it were a substantive fluid. In explaining what happens when a metal rod is heated at one end, for example, a child says:

The heat builds up in one part until it can't hold anymore then it moves along the rod.

In a study of 12–13-year-old French children, Tiberghien (1980) noted the same type of response. In some cases children use terms like 'steam' or 'smoke' to describe the transmission of heat. One child from this study said that:

Heat comes from the radiator, it's like smoke, for example, that comes and pervades the whole house.

Heat and cold are sometimes talked about as though they are different substances. In explaining how the water surrounding a block of ice cools down, a 10-year-old in Erickson's study suggested:

'Some of the cold left the ice cube and went into the water.'

Heat and temperature. There are a number of difficulties which children have in distinguishing between heat and temperature. It is part of children's everyday experience that some objects tend to feel warmer to the touch than others; they therefore tend to suggest that temperature is a property of the material—that, for example, metal is naturally colder than plastic. Tiberghien (1980) asked children to choose from a number of containers made of different materials the one which would be most suitable for keeping ice cool. The majority chose a metal container giving reasons like 'because iron is cold'.

There is also a problem in making the distinction between the intensity and the amount of heat possessed by a body (e.g. Albert 1978; Andersson 1980). Erickson (1979) found that the temperature of a body was thought to be related to its size (or to the amount of stuff present)—so, for example, his 12-year-old students thought large ice cubes took longer to melt than small ones because they had 'colder temperatures'. In mixing experiments carried out with Israeli students aged 4–12 years Strauss (1977) also reports children's difficulties with the concept of temperature and confusion between the amount and intensivity criteria.

Finally, there is some evidence (Dow *et al* 1978; Brook *et al* 1984) that the early introduction of kinetic theory into the secondary science curriculum has had little influence on understanding of other physics concepts including heat. Students tend not to use particle theory in explanations of experiments and events concerning heat.

Most of the work outlined above was carried out with pre-school or primary age children, who had had little or no formal teaching on heat. The naive ideas described as typifying the thinking of young children would, it might be supposed, be dispelled by science lessons. This article describes an interview study with 12–16 year olds; the results suggest that many of the same viewpoints are held by secondary students up to compulsory school-leaving age.

The study

The work described here was carried out as part of a larger-scale interview study in understandings of several scientific concepts (Engel 1982; Engel Clough and Driver 1984). Eighty-four students (aged 12–16 years) from three city comprehensive schools were interviewed on three tasks related to conduction of heat (see table 1). These students were selected to represent the full range of ability, since we wanted to comment on the understanding of age groups across this range. A consequence of adhering to this principle of investigating students of all abilities, however, was that individuals in the sample were following a considerable variety of school science courses within the three schools.

Table 1 Tasks used to explore understanding of conduction of heat

Tasks presented	*Initial questions asked*
Spoons	
Students were presented with four spoons, made of metal, pot, wood and plastic, dipping in a mug of hot water. They felt the handles of the spoons.	Can you explain why the metal spoon feels hottest, the wooden and plastic ones least hot?
Plates	
Students were told that the metal and plastic plates placed in front of them had been in the room overnight.	If you could put thermometers in close contact with these two plates, would you expect any difference in the readings or would they be the same?
Students then felt the plates with the palms of their hands.	Can you explain why the metal one *feels* colder?
Handlebars	
On a frosty day Sally noticed the metal part of the handlebars of a bicycle felt colder than the white plastic grips.	Can you explain why the metal part of the handlebar feels colder than the grips?

This poses a real problem since it would have been useful to make some statements about, say, the work on heat encountered by all the 14-year-olds in the sample, or all the 12-year-olds. This we were unable to do, although we can say that the topic was studied by all the students in the early years of secondary schooling.

Two of the three tasks used in this investigation (those using spoons and plates) were illustrated by practical apparatus, the third (using handlebars) with a drawing; students were asked to make predictions and give explanations of these tasks. The taped interviews were sufficiently informal and 'chatty' to allow the interviewer to ask follow-up questions to probe reasons for the explanations offered. This, of course, is the greatest single advantage of interviewing over the use of written accounts as data.

The purpose of the study was to identify any common belief patterns which might emerge from scrutiny of interview transcripts and to compare the incidence of these across the three age groups; it is important to appreciate that these patterns were not pre-ordained by the investigators. Answers for each question were grouped according to the type of reason offered, so for each task we derived a set of mutually-exclusive categories based on reasons given by students. However, students quite often put forward several incompatible reasons in response to a question. Sometimes they decided subsequently in the interview that they preferred one of these explanations, in which case this was coded. On other occasions, however, students seemed unable to resolve the confusion and then these mixed responses were categorised as 'uncodeable'. The 'uncodeable' category also included cases where students were unsure about a solution to the task and unable to offer any explanation at all. When explanations occurred within the sample of children studied in response to at least two of the three tasks we called that type of explanation a framework.

Results

Certain 'facts' about heat seem to be almost universally 'known' by children—these include the knowledge that heat rises, that hot things expand and that heat travels through metals. They often have no explanatory power for the children but are produced almost as cliches when the appropriate prompt is given. The extract below, from an interview with Martin (aged 12 years), illustrates the confusion, one which was exposed with many other students, once the 'known fact' that 'metal conducts heat well' was probed further.

Interviewer—'Four spoons made of different kinds of material were in a jug of hot water and it says that she felt that the handle of the metal spoon felt hotter sooner than the others. Why would that be?'

Martin—'Metal conducts heat better than pot and wood and plastic.'

Interviewer—'Now tell me what you mean by that—that's interesting!'

Martin—'Well, wire conducts electricity . . .'

Interviewer—'Yes . . .'

Martin—'Well, heat only really is t'same . . . Well, metal does really t'same, only with heat it conducts it up it and it goes quicker.

Interviewer—'What sort of changes would you get inside the metal as the heat was conducted up it, or would you not get any changes?'

Martin—'It'd feel warmer 'cos heat's escaping from t'water and it's goin up this 'cos heat rises its goin up thro't' spoon handle.'

Interviewer—'Hmmm. When you say the heat rises, does that mean that if you had your heat—y'know, say you had something warming the spoon at this side you couldn't have water, but, y'know, a little heater or a cigarette lighter or something heating up this end of the spoon, what would happen to the handle?'

Martin—'It'd still get warm but it'd be slower than wi' it being t'other way round.'

Interviewer—'Would it?'

Martin—'Wi' t'heat comin' from t'bottom.'

Interviewer—'It would? *Why* would it be slower?'

Martin—'Cos in science they told us that heat rises in water. It goes up, and when you have heat it goes up and it doesn't normally go down.'

Interviewer—'I see. OK, so you're saying that the handle in this position would get hotter, but rather

Table 2 Student frameworks: conduction of heat

Student frameworks	*Spoons* (n = 84)	*Plates* (n = 84)	*Handle-bars* (n = 84)
Different substances feel different because heat travels through them at different rates	56%	6%	6%
Metal attracts/absorbs/ conducts coldness	—	5%	23%
Conductivities of different materials depend on some observable property—e.g. colour, thickness, smoothness etc	2%	19%	17%
Metals let heat in and out more easily	23%	25%	14%
Mixed and other uncodeable responses	19%	45%	40%

slower than in our original problem with the spoon?'

Martin—'Yeh.'

It is interesting to note, in passing, that, in a laboratory setting, with a rapid 'teacher question, pupil answer' routine, it is very possible that a teacher would have been satisfied with Martin's initial response and assumed a good understanding.

It is obvious from table 2 that the direction of heat conduction in relation to the pupil profoundly influences the answers they give. Problems about different conductivities of varying materials elicited many more correct responses when the question asked for an explanation of the sensation of hotness (as in the spoons task) rather than coldness (as in plates and handlebars). Thus, 'spoons' contributed quite high percentages of responses linking different sensations of temperature with different heat conductivities and the incidence of this scientifically-accepted framework increased from 27% in the 12-year-old group to 83% in the 16-year-old group. By contrast, the number of students offering this explanation in response to the plates and handlebars tasks was low, although there was an improvement in performance on these tasks at 16 years (see figure 1). The large numbers of responses which were either uncodeable, or from which a clearly defined framework could not be identified, (table 2) for the plates and handlebars tasks also in part reflects the difficulty which students had with these tasks.

Student frameworks

The student framework, reported in studies with younger children, that cold is an entity which, like heat, has the properties of a material substance, suggests that some students do not consider 'heat' and 'cold' to be poles of a single dimension. This seemed to be a general underlying assumption in many interviews and was explicitly expressed in response to both the plates and handlebar tasks. For example, figure 1 indicates that nearly a quarter of the 12- and 14-year-old groups and even 21% of 16-year-olds offered such an explanation in response to the handlebars task. The following short extracts illustrate students' belief in "coldness" as a substance, frequently one capable of movement:

'The metal is colder because cold passes through it much quicker than the plastic.' (From a 16-year-old.)

'Metal absorbs more cold than plastic does.' (From a 12-year old.)

'Well, the handlebars are made of steel, you know, some sort of metal—and they'd be affected by the air with it being a conductor, but the plastic won't—it'll stop just the same temperature. It'd not be affected at all by the air, but the metal one will. It (the metal)'ll take in the . . . you know, with the air being cold . . . it'll take in the cold—yes, and retain it.' (From a 16-year-old.)

The extract below, again from Martin's interview, illustrates one student's attempt to reconcile the 'fact' known to him that metal conducts heat well with his actual experience in interview that the metal plate felt colder than the plastic one.

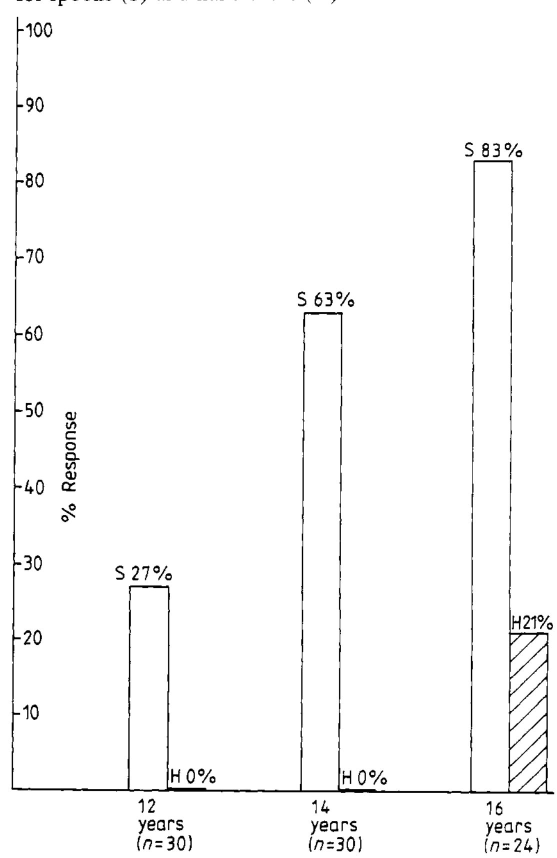
Interviewer—'One metal and one plastic. If you could put thermometers on those two plates, would you expect to get any difference in the readings, or would they be the same?'

Martin—'They'd be different.'

Interviewer—'Can you tell me how?'

Martin—'Er, 'cos heat'd conduct heat, 'cos the metal'd conduct heat better, that'd probably be a higher temperature than that, 'cos at room temperature it'd heat that one slightly, not very much on that one.'

Figure 1 Scientifically-accepted framework by age: data for spoons (S) and handlebars (H) tasks



Interviewer—'So the metal one would be hotter because metal is a good conductor of heat?'

Martin—'Yeh, or it if were a cold room that'd be colder cos it conducts heat.'

Interviewer—'OK. Would you like to feel both the plates—y'know, with your hands together like that. What do you feel?'

Martin—'This one's slightly colder.'

Interviewer—'The metal one's slightly colder, is it? Now then why d'you think it feels cold?'

Martin—''cos it's conducting cold heat: it's keeping cold heat in it.'

Interviewer—'It's keeping cold heat in it?'

Martin—'It's co. . . it's. . . can't really explain it.'

Interviewer—'No?'

Martin—'The room's. . . it conducts heat 'n'. . . can't really explain how.'

Other students drew on various 'natural' observable properties of the materials, such as colour, thickness and hardness to 'explain' different conductivities. This explanatory framework, again one noted in studies of younger children, was quite common amongst the 12- and 14-year-old groups. For example, 37% of the 12-year-old group explained the plates task in these terms. Typical responses referring to observable properties of materials were, from 12-year-olds:

'The metal is much thinner—the cold air could stay on here.'

'Plastic grips are softer so they feel warmer.'

'I just think it's the surface—it's a lot smoother' and 'Steel is shiny and harder, plastic is dull and softer,' (from a 14-year-old).

Sometimes students simply stated that metals were colder substances than plastic. So, one 12-year-old proposed that:

'It feels colder because it's metal and metal just *is* colder.'

Concomitant with the idea that metal lets, or even actively pulls, heat in and out more easily than other substances (see table 2) is perhaps the notion of heat as a dynamic moving force. Again, children's use of the idea that variable speed of movement of heat explains different conductivities has been noted in other studies (e.g. Tiberghien 1980). This framework, the most popular alternative one occurring in response to the spoons task, was put forward by a third of the 12-year-old students. This figure, however, was reduced to 4% in the 16-year-old group (see figure 2). The two 12-year-olds quoted below offer quite graphic descriptions of the metal spoon pulling in the heat.

'I suppose its a better conductor of heat than the others . . . well, heat . . . it'll be attracted to it . . . like pulls the heat towards it . . . as if it was like a magnet.'

'. . . A metal just pulls heat in—I can't remember the word . . . and it sucks it in and keeps the heat.'

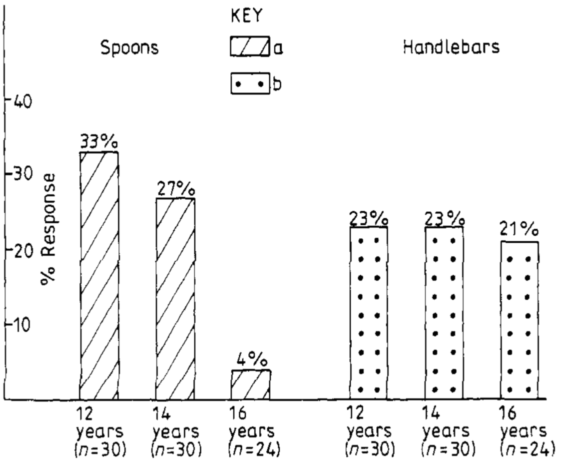
The same type of explanation was offered in response to the plates and handlebars tasks, but, in these cases, heat was described as being released or easily 'let out' of metals. So, a 14-year-old student explained the plates task like this:

'Because that (the plastic) must be keeping the heat in, and not letting it out, while that one's letting heat out . . . from inside the metal.'

Five students proposed the ingenious theory in response to the spoons tasks that metal conducts heat so well because heat concentrates exclusively on the surface and does not penetrate. So one student proposed that the metal spoon would be 'hot on the outside mainly' while another 12-year old explained 'It (the heat), like, puts a film on top of the metal and it feels warm . . . because wood's absorbing heat—it'd be warm inside but not outside.'

This student went on to illustrate her point in the interview by sketching a cross section of the handle of the metal spoon showing a central area of cold metal surrounded by a periphery of hot. In addition, one student explained the plates task by suggesting that the metal plate felt colder because it was cold on the outside only. The kind of thinking demonstrated in these responses was also reported by Tiberghien in one of the pupils whom she studied in depth. Unlike some of the other children's conceptualisations described in this article, this particular theory (that heat is concentrated on the surface of good conductors and does not penetrate the material) was unfamiliar to physics teachers with whom we have informally discussed these results.

Figure 2 Alternative frameworks by age: data for the most commonly occurring alternative frameworks for spoons and handlebars tasks; **a** metals let heat in and out more easily; **b** metal attracts/absorbs/conducts coldness



Implications for physics teachers

The evidence presented here strongly suggests that many of the ideas about heat previously associated with the thinking of young children remain with many of our secondary school students up to the age of 16. This is perhaps not surprising; as we indicated at the beginning of this article, we all have built up a fund of experiential knowledge about heat from an early age.

Two hundred years ago, Count Rumford (1798) explained his reasons for embarking on his experimental work on heat like this:

'There is not, perhaps, any phenomenon that more frequently falls under our observation, than the propagation of heat. The changes of the temperature of sensible bodies—of solids—liquids—and elastic fluids, are going on perpetually under our eyes; and there is no fact which one would not as soon think of calling in question, as to doubt of the free passage of heat, in all directions, through all kind of bodies. But, however obviously this conclusion appears to flow, from all that we observe and experience in the common course of life, yet it is certainly not true;—and to the erroneous opinion respecting this matter, which has been universally entertained—by the *learned* and by the *unlearned*—and which has, I believe, never even been called in question, may be attributed the little progress that has been made in the investigation of the science of heat:—a science, assuredly, of the utmost importance to mankind!'

Our scientific understanding of heat has developed in 200 years, but the problem outlined by Rumford is still with us. Sensory experience is the basis on which we 'cope with the world', and teachers face formidable problems when the conclusions we draw from this experience conflict with scientifically accepted theory. Research suggests (e.g. Champagne *et al* 1981) that physicists themselves think about physical phenomena in 'everyday terms' when they are operating in 'everyday contexts'. Perhaps, as Solomon (1980) has argued, it is not so much a question of devising ways of obliterating alternative conceptualisations in our students (indeed, this would almost certainly be impossible) but of encouraging the use of more scientifically-accepted ways of thinking in contexts which are more 'scientific'.

We may ask, since these alternative ideas do seem to persist in students' thinking, why are they not more apparent in science lessons in secondary schools? There are, we suggest, a number of reasons for this. First, students are usually relatively quick at learning verbal labels and scientific-sounding phrases. In the usual classroom interaction between teacher and student exchanges are rarely long enough to reveal what kind of understanding lies behind such words or phrases. The second reason is that in teaching an idea such as conduction of heat we tend to focus on one or two simple phenomena and students' discussion or writing about these may suggest that they understand them. However, when students are asked to use the ideas in an other, slightly novel context (as for example in explaining why metal handlebars feel cold) they have difficulty in using the ideas they seemed to use with confidence in a standard context. Lastly we would suggest that students' alternative perspectives have not been noticed before because of the way teaching is conceptualised and carried out. There is a tendency, perhaps particularly in science teaching, to have a very clear idea of where a lesson is to go and teachers therefore tend to 'tune in' to the answers they are looking for in the class and to ignore other responses; it is a case of selective attention.

In displaying some of the ideas that students do use in this area, and by showing how they persist in the thinking of many students throughout their secondary schooling, we hope to alert science teachers to the possible perspectives students use and to encourage them to take these ideas seriously. Only if we are able to interact with their ideas can we begin to consider how to change them.

Encouraging change

This leads to the final point. How can we help students to change their way of thinking? The answer to this question lies mainly with teachers and can only result from development work in classrooms and laboratories. Research projects such as the Children's Learning in Science Project (Bell and Driver 1984) are beginning to tackle these practical questions. The work reported in this article may be seen as part of the 'basic spade work' necessary for such development work. Our purpose here was to document secondary students' ideas about conduction of heat; so we can only make the most tentative suggestions for improvement of classroom practice.

The study suggests that a number of alternative ideas about heat conductivity are likely to be held by substantial numbers of students in secondary science classes. The notion of 'heat' and 'cold' as material substances, often with dynamic properties, seems to be both powerful and persistent. The direction of conduction of heat in relation to the human body appears to influence thinking; quite simply students find it difficult to think of conduction of heat when they *feel* cold.

Since many of the ideas expressed by children (from 4 to 16 years) reflect historically-held understandings of heat it may be that discussion and exploration of the historical development of thinking would be a strategy useful for both teachers and learners. Such treatment in the classroom could provide a forum for discussion of alternative ideas, their relative merits and demerits, their deviation from currently accepted scientific ideas etc. To be identified with the great scientists of 200 years ago carries rather more status than being merely 'wrong'!

We do believe that if many students are to change the way they think about heat in the context of school science they need opportunities to explore their ideas in a non-threatening atmosphere. Creating this atmosphere and devising strategies for the open exploration of ideas constitute real challenges for science teachers. The one 'practical' recommendation we feel confident to make, however, is this: if we want to know what children think, we must ask them; this means more open questioning and more discussion, not only in whole classes but in small groups. Underlying such an approach would be a recognition that students will bring ideas from 'everyday experience' into our laboratories. We have to find ways of using them!

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References

Albert E 1978 'Development of the concept of heat in children' *Sci. Educ.* **62** 389–99

Andersson B 1980 'Some aspects of children's understanding of boiling point' *Cognitive Development Research in Science and Mathematics* 252–9 W F Archenhold *et al* (eds) (The University of Leeds)

Bell B and Driver R 1984 'The Children's Learning in Science Project' *Education in Science* **108** 19–20

Brook A, Briggs H and Driver R 1984 *Aspects of Secondary Students' Understanding of the Particulate Nature of Matter* CLISP (University of Leeds)

Champagne A B, Klopfer L E and Gunstone R F 1982 'Cognitive research and the design of science instruction' *Educational Psychologist* **17** 31–53

Dow W M, Auld J and Wilson D 1978 *Pupils Concepts of Gases, Liquids and Solids* (Dundee College of Education)

Engel M E T 1982 *The Development of Understanding of Selected Aspects of Pressure, Heat and Evolution in Pupils aged between 12 and 16 years,* unpublished PhD thesis (University of Leeds)

Engel Clough E and Driver R (1984) 'A study of consistency in the use of students' conceptual frameworks across different task contexts' paper accepted by *Sci. Educ.*

Erickson G L 1979 'Children's conceptions of heat and temperature' *Sci. Educ.* **63** 221–30

—— 1980 'Children's viewpoints on heat: a second look' *Sci. Educ.* **64** 323–36

Rumford, Count B 1798 *Essays, Political Economic and Philosophical* **2** 200–1

Strauss S 1977 *Educational Implications of U-shaped Behavioural Growth*—a position paper for the Ford Foundation (Tel-Aviv University School of Education)

Solomon J 1980 *Teaching Children in the Laboratory* (London: Croom Helm)

Tiberghien A 1980 'Modes and conditions of learning. An example: the learning of some aspects of the concept of heat' *Cognitive Development Research in Science and Mathematics,* W F Archenhold *et al* (eds) (The University of Leeds) 288–309