The Development of Understanding of Selected Aspects of Pressure, Heat and Evolution in Pupils aged between 12 and 16 years

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ABSTRACT

The study is founded on the belief that knowledge based on an individual's prior experience contributes to scientific learning. This is contrasted with a perspective in which it is assumed that concepts have a reality completely independent of the learner.

The research is a description of pupils' personal scientific knowledge about several aspects of pressure, heat and evolution. Eighty-four children (aged between 12 and 16 years) were interviewed and asked to give their explanations of scientific problems set in everyday contexts. Categories of response were identified from pupils' words; some of these recurred across different question contexts testing the same scientific concept. They represent frameworks of thought which pupils employ, though they may completely contradict the currently-acceptable scientific notion.

Pupil frameworks were identified for the nature of pressure (including a molecular explanation), aspects of fluid pressure, the distinction between heat and temperature, the idea of conduction of heat, aspects of inheritance (including the notion of non-inheritance of acquired characteristics) and for biological adaptation. Their frequencies across three age groups are reported.

There was some stability of the frameworks of individual pupils across questions testing the same scientific idea, though the pattern varied from idea to idea.

Fifty-eight pupils were re-interviewed after a 20-month interval and the change or stability in thinking of individual pupils was monitored over this period. These results were equivocal. Pupil frameworks relating to some scientific ideas appeared to remain fairly stable over time, whereas for others pupils drew on different frameworks on the two occasions, frequently on different alternative frameworks.

The implications for pedagogy are discussed and it is tentatively suggested that more effective learning might occur if teachers took serious account of pupils' alternative frameworks in their classrooms and laboratories.

Dedication

This study is dedicated to Thomas and Anna Engel who, between them, have taught me a great deal about children's thinking.

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ABBREVIATIONS

APU	Assessment of Performance Unit
DES	Department of Education and Science
FDI	Field dependence/independence
LEA	Local Education Authority
SCIS	Science Curriculum Improvement Study, Chicago, Illinois: Rand McNally & Co. 1978
SSRC	Social Science Research Council

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"All my knowledge of the world, even my scientific knowledge, is gained from my own particular point of view, or from some experience of the world without which the symbols of science would be meaningless. The whole universe of science is built upon the world as directly experienced, and if we want to subject science itself to rigorous scrutiny and arrive at a precise assessment of its meaning and scope, we must begin by reawakening the basic experience of the world of which science is the second-order expression....Scientific points of view, according to which my existence is a moment of the world's, are always both naive and at the same time dishonest, because they take for granted, without explicitly mentioning it, the other point of view, namely that of consciousness, through which from the outset a world forms itself round me and begins to exist for me."

M Merleau-Ponty

(Phenomenology of Perception, 1962, London, RKP, p.viii)

INTRODUCTION - STATEMENT OF THE PROBLEM

The central aim of the study is to describe in detail pupils' understandings of selected aspects of pressure, heat and evolution. Recorded explanations offered in response to interview questions on these topics are scrutinized for any common belief patterns which may emerge.

The study follows in the wake of a small, but now rapidly expanding, body of ideographic research into children's understanding in science. Some aspects of both heat and evolution have been investigated, though many of the studies involved subjects who were either younger (in the heat studies) or older (in the evolution studies) than the pupils in the present investigation. Little work has previously been carried out on pressure.

Although the work is not bound by a single psychological theory, several principles underlie the approach. Firstly, it is assumed that the prior knowledge which a learner brings to a task has a profound effect on that learning, and therefore that effective teaching should take this into account. No firm distinction can be made, nor is one attempted here, between learning based on experiences in school science and on those from out-of-school sources. Secondly, it is assumed that the best way to find out how pupils think about certain scientific ideas is to ask them. This means that pupils' own words must be attended to closely, and inferential interpretation on the part of the investigator should be delayed as long as possible. Finally, there is some research evidence to indicate that there may be some commonality of belief patterns (or conceptual frameworks) to be found amidst children's imaginative efforts to explain phenomena. This idea is also used in the present study.

Answers to the following research questions are sought:-

(a) What are the main conceptual frameworks which pupils bring to bear on ten scientific ideas related to pressure, heat and evolution?

(b) With what frequencies do these frameworks occur in samples of secondary pupils of different ages?

(c) Are these frameworks consistent for given individuals over different questions which test the same scientific idea?

(d) How do individual pupil frameworks change (if they do so at all) over a period of time?

After some theoretical discussion these issues are to be explored in this thesis.

CHAPTER 1

METHODS OF INVESTIGATION OF PUPILS' UNDERSTANDING IN SCIENCE

I Theoretical Frameworks

At the outset, it is necessary to distinguish between two radically different ways of thinking about scientific learning. The first emphasises the learning of a body of accepted scientific conceptualizations (that is, one reached by the consensus of scientists). The second perspective includes children's scientific learning from their perceptual experiences of phenomena in the natural world. The former suggests that scientific concepts, having an independent reality, merely await comprehension and acceptance. The educational implication here is perhaps that successful learning follows naturally from a careful structuring and organization of the material to be learnt. By contrast, the inclusion of learners' experience-based knowledge as an integral part of scientific learning suggests that sensory experience and the learner's own prior ideas and hypotheses (partly products of the imagination) are not distinct in concept formation. In other words, learning takes place as a result of a reciprocal interaction of cognitive and environmental events. This latter view emphasises an active negotiation for meaning, and the learner's intuitive knowledge and his existing notions become an important focus of study.

Aspects of Piaget's cognitive psychology have been used extensively over the past fifteen years as a guiding paradigm for both research studies and the development and evaluation of new curricula in science education. Some research workers find Ausubel's theory more appealing, though, in general, it has been much less widely applied. Both theories describe cognitive development as a dynamic, interactive process with cognitive structure modified through experience. According to Piaget, intellectual growth involves the building of cognitive structures which are universal and independent of content. These structures are constantly modified as the child interacts with the environment, and, in time, qualitative changes are discernible which mark new stages or levels. It is this mental operative structure which determines what can and cannot be meaningfully known. Lack of understanding is explained by the fact that the pupil has not reached a given operational level. This framework leads to general statements about the capabilities of thought at different ages. Piaget's ideas have been used by others to make general predictions about the selection and sequencing of science content, and for the diagnosis of learning difficulties. Underlying these applications is the idea that, although experience may hasten the natural development of thought processes, there can be no radical alteration in the rate or order of their appearance.

Ausubel, on the other hand, envisages the assimilation of new knowledge which is specifically linked to relevant concepts in the existing cognitive structure, and the progressive differentiation of structure as a continuous, and not stage-dependent, process. It is this hierarchically-organized framework of specific concepts which determines what can or cannot be meaningfully known, and lack of understanding is explained by gaps in the conceptual structure, gaps so great that new knowledge cannot be anchored to old. Adoption of Ausubel's ideas leads to an emphasis on the elucidation of conceptual structures of individual learners and carries the pedagogic implication that some degree of learning is possible for any concept, provided proper instructional sequences are followed.

Both Piaget's and Ausubel's theories offer support for the idea of the learner as an active sculptor of meaning. However, Piaget's writings contain scant reference to the relevance of a person's perceptual experience to a learning problem; little account is taken of the preconceptions with which a learner approaches a task, though there is evidence that these preconceptions and beliefs have an effect on thinking. Does a child's performance depend primarily on the logical structure of the task, or does it depend heavily on the context (that is the familiarity with the content, the overall meaningfulness of the task to the individual learner)? Piaget contends that, at formal operational level, the content of a task has been subordinated to the form of relations in it. Critics propose that content and meaning influence intelligence much more than Piaget allows. The learner's assessment of the content and meaning of a task depend on how easily he can relate these to his previously-existing ideas. Donaldson (1978) has demonstrated that young children's reasoning needs the prop of contexts which make what she calls 'human sense' to the individual. Her experiments show that three to four year olds frequently find the procedures of a task perplexing, but that, when the same problem is couched in a familiar and realistic guise, dramatic improvements in performance result. Wason (1977) reports exactly the same influence with intelligent adults tackling tasks which require, in Piagetian terms, formal operational thought. Both authors argue that context is a powerful aid to understanding in our everyday lives and that the attempt to formulate general, context-independent laws denies this fact. The learner's interpretation of a task depends on pre-existing notions - and these arise from experienced-based intuitions as well as more formally-acquired concepts. Fischbein (1975) classifies concepts into those which are consistent with intuitions, those which are counter-intuitive and those which have few intuitions relating to them. There is evidence that children stick with their intuitions when contradictory experimental findings are encountered, even if they have the requisite thinking skills to 'overcome' the intuitions (Driver, 1981; Viennot, 1979).

In view of the neglect of the intuitive base underlying learning, a Piagetian stage framework is not altogether adequate for a study which purports, as this one does, to produce detailed documentation of pupils' scientific ideas.

II Methodological Approaches

Debates over theory and perspective are reflected in debates over methods. Thus the two different views of scientific learning outlined above lead to distinctive methodological approaches.

Within the positivist perspective research workers seek causes and facts, with little regard for the subjective state of the individual. In studies of scientific understanding, this research stance would be favoured by those who believe that scientific learning involves the understanding of concepts which have a reality independent of the learner. Investigators operating within the phenomenological perspective, on the other hand, are concerned with understanding human behaviour from the pupil's own frame of reference. This research orientation reflects a belief in the importance of experience-based knowledge as an integral part of scientific learning.

The distinction implies a radical polarization which does not, however, exist in practice. The research styles of most studies fall somewhere between these two extreme theoretical standpoints. It is possible, therefore, to give only loose characterizations of the two approaches in relation to learning in science studies.

Research from the positivist perspective attempts to assess pupils' ideas against currently-held scientific ideas. These studies are often normative (that is, directed towards the establishment of norms or standards); the design is frequently experimental and 'objective' methods of enquiry are favoured which yield quantifiable data from groups of pupils. Interpretation of data focusses, from the beginning, on similarities and generalizations about thought processes - these may be cognitive styles, ability levels, or Piagetian stages depending on the theoretical framework of the particular study.

In contrast, studies from the phenomenological perspective do not initially involve the testing of hypotheses and so are not experimental in design. The aim is analysis of experiential descriptions - pupils' conceptualizations are analysed in their own terms and not exclusively against externally-defined criteria. Such studies have been described as <u>ideographic</u> in character. The nature of partial understanding is fully documented, because pupils' alternative conceptual frameworks, arising from prior experience, are described. Contextual limitations are thus also fully recognized. Generalizations arise only when common patterns are detected amongst these alternative frameworks - their formulation is not the central and initial objective behind ideographic studies. Ideographic studies tend to depend on qualitative, descriptive data obtained by 'subjective' methods.

Testing the present investigation against these characterizations illustrates the crudity of the polarization. Philosophically, the study fits towards the phenomenological end of the spectrum since it focusses on the experience of individuals, and the empirical data, obtained by non-objective methods, is qualitative and descriptive. Yet there is some quantitative treatment of data, results of pupil groups of different ages are compared and the analysis of interview data is independently checked to show, in fact, a high level of reliability. All these might be considered to be features of positivist research.

Traditionally, naturalistic description has been a second class method of study, to be used by default and not choice. Several writers (Entwistle, 1979; Jacobson, 1970; Marton, 1978; McCall, 1977; Wilson, 1972) have commented on the positivist stranglehold on our thinking about research - a grip so tight that many important questions about pupils' concept acquisition and development have been disparaged and excluded, because they cannot be treated experimentally. Wilson (1972, p.82) suggests that "there is a crying need for clear and accurate detailed descriptions of what happens when someone tries to acquire a concept." Without these, he suggests, it is premature to start talking about causes (why the concept has not been acquired, for example), 'stages of development' or deep explanatory theories and hypotheses. He proposes that, as with botany, zoology and anthropology, the first job is description and classification.

The processes by which conceptual growth occurs constitute a fundamental concern for educators. The literature contains exhortations for the adoption of psycho-dynamic methods (for example, Sutton, 1980), but, in fact, the methodologies for studying conceptual growth as it occurs are poorly developed. A rare example of a psycho-dynamic study is provided by the work of Karmiloff-Smith and Inhelder (1974). They meticulously described the interplay between children's action sequences (in a block-balancing test) and implicit theories (inferred from actions). By observation of the organization and re-organization of the sequence and length of actions, they concluded that children's actions changed the theories they held about the task as they progressed through it and that the theory-of-the-moment influenced actions. But, in most cases, investigators have had to be satisfied with 'snapshots' - static portrayals of single performances - as measures of conceptual development. Performances are only ever approximate manifestations of cognitive capabilities, of course, and Strauss (1977) has warned that they may sometimes be extremely misleading ones. Strauss and his colleagues described U-shaped behavioural curves for tasks relating to physical intensivity (e.g. sweetness, temperature), where drops in performance levels correspond to increases in power and efficiency of children's competence; so, from this evidence it cannot even be assumed that a higher achievement has a higher level of competence underlying it. But even if it is not methodologically feasible, at the moment, to monitor concept acquisition in progress, it is at least possible to make rough tracings of the routes whereby individuals acquire concepts, by taking more than one 'snapshot' of the same individual over time. Wohlwill (1973), McCall (1977) and others have stressed the need to focus on change in the individual, as distinct from stability or continuity in populations. Longitudinal studies provide data on patterns of change in the individual, but there are very few examples of this approach in cognitive development studies (for exceptions, see Wallace, 1972; Deadman, 1976). McCall (1977) suggests that naturalistic development has been under-investigated because it is less amenable to the traditional experimental, manipulative methods used in the study of static behavioural events. He suggests that a major modification of research attitudes and methods is required, with a shift towards a more developmental, as well as a naturalistic, orientation.

One argument put forward by the advocates of ideographic studies is that they are potentially more useful to educators in decision-making about classroom practice and curricular planning. Whether or not this claim can be substantiated will be considered later, after a more detailed discussion of methodological problems in the context of specific examples of normative and ideographic studies of science concepts.

III Normative Studies

The following groups of normative studies of understanding in science are not entirely mutually exclusive, but the classification offers a useful general guide.

A. Studies which outline conceptual hierarchies - both logical analyses and psychological ordering.

B. Studies which measure selected aspects of thinking which are considered to be related to scientific learning.

Cutting across this grouping, investigations vary in the degree of emphasis put both on the effects of instruction and on the influence of a whole range of variables (such as I.Q., sex, etc.) on concept acquisition. They vary too in the method of data collection, although the majority of studies rely on written tests.

A. Conceptual Hierarchies

A distinction is not always made between logical hierarchies inherent in topics and the understanding hierarchies of the learner (Trowbridge, 1979; Hart, 1981). Some studies based on the logical analysis of concepts seem to carry the assumption that pupils' learning closely follows a sequence identical to the logical ordering of sub-concepts. So, for example, investigations of the particle nature of matter by Pella and Carey (1967) and of the concept of the biological cell (Pella and Strauss, 1968) began with an identification and sequencing of related sub-concepts, made first from text books and then checked by experts. Attainment in the knowledge, comprehension and application of these component ideas was then measured by objective tests, and correlations between concept test scores and variables such as age and I.Q. allowed recommendations to be made for optimal ages for teaching the sub-concepts. Gower et al (1977) identified a series of sub-concepts underlying the chemical concept of the mole and arranged these in a hierarchy, according to principles laid down by Gagné, by asking the question "What concepts must the learner already understand before he can learn another specified concept?" Elements in the hierarchy were then tested, and a measure of its validity was obtained from a consistency ratio - that is the ratio of the number of responses consistent with the hierarchy to the total number of test responses. These analyses do not purport to give information about individual learning approaches, or about learning difficulties.

Raven's study (1968) on the concept of momentum began with a similar logical analysis of sub-concepts and he postulated the following sequence:-

conservation of matter $\rightarrow$ speed $\rightarrow$ proportional use of mass and speed $\rightarrow$ momentum

But he also advanced the hypothesis that the learning sequence may differ from this, so the assumptions behind his study are very different from those described above. He administered practical tests of the component concepts to a cross-sectional sample of primary children and found that the learning sequence turned out to be:-

momentum $\rightarrow$ conservation of matter $\rightarrow$ proportional use of mass and speed $\rightarrow$ speed

These interesting findings suggest that young children (aged 5 - 8 years) may have a global, intuitive understanding of momentum, without understanding its component parts.

B. Selected aspects of thinking relevant to the learning of science

Investigations in this large and diverse group all carry a common underlying assumption that scientific understanding requires certain cognitive skills - for example, the ability to think abstractly, to disembed problems from misleading contexts, to formulate mental models, to control variables, to manipulate relations between relations (that is, so-called second degree relations, as between two ratios) etc. The relevance of some of these cognitive skills to scientific understanding remains unsubstantiated. Some may be good predictors of understanding in specific concept areas, but less useful as indicators of general scientific achievement.

1. Piagetian levels

Many studies (Lovell and Shayer, 1978) indicate that tasks of Piagetian level have very good predictive power for scientific achievement.

Some investigators report at a very general level. Sayre and Ball (1975), for example, examined the relationship between school science grades and performance on formal operational tasks, and found that 88% grade A students, but only 19%

grades D - E students, were formal thinkers. Lawson and Renner (1975) compared the scores on four Piagetian tasks with multiple-choice test scores for a variety of concepts requiring both concrete and formal thought. They concluded that understanding (as measured by the multiple-choice tests) of the formal concepts did not occur until at least some of the responses on the Piagetian tasks reached the formal level. In a more detailed study Rowell and Dawson (1977) used Piagetian tasks specifically related to the concepts under investigation - density and relative density. They found that the abilities to conserve weight and volume proved to be highly predictable indicators of success in post-instructional written tests. Most studies on Piagetian levels measure group means, but, in an evaluation of the developmental change as a result of instruction in aspects of space conception (as presented in the 'relativity' unit of SCIS), Nussbaum (1979a) used a Piagetian framework to identify cognitive change in individuals. Pupils were assigned to a developmental level from total scores on interview tasks, and then individual shifts were monitored after instruction. Nussbaum argued that the really significant transition was from Stage II to Stage III, because it represents an overriding of the egocentric perspective. He found that 27% of nine year olds demonstrated this change, and maintained it over time (a delayed post-test was administered twelve weeks after the first post-test). Okeke (1976) did not use Piagetian tasks at all, but linked pupil understanding with Piagetian ideas by a novel and very detailed approach. She carried out a meticulous 'armchair analysis' of ideas subsumed in the topics of reproduction, transport mechanisms and growth, and produced maps of conceptual difficulty, using the characteristics of concrete and formal thought. She then interviewed a large sample (n=120) of Nigerian examination candidates to assess conceptual understanding (understanding of ideas was rated on a five-point scale). A close relationship was found between the difficulty experienced by pupils and the conceptual difficulty of component ideas, based on Piagetian characterization of thought.

2. Cognitive styles

Cognitive styles describe the form and not the content of cognitive activities. They have been characterized (Kempa, 1980) as relatively stable modes of psychological functioning, and appear as bipolarities, with no value assignment, since styles at either end may be advantageous under certain circumstances. Field dependence/independence (FDI) is probably the best documented cognitive style. Thurstone (1949) identified a Flexibility of Closure construct (C_2), which was later measured by Gottschaldt's embedded figures test. MacFarlane Smith (1964) interpreted C_2 as the k factor (spatial ability) and the construct has since been elaborated at length by Witkin et al (1971, 1977), and named FDI. It concerns the perception of information (field independent subjects are able to disembed items from an organized background, and to ignore compelling and irrelevant cues), but MacFarlane Smith and Witkin both believe that the construct describes, not just visual perception, but distinct modes of general cognitive functioning. It has been suggested (e.g. Case and Globerson, 1974; Kempa, 1980) that the ability to disembed problems from their contexts may be important in the development of science concepts, and particularly relevant to the explanation of individual differences within a given developmental level. Kempa and Ward (1975) found good correlations between observational attainment on chemical tasks and a specially-constructed embedded figures test. The distinction between field dependent and field independent subjects was clearest when the observational tasks were non-cued (that is, there were no hints as to what to look for). But Saarni (1973) obtained results which indicated that for complex problem-solving tasks (children were asked to solve mysteries in detective-type stories) the level of FDI within each Piagetian developmental level did not affect performance. Kempa (1980) has recently pointed out that the link between FDI and scientific understanding is obscure, and needs further research.

IV Ideographic Studies

Sensitive techniques are required in order to elucidate children's beliefs and the connections linking these beliefs. The identification of misconceptions (e.g. Milkent, 1977; Kuethe, 1963; Za'rour, 1975) cannot, on its own, illuminate the reasons for which pupils subscribe to these ideas. Since there is evidence (Rowell and Dawson, 1977; Driver and Easley, 1978; Viennot, 1979) that pupils hold tenaciously to their preconceived ideas, even when instruction includes deliberate attempts to refute misconceptions, it seems clear that more detailed research is needed on the reasons for those misconceptions. This proposition involves a shift in research focus to children's interpretations of events and to the illumination of individual personal experience.

Written tests, the mainstay of normative studies, yield insufficient information on the strategies used to arrive at given answers, and, since dialogue is impossible, they preclude probing follow-up questions. But, as well as the adoption of appropriate in-depth methods, another factor influences the outcome of ideographic studies. Investigators who attempt to describe children's frameworks must assume a non-judgmental rôle and accept more of the responsibility for deciphering meaning. In normative studies in science, investigators ask the question "To what extent do you understand X?" - the onus is on the pupil to interpret the question correctly (that is, from a scientist's perspective) and the answer is judged against those external criteria. But if the aim is to describe children's interpretations of events in a more open-ended way, the question becomes "What do you understand by X?", and the main responsibility for construing meaning transfers to the investigator. So, the successful execution of ideographic research depends very much on the investigator's preparedness to encounter conceptions which are qualitatively different from accepted scientific ones and his/her ability to be as free as possible from a mental set.

If experimental, hypothesis-testing methods are inappropriate for the description of children's beliefs, what are the alternatives? There are very few examples of purely observational studies on scientific understanding. Knamiller (1974) observed two eight year olds working with science materials (tasks were not fixed by the investigator) and offered an 'interpretive description' of their activities, as they sought out new experiences and formulated explanatory theories. One advantage of observational studies is that they provide information about learning in settings which are more natural than either test situations or interviews with tasks set by the investigator. On the other hand data from pure observation are bound to be diffuse; their interpretation and, even more, their pedagogical relevance, must be highly inferential.

Piaget outlined his 'clinical method' in 1929 (Piaget, 1929) and this semi-structured interview, or variants of it, has remained the key method for ideographic studies ever since. Piaget described it as containing some elements of both the experimental and the purely observational approaches. The interview centres on set tasks, and Piaget advised that interviewers should have some hypothesis to check at every moment as the interaction proceeded - in these senses it is 'experimental'. At the same time the interviewer should carefully observe, as the child is encouraged both to talk freely and to influence the direction and emphasis of the dialogue. The central objective is to elucidate explanations for responses. Piaget later revised the method to include the manipulation of apparatus, because he thought that the original formula relied too heavily on spoken language. This is still regarded as the fundamental problem with clinical interviews and most modifications made by other workers are attempts to circumvent this.

The link between verbal (and non-verbal) behaviour and ideas is not always a direct one, but the observer has access to the child's ideas only <u>through</u> his behaviour and must make inferences about mental events from this. In an interview the child is required to listen with understanding, to interpret and respond according to his conceptual powers and to communicate orally the reasons for his responses. It is clear from the recent report of a large-scale study of primary children's understanding of some mathematical concepts that the research workers involved in this particular study gave laudable attention to the clarity of language in their test items, and yet they commented (Hughes, 1979, pp. 34-35) - "We recognized with increasing conviction as our work progressed that this field of enquiry into children's understanding of concepts has as its weakest link the form of communication used between the tester and the child." They found, for example, that the ability to communicate reasons for choices did not always match up to the conceptual ability of the child. This discrepancy, and the reverse one, (that is the use of words as labels, with no understanding of the related concepts), have been well documented (Lovell, 1966; Barnes, 1976; Greene, 1975). Donaldson (1978) suggested that children's interpretation of language can be powerfully influenced by context, and that sometimes, in putting their own meaning on situations, children simply do not attend to the purely linguistic meaning, and so do not 'read the message' as intended. She also explains the fact that the ability to use language is sometimes in advance of the ability to understand it, by suggesting that contexts can support incompletely-understood words in a meaningful flow. Clearly, communication between interviewer and child is an immensely complex process, with many points at which inaccurate translation of what is intended or known can occur.

One way to reduce reliance on verbal expressions of understanding is to incorporate manipulation of materials into the interview. Demonstrations of the phenomena under investigation have become standard practice. It has been claimed by Piaget and many others (e.g. Trowbridge, 1979) that observation of the child's handling of apparatus gives valuable additional information about understanding. It has also been suggested (Linn, 1977; Karmiloff-Smith and Inhelder, 1974) that handling materials can change both the difficulty of the problem, and the theories the child holds about the task as he progresses through it. Linn (1977) administered Piagetian and other specially-developed tasks and found contradictions between verbal statements and actions in handling apparatus. She decided that verbal statements alone were not enough to understand students' thought patterns and concluded "the implication is that it is necessary to gather information from many different sources and combine it to characterize a thought pattern." (Linn, 1977, p. 367). The study by Karmiloff-Smith and Inhelder (1974), described earlier, is unusual in that actions were the primary indicator of understanding. It is not, however, possible to translate abstract thought into actions and so some topics are more suitable for investigation in this way than others. Von Pfuhl Rodrigues (1980) presented problems to children in the form of comic strip drawings - all were of situations where Archimedes' Principle, gravitation or fluid mechanics played a role. The children (aged 7-13 years) had to describe the drawings, to judge whether the situations depicted would be possible in the real world and to give explanations for their answers. Separate ideas about the concepts under investigation were tested by several different cartoons. She used drawings in order to avoid being restricted to physically-possible situations, as in the direct manipulations of objects, and she also hoped to avoid a purely verbal approach. She found that even the young children were capable of formulating laws to explain the phenomena in the drawings, but she detected very little pattern in the data and very little consistency of response across the ideas tested. Gilbert and his group (Gilbert and Osborne, 1980; Osborne and Gilbert, 1980) have also used line drawings to depict instances and non-instances of scientific concepts (such as work, electric current, force). Pupils were asked to categorize each drawing, and to explain the basis on which the categorization was made. They thus obtained lists of pupil view-points about a topic.

Finally, it should be added that, although written tests are considered to be an inappropriate method for initial data collection in ideographic studies, they can make an important contribution if, for example, the questions are based on preliminary interview data (as in studies by Dow et al, 1978; Erickson, 1979; Trowbridge, 1979). Free writing about scientific phenomena has proved to be a powerful illuminative method (e.g. Carré and Head, 1974). Indeed, Sutton (1980) has emphasised that methods involving the written word for the elucidation of children's beliefs are the only practicable ones in the classroom.

Ideographic studies vary, not only in the exact methods adopted, but also in the degree of concern with pedagogic issues and in the level of detail at which results are reported. The stated aim of some investigators (such as Deadman, 1976; Erickson, 1979) is to contribute to the improvement of teaching methods and curricula, whereas others (such as Albert, 1978; Von Pfuhl Rodrigues, 1980) are not directly concerned with school learning. For obvious reasons many studies focus on topics which children find conceptually difficult and specifically ones which, according to Fischbein's classification, are either counter-intuitive or have few intuitions relating to them. So, the particle nature of matter (Novick and Nussbaum, 1978; Novick and Nussbaum, 1981), aspects of heat (Albert, 1978; Erickson, 1979; Tiberghien, 1979), the concept of the mole (Novick and Menis, 1976), the Earth and space (Nussbaum and Novak, 1976; Nussbaum, 1979b; Mali and Howe, 1979) and genetics and biological evolution (Deadman and Kelly, 1978; Kargbo, Hobbs and Erickson, 1980) tend to recur as topics for investigation.

The review of literature on the understanding of concept areas chosen for this investigation (Chapter 2) contains more detailed discussion of examples of ideographic studies.

There is evidence from research in the ideographic tradition that children's ideas can often be grouped into relatively stable belief patterns. But a major problem exists: the balance between reporting of predominant conceptual structures and kinds of development (which therefore have some degree of general applicability) and retention of some detail of individual variation in conceptual structures is a very difficult one to achieve. It is, nevertheless, particularly important to get the balance right, if teachers are to be persuaded of the usefulness of these results for classroom practice.

V Application to classroom practice

There is almost unanimous agreement that children's existing beliefs are important to learning, so it is logical that classroom practice should take account of this. It can be argued, of course, that good teaching has always included listening carefully to children's ideas and then beginning from the vantage point of the learner's own experience; and that experienced teachers are aware of children's alternative ideas and of the misconceptions which block understanding. But it is evident from the small amount of research in the field that too little is known about children's ideas - particularly those relating to difficult topics - and that detailed analyses of conceptual areas are not available.

It has been suggested (Driver and Easley, 1978; Trowbridge, 1979; Erickson, 1979; Deadman and Kelly, 1978) that the most likely outcome of research into pupils' understanding will be a heightening of teachers' awareness of the possible perspectives their pupils may bring to new learning - an increased awareness which should result in more perceptive understanding of learning difficulties. Teachers would, in other words, have a greater insight into the intellectual worlds of their pupils. This presupposes, of course, that teachers are willing and able to give status to children's ideas. Finch (1971) makes an interesting distinction in this connection. She suggests that teachers of English show interest in children's own ideas and opinions, but by contrast, science teachers frequently give the impression that children's ideas are not worth much consideration beside those of great scientists. She goes on: "But the English teacher is not, and cannot, be aiming at producing a class of Shakespeares, and we cannot be aiming at producing a class of scientists . . . Somehow we must arrange for children to produce useful scientific ideas in our lessons, and to get credit and kudos for them." (Finch, 1971, p. 407). She is advocating a change of attitude which, undoubtedly, will be hard to achieve, and it is possible that the nature of science poses particular problems. How genuinely can pupils' scientific ideas, which contradict long-established scientific theories, be considered 'worthwhile'? Is it perhaps <u>easier</u> for teachers of English or technology or political science to treat pupils' alternative ideas in this way?

It has been suggested too (Driver and Easley, 1978; Deadman and Kelly, 1978) that the design of new curricula should take account of pupils' ideas, including their intuitions. Deadman and Kelly (1978) propose that the traditional Curriculum ⟶ Pupil model of development should be reversed, so that pupil understanding would be investigated <u>first</u> and then gradually incorporated into teaching and curricular planning. A rare example of this ordering can be found in the work of Stavy and Berkovitz (1980) who incorporated knowledge about the development of the concept of temperature in children (Strauss, Stavy and Orpaz, 1977; Strauss, 1977) into the construction of an effective curriculum unit (Stavy R., Bar V. and Berkovitz B., Heat: Teacher's guide and student manual Tel-Aviv: Israel Science Teaching Center, School of Education, Tel-Aviv University, 1974 (in Hebrew)).

Clearly the usefulness of ideographic studies in science has not been proved. Indeed this is impossible at the moment, since they represent only the starting point of what Erickson (1980) describes as a three-stage process. This process consists of:-

(a) description of common belief patterns
(b) determination of their generalizability to larger populations of students
(c) translation of these results to the classroom

Erickson's work includes a follow-up study based on his descriptive investigation of understanding of heat phenomena. He developed a questionnaire - a Conceptual Profile Inventory - which comprises different explanations for heat-related experiments, accompanied by a series of bipolar scales to measure judgements of preference about each explanation. He took explanatory statements from previous interviews to comprise the 'Children's Viewpoint', and constructed a 'Kinetic Viewpoint' and a 'Caloric Viewpoint' for comparison. Erickson administered this to 276 pupils (11-15 years old) and found that many children at all three grade levels were prepared to subscribe to the 'Children's Viewpoint'. In other words, the ideas contained in it were not confined to a small group of 12 year olds - his original sample. Erickson considers his Inventory to be a practicable instrument for teacher use.

It seems clear that stage (a) of the process of application can only, realistically, be carried out by research workers, at least if interview methods are used. Sutton (1980) has pointed out that it is manifestly impossible for practising teachers to interview all their pupils to give insight into their dominant thought patterns, and he concludes that other diagnostic procedures need to be developed for teacher use. He suggests, for example, pupil 'overviews' of a new topic written in response to several tasks, and also sorting tasks with words and objects. It is debatable, though, whether these 'short-cut' measures would yield sufficiently detailed and illuminative data. The second part of the process - testing the generalizability of the results - is perhaps the easiest and quickest stage of the process, and certainly the one where methodologies are best developed. As well as generalizability, it is clearly important to measure the degree of stability of pupils' belief patterns. This can only be done by adding a developmental dimension to ideographic studies, through the adoption of longitudinal methods. It seems equally clear that stage (c) of the process - the translation of the results into the classroom - should be the subject of classroom-based research, with, ideally, teachers themselves acting as research workers. The aim of this action research would be to provide concrete examples of how pupils' understandings may be utilized in teaching.

It has been argued in this chapter that ideographic studies of understanding in science concepts reflect a fundamentally different perspective (as compared with the majority of investigations, which are normative), and that the outcome of these studies may be equally valuable and have considerable potential usefulness in the classroom.

CHAPTER 2

THE CHOSEN CONCEPT AREAS

The purpose of this chapter is to justify the choice of concept areas and to review the literature on research into pupil understanding of pressure, heat and evolution. The studies discussed fall mostly, though not exclusively, into the ideographic tradition.

I Criteria for choice

The three conceptual areas for this study were selected using the criteria listed below.

(a) The concept areas should be of fundamental importance to physical or biological science. They should be central themes, which recur in different forms and contexts throughout the school curriculum.

(b) The concept areas should, in the opinion of science teachers, present special difficulties for teachers and pupils, so that the research results may have educational relevance and value.

(c) Pupils should have a broad base of intuitive ideas relating to the chosen concepts - ideas formulated from out-of-school sources, such as television, science fiction, sport etc.

(d) Since the study was designed to include a developmental dimension, conceptual areas should be chosen which are likely to yield ' developmental richness' - that is, where significant shifts in understanding with age might reasonably be predicted.

In addition to the above, a fifth practical consideration, namely the availability of a range of test items from the Assessment of Performance Unit (APU), determined the choice of the particular aspects of heat, pressure and evolution to be investigated because those items were to be used in the interviews. On the basis of these criteria, and an examination of the existing literature on children's ideas about pressure, heat and evolution, several aspects of the conceptual areas were selected for investigation. These are presented as lists of scientific ideas overleaf.

Pressure

NATURE OF PRESSURE

Pressure is force per unit area - it can be changed by spreading the same force over a different area.

MOLECULAR BOMBARDMENT

Pressure exerted by a fixed volume of gas increases as the temperature increases because of increased molecular bombardment.

PRESSURE AND DEPTH

Pressure in a liquid depends on the depth of the liquid, the pressure increasing proportionately with depth.

PRESSURE AND DIRECTION

Pressure at any place in a liquid acts equally in all directions.

ATMOSPHERIC PRESSURE

The atmosphere exerts a pressure on objects.

Heat

HEAT AND TEMPERATURE

Heat and temperature - a substance requires a given amount of energy to raise the temperature of unit mass by a given amount.

CONDUCTION OF HEAT

Heat energy travels through different materials at different rates.

Evolution

INHERITANCE

Some variations are inherited - there is a genetic basis, with a recombination of genes at sexual reproduction.

ACQUIRED CHARACTERISTICS

Some variations (those acquired during an organism's lifetime) are not inherited.

ADAPTATION

As the environment changes organisms with favourable variations survive and leave more descendants. Without these they die out.

To what extent do the three conceptual areas meet the four broad criteria outlined overleaf?

(a) There is no question that both heat and pressure are fundamentally important conceptual areas in physics. They are both taught early in secondary school science courses and then, again, in external examination courses in the fourth and fifth years. There is similarly no question that evolution is fundamentally important to modern biological thought. Although as a circumscribed topic on the syllabus it is frequently reserved for the fifth form, crucial subsumed topics, such as variation, the mechanism of sexual reproduction and general treatments of adaptation, are regularly encountered earlier in school biology courses. Viennot (1979) has pointed out that it is difficult to persuade teachers that their students hold ideas about topics which they have not been formally taught. Perhaps for this reason, the justification, to teachers, of evolution as a suitable topic proved more difficult than the justification for heat and pressure.

(b) Similarly, all three conceptual areas broadly satisfy the second criterion. Johnstone and Mughol (1976) investigated the perceived difficulty of physics topics by pre-'O' level students (n = 499), post-'O' level students (n = 414) and first year University students (n = 83). The subjective assessment of a list of twenty-three basic concepts (compiled in consultation with university and school teachers) was matched with an 'objective assessment' (a paper and pencil test). The main peaks of difficulty, reported by more than 30% of the school students, included the idea of pressure and three items on heat - the difference between heat and temperature, the idea of specific latent heat (of fusion and vaporization) and the idea of heat transfer (conduction, convection, and radiation). It is interesting that the majority of items showed indices of difficulty in the subjective assessment which decreased with chronological age, but four concepts were considered to be more difficult at post-'O' level grade than at pre-'O' level grade. These included the idea of pressure. In addition to the evidence from the above study, W K Mace and his colleagues in the physics department, King Edward VII School, Sheffield were consulted about the aspects of heat and pressure which their pupils found most difficult to understand. They pinpointed the distinction between heat and temperature, the existence of atmospheric pressure and the application of kinetic theory to an understanding of the nature of both heat and pressure as areas of particular difficulty for pupils up to 16 years. Evolution is recognized as a difficult subject to learn (Johnstone and Mahmoud, 1980) and to teach (Jungwirth, 1977; Deadman and Kelly, 1978; Maxwell, 1978); and this conclusion is confirmed by my own experience in teaching biology. Indeed, Shayer (1974) suggested that many of the ideas contained within evolution were much too difficult and abstract, and the topic should be abandoned as a pre-'O' level subject. But others (e.g. Deadman and Kelly, 1978) have stoutly defended its inclusion on the grounds of its central importance to biology.

(c) It is obvious that some scientific concepts are more likely than others to have a rich intuitive base, founded on experience. It can be argued that it is pedagogically more useful to choose concepts which are under-pinned by confirmatory and/or contradictory intuitions, rather than concepts which have few intuitions relating to them. Young children will have formulated many ideas about heat based on their own experience ("hot" must be amongst the first few words in many children's vocabularies), and also some ideas about pressure, but very few, if any about evolution. For example, a three-year-old will have contructed firm ideas about hot and cold objects and his own relation to them, about the pressure of solids in, for example, sand or pastry. He may perhaps also have some rudimentary notions about the passing on of characteristics from parent animals to their young. Older children, are, of course, also exposed to all kinds of incidental, as well as planned out-of-school opportunities for learning. Biological topics seem to be covered much more extensively by the media (particularly television) than physical science topics. For example, in the period immediately preceding the first round of data collection for this study, David Attenborough's series about evolution, 'Life on Earth', was shown on BBC TV. These programmes were specifically mentioned by several pupils in the interviews. Indeed, it was common in the evolution interview (though less so in the heat and pressure interviews) for pupils to draw on information gleaned from television, books and magazines, in support of their explanations. To summarize, it is reasonable to assume that secondary-age children bring many ideas related to the three selected areas into the classroom from everyday life.

(d) Clues about the 'developmental richness' of the chosen concepts can be obtained from an examination of the results of Piagetian and ideographic studies. Piagetian studies suggest that understanding of important aspects of all three concept areas are dependent on the development of formal operational thought (Shayer, 1974 on evolution; Lovell and Shayer, 1978 on heat and Shayer, 1978 on pressure). This indicates, of course, that interesting developmental changes should occur in the 12-16 year age range. The paucity of longitudinal studies of concept development has already been discussed, but ideographic studies, including some with cross-sectional designs, also give valuable developmental clues. These ideographic studies are reviewed below. To summarize, there is some evidence that all three conceptual areas broadly satisfy this criterion.

II Review of literature on pressure, heat and evolution

A. PRESSURE

There are no ideographic studies of children's understandings of pressure reported in the literature.

Shayer's analysis of pupil understanding of the work on pressure contained in the Nuffield Combined Science Project (Shayer, 1978) is carried out within a Piagetian interpretative framework. Conceptual demand was assessed according to Piaget's stages and pupil developmental level was measured by two Piagetian group tasks (pupils aged 12-13 years). Eighteen short written questions relating to pressure in air were administered to one class of twenty-six pupils, and ten questions on pressure in liquids were administered to three classes from three different schools (n = 90). Shayer argues that, since pressure is a ratio of two independent variables, an analytic understanding of it is impossible below the stage of early formal reasoning (Stage IIIA). Indeed, he found that no pupils in his sample used the idea of pressure as force per unit area in response to the examination items, though all pupils who were at Stage IIB or above had more intuitive pressure concepts - for example, the idea that pressing as hard on a smaller area will result in greater pressure. Shayer claims that results from other questions in the test indicate that the inability to conceptualize pressure as force per unit area is not merely an inability to calculate. Not very surprisingly, Shayer found that the pass rates on items testing the idea that pressure in liquids is greater at a greater depth were higher than those testing the idea that pressure is the same in all directions. Although this research was not designed to document children's reasons for their answers, the idea of a vacuum exerting a sucking pressure was expressed so frequently (46% pupils) that Shayer included this idea as an 'invalid concept' in his table of results (Shayer, 1978, p. 215).

Barnes (1976) includes extracts from small-group discussions on air pressure, in support of his thesis that exploratory talk between children can result in increased understanding. Barnes describes how some pupils accepted the words 'sucking' or 'suction' as a perfectly adequate explanation of how milk may be drunk through a straw. He also found that explanations using authoritative-sounding labels such as 'air pressure' were later frequently revealed to be vague and inadequate.

The article entitled 'There's no such thing as suction' (Mace, 1961) indicates that some teachers, too, are aware that children find suction an enticing idea.

Okeke (1976) investigated pupils' understanding of pressure as part of her study of biological transport mechanisms. She comments that the word 'pressure' was frequently used by her subjects to mean 'force', and that pupils who had only an intuitive knowledge of pressure as 'push' tended to misunderstand phenomena which depend on an analytic understanding of pressure.

B. HEAT

There have been a number of ideographic studies on heat phenomena. The most useful of these are listed below, together with the ages of the children interviewed:- studies by Albert, 1978 (4-9 year old American children); Andersson, 1980 (12-15 year old Swedish children); Erickson, 1979 (12 year old Canadian children); Strauss, 1977 (4-12 year old Israeli children) and Tiberghien, 1980 (12-13 year old French children). Children's ideas revealed in these and other studies are grouped, for the purpose of the present discussion, under the following three broad headings:- (1) the nature of heat, (2) the nature of temperature and (3) the application of kinetic theory.

(1) The nature of heat

The tendency to perceive heat as a kind of material substance, with properties generally attributable to matter, has been noted by several investigators. Erickson (1979) drew up conceptual inventories from interviews with ten 12 year old pupils, and then scrutinized these for common patterns. Children in this study observed the heating of a metal rod and suggested that heat builds up in one part until it cannot be held any more, and then it moves along the rod (rather like a fluid overflowing). Elsewhere in Erickson's interviews, pupils described heat as a substance like air or steam; they frequently associated 'heat' and 'cold' with 'air' and used the terms interchangeably. So, pupils suggested that metal cubes became hotter than sugar or wood cubes because it was more difficult for air to get into the metal to cool it down. Albert (1978) found that the youngest children in her sample (4 and 5 year olds) thought of heat as residing in objects, and made statements like "sun is hot" or "oven is hot" to explain heat. Slightly older children related the hotness to themselves rather more explicitly, and concluded from the fact that a "coat makes you warm" that the coat was the warm object. At about eight years a distinction was detectable between heat and the object in which the heat resides, and children referred explicitly to heat in spatial terms (e.g. "heat rises"). Moreover, it was often depicted as active and moving (e.g. heat going down, moving away, etc.).

The existence of cold, as opposed to heat, is a recurring theme and cold is also endowed with material properties. So, children in Erickson's study (1979) explained the decrease in water temperature when ice cubes were added, by proposing that cold moved from the ice into the water. He found that pupils tended to describe objects as containing a mixture of heat and cold, and temperature as a measure of this mixture. Albert (1978) identified a primitive form of the idea of a single dimension - cold/warm/hot - in seven year olds who seemed to appreciate that an object becoming hot needs time to pass from a lower to a higher level of heat. Some eight year olds distinguished warm and hot as different instances of the same dimension.

The study by Tiberghien (1980) is an analysis of children's ideas about heat conduction and, because she was concerned with pupils' progress through teaching sessions on the subject, her report is a useful documentation of the development (and stability) of ideas. Pupils were asked amongst other things to explain in interview why cotton felt warmer than copper, and why a metal spoon dipping into hot water was warmer than a wooden one. Eight children were involved in the investigation, but this paper reports in detail on two pupils who were interviewed. They were also filmed during the teaching sessions. One girl (aged 12) modified her explanations profoundly over the period of observation. At first she considered only the sensation of touch (what is cold cools; what is hot heats), but later she referred to a property of heat - its speed of movement. This change represents a radical reorganization of thought. The other pupil (a girl of 13 years), on the other hand, showed no similar fundamental changes in her thinking about heat conduction over the period. She continued to connect one characteristic of the object with the movement of the heat or the cold (heat and cold were both given the properties of a fluid). In the initial interview she mentioned the thickness and solidity of the material, and in the final interview simply the nature of the material. Interestingly, this pupil did not recognize the passage of heat to the interior of materials - for example, she suggested that the cotton was hotter than the copper because the heat stayed on the outside and did not penetrate.

(2) The nature of temperature

Albert (1978) reports that, from the age of eight years, children in her sample had some idea of definite degrees of heat. Typically temperature is thought of as a measure of the amount of heat held by an object, and no distinction is made between the intensity and the amount of heat possessed by a body. In an investigation of pupil understanding of the variables which do not affect boiling point, Andersson (1980) demonstrated that Swedish pupils (aged 12-15 years) had great difficulty with this concept. He administered two tasks. The first tested the idea that extra time will not affect boiling point, once the water is boiling; the second that water temperature will remain similarly unaffected by a change in dial setting (from 3 to 6) of the electric heater. Surprisingly few pupils gave correct answers backed by adequate explanations (Task 1 - 19% of 12 year olds, 45% of 15 year olds; Task 2 - 14% of 12 year olds, 39% of 15 year olds). There was considerable instability of response across the two tasks. (In general pupils did less well on Task 2 than on Task 1.) For example, twenty-one per cent of the pupils who offered top category responses for Task 1 (that is, they stated explicitly that boiling was the cause of temperature invariance) changed their explanations for Task 2 and suggested that the dial number determined the boiling point.

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, large ice cubes were thought to take longer to melt than small ones because the larger cubes had "colder temperatures". In mixing experiments pupils obtained the temperature of a resultant mixture by adding together the two temperatures. Strauss (1977) and Strauss, Stavy and Orpaz (1977) also report children's difficulties with the concept of temperature, and the confusion between the amount and the intensivity criteria. They have described U-shaped behavioural curves for tasks involving several intensive physical quantities (sweetness, temperature, viscosity, hardness), but have found no such curves for other intensive quantities, such as specific weight, which have no 'sensory referent'. Strauss (1977) demonstrated the mixing of liquids of the same and different temperatures and asked children in interview to work out the temperature of the mixture and to account for their answers. He discovered that young children could solve this intensivity task, that 8-9 year olds had great difficulty with the same task and that older children (12-13 year olds) could also solve them. Strauss makes a distinction between a qualitative understanding of temperature and quantitative manipulation of numbers - to solve the task correctly it is of course necessary to make non-additive manipulations - e.g. $10^{\circ}C + 10^{\circ}C = 10^{\circ}C$. They suggest that the 'dip' in the U curve is because pupils at these ages 'see' the problems simply as mathematical calculations. This results in addition, subtraction, averaging etc. and adoption of these procedures seems to obscure the qualitative, common-sense understanding demonstrated by younger children. There is evidence from the work of Stavy and Berkovitz (1980) that subtraction in mixing problems with liquids of different temperatures is a higher level response than addition. They found that pupils shifted their explanations, and used subtraction rather than addition (thus sometimes getting closer to the correct judgement) after a period of training which involved the deliberate exploitation of the cognitive conflict between the qualitative and quantitative representational systems of temperature.

(3) <u>The application of kinetic theory</u>

There is some evidence (e.g. Dow, Auld and Wilson, 1978) that the early introduction of kinetic theory into the secondary science curriculum has had little influence on understanding of other physics concepts, including heat and pressure. Dow, Auld and Wilson (1978) argue that the 'binding themes' of the new physics syllabuses of the 1960's (and particle nature of matter is one of these) have not been successful. There are several studies which investigate the understanding of the particulate nature of matter per se, rather than its applications to other concepts. Novick and Nussbaum (1978), in an interview study with 13 and 14 year old Israeli pupils, found that three aspects of the particle model were particularly difficult to assimilate. These were the aspects most in dissonance with a sensory perception of matter. They were:-

(a) The idea of empty space. They found that many pupils could not conceive of empty space in ordinary matter, including gases. Instead, pupils reverted to a continuous interpretation and wanted to 'fill' space with more particles, dust, air, etc.

(b) The idea of intrinsic motion of particles. Some pupils viewed air as the mover of particles. And many pupils said that air does not 'settle out' because of its low specific gravity, a property consonant with a conception of continuous matter.

(c) The idea of interaction between particles (chemical change).

Dow, Auld and Wilson (1978) documented in detail secondary pupils' understanding of the particle nature of matter and its applications. They administered written tests, the items of which were based on the results of interviews with younger children. It was found that concepts which pupils had at the sensory level were not in agreement with the concepts which they had at the molecular level. Typically, first year pupils thought of 'particles' as granules or bits, with air in the space between the particles. In a discussion of the application of ideas about particles to changes of state, the authors report that 11-13 year olds had no concept of a sudden jump in molecular speed during a change of state. Instead, they visualized that the speed of the molecules steadily increased from solid to liquid to gaseous state. In general, the liquid-solid interface seemed to cause fewer problems than the liquid-gas interface.

At the liquid-solid interface pupils could visualize a change in molecular movement; they proposed that the molecules either stopped moving altogether in the solid, or that they adopted a different mode of movement, vibratory rather than translatory. At the sensory level these pupils described the change from solid to liquid as going through a 'slushy' stage (that is, a gradual process), whereas at the molecular level the change was regarded as sudden. The same pupils did not visualize sudden changes at the molecular level at the gas-liquid interface, though in this case they described sudden conversions at a sensory level. The report by Dow, Auld and Wilson (1978) indicates clearly that a considerable gap exists between the assimilation of some factual information about particles (e.g. that when a gas becomes hot the molecules move faster) and the development of a more incisive understanding of heat phenomena, as a result of the application of these ideas.

C. EVOLUTION

Introduction

There have been a number of studies on aspects of evolution. The most useful of these are listed below, together with the ages of subjects whose understanding was assessed:- studies by Deadman, 1976 (11-15 year old British boys); Kargbo, Hobbs and Erickson, 1980 (6-14 year old Canadian children); Brumby, 1979 (British university students) and Maxwell, 1978 (18 year old British schoolchildren and British university students).

A number of research workers has commented on the neglect of biological topics in concept development studies (Okeke, 1976; Woolley, 1979 and Kargbo, Hobbs and Erickson, 1980). Various suggestions have been put forward to explain this omission. Piagetian tasks involve physical science concepts (e.g. pendulums, force, motion, etc.) and there are no protocols drawn from biology. Okeke (1976) and Kargbo, Hobbs and Erickson (1980) suggest that the popularity of Piagetian frameworks for investigations has resulted in neglect of biological topics. It has also been proposed (Shayer, 1974) that many biological concepts are more difficult to analyse because they are non-hierarchical, and tend instead to be elaborately interwoven with related concepts. Woolley (1979) makes the very plausible suggestion that biological theories are difficult to investigate because they have a less formalised structure than physical science concepts, and thus there is a much greater reliance on ordinary language, with all its attendant vagueness.

There is no doubt that the concept of evolution as a relationship between changes in the environment and the production of changes in characteristics within the reproductive systems of organisms includes a number of very difficult and sophisticated ideas. It is important to note that several aspects of neo-Darwinian evolutionary theory are currently being challenged in the scientific literature. The lack of palaeontological evidence for the smooth and continuous evolutionary change of species (always a problem for evolutionary theorists) is under scrutiny, and a reinterpretation is proposed. The theory of 'punctuated equilibrium' (Ridley, 1981) suggests that evolutionary change has in fact occurred more jerkily - that is with periods of rapid change (the time of 'speciation') interspersed with long periods of quiescence. In addition, experiments by Steele and Gorczynski (1981) provided evidence of inheritance of an acquired characteristic (of immune tolerance in mice), though replication of these results is proving problematic (Robertson, 1981).

Some blocks in pupils' understanding have been identified in the studies mentioned above. For example, evolutionary adaptations tend to be discussed with respect, not to populations, but to individual organisms (Maxwell, 1978; Brumby, 1979). The time-scale of evolution is obviously also an extremely difficult aspect to grasp, as was demonstrated in the studies by Brumby (1979), Maxwell (1978) and Deadman (1976). It is possible to tease out from the literature a number of general problem areas relating to the understanding of evolution.

Understanding of evolution

(1) Teleological and anthropomorphic interpretations

A central theme in published studies is the teleological interpretation given by students to several concepts within evolution. Teleological interpretations indicate the belief, for example, that adaptations are due to the purpose or design that is served by them - that is, evolution. A number of investigators (e.g. Deadman, 1976; Brumby, 1979; Jungwirth, 1977 and Angseesing, 1978) comment on the Lamarckian flavour of explanations, with frequent references to 'inner needs', to some undefined internal, unconscious drive. Explanations are also often found to be anthropomorphic (Jungwirth, 1975, 1977) - for example, adaptation may be described as a conscious process, with reference to animals' needs or wants. Jungwirth (1977) has shown that many biology educators (teachers, text-book writers) describe evolution in stridently teleological and anthropomorphic terms. He castigates biologists for these modes of expression, and fears that students are likely to interpret them literally rather than metaphorically. Examples are certainly not hard to come by. The following quotations are taken from one episode (Episode 2) of David Attenborough's commentary to 'Life on Earth' (B.B.C. television, 23.1.79):

"This creature, encountering no change, sees no cause for change."
(these modifications are) "experiments in animal design."
"Crustaceans have modified their limbs into many different tools."

It seems possible, though, that the use of teleological and anthropomorphic expressions in relation to evolution may reflect linguistic difficulties in some cases, as well as genuinely representing these interpretations in others. It is, quite simply, very difficult to talk about the process of adaptation in any other way. In order to avoid possible teleological implications, complicated circumlocutions must be used (Ghiselin, 1966). Some of the instruments designed to diagnose a teleological interpretation rely on extremely precise understanding and use of language by the respondents. An example is the linguistic hair-splitting required to distinguish the alternatives in Maxwell's Questionnaire A (Maxwell, 1978). His subjects were post-graduate biologists, so perhaps in this case it was justifiable. Deadman (1976) (see also Deadman and Kelly, 1978) conducted a detailed ideographic study on pupils' thinking about evolution based on interviews with 52 Grammar school boys, aged 11-15 years. Deadman identified seven 'foci' of pupils' thinking about evolution (examples of foci are the process of adaptation and chance in evolution). He then grouped pupil ideas for each aspect or focus. Not surprisingly, he found large gaps in the boys' interpretative frameworks. Deadman and Kelly (1978) suggest that 'naturalistic' (i.e. Lamarckian) explanations were shown, on deeper probing in interview, to be a way of saying "I don't know". They found that the boys were very ready to abandon naturalistic answers.

But, despite the linguistic complexities, it does seem likely that Lamarckian interpretations of evolution are often sincerely held, not only by younger children, but also by university students (Brumby, 1979; Maxwell, 1978).

(2) Adaptation - several meanings

The term 'adaptation' is fraught with difficulties and it is this aspect of evolution which constitutes a key focus for investigation in the present study. The term refers both to the characteristics of an organism which fit it for a particular environment, and also to the process whereby a population is modified towards greater fitness for its environment. Several workers have commented on this bipolarity (Deadman and Kelly, 1978; Maxwell, 1978 and Lucas 1971) and it is clear that these two aspects of adaptation must be kept distinct when exploring children's understandings. Maxwell (1978) found that the two aspects (feature and process) were rarely linked by 'A' level and university students. Adaptation as a process is, of course, inextricably bound up with the concept of evolution. Deadman (1976) reports that the younger boys in his sample described adaptation as an end-product (feature) of a change in response to environmental change, whereas some older boys, who had a good understanding of the concept of survival, described adaptation as a process. Most of the boys in Deadman's study talked in interview about <u>why</u> rather than <u>how</u> adaptation occurred.

A further complication arises because 'adaptive features' may be inherited or they may not. The word 'adaptation' can perfectly legitimately be used to describe changes acquired in an individual organism's life-time. Such changes are not themselves inherited but they do, of course, only come about in the first place because the individual possesses some genetic predisposition for change. There is evidence (outlined below) that the distinction between inherited and non-inherited adaptive features also causes problems of understanding.

(3) <u>Evolution and genetics</u>

Investigators report that links between genetics and evolution are rarely made. Deadman and Kelly (1978) found that the pupils in their sample had few valid concepts concerning the source of variation. Indeed, the subtlety of the process of natural selection was not recognized - it was generally referred to at an inter-specific level. Only a few older boys revealed an awareness of intra-specific selection, with cumulative effects on the characteristics of the species. Variation was not a focus of concept structure and its links with the concepts of adaptation and selection were not established thus resulting in blocks in understanding of how adaptation occurred. Written tests administered to sixty-three university students, forty-nine of whom had done 'A' level biology, revealed no understanding at all of variation within a population caused by spontaneous mutations (Brumby, 1979). Brumby also reports that the students in her sample were confused between non-inherited changes occurring within the lifetime of the organism and inherited changes occurring in populations over time. Some of the tasks in the incisive study by Kargbo, Hobbs and Erickson (1980) were designed precisely to investigate whether children distinguished between environmentally-produced characteristics and purely inherited traits. They interviewed thirty-two Canadian children of average ability (aged 6-14 years) and found widespread belief in the inheritance of acquired characteristics. The results they describe are so categorical because the examples they presented to the children seem so very improbable to adults. For example, twelve children, including six aged ten years and over, thought that if a man and his wife both lost thumbs in a train accident their child, born subsequently, would also be thumb-less. And fourteen children, including seven aged ten and over, thought that a lame puppy would be born to a female dog who limped as a result of a road accident. The other tasks in this study asked for predictions of offsprings' inherited characteristics from observations of parental phenotypes. The two examples were the inheritance of colour in dogs and height in humans. They found that even the youngest children in their sample (six and seven year olds) had well-established theories to explain inheritance. Eighteen children (including ten aged ten and over) thought that the mother dog gave more colour to the puppies. The questions on human height indicated clearly that most children thought that the same-sex parent was the determiner of this characteristic. The authors found that it was possible to classify the explanations offered for all the questions into four broad categories. These were:-

(a) Environmental, with predictions made only in terms of environmental factors such as sun, water, food or parental care

(b) Somatic, with strictly somatic agents (such as nerves, brain, blood) responsible for the control of inheritance

(c) Naturalistic, with explanations in terms of nature, life cycles, sex-resemblance with parent etc. (50% of pupils fell into this category)

(d) Genetic Principle, found only among pupils over ten years of age, with some kind of genetic principle invoked either directly or indirectly for the determination of an inherited trait.

An examination of the literature thus indicates that teleological and anthropomorphic interpretations of evolution are common, and that the process of adaptation and the link between evolution and mechanisms of inheritance are poorly understood. The ideographic studies of Deadman (1976) and Kargbo, Hobbs and Erickson (1980) indicate that children who have not been formally taught the subject and also very young children possess clearly-formulated alternative frameworks relating to inheritance and evolution.

In the following chapter the design of the present investigation and methods chosen to describe pupil understandings of the three selected concept areas are discussed in detail.

CHAPTER 3

DESIGN OF THE INVESTIGATION AND METHODS OF ENQUIRY

This chapter begins with an overview of the research design. This is followed by a description of group instruments used and then by a detailed account of procedures and problems connected with the collection and analysis of interview data.

I Outline of the research plan

A. Introduction

During the summer term, 1979, interviews were conducted with eighty-four boys and girls of all abilities in order to elucidate their detailed understandings of the selected concept areas. They attended three secondary (comprehensive) schools in Sheffield and were from the first, third and fifth year-groups (ages twelve, fourteen and sixteen years). The interview schedules had been previously developed during a pilot study earlier in the year. In winter 1980-81 (after a twenty month interval) the two younger groups in the interview sample were re-interviewed. Thus, the design incorporates a combination of cross-sectional and longitudinal data collection (referred to as the 'convergence method' by Wohlwill, 1973).

The interviewees were chosen from a larger sample of two hundred and fifty pupils (a stratified sample selected by a relational thinking test). This larger sample completed written science tests consisting of Assessment of Performance Unit (APU) items on the chosen aspects of pressure, heat, and evolution.

The overall plan is represented diagramatically in Figure 1 and the timetable for data collection is given overleaf.

Timetable for data collection

PILOT STUDY

March-April, 1979	Pilot study - interviews and trial administration of Shipley and written science tests in pilot school.

MAIN STUDY

March-April, 1979	Shipley tests in three schools
April-June, 1979	Written science tests in three schools
May-June, 1979	First-round interviews in three schools (84 pupils)
January-March, 1981	Second-round interviews in three schools (58 pupils)

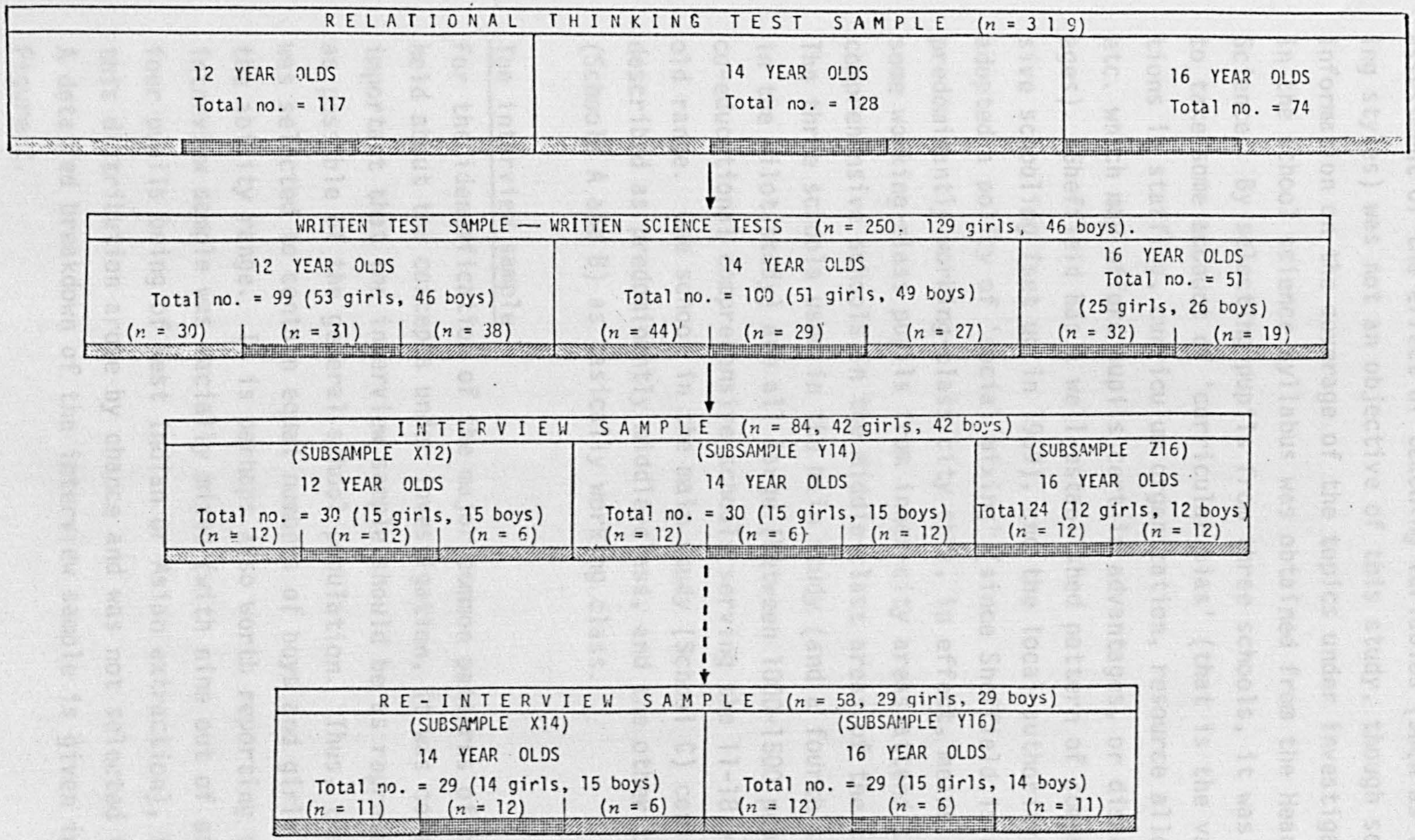

FIG. 1 THE OVERALL DESIGN OF THE STUDY

The written test sample was so much larger than the interview sample because this data was collected for use in a separate study conducted to explore the relationship between performance on written science test items and performances on language tests and tests of field dependence/independence. This study will be submitted for separate publication.

KEY
School A
School B
School C

B. The schools

Assessment of the effect of teaching variables (such as teaching styles) was not an objective of this study, though some information on the coverage of the topics under investigation in the school science syllabus was obtained from the Heads of Science. By selecting pupils from three schools, it was hoped to take some account of 'curricular bias' (that is the variations in staffing, curriculum organization, resource allocation, etc. which may afford pupils certain advantages, or disadvantages). Sheffield has a well-established pattern of comprehensive schooling (set up in 1969), and the local authority has adopted a policy of 'social mixing' (since Sheffield is a predominantly working-class city this, in effect, means that some working-class pupils from inner-city areas attend the comprehensive schools in the middle-class areas of the city). The three schools used in the main study (and a fourth school in the pilot study) are all large (between 1000-1500 pupils), co-educational comprehensive schools serving the 11-18 year old range. One school in the main study (School C) could be described as predominantly middle-class, and the other two (Schools A and B) as basically working class.

C. The interview sample

For the identification of the major common patterns of belief held about the concepts under investigation, it was considered important that the interview sample should be as representative as possible of the general school population. Thus, the sample was selected to contain equal numbers of boys and girls across the ability range. It is perhaps also worth reporting that the interview sample was racially mixed (with nine out of eighty-four pupils being of West Indian or Asian extraction), though this distribution arose by chance and was not selected for. A detailed breakdown of the interview sample is given in Figure 2.

II Group Instruments

A. Relational thinking test - sample selection

At the beginning of the Summer Term, 1979 a short (10 minute)

<table>
<tr><td colspan="24">INTERVIEW SAMPLE (n = 84)</td></tr>
<tr><td colspan="9">12 YEAR OLDS
(n = 30)</td><td colspan="9">14 YEAR OLDS
(n = 30)</td><td colspan="6">16 YEAR OLDS
(n = 24)</td></tr>
<tr><td colspan="3">(n = 12)</td><td colspan="3">(n = 12)</td><td colspan="3">(n = 6)</td><td colspan="3">(n = 12)</td><td colspan="3">(n = 6)</td><td colspan="3">(n = 12)</td><td colspan="3">(n = 12)</td><td colspan="3">(n = 12)</td></tr>
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FIG. 2 THE INTERVIEW SAMPLE

This diagram shows the sample for the first-round interviews. Only the two younger age groups were followed up and interviewed in the second round. In each case an equal number of girls and boys were interviewed.

KEY

(1) SCHOOLS

School A

School B

School C

(2) GENERAL ABILITY LEVELS
(Shipley Test)

High H

Middle M

Low L

relational thinking test was administered to 319 pupils in eight mixed-ability groups (three first year groups, three third year groups and two fifth year groups) - see Figure 1. The written science test sample (n = 250) was selected from these slightly larger groups, to ensure an adequate spread of ability. The relational thinking test is well-tried and measures the mental ability to see relationships and correlates. It is known to have a high general ability (g) component. It originated as the Shipley abstraction test (20 items) (Shipley, 1940), which comprised half of a scale devised to provide a quick, objective, self-administered measure of mental deterioration.

Since then the test has been used as a measure of general ability. The version used in the present study (Appendix 1) was devised by Lovell for use with adolescents (Lovell, personal communication).

Shipley Test scores for the interviewees are given in Appendix 2. From this information, identification numbers were designated to pupils in the following way:-

Nos. 1 -30	12 year old pupils (in 1979), in rank order Shipley scores
Nos. 31-60	14 year old pupils (in 1979), in rank order Shipley scores
Nos. 61-84	16 year old pupils (in 1979), in rank order Shipley scores

Because many fifth year pupils spend little time in school in the summer term, the 16 year old group (pupils 61-84) represented an opportunity sample - that is it was made up of pupils who were in school (many for examination work) and who were willing to take part in the study. This, in effect, probably meant that this group contained a disproportionate number of more able pupils.

B. <u>Science test - Assessment of Performance Unit (APU) items</u>

The present study uses some APU science items relating to pressure, heat and evolution as the starting point for an ideographic study of children's ideas.

Not all the written questions administered in this study were used in the final form of the questions in the APU item bank (e.g. some questions were shortened, others were changed from an open-ended to a fixed-response mode). There were several advantages to using APU items rather than constructing original questions:-

(a) they were written by experts with much attention paid to clarity and language use

(b) they were designed for two, and some for all three, age groups tested in this study and

(c) all but one of the questions presented problems in an everyday as distinct from a 'science' context, thus satisfying the requirement for realistic and familiar contexts stressed by Wason (1977) and Donaldson (1978).

To summarize, they constitute readily-comprehensible, specific examples on which to base probing investigations of pupil understanding.

The written science tests were administered to the eight mixed-ability groups (n = 250) (see Figure 1) shortly after the relational thinking test. Before the test began pupils were encouraged to write freely and to use ideas, not just from school science lessons, but from all 'out-of-school' sources in answering the questions. The test was not strictly timed, and took between 50 and 60 minutes to complete. The three age groups completed booklets of science items of slightly different composition. For example, it was assumed that the 12 year old pupils would not necessarily have encountered molecules, and so items on particle theory were not included for them. The written test items which were used as the basis of interview questions are presented in the detailed reporting of results in Chapters 4, 5 and 6.

III Interviews - Procedures and problems

It was argued in Chapter 1 that interviews constitute the most incisive method for ideographic investigations, since children's reasons for their understandings can be elucidated. The purpose of this section is to describe the methods used in the present investigation. Analysis of data which is intended to generate theory, rather than to verify it, cannot, by definition, be standardized. It is because the methods for the collection and analysis of interview data are not standard that they are described in some detail here. Some helpful guidelines for data collection and organization can be obtained from reports of similar interview studies. The doctoral theses of Deadman (1976), Okeke (1976) and Trowbridge (1979) were found to be particularly useful in this respect.

A. <u>The pilot study</u>

A pilot study was carried out in which twenty-two pupils (aged 11-15 years) were interviewed. These pupils had previously completed written science tests. Several days later some of these questions were asked orally in two interview sessions, but this time the data were supplemented by additional probing questions and by practical tasks. All the interviews were taped. The purpose of the pilot study was two-fold:-

(a) to provide an opportunity for the evaluation of interviewing technique

(b) to test the suitability of questions for inclusion in the final interview schedules.

1. <u>Interviewing technique</u>

A number of difficulties, common to many interview studies, were identified as a result of reflection on the progress of the pilot interviews. The interviewer's awareness of these problems was thus increased and pitfalls could be avoided in subsequent interviews.

(i) <u>Tendentious questioning</u>

Pupils' initial responses to supplementary questions were frequently vague or ambiguous, and in early pilot interviews the interviewer was tempted to suggest possible answers in the probing questions. It was in fact quite easy to replace tendentious questions of the "Do you mean so and so?" type by more open, neutral supplementary questions such as "Could you explain a little more what you mean by that?".

(ii) Interviewer dominance

There was a tendency for the interviewer to talk too much and interrupt too frequently, which was disconcerting for shy, quiet children. But several practical considerations also had to be taken into account. Interview sessions of more than forty-five minutes were found to be too demanding and exhausting for pupils, so it was essential to keep up the pace of the interview. This sometimes required intervention by the interviewer. Secondly, it was necessary for the interviewer to repeat quiet or indistinct responses - this was important since there was to be a considerable time lag (up to nine months in the main study) between data collection and data analysis. It was also necessary for the interviewer to describe all non-verbal cues given by pupils.

(iii) Non-judgemental reactions by the interviewer

Because the interview schedules contained several questions which tested a single idea and also because many pupils in the main study were to be re-interviewed after a twenty-month interval, it was important to give no indication of the correctness or otherwise of pupil responses. This policy was made clear to pupils before the interview sessions began. It was, however, not always so easy to execute! The initial tendency was to give replies which were too encouraging - either in form of words or tone of voice - replies which perhaps indicated to pupils that the content of their responses was being endorsed. On the other hand, there was a danger that communication became stilted and cold if completely neutral phrases were always employed. So, it was essential, as well, to convey to pupils that their ideas were interesting and that further expansion would be appreciated.

(iv) Pupils of different ages, abilities and personalities

Five or six interviews were usually conducted in one day. It was not always easy to make the necessary adjustments in general approach and in pacing for pupils of different ages, abilities and personalities. Some account was taken of this in the main study by restricting all the interviews in one day to a given age level and, if possible, to the same broad ability level. But the personality of the pupil - a most important variable - was largely unknown to the interviewer before the interviews began.

2. Development of schedules

The interview schedules were re-designed by the addition or recasting of ancillary questions, by complete omission of some questions and by modification of practical tasks. In general, there was a need to shorten and to simplify - to make the questions clearer, more straight-forward and less subtle.

From a critical evaluation of the pilot interviews, it was possible to make improvements in interviewing technique. Some preliminary analysis of pilot data indicated that there was adequate information feeding on to the aspects of heat, pressure and evolution to be tested in the main study. A more detailed analysis might have revealed, at this early stage, the need to restrict the scope of questions, so that pupils focussed only on the intended aspects.

B. The main study

1. Conduct of interviews

The selection and composition of the interview sample (eighty-four pupils) was described earlier. The interviewees had all completed the written science test (scores for these tests are given in Appendix 2). Two interview sessions (heat, 30 minutes, followed by pressure and evolution, 45 minutes) were separated by an interval of one to five days in the first round of interviews. The interviews were prefaced by a brief explanation of the purposes of the study, and interviewees were encouraged to talk freely about all their relevant ideas, gleaned both from out-of-school sources and from science lessons. Brief biographical notes were made, including details of science courses followed. The same pattern and procedures were followed with the second round of interviews (fifty-eight pupils). The schedules for these were shortened, because pupil responses to a few questions were not analysed in the first round (they yielded uninteresting or thoroughly confused data). These questions were therefore omitted.

The interview schedules (Appendices 3a - 3c) were based on some of the written science test questions, but also contained probing questions on these, additional questions designed to test the same ideas and a few broad, open-ended questions. The latter were difficult to analyse but provided valuable clues about the pupil's general stance towards a topic. There were also a number of practical demonstrations devised to illustrate problems and to extend children's thinking about them. A short written quiz (see Ch. 6), administered at the end of the interview, provided supplementary data on biological adaptation. The schedules thus contained set questions, but supplementary questioning depended on the pupil's responses.

Many pupils talked at length and almost all seemed to enjoy the interviews, even those who professed themselves uninterested in science. Nevertheless, reservations about the method, expressed in general terms in Chapter 1, must be borne in mind. There is heavy reliance on spoken language and the link between verbal behaviour and ideas is not always a direct one. In addition, communication between pupil and interviewer is a vastly complex process. So the degree of success in the probing of understanding must have varied from pupil to pupil. No sweeping claims can or should be made. It must be conceded that interviews are learning experiences, sometimes very intensive ones. This was particularly obvious when pupils manipulated and discussed practical apparatus, but could also be seen as pupils talked, sometimes ponderously, through their own ideas.

In addition to difficulties identified at the pilot stage, several specific problems were pinpointed in connection with the conduct of the interviews. These are discussed overleaf.

(i) Language in schools

Children's experience of school and of teachers' use of language must influence their interpretations of interviews in pedagogic settings. Many pupils in this study seemed to believe that questions always have 'right' answers. They often interpreted the interviewer's probing interjection as a correction - a sort of setting right after a derailment of thought - rather than a genuine enquiry. Since there is good evidence (Eggleston, Galton and Jones, 1976; Barnes, 1977) that science teachers use language mainly to impart information, and rarely to explore personal meanings, these interpretations are neither surprising nor unreasonable. But they must influence the conduct of interviews.

(ii) The demands of frequent contextual changes

The schedules contained a variety of problems, and pupils were required to cope with frequent contextual changes as the interview progressed. There was evidence that pupils differed in their ability to do this. In a few cases, pupils became confused and answered a question by referring to the context or setting of the preceding question.

(iii) Pupil perceptions of parallel questions

In general, older, more able pupils perceived that parallel questions were designed to test the same scientific idea. In some cases, it seemed that pupils who had given good answers got tired of repeating the same ideas in response to subsequent parallel questions.

(iv) Problems with the collection of developmental data

Some standardization of procedures and approach across ages is important for the interpretation of developmental data, and yet this requirement had to be balanced against the advantage of flexibility which a semi-structured interview offers. The age range 12-16 years is a broad one and it was found, for example, that some older children responded better to a matter-of-fact approach, with more persistent supplementary questioning as necessary. Youngerchildren, on the other hand, often responded better to a more gentle approach. Such differences, often adopted unconsciously, may distort the validity of the developmental results. This is also true for other uncontrolled factors, such as an improvement in interviewing expertise as the data collection proceeded.

Despite the reservations and problems associated with data collection which are outlined above, there is no doubt that the interviews in this study yielded a rich and varied body of data, which would have been unobtainable by other methods. The procedures adopted for the analysis of this data will be discussed in the next sections.

2. <u>Initial analysis of interview data</u>

One fifth of the first round interviews (n = 18) for each concept area, including some from each age group, were transcribed. Two transcripts are given in Appendix 4.

A preliminary analysis of this sample allowed:-

a) the identification of distinct ideas

b) the arrangement of these ideas on ordinal and nominal scales

a) <u>Identification of ideas</u>

From the transcriptions, responses to individual questions could be examined side-by-side, and salient ideas identified. The number of these ideas varied from question to question but, typically, would include a good, correct answer, two partially-correct variants and three or four ideas which were wrong but distinguishable. These groups of children's ideas were labelled <u>categories</u>. The reasons and strategies which pupils employed in the solution of problems were the primary considerations in the generation of distinct categories. Category designation was restricted to <u>one</u> per question for each pupil.

b) <u>Arrangement of categories on two scales</u>

It was then possible to draw up a provisional category set for eachquestion. For most questions this was arranged on two scales as shown in Figure 3. The ordinal scale contained correct and partially-correct categories and the alternative responses were put on the nominal scale. These scales are not strictly orthogonal but are employed simply as a convenient way of presenting the two types of response category. Questions asking for definitions and open-ended introductory questions posed special problems, because pupils quite legitimately addressed themselves to different aspects of these. This made it impossible to rank the categories, and their arrangement on a single, descriptive scale seemed more appropriate.

The responses of the remaining sixty-six pupils were then examined for degree of fit to this provisional framework of categorization. Heat and pressure categorizations were made directly from tape but all the evolution results were obtained from transcripts. Not surprisingly, considerable modification was needed for some category sets. In some cases, the categories proved to be isolated ideas and were deleted, whereas in others new categories had to be added. Each revision and the reason for making it was recorded. Categorizations of second-round interviews were all made directly from tapes, using the category sets already established.

Problems encountered in the generation of categories and the assignment of responses are discussed below. The first point illustrates difficulties associated with the key theoretical issue of the relationship between understanding and spoken language. The other points are technical ones related to data handling.

(i) <u>Ideas and their expression</u>

Problems arose with pupils who had difficulty in expressing sound ideas in an explicit, articulate manner. This was most obviously manifest at the beginning of the evolution interview because many pupils lacked an adequate

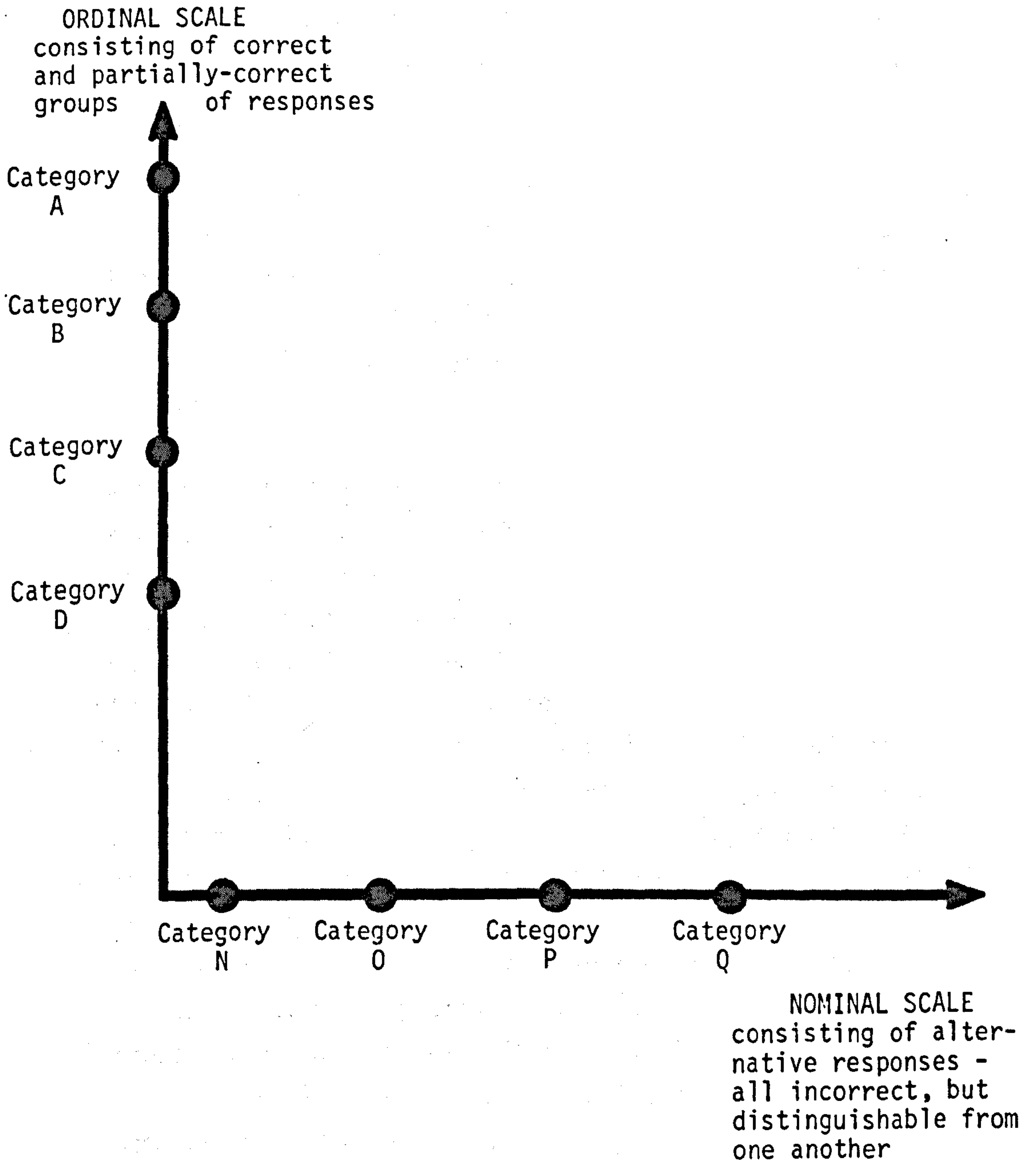


FIG 3 : CATEGORY ARRANGEMENT ON TWO SCALES vocabulary for an accurate explanation of their ideas on elementary genetics. Several children described their frustration at not finding the 'right words' to express their ideas. There was evidence of the reverse problem as well - pupils frequently used, but could not explain, correct technical terms.

In analysis, an attempt was made to identify the basic ideas behind the words, however inelegant or inexplicit the expression. In the assignment of responses to categories, pupils' use of scientific terminology, both incorrect and correct, was interpreted with considerable caution.

A further problem was identified relating to the interpretation of children's words. Unjustified assumptions were sometimes made in the early analyses about the connectedness of ideas in the pupil's mind. For example, when pupils explained that the air in an upturned cup "cools and contracts" it was tempting to extrapolate and assume that they also understood that the volume of air and the pressure were reduced as well. It would, though, have been quite invalid to incorporate these assumptions into the categorizations, because there was evidence that the connectedness of ideas present in the interviewer's mind was frequently not present in the child's. The danger of 'overinterpreting' the data in this way was greater when correct scientific terminology was used - this gave explanations an air of authority which, in some cases, was misleading.

(ii) Explanatory versus descriptive categories

Pupils sometimes offered articulate and superficially-convincing descriptive or tautological responses, and detection of the inadequate nature of these 'explanations' was not always easy. Purely descriptive categories were placed on the nominal scale.

(iii) Poor interviewing technique

It was possible to make allowances for lapses in interviewing technique at the analysis stage by concentrating on initial pupil explanations as the material for categorization. So responses to tendentious questions were ignored and, similarly, any interviewer summaries which were inaccurate reflections of pupil responses were discounted.

(iv) Protracted, mixed responses

A major problem in the analysis arose with the many mixed responses (that is, responses with different parts fitting into different categories). A number of ground rules were established to deal with these.

(a) If an ordinal response was included then this was categorized, provided that it was expressed convincingly, and that an alternative response which contradicted it directly was not offered as well.

(b) When several alternative responses were offered an attempt was made to identify the dominant line of thought (this was frequently judged to be the initial response). If this was impossible the response was put into an 'Uncodeable' category. This category was reserved for muddled, confused responses, where there was no discernible pattern or where several ideas were expressed without conviction. Self-confessed 'Don't knows' were put into the same category.

(c) Pupils sometimes retracted a response and offered another one after further thought. In these cases the last convinced response was categorized.

(v) Idiosyncratic responses

If all responses which comprised a clear line of thought had been separately categorized the total number would have been unwieldy. A 'Miscellaneous' category was added to some category sets, and idiosyncratic responses (where numbers were too few to merit a separate category) were put into this.

(vi) Cross-referencing in category assignment

It was occasionally necessary to take account of answers to other related questions when making a categorization, though in general categorizations were kept discrete. There was a tendency for able pupils to answer several related questions in one extended response - then appropriate categorizations were made from this answer.

Further analytic procedures are described later in this chapter (section 4) but, before that, certain methodological checks applied to the initial analytic procedures are described below.

3. Methodological Checks

A number of checks were built into this study at key points. The first constitutes an attempt to check the method of data gathering, and the others relate to data analysis.

(a) Justification for interviews: do interviews yield different pupil responses to those from written tests?

It was possible to compare the written and interview responses of first round interviewees. Since the validity of neither measure (written science test nor interview questions) was previously established, such a comparison of performance levels is not, strictly, a measure of concurrent validity. It does represent, however, some check on the influence of interviewer bias on data collection. Written test responses were assessed and allocated to ordinal categories parallel to those obtained from interview responses. The table below provides a summary of results.

Table 1 Comparison of written and interview responses in three concept areas

No. responses compared	Poorer response in interview	Better response in interview
1995	167 (8%)	345 (17%)

The figures provide no evidence that the presence of an interviewer leads to poorer pupil performance. On the contrary, the interviews yielded more scoring responses than the written test.

(b) Generation of response categories: would the same categories of response be identified from the data by other assessors? Category generation from interview transcripts was informally checked and discussed with the supervisors of this research study and a consensus was reached. It is undoubtedly an impressionistic process, and real difficulties lie in delineation and distinction of key ideas for both scales.

(c) Cross-checking of categorization of responses: would independent raters assign responses to the same categories? The reliability of the method of assignment of responses to categories was checked by two scientifically-qualified independent raters after the first round of interviews. One rater checked all the questions relating to pressure and the second checked both heat and evolution. For each concept area 25% of the sample (n=21) was checked (every fourth pupil from lists of the three age groups arranged in rank order of Shipley test scores). The pupil responses of a different quarter of the total sample were examined for each of the three concepts areas.

Preliminary meetings provided an opportunity for the cross-checkers to become familiar with the aims and philosophy of the study and to listen to some tapes. They were given copies of interview questions and category sets for each question, together with illustrative quotations and detailed notes for interpretation of the category sets. A trial categorization was independently carried out for three pupils (two transcripts and one tape) and the results of this, together with problems arising from it, were discussed. At this stage many discrepancies in categorization between interviewer and cross-checker resulted from simple procedural errors on the part of the cross-checker. The trial exercise proved to be a useful check, as well, on the intelligibility of the category descriptors. In fact it was necessary to make a few of these more explicit. At this early stage the cross-checkers tended to be deceived by tautological responses.

Twenty-one interviews were then cross-checked - the interviews which had been analysed from tape by the interviewer were similarly analysed by the cross-checker, and the same was true for those in transcript form. Ratings were made independently and then the discrepant categorizations were jointly re-examined. A few simple errors of interpretation were still made at this stage. If the rater quickly and unreservedly changed her mind then this was recorded, but no lengthy negotiations were entered into, in an attempt to obtain agreement. On the contrary, if the slightest doubt remained, the original descrepancy was retained and recorded as such.

The cross-checking provided a measure of the overall reliability of the method of category assignment at concept and at question levels. It is interesting that both cross-checkers reported that they found categorization from tape easier than from transcript, though it also took more time. They predicted that the assignments done from tape would be more reliable, because many clues could be gleaned from emphases, tone of voice etc., the most subtle of which were lost in transcription.

Detailed results of this check are given in Appendix 5 but the following table provides a summary statement of the results obtained.

Table 2 Cross-check results for three concept areas

	HEAT (n=21)	PRESSURE (n=21)	EVOLUTION (n=21)
Discrepant Categorizations	34/462 = 7%	16/447 = 4%	29/382 = 8%
% Agreement	93%	96%	92%

It is clear that the reliability of category assignment, as measured by the method overleaf, is high.

4. Further analysis of interview data

The interview questions probe the understanding of the ten scientific ideas outlined in the previous chapter (five for pressure, two for heat and three for evolution) as shown in the grids in Appendix 6. Each Idea (and when used to denote the ten scientific notions this key word in the analysis will be written with a capital I) was tested by several tasks or questions.

Category sets of questions feeding a given Idea were examined side-by-side in order to identify pupils' scientific explanations which had arisen within several different question contexts. I have called these explanations pupil frameworks - they were taken from both the ordinal and nominal scales. It is important to emphasise that these supra-ordinal groupings emerged from the data (that is, they do not represent categories of scientific thinking which were formulated prior to collection and initial analysis of data). The process of framework identification, which involves a reduction of the data, focusses on the scientifically-relevant aspects of the results (so, for example, responses prompted by the particular context of the question become less important at this stage of the analysis). Several different categories (sometimes two or more from one category set) were drawn upon in the formulation of these frameworks. Distinctions sometimes had to be made between responses within a given Miscellaneous category - in fact, it was possible to identify those pupils from a Miscellaneous category who subscribed to a given framework from the detailed diary notes made during initial analysis Some questions were not used directly for framework identification but provided descriptive information for later discussion of understanding of Ideas. As a general rule it was considered important to take account of responses in more than one question context, since many responses turned out to be context-bound. (This, of course, reflects a fundamental difficulty and has been discussed earlier. Can the pupil 'see behind' the immediate context of the question and address the scientific problem embedded in it?) Arguably, more credence could be given to the validity of the frameworks as firmly-held ways of thinking if they had been identified from two or more contexts. No quantitative criterion (e.g. a threshold percentage frequency) was applied to this process of establishment of frameworks. The interview sub-samples are simply too small to justify this. Other factors, for example the reporting of the same framework in other research studies, influenced the process. In one or two cases frameworks with very few pupils subscribing to them were included because the same idea had been reported elsewhere. Because frameworks code explanations rather than predictions, not all question response categories represented an identifiable framework - this applies, for example, to the 'no reason' categories (where no explanation was offered by the pupil) and the Uncodeable categories.

Frequencies of incidence of both question response categories and of pupil frameworks are presented in the results chapters within the following five pupil sub-samples:-

Table 3 Description of sub-samples

Sub-sample	Description	
X12	(n=30)	12 year old pupils in 1979
X14	(n=29)*	Same pupils as X12, now 14 years old in 1981
Y14	(n=30)	14 year old pupils in 1979
Y16	(n=29)*	Same pupils as Y14, now 16 years old in 1981
Z16	(n=24)	16 year old pupils in 1979

* The two rounds of interviewing yielded two categorizations per question for pupils 1-60, except pupils 14 and 43 who had left Sheffield by 1981, and one per question for pupils 61-84.

All category scores are given in Appendix 7.

The first three results chapters (Chapters 4, 5 and 6) arranged according to concept area, report the results of these analytic procedures. Questions are arranged according to Ideas and the response categories are reported in detail. Since it has been a basic strategy in this research to attend to pupil explanations and to stay with the pupils' own words during the procedures of analysis, extensive quotations are given to illustrate the categories. Additional notes on the interpretation of some categories are given in Appendix 8.

Each group of questions is then followed by analysis and comment at the Idea level. Tables of frequencies of occurrence of pupil frameworks are included in the reporting on eight of the ten Ideas. These frequencies should not be over-interpreted. Some frameworks emerged from responses to direct and fairly tight questions whilst others represent notions which were volunteered and occurred incidentally. Obviously, the percentage frequencies of the former are much greater than those of the latter. The figures thus provide only a loose indication of the popularity or otherwise of the framework. It was not possible to treat two of the Ideas (INHERITANCE and HEAT and TEMPERATURE) in this way and, for these, the analysis at the Idea level is handled entirely qualitatively.

In Chapter 7 further analysis on pupil frameworks is reported. Here, trends in the responses of <u>individual pupils</u> are examined to determine

(a) whether pupils employ the same or different frameworks to explain phenomena across different question contexts

(b) how pupils' thinking develops, if it does at all, over a time interval of 20 months.

The focus, then, is on shifts or stability of response in individuals - something which may be masked or distorted by group results.

CHAPTER 4

PUPIL UNDERSTANDINGS OF PRESSURE

Introduction:

This chapter on pressure presents the results of analytic procedures described in Chapter 3. For each of the five Ideas reporting is at two levels:

(i) Question level - questions are grouped together according to the Idea which they feed. Response categories and their frequencies are given.

(ii) Idea level - pupil frameworks relating to each Idea are given together with their frequencies. This is followed by general comment on pupil understanding at Idea level.

Commentary at these two levels focusses on age-related trends within pupil groups. For this reason, results for the two groups of 14 year old pupils (X14 and Y14) and the two groups of 16 year olds (Y16 and Z16) are sometimes summated.

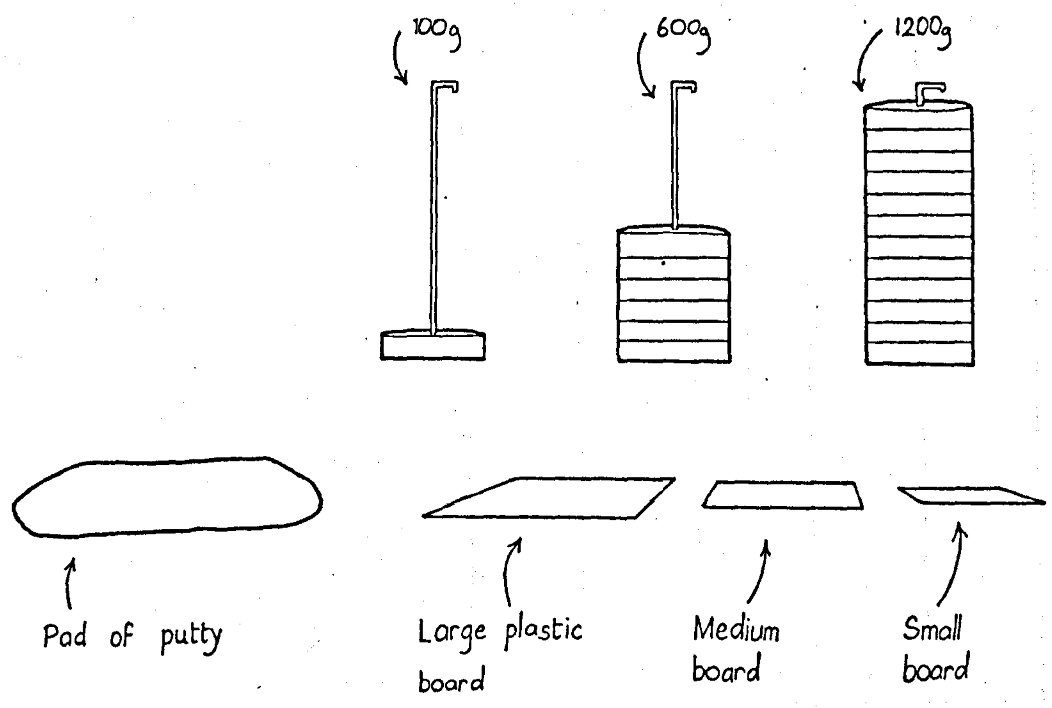
NATURE OF PRESSURE

PRESSURE IS THE MAGNITUDE OF THE FORCE ACTING ON A UNIT AREA OF A SURFACE - IT CAN BE CHANGED BY SPREADING THE SAME FORCE OVER A DIFFERENT AREA.

Five questions are related to this Idea, which incorporates a description of pressure as a relationship between force and area. Both qualitative and quantitative handling of this relationship are explored, though one question set in a quantitative mode (FURNITURE) was administered only to 16 year old pupils.

Q.1. BOARDS AND WEIGHTS

Pupils were shown the apparatus in the diagram below, indentations in the putty were demonstrated, and they were encouraged to try it for themselves. They were then asked the following questions.



(a) *Can you pick out the board and the weight which would give you the deepest mark in the putty? Can you explain why you have chosen those?*

(b) *Can you pick out the board and the weight which would give you the shallowest mark in the putty? Can you explain why you have chosen those?*

COMMENT ON RESULTS

Few pupils offered a formal definition of pressure, though many more pupils expressed some qualitative understanding of the relationship between force and area, and there was a clear increase in this understanding with age.

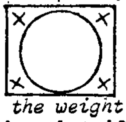
The alternative response categories were generated mainly from the responses of the 12 year old group.

QUESTION 1 BOARDS AND WEIGHTS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. WEIGHT/UNIT AREA *"Pressure equals force over area."* (pupil 68)	0	0	2	7	0	0	3	10	1	4
B. WEIGHT DISTRIBUTED OVER AREA *" . . . it's going to make the biggest dint if you put it on a little thing . . . if I put the big one on the weight'd be distributed over a bigger surface area . . . it wouldn't make as deep a mark. But with it only being a little thing it's more concentrated - the weight's more concentrated."* (pupil 64) *" . . . because the weight's heavier and there's not as much plate to push down into the putty. All the big weight's concentrated on a small area, and so there seems to be much more weight on the plate so it pushes it down . . . "* (pupil 38)	5	17	8	28	14	47	13	45	14	58
C. CORRECT CHOICES, WITH WEIGHT AND AREA STATED AS THE TWO IMPORTANT VARIABLES *"Because this is the smallest and it takes less space than this. And this is a heavier weight. The more force . . . pressure that you put on the plate the more deeper it goes . . . "* (pupil 57)	12	40	14	48	9	30	11	38	6	25
TOTAL ORDINAL RESPONSES		57		83		77		93		88
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	1	3	2	7	1	3	0	0
N. WEIGHT AND THE WEIGHT OF THE BOARD ADDED TOGETHER *"This weight is the smallest and this is the smallest board and that'll make the most shallow mark, because this is much lighter than the 1200g. When you put this on it'll make quite a shallow mark because this is much lighter than the big green board."* (She confirms that she means lighter in weight, pupil 22)	2	7	0	0	0	0	0	0	1	4
O. HEAVY WEIGHT AND LIGHT BOARD MAKE DEEPEST MARK BECAUSE THE WEIGHT IS ALLOWED TO HAVE MAXIMUM EFFECT (and vice versa) (For Q1a) *"The smallest board and the biggest weight . . . because the weight'd be heavier and that* (the board) *would be light . . . so it'd press it down."* (pupil 5) (For Q1b) *"Because the large board is heavier than the little one. If you put a small weight on it it won't weigh it down as much as the little one with a large weight on."* (pupil 12)	4	13	0	0	0	0	0	0	0	0

Category set continued on next page.

QUESTION 1 BOARDS AND WEIGHTS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
ALTERNATIVE RESPONSE CATEGORIES (continued)										
P. COVERAGE OF THE BOARD BY THE WEIGHT IS IMPORTANT *"And this one* (large board 100g) . . . *well it's not really heavy - it's not really pushing. Say when it's like that it's not on the corners or anything like that, so it can't push these corners down."* (then he illustrates the point, pupil 60)  *" . . . all the weight'd be on that one small piece but if you choose the large board, it'd just be in the middle."* (pupil 67)	4	13	1	3	2	7	0	0	1	4
Q. WEIGHT AND DEPTH OF BOARD ARE THE TWO IMPORTANT VARIABLES Chooses small board for deepest mark *"because that's thicker than the others."* (pupil 82)	1	3	3	10	2	7	1	3	1	4
R. MISCELLANEOUS Both pupils chose 1200g and large board for the deepest mark because they were heaviest and largest. Vice versa for shallowest. (pupils 7 and 52)	1	3	0	0	1	3	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		43		17		23		7		12

Q.2. SKIS

Pupils were reminded of the written test item by showing them the question below and then the following question was posed in interview.

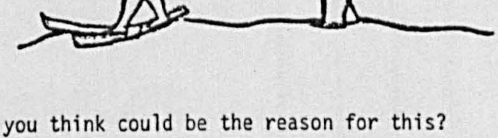
What is it about the skis that keeps Mr. X from sinking in? Why did Mr. Y sink?

Mr X and Mr Y, who weighed the same, were walking in snow.

Mr X was wearing skis.

Mr Y was wearing ordinary boots.

They came to a deep drift of snow. Mr X walked over the top of the snow. Mr Y sank up to his knees.



What do you think could be the reason for this?

1 I think Mr X did not sink in with his skis on because ____________

2 I think Mr Y sank in with his ordinary boots on because ____________

Q.2. SKIS (contd.)

COMMENT ON RESULTS

The pattern of distribution of responses was similar to that for BOARDS AND WEIGHTS with few pupils expressing their understanding of pressure formally as force acting on a unit area. There was an increase with age of responses which indicated a lower-level, qualitative understanding.

Several alternative response categories were generated which were specific to the context of the question - that is, pupils' explanations were couched entirely in terms of skis and snow, with no evidence of extension beyond this to a generalization about the underlying scientific principle.

This question was not put to all pupils in subsample Z16, so these figures are excluded from the frequency table.

QUESTION 2 SKIS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES							
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29	
	No.	%	No.	%	No.	%	No.	%
A. SINKING DEPENDS ON FORCE PER UNIT AREA Skis *"adjust his weight on more snow, so there's less weight on 1 sq.in. of snow."* (pupil 51)	2	7	3	10	1	3	1	3
B. WEIGHT DISTRIBUTED OVER AREA/SIZE/LENGTH OF SKIS *"It's the fact that his body weight is spread over a larger area . . . "* (pupil 39) *"Well it'll spread the weight out like this board did here . . . while boots concentrate on one part and where you put your foot down the pressure is going at that moment, so the whole of your body weight would be on that foot . . . "* (pupil 8)	7	23	9	31	17	57	19	66
C. SKIS ARE LARGE/LONG - BOOTS ARE SMALL (The skis) *"It's the greater surface area underneath his feet . . . He's just got normal shoes on, and they're not very large underneath so he'll just sink in."* (pupil 40)	9	30	9	31	3	10	2	7
TOTAL ORDINAL RESPONSES		60		72		70		76
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW	3	10	1	3	5	17	2	7
N. SKIS ARE LIGHT/BOOTS HEAVY *"They're very light, not heavy. The skis are lighter than his feet. And they slide so they wouldn't have much time to sink."* (pupil 60)	1	3	4	14	2	7	0	0
O. SKIS ARE HEAVY *"And they're quite heavy so they can support the man's weight . . . "* (Part of a protracted response, pupil 28)	2	7	0	0	0	0	0	0
P. SKIS SLIDE/ALLOW EASY MOVEMENT/ARE FLAT/ARE REGULAR *"They support his body . . . with them being a flat surface, they don't sink as much as his feet would . . . "* (pupil 18) *"Mr X slides on snow. Mr Y plods along, doesn't slide."* (pupil 55)	3	10	2	7	2	7	3	10
Q. SKIS ARE 'MEANT FOR SNOW' *"They're made specially for snow, designed for snow, and shoes are designed for walking on pavements."* (pupil 17)	3	10	0	0	0	0	2	7
R. MISCELLANEOUS	0	0	1	3	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		40		28		30		24

Q.3. SKIS - QUANTITATIVE

The ski question was extended to include a quantitative problem which was presented to pupils as shown below.

Mr. X weighs 200 pounds and the total area of his 2 skis was 2 square feet.

Total area of the skis - 2 square feet

Mr X - 200 pounds

Can you work out what pressure he would exert standing on the snow?

COMMENT ON RESULTS

The salient feature of the results of this simple quantitative problem is the very large number of pupils of all ages who gave 'uncodeable' responses. The majority of these said that they did not know how to approach the problem. Indeed, many pupils seemed to 'cut-off' completely as soon as the question was posed. The attitude is typified by the immediate reaction of one 14 year old pupil:

> *"I can't do maths at all"*

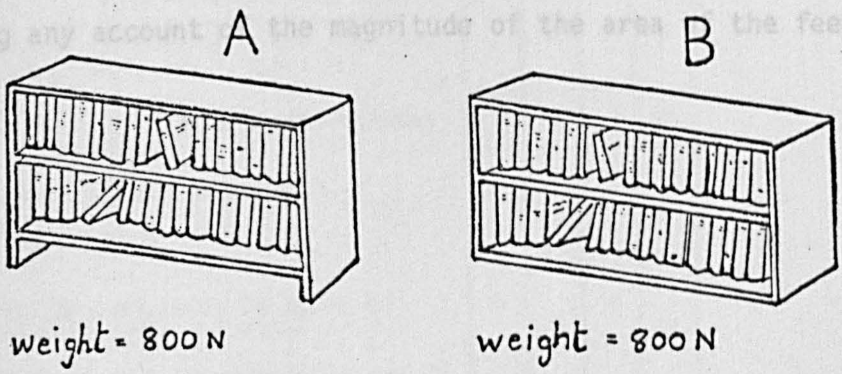
QUESTION 3 SKIS - QUANTITATIVE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES							
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29	
	No.	%	No.	%	No.	%	No.	%
A. 100 lbs/sq.ft.	4	13	5	17	7	23	6	21
B. 100 lbs per ski	3	10	1	3	1	3	1	3
C. 100 or 100 lbs	2	7	5	17	3	10	4	14
TOTAL ORDINAL RESPONSES		30		38		37		38
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW	19	63	15	52	16	53	14	48
N. MATHEMATICAL JUGGLING 200 x 2^2 202 600 (2 x 200)	2	7	2	7	0	0	2	7
O. PRESSURE EQUALS WEIGHT i.e. 200 lbs	0	0	1	3	2	7	2	7
P. MISCELLANEOUS Pressure = surface area/force	0	0	0	0	1	3	0	0
TOTAL ALTERNATIVE RESPONSES		70		62		63		62

Q.4. FURNITURE

This question was designed for use with the older age group only. 16 year old pupils were presented with the written test item below and asked the following question.

The second picture shows these two tables of different weights - you are asked to work out which would make the deepest impression on the carpet. How would you do that?



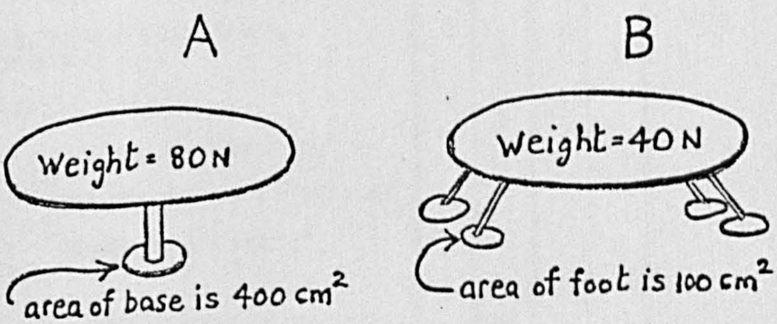
1 You may have noticed that some furniture flattens down the carpet. Which bookcase shown here will make the deepest impression on the same carpet? ______________________

Give the reason for your answer.

____

____

____



2 Which of these coffee tables will make the deepest impression on the same carpet? ______________________

Explain your answer, showing your working.

____

____

____

____

Q.4. FURNITURE (contd.)

COMMENT ON RESULTS

About a fifth of the 16 year olds in the two sub-samples could handle the problem quantitatively.

A third of the pupils considered only the number of table legs in making their estimations (in this example, the table with one leg was exerting more pressure). These responses represent a primitive idea of pressure as a ratio of weight per leg, without taking any account of the magnitude of the area of the feet.

QUESTION 4 FURNITURE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES			
	Y16 n = 26		Z16 n = 24	
	No.	%	No.	%
A. PRESSURE = FORCE/AREA, QUANTITATIVELY HANDLED *"A = 2/10 N/cm²* *B = 1/10 N/cm²"* (pupil 69)	5	19	6	25
B. AREAS ARE THE SAME BUT A WEIGHS MORE, THEREFORE MORE FORCE OVER SAME AREA *"A. will make the deepest impression. Well, it's got the same area of support as Table B., but the weight is twice as much, so there'll be more force down on that small area."* (pupil 75)	5	19	4	17
TOTAL ORDINAL RESPONSES		38		42
ALTERNATIVE RESPONSE CATEGORIES				
U. UNCODEABLE/DON'T KNOW	6	23	1	4
N. ONE LEG CONCENTRATES THE WEIGHT AND FOUR LEGS SPREAD THE WEIGHT *"I still think the round one because it's all concentrated on one area. That's distributed over a larger area."* (pupil 64) *"I'd say A. would. Well, it's got more weight on it than these two, but the weight is spread out - on that - on the corners - so there wouldn't be as much pressure on each side as there would be just on one."* (pupil 70) *"Well with it being heavy it's all on one stand - this is on four - the weight's separated out."* (pupil 83)	8	31	8	33
O. TABLE B. BECAUSE 4 IS A BIGGER NUMBER THAN 1	0	0	2	8
P. MATHEMATICAL JUGGLING *'For A - 80 x 400, for B-40 x 400'* (pupil 73) *'For A - 80 x 400, for B - 4 x 100 x 40'* (pupil 77) *'For A - 400/80, for B - 100/40'* (pupil 79)	2	8	3	13
TOTAL ALTERNATIVE RESPONSES		62		58

Q.5. DEFINITION OF PRESSURE

As a final question in the pressure interview the following very open-ended summary question was posed.

If I asked you to say, in a couple of sentences, what pressure is, what would you say?

Response categories were arranged on a single descriptive scale.

COMMENT ON RESULTS

Few pupils chose either to describe pressure as molecular bombardment or to offer a formally correct definition of pressure, by describing it as force/area.

The majority of pupils of all ages described pressure as a force pressing or just as a force. The latter suggests that pupils are considering a single variable only.

The frequency table shows no clear age trends at all for answers to this question.

QUESTION 5 DEFINITION OF PRESSURE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
H. FORCE EXERTED ON A SURFACE/FORCE PER UNIT AREA *"Pressure is a force pressing down and all around on to the surface of things."* (pupil 28) *"Force per unit area."* (pupil 68)	3	10	2	7	1	3	7	24	3	13
I. MOLECULAR BOMBARDMENT *"The rate at which molecules bombard something. It's only usually noticeable if there's a difference in pressure - otherwise you don't really notice it's there."* (pupil 62) *"Force exerted on molecules by molecules."* (pupil 39)	0	0	1	3	1	3	1	3	1	4
J. A FORCE// A FORCE/SOMETHING/ AIR THAT PUSHES/PULLS/PRESSES *"Force pushing down."* (pupil 15) *"Amount of air pushing against enclosed area, causing a force."* (pupil 37) *"A force."* (pupil 57) *"A force pressing down on something."* (pupil 66) *"Air pressing on to things."* (pupil 6)	18	60	17	59	20	67	16	55	11	46
K. MISCELLANEOUS (i) Air (6 pupils) (ii) Energy (2 pupils) (iii) Magnetic force (2 pupils) (iv) Suction (1 pupil) (v) Something trying to escape (1 pupil) (vi) Movement of the air (particles move further apart and closer together) (1 pupil) (vii) A vacuum exerts pressure (1 pupil) (viii) More molecules with high pressure (1 pupil) (ix) Harrassing (1 pupil)	6	20	4	14	6	20	2	7	4	17
U. UNCODEABLE/DON'T KNOW	3	10	5	17	2	7	3	10	5	21

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understandings of the NATURE OF PRESSURE. The Table below lists the pupil frameworks identified for this Idea and gives their frequencies of occurrence as percentages of sub-samples of pupils.

TABLE 4 PUPIL FRAMEWORKS - NATURE OF PRESSURE

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES						
		12 Yr (X12)		14 Yr (X14 & Y14)		16 Yr (Y16 & Z16)		
		Q.1 Boards (n=30)	Q.2 Skis (n=30)	Q.1 Boards (n=59)	Q.2 Skis (n=59)	Q.1 Boards (n=53)	Q.2 Skis (n=29)	Q.4 Furniture (n=50)
1. Pressure = Force acting on a unit area	1A,2A,4A	0%	7%	3%	7%	8%	3%	22%
2. Pressure involves distribution of force over area	1B,2B,4B	17%	23%	37%	44%	51%	66%	18%
3. Pressure involves only one variable- either weight or area	1N,1O,2C,2N	20%	33%	0%	31%	4%	7%	-
4. Context-dependent reasoning applied	1P,1Q,2P,2Q, 4N,4O	17%	20%	14%	7%	6%	17%	36%
No identifiable framework	1C,1U,1R,2U, 2O,2R,4U,4P	47%	17%	46%	12%	34%	7%	24%

Note: Since percentages are given only to the nearest 1%, the figures do not always add up exactly to 100%.

GENERAL COMMENT ON PUPIL UNDERSTANDING OF THE NATURE OF PRESSURE

Pupil Frameworks 1 and 2 together represent some understanding of the relationship between force and area. There is a clear trend with age, with an increase in the proportion of children subscribing to these frameworks from 12-16 years. Few pupils of any age offered a formal definition of pressure as force/area, though more 16 year old responses to FURNITURE fitted into this framework (Framework 1). These pupils were probably helped by the quantitative presentation of force and area in this question. Shayer (1978) makes a categorical three-level breakdown of understanding of the nature of pressure:

(i) an intuitive 'stiletto-heel effect'.
(ii) a more analytic distribution of a force concept
(iii) an understanding of pressure as force per unit area.

He argues that the third level can only be achieved when the pupil has reached Piagetian level IIIA (formal operational). Results presented here suggest that clear designation of pupil responses into these three levels is difficult, though some distinction between (ii) and (iii) was possible.

The pupils who used one variable only to describe pressure (Framework 3) had to be extremely explicit about this in response to BOARDS AND WEIGHTS. It is therefore interesting that one fifth of the 12 year old group subscribed to this notion. The larger percentages allocated to this framework from SKIS may include some pupils who did, in fact, have an intuitive understanding of distribution of force over area but were inexplicit about it.

The percentages for 'No identifiable framework' are much higher for BOARDS AND WEIGHTS than for either SKIS or FURNITURE. This is probably because responses which incorporated correct choices of boards and weights, with no explanation of the relationship between them were put into this framework. Some of these pupils almost certainly did have some intuitive idea of the relationship between force and area but they gave no indication of this understanding in response to this practical task.

MOLECULAR BOMBARDMENT

PRESSURE EXERTED BY A FIXED VOLUME OF GAS INCREASES AS THE TEMPERATURE INCREASES BECAUSE OF INCREASED MOLECULAR BOMBARDMENT.

The questions related to this Idea test the view of pressure as molecular bombardment. In both question contexts (TYRES and FOOTBALL) this is tested against a background of temperature change in a fixed volume of air.

Only 14 and 16 year old pupils were asked these questions.

Q.6. TYRES

Pupils were reminded of the written test item below and asked the following question in the interview.

This question asked about particles. Can you explain why the tyre pressure goes up during a journey?

Scientists have a theory that everything is made of small particles.
The theory states that:

1 Particles move in all directions.

2 Particles move faster the higher the temperature.

3 Particles exert forces on each other.

4 Particles are too small to see through a microscope.

5 Particles of different substances are different sizes.

Choose the statement about particles which best explains each situation below. In each case say how the statement you choose explains the situation.

The pressure in car tyres increases during a journey.

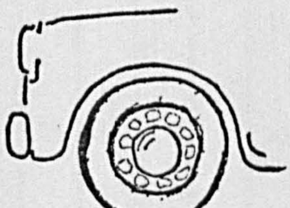
____

____

____

____

____



APU item.

COMMENT ON RESULTS

There is an increase with age in the percentages of pupils who used the idea of pressure as molecular bombardment from 7% in all 14 year olds to 36% in all 16 year olds.

About one fifth of all responses contained incorrect notions about particles in relation to pressure - for example, that they expand on heating or that the bonds between them get weaker.

Q.6. TYRES (contd.)

Again, as with the previous Idea, context-dependent responses were not uncommon. For example, the idea of the rotation of car wheels seemed to intrude on the thinking of some pupils, and their explanations were bound by this context.

QUESTION 6 TYRES

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES*							
	X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%
A. AS TYRE HEATS, MOLECULES OF AIR SPEED UP AND PRESSURE INCREASES BECAUSE OF INCREASED BOMBARDMENT AGAINST TYRE WALLS *"I presume the tyre would get hotter 'cos' of the friction on the road, so the molecules would move faster because of the higher temperature . . . all molecules are bouncing around, trying to move out, so they create a force on the outside of the tyre, which would get greater as the heat increased, so raising the pressure."* (pupil 39) *" . . . molecules vibrate faster - more collisions per unit area of tyre - therefore pressure increases."* (pupil 68)	1	3	4	13	9	31	10	42
B. AS TYRE HEATS, MOLECULES SPEED UP AND PRESSURE INCREASES, NO FURTHER EXPLANATION *"As the tyres get warm the particles move faster and . . . er . . . greater pressure if they're moving faster. I'm not really sure* (why pressure does increase)". (pupil 66)	2	7	3	10	4	14	1	4
TOTAL ORDINAL RESPONSES		10		23		45		46
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW *"It might be going over bumps."* (pupil 82)	9	31	5	17	7	24	5	21
N. AS TYRE HEATS, THE AIR PARTICLES EXPAND/PARTICLES MOVE FURTHER APART, AND PRESSURE INCREASES "(Particles) *. . . they'd be further apart . . . when you heat it, it* (the bonds) *gets weaker and they get further apart and eventually they snap."* (pupil 60) *"Molecules move faster or expand with heat and pressure increases . . . Air in tyre expands with the heat and pressure increases."* (pupil 31)	6	21	6	20	4	14	3	13
O. ROTATION OF WHEELS CAUSES PARTICLES TO MOVE AND PRESSURE TO INCREASE *"Particles move about, because of the tyre spinning around, and they would put forces on each other."* (pupil 61)	4	14	7	23	3	10	3	13

Category set continued on next page

QUESTION 6 TYRES (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES*							
	X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%
P. MISCELLANEOUS (i) Particles warm and air rises. (pupil 43) (ii) Heat soaks into tyre, warms air, mixes with pressure and this makes tyre wider. (pupil 44) (iii) People in car increase weight, therefore increase pressure. (pupils 49 and 53) (iv) Hot air would want to get out and turn to steam. (pupil 57) (v) Constant rotation allows no time for pressure on any one part of the tyre. (pupil 74) (vi) With heat, number of molecules increases, therefore pressure increases. (pupil 76)	7	24	5	17	2	7	2	8
TOTAL ALTERNATIVE RESPONSES		90		77		55		54

* This question was not put to 12 year old pupils (X12).

Q.20. FOOTBALL - MOLECULAR NUMBER
Q.21. FOOTBALL - MOLECULAR SPEED
Q.7. FOOTBALL - PRESSURE

These three questions were presented in interview as exact reiterations of the written test item on pressure of air in a football (see below).

A footballer pumps up his football until it feels hard. Later in the day the temperature falls.

Assume the football does not leak.

What changes, if any, are there to:

1. *the number of molecules in the football?* ....
   ....
2. *the average speed of the molecules in the football?* ....
   ....
3. *the pressure in the football?* ....
   ....

COMMENT ON RESULTS

There was an overall increase in ordinal responses from 14 years to 16 years.

About two thirds of pupils in both age groups recognized that the number of molecules in the football would not change. A majority of pupils also recognized that a reduction in outside temperature would result in a lowering of molecular speed of air in the football, but only a small proportion of these could offer an explanation for this. 10% of 14 year old responses and 26% of 16 year old responses explicitly used the idea of pressure as molecular bombardment against a surface. An additional small number of 14 and 16 year olds connected the pressure fall with lowered molecular speed but could not explain the connection.

QUESTION 20 FOOTBALL - MOLECULAR NUMBER

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES*							
	X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%
A. THE NUMBER OF MOLECULES STAYS THE SAME	19	66	20	67	17	59	15	63
TOTAL ORDINAL RESPONSES		66		67		59		63
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW	2	7	0	0	3	10	0	0
N. LESS MOLECULES WHEN COLDER, NO REASON	4	14	5	17	5	17	8	33
O. LESS MOLECULES/SAME NUMBER BECAUSE THEY CONTRACT/ MERGE IN THE COLD *"Well, when they* (the molecules) *heat up they expand . . . so I would think that when they cool down they get smaller and less of them."* (pupil 40)	2	7	3	10	4	14	0	0
P. MORE MOLECULES, NO REASON/MORE MOLECULES BECAUSE THEY SPLIT UP IN THE COLD *"It would split like a cell, and multiply."* (pupil 74) *"I think it might increase. Because if it dropped it would make more and more particles, and they'd separate up a bit more . . . to try and keep the temperature up inside the ball."* (pupil 36)	1	3	2	7	0	0	1	4
Q. MISCELLANEOUS Response contains assumption that *"particles"* are germs.	1	3	0	0	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		34		33		41		37

* This question was not put to 12 year old pupils.

QUESTION 21 FOOTBALL - MOLECULAR SPEED

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES*							
	X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%
A. MOLECULAR SPEED WILL BE REDUCED, BECAUSE MOLECULES LOSE ENERGY/HEAT TO THE SURROUNDINGS *"Speed decreases because the molecules are given less energy - they don't move as quickly, don't come into contact with the surface of the ball as often."* (pupil 77) Molecular speed reduced *"because they'd lose heat to the surrounding area, which was cooler."* (pupil 62)	2	7	0	0	7	24	3	13
B. SPEED REDUCED, NO REASON/INCONSEQUENTIAL REASON/TAUTOLOGY *"Because when it's hot they go faster, don't they?"* (pupil 56) *"They'd slow down, because it's heat that makes them move around a lot. They move more if it's hot."* (pupil 61)	13	45	20	67	16	55	14	58
TOTAL ORDINAL RESPONSES		52		67		79		71
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW	5	17	4	13	4	14	3	13
N. NO CHANGE IN MOLECULAR SPEED	4	14	4	13	2	7	2	8
O. MOLECULAR SPEED INCREASES, NO REASON	2	7	2	7	0	0	1	4
P. MISCELLANEOUS *" . . . when it's warm, the air expands so it's going to be more bouncier, so faster."* (and so slower in cold.) (pupil 80)	3	10	0	0	0	0	1	4
TOTAL ALTERNATIVE RESPONSES		48		33		21		29

* This question was not put to 12 year old pupils.

QUESTION 7 FOOTBALL - PRESSURE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES*							
	X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%
A. TEMPERATURE FALLS, PRESSURE FALLS BECAUSE OF LOWER MOLECULAR SPEED - LESS BOMBARDMENT *"If molecules are moving fast, the collisions would be more fierce, whereas when they're going slower they wouldn't be re-bounding as hard."* (pupil 32)	2	7	4	13	7	24	7	29
B. TEMPERATURE FALLS, PRESSURE FALLS BECAUSE OF LOWER MOLECULAR SPEED	3	10	2	7	5	17	4	17
C. TEMPERATURE FALLS, PRESSURE FALLS, NO OR INCONSEQUENTIAL REASON	3	10	7	23	5	17	6	25
TOTAL ORDINAL RESPONSES		28		43		59		71
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW	4	14	0	0	2	7	1	4
N. TEMPERATURE FALLS, PRESSURE STAYS THE SAME	6	21	6	20	4	14	4	17
O. TEMPERATURE FALLS, PRESSURE FALLS BECAUSE LESS AIR/LESS MOLECULES	3	10	2	7	1	3	0	0
P. TEMPERATURE FALLS, PRESSURE FALLS BECAUSE MOLECULES CONTRACT	3	10	2	7	2	7	1	4
Q. MISCELLANEOUS (i) Atmospheric pressure is higher when it's cold, therefore more pressure on the ball. (2 pupils) (ii) Pressure falls because molecules clump together. (2 pupils) (iii) Know from experience that football softens in the cold. (2 pupils) (iv) Pressure is raised, no reason. (1 pupil) (v) Know that plastic goes harder in the cold (but no indication that this has anything to do with pressure). (1 pupil)	5	17	7	23	3	10	1	4
TOTAL ALTERNATIVE RESPONSES		72		57		41		29

* This question was not put to 12 year old pupils.

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understandings of pressure as molecular bombardment. The Table below lists the pupil frameworks identified for this Idea and gives their frequencies of occurrence as percentages of sub-samples of pupils.

TABLE 5   PUPIL FRAMEWORKS - MOLECULAR BOMBARDMENT

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES			
		14 Yr (X14 & Y14)		16 Yr (Y16 & Z16)	
		Q.6 Tyres	Q.7 Football	Q.6 Tyres	Q.7 Football
1. Pressure as molecular bombardment	6A,7A	8%	10%	36%	26%
2. Relationship between temperature and molecular speed recognized but no link made with pressure	6B,7B	8%	8%	9%	17%
3. Variations on incorrect use of kinetic theory	6N,6O,6P(some) 7O,7P,7Q(some)	49%	25%	28%	8%
4. No use of kinetic theory in application to pressure	6P(some),7C, 7N,7Q(some)	10%	49%	4%	43%
No identifiable framework	6U,7U	24%	7%	23%	6%

Note: Since percentages are given only to the nearest 1% figures do not always add up to 100%.

GENERAL COMMENT ON PUPIL UNDERSTANDING OF THE IDEA OF PRESSURE AS MOLECULAR BOMBARDMENT

The table of framework frequencies shows clearly that the number of pupils who use the idea of molecular bombardment in their understanding of the nature of pressure (Framework 1) increases from 14 to 16 years, with about a third of 16 year olds using the idea.

Just over half the pupils of both age groups appreciated the fact that temperature drop and lowered molecular speed are linked but seem to be unable to apply this, to explain it, or indeed to expand in any way. This confirms the findings of Dow et al (1978) which highlighted the gap between the assimilation of factual information about particles and its application to explain physical phenomena.

About a third of all pupils made incorrect use of kinetic theory, by linking temperature changes with a change in the number or size of molecules.

The numbers of pupils who did not use a kinetic theory explanation were different for TYRES and FOOTBALL. It seems likely that the form of questioning in TYRES, with its direct request to the pupil to use the idea of particles, elicited more responses in this mode. It is interesting that about half the pupils used no aspect of kinetic theory in response to FOOTBALL-PRESSURE, despite the fact that this question was preceded by two questions (FOOTBALL-MOLECULAR NUMBER and FOOTBALL-MOLECULAR SPEED). which very explicitly cued pupils into thinking in terms of molecules.

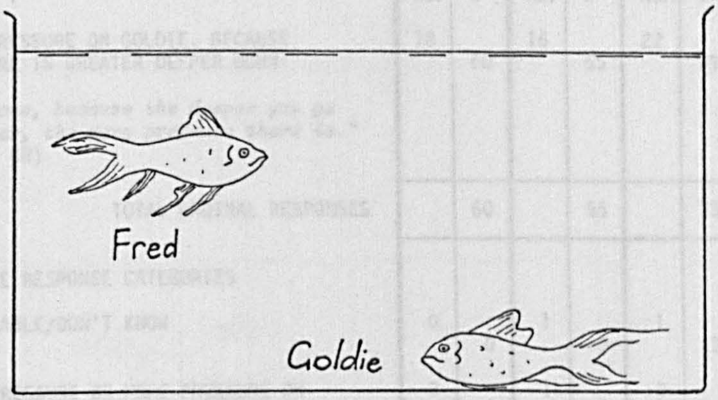
PRESSURE AND DEPTH

PRESSURE IN A LIQUID INCREASES WITH DEPTH

Two questions related to this Idea (PRESSURE ON FRED AND GOLDIE and SUBMARINE AT 50m.) test the notion that pressure increases with depth. One question (FISH TANKS) explores the possibility that pupils consider that the total volume of liquid surrounding the object determines the pressure on it, irrespective of depth.

Q.8. PRESSURE ON FRED AND GOLDIE

The following problem was presented to pupils in interview.



The two goldfish in this tank are the same size (about 10 centimetres). The water is exerting pressure on the fish. Which fish has more pressure on it?

Can you explain why?

COMMENT ON RESULTS

The percentages of ordinal responses were high for this question for all three age groups, though there was some increase in the figure with age.

A small number of pupils answered the question with reference to air pressure only. This perhaps suggests that they were discounting the possibility that water was exerting pressure on the fish at all.

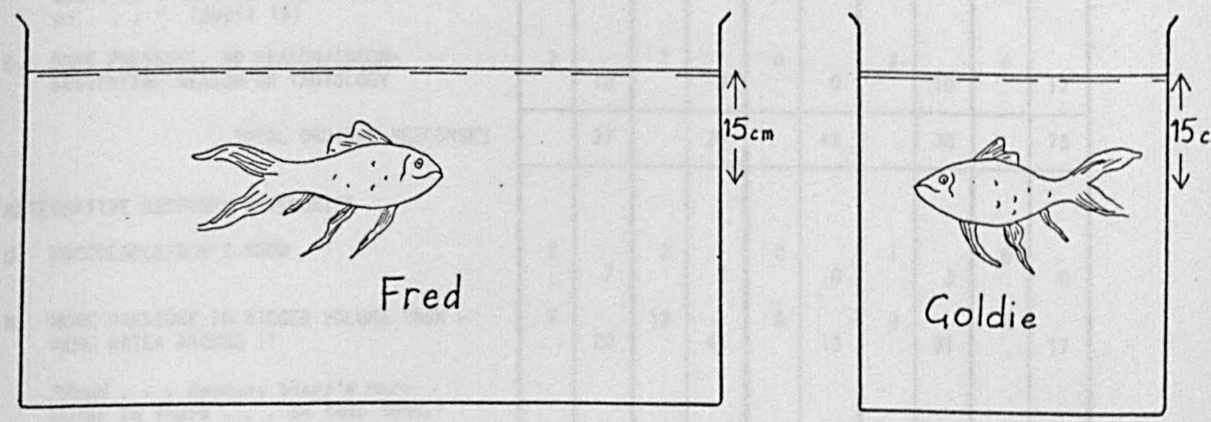
QUESTION 8 PRESSURE ON FRED AND GOLDIE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. MORE PRESSURE ON GOLDIE, BECAUSE PRESSURE IS GREATER DEEPER DOWN *"That one, because the deeper you go in water, the more pressure there is."* (pupil 48)	18	60	16	55	22	73	23	79	21	88
TOTAL ORDINAL RESPONSES		60		55		73		79		88
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	1	3	1	3	0	0	0	0
N. SAME PRESSURE OR MORE PRESSURE ON FRED, BECAUSE ONLY AIR PRESSURE CONSIDERED *"I'd say they were the same . . . because they're both in the same water and there's the same amount of air around them - on top of the water."* (pupil 36) *"Fred's got more pressure. Because with him being on top of the surface the air presses down on to him more than it would on the bottom."* (pupil 18)	3	10	1	3	3	10	1	3	0	0
O. MORE PRESSURE ON FRED, BECAUSE HE IS NEARER THE TOP *"Fred, because it's nearer the top."* (pupil 5)	5	17	2	7	3	10	2	7	3	13
P. MISCELLANEOUS (i) Same pressure because fish are the same size. (pupil 9) (ii) Goldie has more pressure because he's heavier and has sunk. (pupil 29) (iii) Pressure goes down from the surface to the bottom of the tank and then rebounds back to the surface. (pupil 25) (iv) Same pressure because pressure equal in all directions, therefore depth irrelevant. (pupil 14) (v) Same pressure because pressure moves all around the tank. (pupil 50)	4	13	9	31	1	3	3	10	0	0
TOTAL ALTERNATIVE RESPONSES		40		45		27		21		12

Q.9. FISH TANKS

This problem was then presented in interview.

The owner of these fish moves Goldie into another tank - a smaller one.



If they are in these positions (see diagram) - how does the pressure on Fred compare with the pressure on Goldie now?

Can you explain your answer?

COMMENT ON RESULTS

In general, less than half the pupils suggested that the tank size would make no difference and there were no clear age trends. It would appear, therefore, that many pupils were distracted by this problem from their scientifically correct explanations to the previous question.

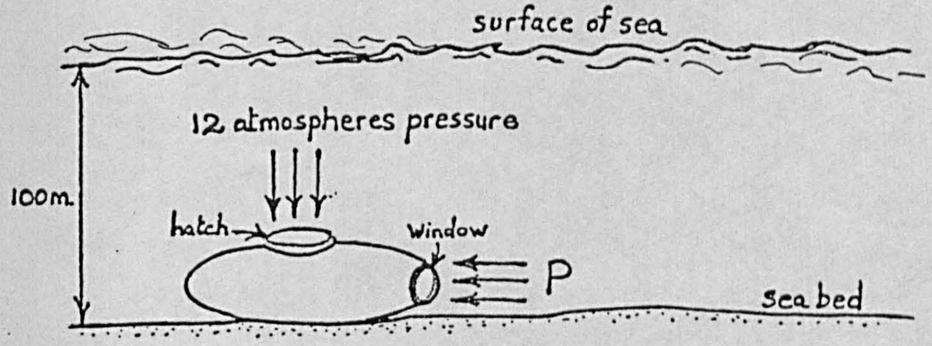
The suggestions that there was more pressure in the larger tank, and that there was more pressure on Goldie in the confined space were almost equally popular. There were no clear age trends here either.

QUESTION 9 FISH TANKS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. SAME PRESSURE, BECAUSE SAME DEPTH/ TANK SIZE IRRELEVANT *"They'd be the same. Well, they're both the same depth and both the same size, so they'd take up the same area so . . . "* (pupil 15)	8	27	6	21	13	43	8	28	14	58
B. SAME PRESSURE, NO REASON/INCON-SEQUENTIAL REASON OR TAUTOLOGY	3	10	1	3	0	0	3	10	4	17
TOTAL ORDINAL RESPONSES		37		24		43		38		75
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	2	7	2	7	0	0	1	3	0	0
N. MORE PRESSURE IN BIGGER VOLUME TANK - MORE WATER AROUND IT *"Fred . . . because there's more water in there . . . in that tank."* (pupil 7)	7	23	12	41	4	13	9	31	4	17
O. MORE PRESSURE IN SMALLER VOLUME TANK - LESS WATER AROUND IT *"Fred hasn't got as much pressure on him as Goldie, because it's a bigger tank so less pressure hits him."* (pupil 9)	4	13	6	21	13	43	8	28	2	8
P. SAME PRESSURE, OR MORE PRESSURE ON FRED, BECAUSE ONLY AIR PRESSURE CONSIDERED *"On Fred there's more pressure because there's a wider area on there - there's more air pressure spread about across there."* (pupil 13) *"The same . . . there's air pressure on the top pressing down and if they're both at the same distance, then there's as much pressure on each of them."* (pupil 4)	5	17	2	7	0	0	0	0	0	0
Q. MISCELLANEOUS Same pressure because fish's back has the same area. (pupil 6)	1	3	0	0	0	0	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		63		76		57		62		25

Q.10. SUBMARINE AT 50m.

Pupils were reminded of the written test item by showing them the question below. The question was reiterated in interview. Pupils were encouraged to produce their own idea in interview and not to dwell on the choices offered in the multiple-choice question.



Submersible craft are used by divers to explore deep under water and on the sea bed.
A submersible craft was on the bottom of the sea. The pressure on the outside of the hatch of the craft was 12 atmospheres.

When the craft rises to a depth of 50m. the pressure on the hatch will be about:

- ☐ A 24 atmospheres
- ☐ B 12 atmospheres
- ☐ C $6\frac{1}{2}$ atmospheres
- ☐ D 6 atmospheres
- ☐ E $5\frac{1}{2}$ atmospheres

APU item

COMMENT ON RESULTS

No pupils apparently took account of the fact that the atmosphere exerted one atmosphere of pressure on the sea surface, and so none gave the correct answer of $6\frac{1}{2}$ atmospheres, despite the multiple-choice form of the question.

Q.10. SUBMARINE AT 50m. (contd.)

A large proportion of pupils in all age groups selected the response indicating that pressure decreased with decreasing depth. There was some increase in this response with age.

QUESTION 10 SUBMARINE AT 50 metres

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. 6½ ATMOSPHERES, BECAUSE WATER PRESSURE ONLY ACCOUNTS FOR 11 ATMOSPHERES None.	0	0	0	0	0	0	0	0	0	0
B. 6 ATMOSPHERES *"Six, if that's moving up half way - this'll change as well - the same - so that'll go halfway to six."* (pupil 50)	20	67	20	69	27	90	24	83	22	92
C. GETS LESS *"About 8."* (pupil 29)	2	7	3	10	0	0	0	0	1	4
TOTAL ORDINAL RESPONSES		73		79		90		83		96
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	1	3	0	0	3	10	0	0
N. NO CHANGE IN PRESSURE *"Still about the same - 12. But as soon as it got to the top there'd be more pressure on it."* (pupil 28)	2	7	1	3	0	0	1	3	0	0
O. GETS MORE	0	0	3	10	1	3	0	0	0	0
P. 24 ATMOSPHERES *"About 24 - when it's rising more pressure comes down on to it."* (pupil 59)	5	17	1	3	2	7	1	3	1	4
TOTAL ALTERNATIVE RESPONSES		27		21		10		17		4

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understanding of PRESSURE AND DEPTH. The Table below lists the pupil frameworks identified for this Idea and gives their frequencies of occurrence.

TABLE 6 PUPIL FRAMEWORKS - PRESSURE AND DEPTH

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES					
		12 Yr (X12)		14 Yr (X14 & Y14)		16 Yr (Y16 &Z16)	
		Q.8 Fish (n=30)	Q.10 Sub. (n=30)	Q.8 Fish (n=59)	Q.10 Sub. (n=59)	Q.8 Fish (n=53)	Q.10 Sub. (n=53)
1. Pressure increases with depth	8A,10B	60%	67%	64%	80%	83%	87%
2. Pressure in a liquid depends on the pressure of the atmosphere	8N	10%	-	7%	-	3%	-
3. Pressure decreases with depth	8O, 10O,10P	17%	17%	8%	12%	9%	4%
No identifiable framework	8U,8P,10C,10U,10N	13%	17%	20%	8%	6%	9%

The symbol - in the above table indicates that there is no contribution to the framework from that question.

Note: Since percentages are given only to the nearest 1%, the figures do not always add up exactly to 100%.

GENERAL COMMENT ON PUPIL UNDERSTANDING OF PRESSURE AND DEPTH

The idea that liquid pressure increases with depth seemed to be understood by large numbers of pupils in the three age groups (Framework 1). This may be because it is consistent with common sense notions.

The consideration of the pressure of the atmosphere only in solution to these problems on pressure in liquids (Framework 2) is interesting. Support for the existence of this framework comes from two other questions - FISH TANKS where, for example 17% of 12 year olds offered the same response, and FRED'S BACK AND NOSE, a question related to the next Idea to be discussed. Consideration of atmospheric pressure only occurred mainly amongst younger pupils and may perhaps be linked to early coverage of the topic in the secondary science syllabus.

FISH TANKS tested only one aspect of this Idea and, indeed, a large proportion of pupils of all ages (37% 12 year olds, 59% 14 year olds, 43% 16 year olds) subscribed to the view that the total volume of liquid surrounding the fish influenced the pressure.

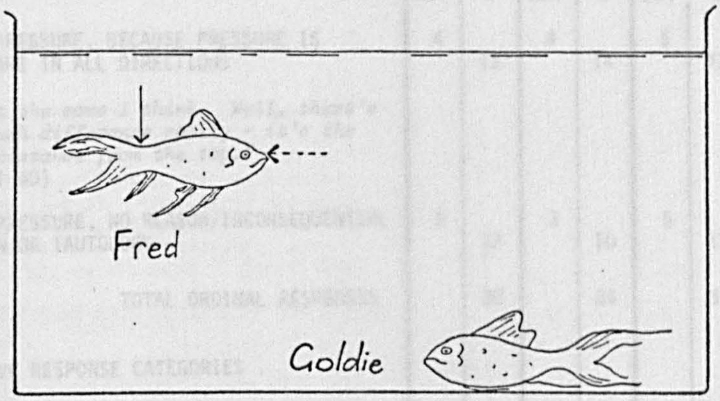
PRESSURE AND DIRECTION

PRESSURE IN A LIQUID ACTS EQUALLY IN ALL DIRECTIONS

Two questions, set in the same contexts (FISH and SUBMARINE) as those related to the previous Idea test the understanding that pressure in a liquid acts equally in all directions.

Q.11. FRED'S BACK AND NOSE

A further problem on the goldfish was posed in interview as shown below.



How does the pressure on Fred's back (⟶) compare with that on his nose (-->)?

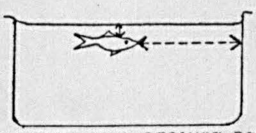
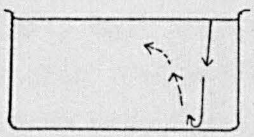
COMMENT ON RESULTS

The two younger age groups produced similar overall numbers of ordinal responses but there was an increase in the figure for the 16 year old groups.

11% of the total responses from all pupils contained consideration of atmospheric pressure only. This may suggest that pupils did not recognise the existence of the pressure of the water.

The idea of moving, re-bounding pressure is subscribed to by only one pupil in this question, but is retained as a category because it appears in response to other questions.

QUESTION 11 FRED'S BACK AND NOSE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 23	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. SAME PRESSURE, BECAUSE PRESSURE IS THE SAME IN ALL DIRECTIONS	4	13	4	14	5	17	10	34	6	26
"About the same I think. Well, there's not much difference really - it's the same distance from the top." (pupil 60)										
B. SAME PRESSURE, NO REASON/INCONSEQUENTIAL REASON OR TAUTOLOGY	5	17	3	10	5	17	4	14	6	26
TOTAL ORDINAL RESPONSES		30		24		33		48		52
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	2	7	1	3	3	10	1	4
N. MORE PRESSURE DOWN, NO REASON/ INCONSEQUENTIAL REASON OR TAUTOLOGY	4	13	2	7	10	33	3	10	1	4
O. MORE PRESSURE DOWN, ZERO PRESSURE ACROSS	4	13	5	17	1	3	2	7	4	17
"Oh well, obviously the pressure on his back would because there would be no pressure whatsoever on his nose almost, because he wasn't moving to cause any water disturbance." (pupil 8) *"Pressure doesn't push across."* (pupil 44)										
P. MORE PRESSURE ACROSS BECAUSE OF THE GEOMETRY OF THE TANK	1	3	3	10	1	3	2	7	1	4
"Pressure on his nose would be greater, because of the greater amount of water, the greater volume of water to him than above him." (pupil 71) (She then draws:- 										
Q. MORE PRESSURE DOWN BECAUSE PRESSURE REBOUNDS OFF TANK BOTTOM AND LOSES FORCE	1	3	0	0	0	0	0	0	0	0
"Pressure on the top is coming straight down on him but that's going to the bottom, and coming up and hitting him at side - so that's a lot heavier. It's going down and then when it comes back up again . . . " (pupil 12) (She then draws:- 										

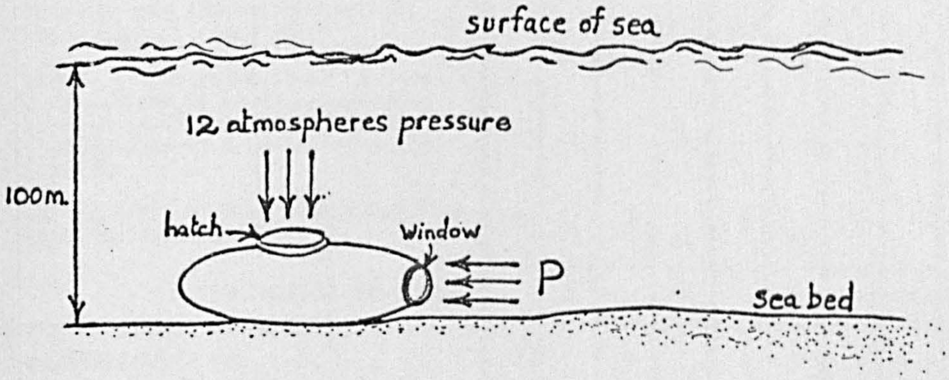
Category set continued on next page.

QUESTION 11 FRED'S BACK AND NOSE (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 23	
	No.	%	No.	%	No.	%	No.	%	No.	%
R. MORE PRESSURE DOWN BECAUSE OF AIR PRESSURE *"Because the atmospheric pressure is downwards."* (pupil 63) *"The pressure down on his back would be more than the pressure on his nose. Well, there's just water round him but there's got the air above him, and everything, on his back."* (pupil 36)	5	17	6	21	2	7	1	3	1	4
S. MORE PRESSURE DOWN BECAUSE OF THE WEIGHT OF WATER *"Pressure down might be more than towards him - you know just with the weight of water on top of him."* (pupil 64)	3	10	0	0	2	7	1	3	1	4
T. MISCELLANEOUS (i) More pressure on back because fish not moving. (pupil 15) (ii) More pressure on back because back bigger than nose/nose more streamlined shape. (pupils 6, 48 75 and 79) (iii) More pressure across, no reason. (pupils 47 and 55)	2	7	4	14	3	10	3	10	2	9
TOTAL ALTERNATIVE RESPONSES		70		76		67		52		48

Q.12. SUBMARINE - HATCH

Another part of the submarine question tested PRESSURE AND DIRECTION and pupils were re-presented with this written test item in interview.



Submersible craft are used by divers to explore deep under water and on the sea bed.

A submersible craft was on the bottom of the sea. The pressure on the outside of the hatch of the craft was 12 atmospheres.

The pressure on the outside of the window of the craft will be:

- ☐ A About 12 atmospheres
- ☐ B About 11 atmospheres
- ☐ C About 6 atmospheres
- ☐ D About 1 atmosphere
- ☐ E Zero atmospheres

APU item

COMMENT ON RESULTS

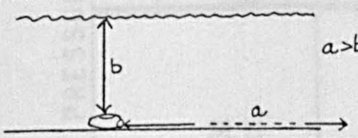
There was a marked increase in the percentage of correct responses for the 16 year old groups.

Nearly half the pupils thought that the pressure down was greater than that across, but could advance no reason to support this. Many respondents simply divided twelve atmospheres by two, to give an answer of six atmospheres.

Q.12. SUBMARINE - HATCH (contd.)

Perhaps the multiple-choice format of the SUBMARINE question was unhelpful, in that pupils could too easily point to one of the alternatives without thinking the problem through for themselves.

QUESTION 12 SUBMARINE - HATCH

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. SAME PRESSURE BECAUSE PRESSURE IS THE SAME IN ALL DIRECTIONS	4	13	6	21	5	17	11	38	7	29
"Slightly more than 12 because it's deeper again." (pupil 62)										
"About . . . 12 atmospheres. Because 12 atmospheres is pressing down here, and so it goes on bottom, so it must be 12 atmospheres on bottom as well." (pupil 7)										
B. SAME PRESSURE, NO REASON/INCONSEQUENTIAL REASON OR TAUTOLOGY	3	10	4	14	6	20	9	31	10	42
TOTAL ORDINAL RESPONSES		23		34		37		69		71
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	5	17	0	0	3	10	1	4
N. MORE PRESSURE DOWN, NO REASON/ INCONSEQUENTIAL REASON OR TAUTOLOGY	11	37	7	24	14	47	5	17	4	17
O. MORE PRESSURE DOWN, ZERO PRESSURE ACROSS	8	27	5	17	2	7	1	3	2	8
"Zero." (pupil 15)										
"I don't think there'd be any pressure." (pupil 10)										
P. MORE PRESSURE ACROSS BECAUSE OF THE GEOMETRY OF THE SEA-BED	1	3	1	3	0	0	0	0	0	0
"About 15 . . . there's only a bit of sea going up but there's a right lot . . . if you're with me." (pupil 20, this explanation accompanied by a demonstration on the drawing to the effect that:-										
										
Q. MORE PRESSURE DOWN, BECAUSE REBOUNDS AND LOSES FORCE	1	3	0	0	1	3	0	0	0	0
"About 6 . . . it goes down, as it hits it, but not quite as hard as when it's coming straight down." (pupil 12)										
R. MISCELLANEOUS	1	3	1	3	2	7	0	0	0	0
(i) 24 atmospheres, no reason. (pupil 55)										
(ii) 24, because sea is moving from side to side. (pupil 17)										
(iii) Waves cause pressure, 6 atmospheres on hatch if no waves. (pupil 37)										
TOTAL ALTERNATIVE RESPONSES		77		66		63		31		29

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understanding of PRESSURE AND DIRECTION. The Table below lists the pupil frameworks identified for this Idea, and gives their frequencies of occurrence.

TABLE 7 PUPIL FRAMEWORKS - PRESSURE AND DIRECTION

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES					
		12 Yr (X12)		14 Yr (X14 & Y14)		16 Yr (Y16 & Z16)	
		Q.11 Fred (n=30)	Q.12 Sub. (n=30)	Q.11 Fred (n=59)	Q.12 Sub. (n=59)	Q.11 Fred (n=53)	Q.12 Sub. (n=53)
1. Pressure acts equally in all directions	11A,12A	13%	13%	15%	19%	31%	34%
2. Pressure downwards is greater than pressure across	11N,11O,11S,11R, 12N,12O	53%	63%	47%	47%	27%	23%
3. Pressure in different directions depends on distance to containing surface	11P,12P	3%	3%	7%	2%	6%	0%
No identifiable framework	11B,11U,11T,11Q, 12Q,12B,12U,12R	30%	20%	31%	32%	37%	43%

Note: Since percentages are given only to the nearest 1%, the figures do not always add up exactly to 100%.

GENERAL COMMENT ON PUPIL UNDERSTANDING OF PRESSURE AND DIRECTION

It seems likely that, for most people, this Idea is a counter-intuitive one. Even at 16 years only about one third of the pupils interviewed suggested that pressure acted equally in all directions (Framework 1), and the percentages for 12 and 14 year olds were much lower. Correspondingly, many more pupils subscribed to the notion that pressure in a downwards direction is greater than across, though the percentage figures for this framework (2) are roughly halved from 12 to 16 years.

The suggestion that pressure in different directions depends on the distance to the containing surface (Framework 3) is interesting and may be similar to one of the results from the previous Idea PRESSURE AND DEPTH - namely, that the total volume of liquid surrounding an object determines the pressure on it.

The small number of pupils who subscribed to the idea that pressure re-bounds and loses force was put into 'No identifiable framework'. This was because the same sort of dynamic explanation occurred much more frequently in response to questions related to the next Idea and will be discussed there.

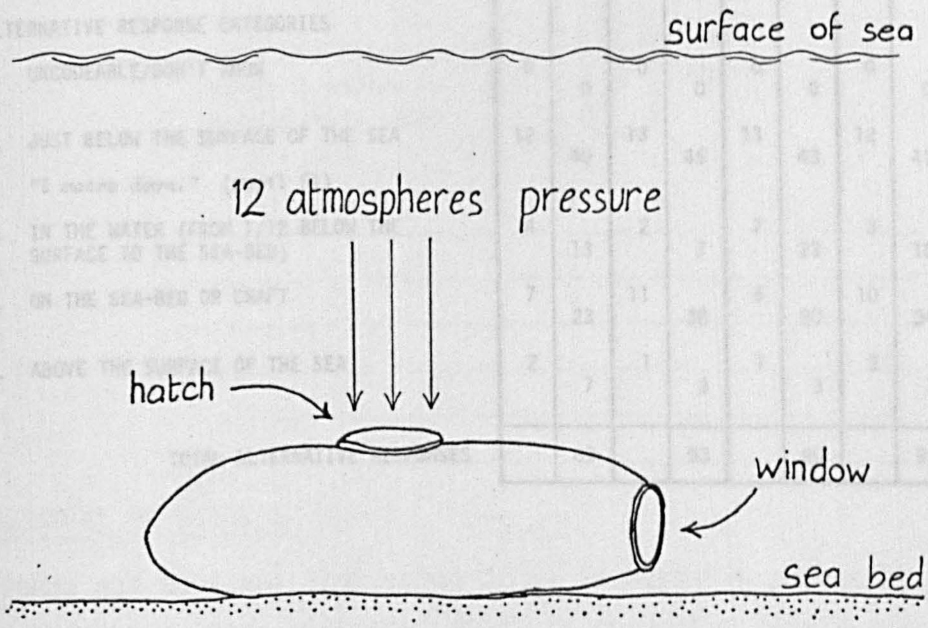
ATMOSPHERIC PRESSURE

THE ATMOSPHERE EXERTS A PRESSURE.

The following questions test understanding of the Idea of ATMOSPHERIC PRESSURE, by exploring its effect in several different contexts.

Q.13. ONE ATMOSPHERE

An extension to SUBMARINE was put in interview (see below) to test whether pupils approached this problem using the idea of atmospheric pressure.



Can you mark in on the diagram where you think 1 atmosphere is being exerted?

COMMENT ON RESULTS

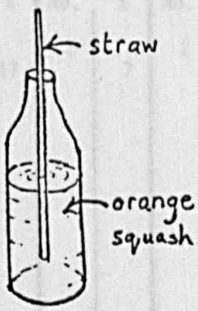
A low overall percentage of pupils (16% across all responses) drew the arrow pointing down to the surface of the sea. However, this question requires pupils to know (or to have deduced from earlier SUBMARINE questions) that pressure is measured in units called 'atmospheres'. In this sense, it is not a very straightforward test of this Idea.

QUESTION 13 ONE ATMOSPHERE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. ON THE SURFACE OF THE SEA	5	17	2	7	3	10	2	7	11	46
TOTAL ORDINAL RESPONSES		17		7		10		7		46
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	0	0	0	0	0	0	1	4
N. JUST BELOW THE SURFACE OF THE SEA *"1 metre down."* (pupil 51)	12	40	13	45	13	43	12	41	8	33
O. IN THE WATER (FROM 1/12 BELOW THE SURFACE TO THE SEA-BED)	4	13	2	7	7	23	3	10	0	0
P. ON THE SEA-BED OR CRAFT	7	23	11	38	6	20	10	34	1	4
Q. ABOVE THE SURFACE OF THE SEA	2	7	1	3	1	3	2	7	3	13
TOTAL ALTERNATIVE RESPONSES		83		93		90		93		54

Q.14. STRAW - OPEN TOP

This written test item was re-presented in interview.



Use the idea of atmospheric pressure to explain how you can drink orange squash through a straw

APU item

COMMENT ON RESULTS

There was no clear indication of an increase in percentage of ordinal responses with age, which is perhaps a little surprising. Nearly half of all pupils gave a simple description of what happens when liquid is sucked through a straw, without offering any explanation at all.

QUESTION 14 STRAW - OPEN TOP

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. THERE IS A PRESSURE DIFFERENCE, WITH PRESSURE IN MOUTH/STRAW BEING LESS THAN ATMOSPHERIC PRESSURE	5	17	2	7	2	7	5	17	7	29
"Well, you create a vacuum in the straw, or a partial vacuum when you suck, and the pressure of the atmosphere forces the orange squash down, and up the straw. (He points to the surface of the orange to show where the pressure of the atmosphere is exerted.) *Well, if there's a lower pressure there than there, the higher pressure will try to equalize, so the higher pressure will go up . . . to make the orange juice fill the straw."* (pupil 3)										
B. ATMOSPHERIC PRESSURE INSIDE THE BOTTLE IS RESPONSIBLE FOR THE ORANGE COMING UP	6	20	8	28	6	20	5	17	6	25
"Well pressure of air pushes down on orange juice and when you suck up like . . . sucks it up . . . as though it's a syringe and it brings it up, because that's pressing down and you're sucking up." (He points to the air above the orange. pupil 48)										
C. AIR IN BOTTLE IS SOMEHOW RESPONSIBLE FOR ORANGE COMING UP	2	7	4	14	1	3	1	3	0	0
"Is it that - because there's air inside here - when you suck up from where it's inside the orange squash - it'll like - because there's air in it - it'll force it upwards." (She confirms that she means air in the bottle. pupil 2)										
TOTAL ORDINAL RESPONSES		43		48		30		38		54
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	3	10	3	10	1	3	0	0	1	4
N. VACUUM IN STRAW SUCKS ORANGE UP	0	0	3	10	1	3	1	3	2	8
"You suck on a straw and it creates a vacuum inside the straw and the orange squash is pulled up through the straw . . . the vacuum (pulls it up)." (pupil 77)										
O. JUST SUCK IT/THE AIR UP, THE ORANGE FOLLOWS	11	37	6	21	18	60	17	59	8	33
"The liquid inside gets sucked up . . . as the pressure in the straw gets . . . less. It's the suction caused from sucking." (pupil 40)										

Category set continued on next page.

QUESTION 14 STRAW - OPEN TOP (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
P. MISCELLANEOUS	3	10	3	10	1	3	0	0	0	0
(i) *"Pressure from underneath the orange here* (at the bottom of the straw) *will push the orange up the straw."* (pupil 5)										
(ii) Air only presses down on the surface when you suck. (pupil 24)										
(iii) A vacuum created in the straw - something has to go in to fill the vacuum up. (pupil 31)										
TOTAL ALTERNATIVE RESPONSES		57		52		70		62		46

Q.15. PRESSURE IN STRAW

The following supplementary question was asked after Q.14 STRAW - OPEN TOP.

Would there be any change in pressure inside the straw as you suck?

COMMENT ON RESULTS

No clear age-related trends emerged.

Many pupils (38% of all responses) thought that pressure in the straw would become greater as you sucked. This may be a fundamental block to unravelling the correct explanation to the problem posed in the STRAW question.

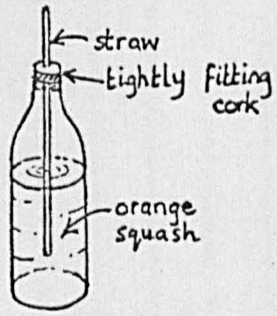
QUESTION 15 PRESSURE IN STRAW

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 26		X14 n = 29		Y14 n = 28		Y16 n = 29		Z16 n = 22	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. PRESSURE IN MOUTH/STRAW IS LESS WHEN YOU SUCK *"When you suck the pressure in the straw has got to be less than the pressure in the bottle."* (pupil 40) *"Well, when you suck you reduce the pressure in your mouth, and the pressure on the surface remains constant . . . "* (pupil 62)	6	23	6	21	7	25	8	28	12	55
TOTAL ORDINAL RESPONSES		23		21		25		28		55
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW *"I don't know. You suck the air up and the orange follows."* (pupil 38)	6	23	6	21	5	18	5	17	4	18
N. NO PRESSURE CHANGE IN STRAW WHEN YOU SUCK	2	8	6	21	2	7	4	14	4	18
O. PRESSURE IN THE STRAW GREATER WHEN YOU SUCK *"It's great. Pressure's great."* (pupil 60) *"Yes, it gets greater - the harder you suck the more orange comes up."* (pupil 48)	12	46	11	38	14	50	12	41	2	9
TOTAL ALTERNATIVE RESPONSES		77		79		75		72		45

Q.16. STRAW - CLOSED

Before the second part of the written test item on STRAW was re-presented in interview, pupils were invited to try the apparatus (containing orange squash) for themselves. They were asked what they could do to the bottle to get more squash out and almost all of them suggested taking the cork out. They were then encouraged to discuss why this worked so well. Finally, they had a drink of orange!

You could not suck all the squash out of this bottle. Why not?



APU item

COMMENT ON RESULTS

As with the other questions on STRAW no obvious age-related trends were detectable.

The three categories on the ordinal scale are identical for STRAW - OPEN TOP and for this question (they are, of course, exactly the same question, phrased differently). They represent the following stages in the solution of this quite complex problem:

(i) a recognition of the importance of a pressure difference and of the fact that atmospheric pressure is only observable when there is this difference.

Q.16. <u>STRAW-CLOSED</u> (contd.)

(ii) a recognition of the existence of air pressure

(iii) some idea that air inside the bottle is responsible, but no indication of the mechanism of this.

This question produced many more ordinal responses than STRAW - OPEN TOP (61% instead of 42% over all responses). This difference is probably partly attributable to the fact that pupils had an opportunity to handle the apparatus, and also perhaps simply that they had had more time to think.

QUESTION 16 STRAW - CLOSED

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. NO AIR ENTERS, THEREFORE PRESSURE IN BOTTLE DECREASES, THEREFORE NO PRESSURE DIFFERENCE BETWEEN BOTTLE AND STRAW *" . . . you will reduce the pressure in your mouth . . . it'll go up for a while . . . then slowly the pressure in this will be reduced by the water level going down . . . and the volume expanding . . . until an equilibrium is reached."* (pupil 62)	3	10	1	3	1	3	5	17	6	25
B. NO/LESS AIR IN BOTTLE, THEREFORE NO/LESS PRESSURE *"Because there's no air to press down on orange when you suck up . . .* (he suggests removal of bung) *. . . because the air's getting back into the bottle and shoving all orange up tube again."* (pupil 48)	9	30	13	45	7	23	5	17	7	29
C. AIR CAN'T GET IN/THERE IS NOT ENOUGH OR LESS AIR IN THE BOTTLE TO REPLACE ORANGE *"Because there's no air inside the bottle . . . as you first suck up, the air's got to come out, so the orange will follow - so all the time there's a constant supply of air in the bottle - so you'll be able to suck out."* (pupil 2) (Bung released) *. . . Because air can get in through the top of the bottle and replace the volume that you drink."* (pupil 72)	5	17	7	24	4	13	8	28	5	21
TOTAL ORDINAL RESPONSES		57		72		40		62		75
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	2	7	2	7	6	20	1	3	1	4
N. STRAW IS SQUEEZED BY THE BUNG *"Because the air . . . the cork is squeezing the straw so it's much harder for you to suck.* (Bung released) *. . . Well, because there's not so much pressure on the outside of the thing to squeeze it together."* (pupil 15)	7	23	3	10	4	13	2	7	2	8
O. AIR CAN'T GET OUT/IS TRAPPED IN THE BOTTLE *"Because the air in the bottle isn't coming out . . . it doesn't help the pressure push up, because there's still a lot of air in."* (pupil 5) *" . . . air can escape when you take out the bung."* (pupil 34)	4	13	2	7	3	10	3	10	1	4

Category set continued on next page.

QUESTION 16 STRAW - CLOSED (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	X12 n = 30 No.	%	X14 n = 29 No.	%	Y14 n = 30 No.	%	Y16 n = 29 No.	%	Z16 n = 24 No.	%
P. PRESSURE IS HIGH IN THE BOTTLE *"There's more pressure in the bottle because you're not letting any air out, so there's more pressure . . .* (in the open bottle) *. . . you're letting the air out and there's less pressure."* (pupil 46) "(When bung is removed) *Well there's no pressure inside, because air can go in . . . "* (pupil 54)	0	0	1	3	5	17	5	17	2	8
TOTAL ALTERNATIVE RESPONSES		43		28		60		38		25

Q.17. SYRINGE - WHAT'S INSIDE?

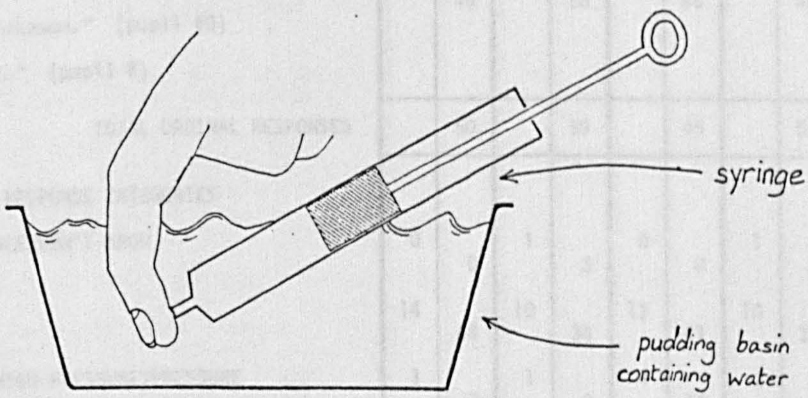
Q.18. SYRINGE

The apparatus shown below (see footnote) was demonstrated. The plunger was depressed and, with a finger firmly over the end under the water, the plunger was then pulled upwards.

Q.17 What is inside the Syringe now?

The finger was then removed. Water rushed into the syringe with force.

Q.18. What makes the water rush in like that?



COMMENT ON RESULTS

For both these questions, as with others testing the Idea of ATMOSPHERIC PRESSURE there were no clear age-related trends in overall percentages of ordinal and alternative responses.

38% of all responses supported the idea that the syringe contained air when the plunger was raised, though some of these pupils said 'Nothing' and it later transpired that they meant 'Air'. For example, one 14 year old pupil said:

"*Nothing ... oh yes, yes ... that there was air. No water.*"

It was not easy and sometimes it was impossible to unscramble this kind of linguistic complexity.

23% of all responses to SYRINGE contained a description of pressure as an active pulling agent and another 16% quite explicitly attributed the rush of water to the pull of a vacuum.

F. This demonstration was kindly suggested by Mr. W. Mace of the Physics Department, King Edward VII School, Sheffield (Ref: Sch. Sci. Rev., 42 p. 328).

QUESTION 17 SYRINGE - WHAT'S INSIDE?

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 29		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. A LITTLE AIR AT LOW PRESSURE/A PARTIAL VACUUM *"If air was in it before, air is in it again . . . the air inside there is at very low pressure because you had sealed the container up and then expanded the volume. There was the same amount of air in a much increased volume."* (pupil 62)	1	3	1	3	0	0	3	10	3	13
B. NOTHING/NO AIR/A VACUUM *"It's a vacuum."* (pupil 40) *"Nothing."* (pupil 8)	14	48	16	55	13	45	13	45	14	58
TOTAL ORDINAL RESPONSES		50		59		45		55		71
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	1	3	0	0	1	3	0	0
N. AIR	14	48	10	34	12	41	10	34	7	29
O. AIR AT HIGH PRESSURE/PRESSURE *"A very great amount of pressure . . . "* (pupil 37) *"Air and pressure."* (pupil 53)	1	3	1	3	4	14	2	7	0	0
TOTAL ALTERNATIVE RESPONSES		50		41		55		45		29

QUESTION 18 SYRINGE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 29		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. ATMOSPHERIC PRESSURE OUTSIDE IS GREATER THAN PRESSURE INSIDE, THEREFORE WATER ENTERS SYRINGE *"Well, there was a vacuum before when you had your finger over the end and as soon as you let go the air pressure outside pushes the water in at a fast rate. Eventually it stops when the pressure inside the syringe and the water are the same."* (pupil 39, he demonstrates that he means that the pressure is pushing on the surface of the water.)	4	13	3	10	3	10	7	24	4	17
B. ATMOSPHERE PRESSES ON SURFACE OF THE WATER, PUSHES WATER UP INTO SYRINGE *"Well, the water tries to fill the vacuum up . . . because there's air pressure here* (on the surface of the water) *and it pushes the water up into the syringe."* (pupil 81)	3	10	4	14	0	0	0	0	3	13
C. WATER GOES IN TO FILL THE SPACE *"It's like in that straw - as you like suck all the air out - it rushes in - as you take your finger off - to take the place of the air."* (pupil 74)	0	0	4	14	2	7	4	14	3	13
TOTAL ORDINAL RESPONSES		23		38		17		38		42
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	3	10	4	14	6	21	3	13
N. AIR OUT, WATER GOES/IS PULLED IN *"Well, the air is in it and when you let the bottom go the air rushes down so it squirts the water up into the thing . . . "* (pupil 15)	6	20	5	17	4	14	3	10	2	8
O. AIR/AIR UNDER HIGH PRESSURE/PRESSURE IN THE SYRINGE PULLS THE WATER IN *"Because there's a high pressure in the syringe which is pushing the air out. And as the air goes out the water comes in."* (pupil 38) *"Air's like pulling it up . . . "* (pupil 6) *"Air in syringe is wanting to suck water up."* (pupil 16) *"Pressure sucks water in."* (pupil 19)	11	37	5	17	8	28	4	14	4	17

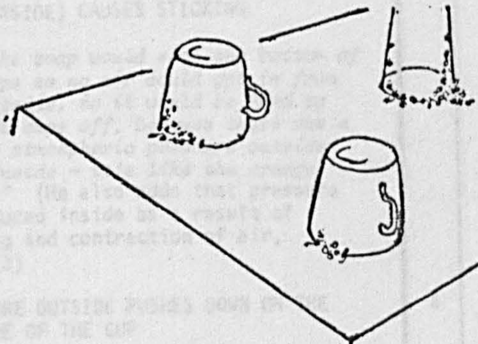
Category set continued on next page.

QUESTION 18 SYRINGE (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 29		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
P. VACUUM PULLS/SUCKS WATER UP *"There's nothing there . . . the vacuum pulls it up."* (pupil 64) *"Well there's nothing inside that glass tube so the suction pulling things in would be so much that the water would really go in fast. . . . . . The pressure* (inside the tube) *is low but the suction is a pull to make the water or whatever it is go into the glass."* (pupil 8)	4	13	5	17	6	21	4	14	5	21
Q. MISCELLANEOUS (i) Both suction and air pressure on surface cause water to rush in. 2 factors clearly stated as operating together. (pupils 23 and 28) (ii) Air enters syringe and pulls water in with it. (pupil 42 and 47)	2	7	0	0	2	7	1	3	0	0
TOTAL ALTERNATIVE RESPONSES		77		62		83		62		58

Q.19. WASHING UP

Pupils were reminded of the written test item below. The following category set refers to the second part of the question - i.e. why were the glasses hard to lift up after a few minutes.



John was washing up the dishes using hot soapy water. He put the cups and glasses upside down on a flat surface to drain. When he lifted them to dry them he found they seemed to stick to the surface. When he lifted them they came away with a small pop. John correctly thought this was something to do with the air in the glass.

(a)
What happens to the air in the glass when the glass is first put down on the surface?
(Remember that the washing-up water was hot).

(b)
Explain why it is hard to lift the glass up after a few minutes.

APU item

COMMENT ON RESULTS

The majority of pupils of all three ages subscribed to alternative response categories (with corresponding low percentages of ordinal responses)

The notion that trapped air and/or pressure inside the cups was forcing them onto the table was a powerful one. 13% of responses across all three age groups attributed the sticking to a sucking vacuum.

QUESTION 19 WASHING UP

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 29		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. THE PRESSURE DIFFERENCE (MORE OUTSIDE THAN INSIDE) CAUSES STICKING *"And the soap would seal the bottom of the cups so no air could get in from the outside, so it would be hard to get the cups off, because there was a higher atmospheric pressure outside than inside - it's like the orange juice."* (He also adds that pressure is reduced inside as a result of cooling and contraction of air, pupil 3)	2	7	7	24	3	10	3	10	5	21
B. PRESSURE OUTSIDE PUSHES DOWN ON THE OUTSIDE OF THE CUP *"Because the pressure is pressing on your cup and the air inside the cup was . . . couldn't get out because of the pressure . . .* (Where is the pressure?) *All around the cup, especially on top of the cup."* (pupil 28)	4	14	0	0	0	0	0	0	0	0
TOTAL ORDINAL RESPONSES		21		24		10		10		21
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	3	10	5	17	7	23	8	28	5	21
N. VACUUM/PARTIAL VACUUM/LESS AIR CAUSES CUP TO STICK DOWN *" . . . because it's pulling on it . . . the vacuum . . . you know there's all air in it and suddenly shrinks a bit, and pulls on to the table, pulls the glass on to the table."* (pupil 64)	3	10	4	14	2	7	2	7	7	29
O. A SEAL IS MADE (BY SOAP, STEAM, ETC.) *"Well, because when it cools, sometimes little water falls . . . down on to the board and sticks it."* (pupil 15)	4	14	4	14	0	0	4	14	2	8
P. AIR TRAPPED INSIDE THE CUP PULLS THE CUP DOWN *"The air inside the cup is sucking on to the surface - like stopping the cup being picked up . . . because the air is trapped under the cup."* (pupil 13)	6	21	5	17	9	30	5	17	1	4
Q. PRESSURE INSIDE CUP IS GREAT/GREATER THAN OUTSIDE, AND THIS STICKS THE CUP DOWN *"It's a force. A sort of magnetic force . . . if you hold things down. Well, magnets hold things down - well pressure holds cups and things down."* (pupil 60)	4	14	2	7	7	23	6	21	2	8

Category set continued on next page.

QUESTION 19 WASHING UP (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	X12 n = 29 No.	X12 n = 29 %	X14 n = 29 No.	X14 n = 29 %	Y14 n = 30 No.	Y14 n = 30 %	Y16 n = 29 No.	Y16 n = 29 %	Z16 n = 24 No.	Z16 n = 24 %
R. MISCELLANEOUS (i) Heat makes it stick. (pupils 7, 9 and 56) (ii) Hot air rises, cold air sucks to bottom. (pupils 1, 70 and 80)	3	10	2	7	2	7	1	3	2	8
TOTAL ALTERNATIVE RESPONSES		79		76		90		90		79

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understandings of ATMOSPHERIC PRESSURE. The Table below lists the pupil frameworks identified for this Idea, and gives their frequencies of occurrence.

TABLE 8   PUPIL FRAMEWORKS - ATMOSPHERIC PRESSURE

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES								
		12 Yr (X12)			14 Yr (X14 & Y14)			16 Yr (Y16 & Z16)		
		Q14 (n=30) straw	Q18 (n=30) syringe	Q19 (n=29) wash.up	Q14 (n=59) straw	Q18 (n=58) syringe	Q19 (n=59) wash.up	Q14 (n=53) straw	Q18 (n=53) syringe	Q19 (n=53) wash.up
1. The atmosphere exerts a pressure which is observable only when there is a pressure difference	14A,18A,19A	17%	13%	7%	7%	10%	17%	23%	21%	15%
2. The atmosphere exerts a pressure on surfaces	14B,14C,18B,19B	27%	10%	14%	32%	7%	0	23%	6%	0
3. Vacuums suck or exert pressure	14N,18P,19N	0	13%	10%	7%	19%	10%	6%	17%	17%
4. Pressure is an active agent (pressure or air sucks or pulls)	180,19Q,19P	-	37%	34%	-	22%	39%	-	15%	26%
5. Spaces must be filled ("nature abhors a vacuum").	18C,14P(some)	0	0	-	5%	10%	-	0	13%	-
No identifiable framework	14U,140,14P(some) 18U,18N,18Q,19U, 190,19R	57%	27%	34%	49%	31%	34%	49%	28%	42%

The symbol - in the above table indicates that there is no contribution to the Framework from that question.

Note: Since percentages are given only to the nearest 1%, the figures do not always add up exactly to 100%.

GENERAL COMMENT ON UNDERSTANDING OF ATMOSPHERIC PRESSURE

Responses to questions related to this Idea indicated a two-level breakdown of understanding. Some pupils simply recognized the existence of atmospheric pressure (Framework 2), whereas others seemed able to apply this notion to the solution of fairly complex scientific problems (Framework 1). The percentage frequencies for the 16 year old group were higher for Framework 1, but apart from this there was no clear trend of increase of incidence with age.

"Sucking vacuums" seemed to be a powerful explanatory framework for some pupils. Many linguistic problems are to be found in this connection. Some pupils clearly indicated that vacuums were areas of high pressure (and here the distinction between Frameworks 3 and 4 becomes blurred), while others obviously understood that they were areas of zero pressure. Responses to SYRINGE - WHAT'S INSIDE? confirmed this confusion. Some pupils who said 'nothing' meant 'air' or 'air under pressure', whilst others meant 'a space'.

The framework embodying the notion of pressure as an active agent (Framework 4) represents a dynamic view of pressure. It seems that many pupils attribute a force only to something that has the capability of movement. Echoes of this same notion occurred in relation to pressure in liquids - for example, three pupils described pressure in the fish tank as moving around, as re-bounding and losing force.

CHAPTER 5

PUPIL UNDERSTANDINGS OF HEAT

Introduction

This chapter on heat presents results of analytic procedures already described and applied to two Ideas - HEAT AND TEMPERATURE and CONDUCTION OF HEAT. As with the pressure results, reporting is at both question and Idea levels. However, pupil frameworks do not emerge as cleanly as for pressure, perhaps partly because HEAT AND TEMPERATURE is so broad, incorporating the very nature of heat itself as well as the concept of temperature. Inevitably, if the Idea tested is broad, questions can only probe circumscribed aspects of it. Category sets on these different aspects are obviously not strictly comparable, though, of course, it may be possible to pick out common general notions across these sets. Quantitative presentation and comparison of framework frequencies across different questions would, however, be misleading, since it would presume a unity and coherence which did not exist. In view of this, it is only possible to comment descriptively on some of the results in this chapter.

As in Chapter 4, commentary focusses on age-related trends within pupil groups, particularly at the question level.

HEAT AND TEMPERATURE

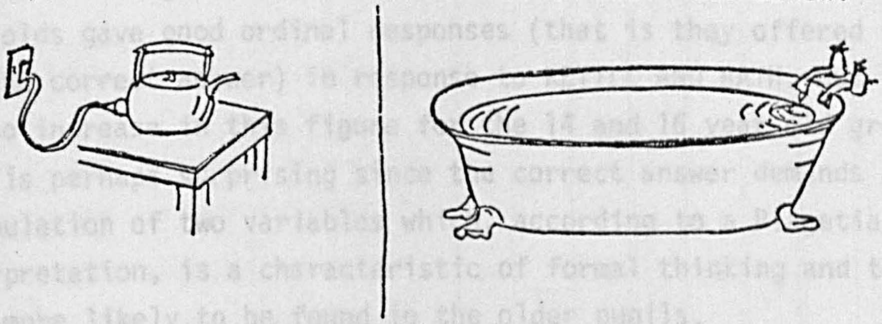
A SUBSTANCE REQUIRES A GIVEN AMOUNT OF ENERGY TO RAISE THE TEMPERATURE OF UNIT MASS BY A GIVEN AMOUNT

Questions mapping on to this Idea test several aspects of it. Some questions (KETTLE AND BATH) explore understanding of the difference between quantity of heat energy and temperature. A series of problems (MIXING LIQUIDS) tests children's ability to differentiate between quantity of matter and temperature. Other questions (POTATOES) test the idea that heat can be supplied with no resultant temperature change (when water has reached boiling point).

Q.22. KETTLE AND BATH - COST

Q.23. KETTLE AND BATH

These questions were based on the written test item below.



An electric kettle was filled with water and brought to the boil.
A bath tub was filled with water just above body temperature to the level shown.

(a) Which of these contains water at a higher temperature?

____

(b) Which of these contains the most heat energy?

____

Give the reason for your answer

____

Having established that pupils understood that 'just above body temperature' was about 40-45^{o}C. the following questions were put in interview.

Q.22. If you had to heat the water for both the bath and the kettle electrically, which do you think would cost the most?

Q.23. Which of the two - the kettle or the bath - contains the most heat energy? Can you explain why?

COMMENT ON RESULTS

Some younger pupils had difficulty in understanding how the bath water was heated, which complicated analysis of the responses. The first question elicited much higher overall percentages of ordinal responses - clearly, the question set in the everyday context of electricity costs was very much easier than the same question set in a science context of heat energy.

Q.22. KETTLE AND BATH - COST
Q.23. KETTLE AND BATH (contd.)

No clear age trends were detectable. So, one third of 12 year olds gave good ordinal responses (that is they offered reasons for the correct answer) in response to KETTLE AND BATH, but there was no increase in this figure for the 14 and 16 year old groups. This is perhaps surprising since the correct answer demands a manipulation of two variables which, according to a Piagetian interpretation, is a characteristic of formal thinking and therefore more likely to be found in the older pupils.

A large proportion of pupils of all ages (29% of all responses) suggested that the kettle had more heat energy because the water it contained was hotter.

A few respondents proposed the interesting idea that there is more heat energy in the kettle because the space is confined and enclosed, whereas the bath is open.

KETTLE AND BATH - COST was not put to all pupils in subsample Z16, so these figures are excluded from the frequency table.

QUESTION 22 KETTLE AND BATH - COST

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES							
	X12 n = 30		X14 n = 29		Y14 n = 27		Y16 n = 29	
	No.	%	No.	%	No.	%	No.	%
A. BATH, BECAUSE, DESPITE LOWER TEMPERATURE, VOLUME OF WATER MUCH GREATER *"Bath, because more surface area . . . in the kettle there's not as much water, and so it doesn't take as long, even though it's at a higher temperature."* (pupil 41)	1	3	1	3	1	4	6	21
B. BATH, BECAUSE MORE WATER *"Bath, because there's more water to heat than the kettle so they're using more electricity to get the water heated."* (pupil 38)	21	70	20	69	18	67	17	59
C. BATH, NO REASON/BECAUSE USES MORE ELECTRICITY *"Bath, because the immersion heater's burning electricity more than the kettle is."* (pupil 58)	0	0	2	7	3	11	3	10
TOTAL ORDINAL RESPONSES		73		79		81		90
ALTERNATIVE RESPONSE CATEGORIES								
U. UNCODEABLE/DON'T KNOW	0	0	2	7	0	0	1	3
N. KETTLE, BECAUSE HOTTER WATER *"The kettle, because that's not as hot as the kettle."* (pupil 5)	2	7	1	3	0	0	0	0
O. KETTLE, BECAUSE HEAT MORE DIRECT/ PLUGGED INTO THE ELECTRICITY *". . . because you have to use electricity to heat it up - the bath you get it out of the tap."* (pupil 17) *" . . . whereas the kettle, you've just got direct heat from the electricity . . so I think the kettle would be the most expensive to heat."* (pupil 36)	3	10	0	0	1	4	0	0
P. KETTLE, NO REASON/BECAUSE USES MORE ELECTRICITY *"Kettle, because when you're using the kettle you have to use more electric."* (pupil 22)	3	10	3	10	4	15	2	7
TOTAL ALTERNATIVE RESPONSES		27		21		19		10

QUESTION 23 KETTLE AND BATH

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 23	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. BATH, BECAUSE, DESPITE LOWER TEMPERATURE, VOLUME OF WATER MUCH GREATER *"Well that's difficult, because the kettle although it has a lesser amount of water is hotter, but the bath has got more water at a lower temperature. Possibly the bath might have more heat energy . . . more water even though it's at a lower temperature."* (pupil 3)	2	7	5	17	2	7	4	14	3	13
B. BATH, BECAUSE MORE WATER *" . . . it's because there's more water - there's got to be more energy."* (pupil 2)	8	27	5	17	9	30	2	7	7	30
C. BATH, NO REASON	2	7	4	14	1	3	3	10	1	4
TOTAL ORDINAL RESPONSES		40		48		40		31		48
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	4	14	1	3	1	3	1	4
N. KETTLE, BECAUSE HOTTER WATER/ GIVES OFF MORE HEAT *"Kettle, because it's hotter."* (pupil 48)	8	27	6	21	7	23	12	41	8	35
O. KETTLE, BECAUSE THE HEAT IS MORE DIRECT/PLUGGED IN *"Kettle, well, water's coming through the taps, but on this - you've got to plug it in and there's electricity coming through as well."* (pupil 30)	2	7	1	3	1	3	2	7	0	0
P. KETTLE, NO REASON/BECAUSE USES MORE ELECTRICITY	0	0	3	10	4	13	1	3	1	4
Q. KETTLE, BECAUSE THE HEAT ENERGY IS CONFINED IN AN ENCLOSED SPACE/BATH HAS LARGE SURFACE AREA AND LOSES THE ENERGY *"Kettle, because it's* (the heat) *all trapped inside."* (pupil 19) *"Kettle because the kettle's more covered up . . . so not much heat can escape - a bit of it can but not as much as the bath. Because the bath is all over air, a lot of heat can get away."* (pupil 23)	3	10	0	0	2	7	2	7	1	4
R. BATH, BECAUSE YOU SOAK UP OR GIVE OFF ENERGY IN A BATH. BATHS ARE ENERGY-GIVING/RELAXING *"Bath, because you need energy and when you go in't bath you get more energy, because you soak your body in it."* (pupil 5)	5	17	0	0	1	3	0	0	1	4

Category set continued on next page.

QUESTION 23 KETTLE AND BATH (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 23	
	No.	%	No.	%	No.	%	No.	%	No.	%
S. MISCELLANEOUS *"Kettle, because it's smaller."* (pupil 59) *"Kettle, because you can make foods and tea and coffee and things with kettle . 'cos food and drink give you energy."* (pupil 49)	0	0	1	3	2	7	2	7	0	0
TOTAL ALTERNATIVE RESPONSES		60		52		60		69		52

Q.28. MIXING LIQUIDS - QUALITATIVE

Q.24. MIXING LIQUIDS I

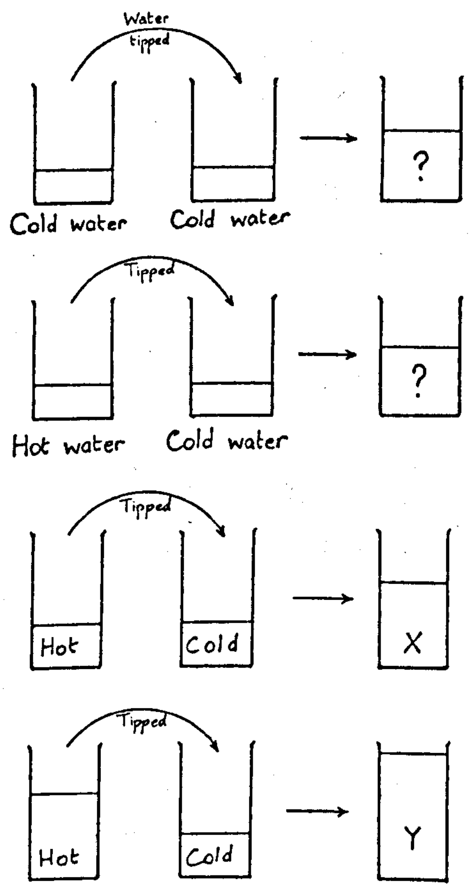
Q.25 MIXING LIQUIDS II

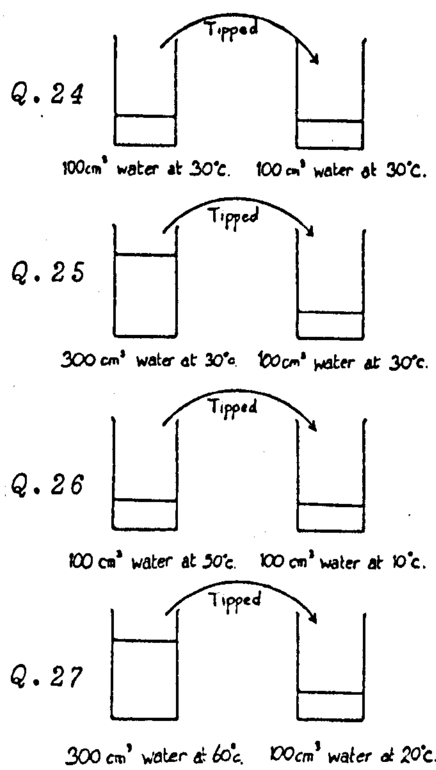
Q.26. MIXING LIQUIDS III

Q.27. MIXING LIQUIDS IV

Pupils were asked to work out the temperature of the mixture in the four problems below (Qs 24-27). These questions are analogous to a four-part written test item, but the figures for volumes and temperatures were changed. The four quantitative problems were preceded in interview by a series of problems cast in a qualitative mode (Q28, see below). The second part of this (a mixing of warm and cold water) was demonstrated in interview, mainly to ensure that pupils understood that they were to comment on the temperature of the resultant mixture.

Q.28





Q.28. <u>MIXING LIQUIDS - QUALITATIVE</u>
Q.24. <u>MIXING LIQUIDS I</u>
Q.25. <u>MIXING LIQUIDS II</u> (contd.)
Q.26. <u>MIXING LIQUIDS III</u>
Q.27. <u>MIXING LIQUIDS IV</u>

<u>COMMENT ON RESULTS</u>

No category sets were generated for the qualitative problems. The majority of pupils found them very easy and there was little variety of response. 7% of all responses did contain the idea that when cold water is added to cold the resultant mixture becomes colder, and 4% of respondents suggested that the water in beakers X and Y would be the same temperature, but most pupils found the problems in this setting were derisorily simple.

Frequencies of ordinal responses for the two quantitative problems with water of the same temperature (MIXING LIQUIDS I and II) show improvement with age from 12 to 14 years, but little change after that. Approximately one quarter of the 14 and 16 year old responses together were incorrect for problem I (same temperature, equal volumes) and about one third for problem II (same temperature, different volumes). These figures are surprisingly large. By contrast, there are no clear age trends in the results of the two quantitative problems with water of different temperatures (MIXING LIQUIDS III and IV) (though one of the two 16 year old groups did much better on problem III).

Mathematical manipulation of temperature values (in contradiction of 'common sense') was very common at all three age levels. Addition of the two values was employed by quite large proportions of pupils in the solution of all four problems, as shown in the table below.

	I	II	III	IV
<u>Additive procedures used to solve problems</u>	24%	15%	33%	23%

In the two problems with water of different temperatures (problems III and IV) subtraction of the figures was an alternative possible procedure.

Q.28. MIXING LIQUIDS - QUALITATIVE
Q.24. MIXING LIQUIDS I
Q.25. MIXING LIQUIDS II (contd.)
Q.26. MIXING LIQUIDS III
Q.27. MIXING LIQUIDS IV

The notion of temperature being proportion to volume occurred in response to problems II and IV

A few pupils proposed that if one of the liquids was hot (as distinct from warm) the temperature of the resultant mixture would remain at this same high temperature.

QUESTION 24 MIXING LIQUIDS I

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. 30°, BECAUSE TEMPERATURE IN THE TWO BEAKERS IS THE SAME/ VOLUME IRRELEVANT *"They're both the same heat . . . it doesn't make no difference if you add that to that - it's not going to go up to double it."* (pupil 11)	15	50	21	72	21	70	22	76	19	79
TOTAL ORDINAL RESPONSES		50		72		70		76		79
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW *"Is that cold water? When you put that in that, it might go down or it might go up. If that's warm water and you put it into cold . . . "* (pupil 25)	3	10	1	3	1	3	0	0	0	0
N. ADDITION i.e. 60° *"Well really all you're doing is doubling the amount of water and doubling the temperature."* (pupil 67)	8	27	7	24	8	27	7	24	4	17
O. CONFUSION WITH FIGURES FOR GIVEN VOLUMES OF WATER 200°C (i.e. the volumes added) (pupil 84) 260°C (i.e. both volumes and both temperatures added together) (pupil 21)	4	13	0	0	0	0	0	0	1	4
TOTAL ALTERNATIVE RESPONSES		50		28		30		24		21

QUESTION 25 MIXING LIQUIDS II

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. 30^{o}, BECAUSE TEMPERATURE IN THE TWO BEAKERS THE SAME/VOLUME IRRELEVANT *" . . . same again. Because it doesn't matter about the amount of water if it's the same temperature.* (pupil 5)	12	40	21	72	18	60	19	66	17	71
TOTAL ORDINAL RESPONSES		40		72		60		66		71
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW *"10^{o}C - more of that water than that . . it's going to make a change in the temperature - it might go down - I'm not quite sure."* (pupil 10)	7	23	2	7	3	10	1	3	2	8
N. ADDITION i.e. 60^{o}C	4	13	4	14	6	20	5	17	2	8
O. CONFUSION WITH FIGURES FOR GIVEN VOLUMES OF WATER *"very very hot - 400"* (pupil 17) *"400 cm^3"* (pupil 18)	4	13	0	0	0	0	0	0	1	4
P. TEMPERATURE IS PROPORTIONAL TO VOLUME *"120^{o}C"* (i.e. 30 x 3 = 90 + 30 = 120) (pupil 23) *"20^{o}C"* (i.e. 300 cm^3 at 30 equivalent to 100 cm^3 at 10, then (10 + 30)/2 = 20^{o}) (pupil 66)	2	7	2	7	1	3	4	14	2	8
Q. MISCELLANEOUS 70^{o}C (30 + 30 + 10) - the 10 comes from the extra 200 cm^3 water. (pupil 16) 80^{o}C (30 + 30 + 20) - 20 is the difference between 300 and 100 (pupil 49) 90^{o}C (30 + 30 = 60 and then 60 + 30 = 90^{o}C) - this sounds like an adjustment for greater volume in one beaker. (pupil 59)	1	3	0	0	2	7	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		60		28		40		34		29

QUESTION 26 MIXING LIQUIDS III

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. 30^{o} - THE AVERAGE OF THE TWO TEMPERATURES *"Warm water to the colder water - it would heat it up, and I just thought that the total temperature was 60 and and then I divided it by two."* (pupil 32)	0	0	3	10	3	10	3	10	7	29
B. TEMPERATURE (OTHER THAN 30) INTERMEDIATE BETWEEN 10 AND 50 *"$45^{o}C$ - they were equal amounts of water, but the hotter one would be cooled down slightly by the cooler one."* (pupil 33)	6	20	2	7	4	13	5	17	6	25
TOTAL ORDINAL RESPONSES		20		17		23		28		54
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	4	13	2	7	2	7	2	7	0	0
N. ADDITION - i.e. 60^{o}	9	30	9	31	13	43	11	38	5	21
O. CONFUSION WITH FIGURES FOR GIVEN VOLUMES OF WATER	4	13	0	0	0	0	0	0	1	4
P. SUBTRACTION i.e. 40^{o} *"40 - I simply deducted 10"* (pupil 80)	6	20	11	38	5	17	5	17	5	21
Q. HOT WATER STAYS THE SAME TEMPERATURE - 50	1	3	2	7	3	10	3	10	0	0
TOTAL ALTERNATIVE RESPONSES		80		83		77		72		46

QUESTION 27 MIXING LIQUIDS IV

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. 50^o, QUANTITATIVELY CALCULATED *"(300 x 60) + (100 x 20) divided by the volume of the final thing, which would be 400."* (he fills in 50^o) (pupil 62)	0	0	0	0	0	0	1	3	1	4
B. 45^o-55^o, TEMPERATURES AVERAGED OUT AND AN ALLOWANCE MADE FOR THE GREATER VOLUME OF HOTTER WATER. *"That's hotter and its got more water so that'll be warmer than it was - so it'll be about 50, I think."* (pupil 43)	4	13	4	14	5	17	2	7	1	4
C. INTERMEDIATE TEMPERATURE WITH NO ADJUSTMENT FOR DIFFERENT VOLUMES 30^o (pupil 13) 40^o (pupil 14)	1	3	1	3	1	3	3	10	4	17
TOTAL ORDINAL RESPONSES		17		17		20		21		25
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW *"50^oC - there's 400 c.c. water but there's 80^o to heat it up, so I reckon it'd go about 50 - because that doesn't add to that - it like takes off."* (pupil 11)	8	27	4	14	7	23	6	21	6	25
N. ADDITION - i.e. 80^o *"By adding the 60 and the 20 together."* (pupil 38)	5	17	8	28	11	37	6	21	3	13
O. CONFUSION WITH FIGURES FOR GIVEN VOLUMES OF WATER *"480 cm^3"* (300 + 100 + 80) = 480 (pupil 18)	4	13	1	3	0	0	0	0	1	4
P. SUBTRACTION - i.e. 40^o	2	7	9	31	1	3	5	17	4	17
Q. TEMPERATURE IS PROPORTIONAL TO VOLUME *"300 at 60 is equal to 150 at 30^o. . ."* (pupil 41) *"120^o"* ($100cm^3$ at 20^oC = 300 at 60^oC, then 60 + 60 = 120^o) (pupil 23)	3	10	0	0	2	7	1	3	2	8
R. HOT WATER STAYS THE SAME TEMPERATURE *"60^o, because there's a lot of water at 60^o, but there's only just a bit at 20^o, so I think that'll have more of an effect on it."* (pupil 79)	1	3	2	7	2	7	3	10	2	8

Category set continued on next page.

QUESTION 27 MIXING LIQUIDS IV (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
S. MISCELLANEOUS 100 (60 + 20 = 80, then 80 + 20 and this 20 is the difference between 300 and 100) (pupil 49) 90^0 (60 + 20 = 80, then + 10 - the 10 comes from the extra volume of water) (pupil 16) 70^0C (20/2 = 10 + 60 = 70) Halved 20 *"because it's cancelling itself down, to a certain extent."* (pupil 24)	2	7	0	0	1	3	2	7	0	0
TOTAL ALTERNATIVE RESPONSES		83		83		80		79		75

Q.29. HEAT AND TEMPERATURE

Q.30. DEFINITION OF HEAT

Pupils were asked the following summarizing question after the mixing problems just described.

Q.29. What would you say the difference was between heat and temperature?

At the end of the heat interview pupils were asked a further summary question as follows:

Q.30. If I asked you to say in a couple of sentences what heat is, what would you say?

COMMENT ON RESULTS

The overriding impression from examination of the results of these two open-ended questions is that pupil responses were very varied, and so correspondingly hard to categorise and impossible to scale. Significant numbers of responses fell into the Miscellaneous and Uncodeable categories for both questions.

In general frequencies for scientifically-acceptable definitions of heat were low and responses to both questions showed that pupils of all ages lacked the ability to differentiate between heat and temperature. There was, however, an increase with age in the association of heat with the word "energy".

Some popular alternative response categories proved interesting. For example, 27% of all responses incorporated explicit statements to the effect that heat and temperature were in fact synonymous. The view that heat is hot but that temperature can be hot or cold was held by nearly a quarter of the 12 year old group, though this category was less popular with older children. Many respondents equated the idea of heat with a hot body or substance or described it as being given off from a heat source. About a third of the 12 year old group chose an egocentric explanation of heat - that is, pupils related it to themselves. This type of definition, again, was less common in older pupils.

QUESTION 29 HEAT AND TEMPERATURE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 29		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
H. QUANTITY OF HEAT DEPENDS ON MASS OF SUBSTANCE, TEMPERATURE DOES NOT *"But temperature is average temperature of everything but heat is different. It very much depends on how much heat you put in, whereas temperature is the average thing."* (pupil 3) *"If heat were like a measurement and you add 30 to 30 it'd go up to 60, but with temperature it doesn't, it stays at 30."* (pupil 11) *"The temperature is like a grade of how hot something is and heat energy is what's inside it - what the object has got . . . "* (pupil 23)	3	10	0	0	0	0	1	3	0	0
I. HEAT IS ENERGY, TEMPERATURE IS THE EFFECT OF HEAT/MEASURES HEAT *"Heat is the amount of energy, and temperature is just a measure of heat."* (pupil 69)	1	3	3	10	5	17	8	28	5	21
J. TEMPERATURE IS A MEASUREMENT OF HEAT *"Temperature you measure heat with, but heat is hot - you can feel heat."* (pupil 60)	5	17	6	21	6	21	2	7	2	8
K. THERE IS NO DIFFERENCE - HEAT AND TEMPERATURE ARE THE SAME THING *"I don't think there is one, is there?"* (pupil 2)	8	27	9	31	8	28	7	24	6	25
L. HEAT IS HOT, BUT TEMPERATURE CAN BE HOT OR COLD *"Below 0^o I don't think it's heat . . . well, you can but it wouldn't be like you think it'd be - really boiling - it's just cold heat."* (pupil 13) *"Temperature - you can have something freezing, whereas heat - you tend to think of something being hot. Heat . . . it's the warm end of the scale."* (pupil 32)	7	23	6	21	1	3	2	7	1	4
M. MISCELLANEOUS 1. Temperature is referred to as "the amount of heat" - although this is obviously wrong, if taken literally, I am not convinced that it is always meant in this way. Therefore I decided that the categorization was not firm enough to merit a separate category. 5 responses fitted into this group. e.g. *"Temperature is the amount of heat in that space . . . it tells you the hotness of the water."* (pupil 53)	4	13	0	0	5	17	3	10	6	25

Category set continued on next page.

QUESTION 29 HEAT AND TEMPERATURE (continued)

CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 29		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
5. 1. continued *"Temperature is the amount of heat, and heat raises the temperature."* (pupil 66)										
2. You have got to make heat, but temperature is natural. 2 responses in this group. e.g. *"Well, temperature, it's just like a thing - like the sun - when you get the sun shining - you get a temperature then. But heat - you've got to get something to make heat. But for temperature - it just comes - it's just natural temperature."* (pupil 22)										
3. Heat has radioactivity in it, some things have heat others have temperature. (pupil 16)										
4. Heat is something you make, but you don't make temperature. (pupil 79)										
5. Temperature is a way of *"seeing heat - like a thermometer, it registers heat."* (pupil 74)										
6. An incorrect reference to particles: *"Temperature is measured just by the expansion of it and temperature is equivalent to the speed of the particles, whereas heat is something else. Heat also depends on the energy of the particles in different ways such as the distance apart they are - the potential they have - which comes into when they change from solids to liquids etc."* (pupil 62)										
7. Temperature is higher than heat. (pupil 50)										
8. Temperature is what you heat something <u>to</u>. (pupil 41)										
9. You can't see temperature - you can see heat - a fire, flame etc. (pupil 37)										
10. Heat keeps you warm, a temperature is when you are ill. (pupil 17)										
U. UNCODEABLE/DON'T KNOW *"Heat is hotter than temperature and temperature is higher than heat."* (pupil 52)	2	7	5	17	4	14	6	21	4	17

QUESTION 30 DEFINITION OF HEAT

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
H. HEAT INVOLVES INCREASED MOLECULAR MOVEMENT *" . . . Perhaps I should say that it was the increased speed of the molecules inside a substance making the actual substance hotter."* (pupil 72)	0	0	2	7	3	10	3	10	2	8
I. ENERGY *"A form of energy."* (pupil 73) *"Heat is energy - when it heats something up, it will transfer the heat energy to what it's heating up."* (pupil 54)	3	10	4	14	8	27	9	31	13	54
J. HEAT IS SOMETHING HOT/HOT OBJECTS/SUBSTANCES *"Heat is warm air."* (pupil 80) *"Something that's at a higher temperature - warmer."* (pupil 45) *"Heat is a warming fluid or solid."* (pupil 24)	5	17	3	10	4	13	5	17	3	13
K. HEAT IS GIVEN OFF BY SOMETHING/HEAT SOURCES/USEABLE ENERGY *"A source of energy."* (pupil 56) *"Particles within an object becoming hotter with another supply of heat - it provides warmth and energy to make things and do things."* (pupil 38)	3	10	2	7	7	23	3	10	2	8
L. HEAT IS SOMETHING YOU FEEL/YOU CAN USE *" . . . when you touch it it feels hot - if anything's got the heat in it."* (pupil 7) *"Heat's a daily use. You use it in most things - one of the main things you use really - heat."* (pupil 17) *I'd say that if it gets too hot, it can burn."* (you) (pupil 19)	9	30	3	10	2	7	2	7	2	8
M. WARMTH/WARM/IT'S HOT *"It's warmth."* (pupil 5) *"It's warm."* (pupil 6) *"It's hot - heat builds up."* (pupil 29)	5	17	5	17	1	3	1	3	0	0

Category set continued on next page.

QUESTION 30 DEFINITION OF HEAT (continued)

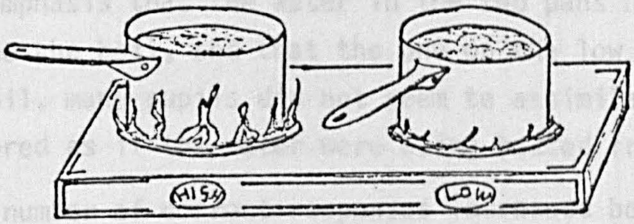
DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
N. MISCELLANEOUS (i) Heat is the opposite of cold/ heat is more than 0°C. (3 pupils) (ii) Heat is particles/air particles warming up. (2 pupils) (iii) Heat is *"conduction of molecules"* (1 pupil) (iv) Heat is *"rays, like light rays"*, which, when they strike something, make the molecules vibrate. (1 pupil) (v) Heat is *" a force that can change things"*. (1 pupil)	2	7	3	10	4	13	1	3	2	8
U. UNCODEABLE/DON'T KNOW *"It's the temperature all round."* (pupil 9)	3	10	7	24	1	3	5	17	0	0

Q.31. POTATOES - WATER TEMPERATURE

Q.32. POTATOES - COOKING TIME

Q.33. POTATOES

The following three questions were based on the written test item shown below.



A cook put two saucepans of potatoes on a stove to boil. When they were both boiling she turned the gas under one down low so that the water was just kept boiling. She left the other on high. She thought the one on high would cook the potatoes faster. A friend said it would make no difference to the cooking time of the potatoes.

Which person do you think is right?

Give your reason.

APU item

POTATOES is a reiteration of this written question. The aim of the preceding two questions was to identify possible basic misconceptions which may be applied to its solution. After a restatement of the problem, with particular emphasis on the fact that both pans of water had already boiled, the following questions were posed.

Q.31. How would the temperature of the water in the two pans compare with one another - would they be the same, or would one be hotter than the other?

Q.32. What would the cooking time of the potatoes (how long it took them to cook) depend on?

Q.33. Who do you think was right - the cook or the friend? Can you explain?

Q.31. POTATOES - WATER TEMPERATURE

Q.32. POTATOES - COOKING TIME (contd.)

Q.33. POTATOES

COMMENT ON RESULTS

These questions were bedevilled by a basic misunderstanding. Despite emphasis that the water in the two pans had already been brought to the boil, and that the one on the low gas remained just on the boil, many pupils did not seem to assimilate this information and answered as if the water were being heated from cold.

The number of correct responses increased between 14 and 16 years (except for POTATOES - COOKING TIME where the pattern was less clear cut).

In general, about one quarter of the responses for each question seemed to imply lack of understanding of a fixed boiling point. So, for example, answers contained the Idea that the gas is the crucial variable; that the pan on 'High' contains hotter water and that the potatoes in this pan would cook faster.

The large number of 'Uncodeable' responses partly reflects the fact that many pupil answers were loosely worded with, for example, a distinction between the words 'heat' and 'temperature' frequently not made.

QUESTION 31 POTATOES - WATER TEMPERATURE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. SAME, BECAUSE BOTH BOILING/ CAN'T GET ANY HIGHER/FIXED BOILING POINT *"No, they'd be the same because they were boiling - water only boils at 100°C - it can't get any hotter."* (pupil 64)	10	33	13	45	10	33	21	72	9	38
B. SAME, NO REASON/SAME BECAUSE GAS UNDER THE TWO PANS WOULD BE ABOUT THE SAME *"Same 'cos there's still gas going because they're still on heat."* (pupil 49) *"They'd be the same, but this one would boil away quicker."* (pupil 68)	3	10	1	3	4	13	1	3	9	38
TOTAL ORDINAL RESPONSES		43		48		47		76		75
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	0	0	1	3	2	7	0	0
N. ONE ON 'HIGH' IS HIGHER TEMPERATURE, BECAUSE THERE IS MORE HEAT *"The higher one is hotter."* (pupil 5) *"The one on 'High' would be higher, because that's getting more heat and it'd boil quicker than the one on the 'Low' stove."* (pupil 22)	15	50	14	48	12	40	3	10	6	25
O. ONE ON 'LOW' GAS IS AT A HIGHER TEMPERATURE BECAUSE FLAMES REACH WATER RATHER THAN GO UP SIDES OF PAN *" . . . because with the 'Low' one the heat's under the pan, with the 'High' one it's rising up over the pan, so it isn't actually going under the pan to boil."* (pupil 18)	1	3	1	3	2	7	2	7	0	0
P. MISCELLANEOUS *"That one - the one on 'High' - is hotter on the edge. And that one - the 'Low' one - is just kept at a steady temperature . . . the potatoes in that will cook faster, because all the water is the same temperature."* (pupil 40)	0	0	0	0	1	3	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		57		52		53		24		25

QUESTION 32 POTATOES - COOKING TIME

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. TEMPERATURE OF THE WATER *"The temperature of the water."* (pupil 62) *"The heat of the water."* (pupil 61) *"How small the potatoes are, whether it's boiling or not."* (pupil 70)	11	37	9	31	12	40	19	66	9	38
TOTAL ORDINAL RESPONSES		37		31		40		66		38
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW *"How much heat the potatoes absorb."* (pupil 77) *"How much heat there is."* (pupil 23)	5	17	9	31	9	30	7	24	10	42
N. HEIGHT OF GAS *"The heat - how much the heat is turned up."* (pupil 58)	12	40	5	17	8	27	1	3	4	17
O. MISCELLANEOUS *"How much water and how many potatoes."* (pupil 46)	2	7	6	21	1	3	2	7	1	4
TOTAL ALTERNATIVE RESPONSES		63		69		60		34		62

QUESTION 33 POTATOES

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. FRIEND, BECAUSE BOTH PANS BOILING/ SAME TEMPERATURE *"Friend, because there's no higher temperature than boiling point."* (pupil 6) *"Both at the same time because they'd both be boiling."* (pupil 34)	9	30	9	31	11	37	19	66	14	58
B. FRIEND, NO REASON/ POTATOES HAVE A SET TIME TO COOK/ KNOW THIS FROM EXPERIENCE *"The friend because they will get ready at the same time."* (pupil 82) *"I can't really understand why but I think it's the friend that's right . . . I think when my mother's cooking at home I turn the gas up and she turns it back low again - she says it'll cook more easily . . . "* (pupil 57)	3	10	6	21	4	13	5	17	3	13
TOTAL ORDINAL RESPONSES		40		52		50		83		71
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW *"The friend. Because they both heat up same time, but that one gets hotter"* (the one on 'High') (pupil 7)	4	13	1	3	4	13	0	0	1	4
N. NEITHER CORRECT. ONE ON 'LOW' WOULD COOK FASTER BECAUSE WATER IS AT A UNIFORM TEMPERATURE/ BOILS MORE 'STEADILY' *"No, I think the lower one would be ready first . . . because with it keeping at a constant level it'd cook all the way through . . . "* (pupil 38)	2	7	2	7	5	17	3	10	2	8
O. COOK, BECAUSE MORE HEAT GOING TO THE ONE ON 'HIGH', THEREFORE COOKS FASTER *"Because the temperature's higher and it'd heat the potatoes up quicker."* (pupil 13)	11	37	10	34	6	20	2	7	4	17
P. MISCELLANEOUS *"Chef - well, chef has to cook things and they know more about them than other people."* (pupil 19)	1	3	1	3	0	0	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		60		48		50		17		29

IDEA LEVEL

Further analysis of data on HEAT AND TEMPERATURE requires rather different procedures from those already described for pressure. The key issue is the conceptual distinction between heat as an extensive quantity and temperature as an intensive one. The questions related to the Idea attempt to tease out pupil understanding of this distinction, though, because they address different aspects of it, the pupil frameworks are necessarily question-context specific. Frameworks are presented as illustrations of two levels of understanding in the Table below. Frequencies are given for the three age groups, but it must be borne in mind that the frameworks are not mutually exclusive.

TABLE 9 PUPIL FRAMEWORKS - HEAT AND TEMPERATURE

LEVEL OF UNDERSTANDING - I. Temperature is an intensive physical quantity whereas heat is not.

PUPIL FRAMEWORK — FREQUENCIES

KETTLE AND BATH
1. Heat energy is an "amount" variable, not an intensive one.in cats.22A,22B, 23A,23B

12 Yrs (n=30) (X12)		14 Yrs (X14 & Y14)		16 Yrs (Y16 & Z16)	
Q22	Q23	Q22 (n=56)	Q23 (n=59)	Q22 (n=29)	Q23 (n=53)
73%	33%	71%	36%	79%	31%

MIXING LIQUIDS
2. When water of the same temperature is mixed, the resultant mixture is the same temp.,independent of volume. in cats.24A,25A

12 Yrs (n=30)(X12)		14 Yrs (X14 & Y14) (n=59)		16 Yrs (Y16 & Z16) (n=53)	
Q24	Q25	Q24	Q25	Q24	Q25
50%	40%	71%	68%	77%	68%

POTATOES
3. Once boiling,water stays at the same temp. independent of heat input.in cats.31A,32A,33A

12 Yrs (n=30) (X12)			14 Yrs (X14 & Y14) (n=59)			16 Yrs (Y16 & Z16) (n=53)		
Q31	Q32	Q33	Q31	Q32	Q33	Q31	Q32	Q33
33%	37%	30%	39%	36%	34%	57%	53%	62%

LEVEL OF UNDERSTANDING - II. Confusion betweem amount and intensivity criteria.

KETTLE AND BATH
4. The amount of heat energy is related solely to temperature (irrespective of volume).in cats. 22N,23N

12 Yrs (n=30)(X12)		14 Yrs (X14 & Y14)		16 Yrs (Y16 & Z16)	
Q22	Q23	Q22 (n=56)	Q23 (n=59)	Q22 (n=29)	Q23 (n=52)
7%	27%	2%	22%	0	38%

MIXING LIQUIDS
5. Temp.is proportional to the volume of liquid in cats.25P,27Q

12 Yrs (X12)(n=30)		14 Yrs (X14 &Y14) (n=59)		16 Yrs (Y16 & Z16) (n=53)	
Q25	Q27	Q25	Q27	Q25	Q27
7%	10%	5%	3%	11%	6%

MIXING LIQUIDS
6. Temp. values are added together to solve mixing problems in cats.24N,25N,26N, 27N

12 Yrs (X12) (n=30)				14 Yrs (X14 & Y14) (n=59)				16 Yrs (Y16 & Z16) (n=53)			
Q24	Q25	Q26	Q27	Q24	Q25	Q26	Q27	Q24	Q25	Q26	Q27
27%	13%	30%	17%	25%	17%	37%	32%	21%	13%	30%	17%

MIXING LIQUIDS
7. Temp. values are subtracted to solve mixing problems in cats.26P,27P

12 Yrs (X12)(n=30)		14 Yrs (X14 &Y14) (n=59)		16 Yrs (Y16 & Z16) (n=53)	
Q26	Q27	Q26	Q27	Q26	Q27
20%	7%	27%	17%	19%	17%

POTATOES
8. More heat energy (a higher gas setting) increases the temp. of boiling water in cats. 31N, 32N,33Q

12 Yrs (X12)(n=30)			14 Yrs (X14 & Y14) (n=59)			16 Yrs (Y16 & Z16) (n=53)		
Q31	Q32	Q33	Q31	Q32	Q33	Q31	Q32	Q33
50%	40%	37%	44%	22%	27%	17%	9%	11%

COMMENT ON PUPIL UNDERSTANDING OF HEAT AND TEMPERATURE

Many of the alternative frameworks and misconceptions concerning the nature of heat and temperature identified here have been reported elsewhere. However, with the exception of Andersson's study on boiling point (Andersson, 1980), other workers have taken younger children as subjects for investigation, with the oldest age group studied in detail being about 12 years. It is a striking result of the present study that many of the naive ideas which Albert (1978), Erickson (1979) and Strauss (1977) described as typifying the thinking of young children apparently persist beyond 12 years.

It is clear that confusion between the intensity and the amount of heat possessed by a body, reported by Erickson (1979) and by Strauss (1977), is common amongst 12-16 year olds. However, age trends were very inconsistent across question contexts. So, the KETTLE AND BATH problems showed no significant change with age, the easier of the MIXING LIQUIDS problems (those with water of the same temperature - I and II) showed an increase in correct responses from 12 to 14 years but no further increase, and the more difficult MIXING LIQUIDS problems (those with different temperatures - III and IV) showed no clear age trends. The POTATOES questions on the other hand, showed a marked upward trend in ordinal responses between 14 and 16 years.

In the MIXING LIQUIDS problems, it is interesting that mathematical manipulations, both addition and subtraction, were popular solutions for pupils of all three ages. This does not entirely corroborate the work of Strauss (1977), who found that his 12-13 year old pupils could solve mixing problems satisfactorily. The tasks in the two studies, however, are not quite comparable. Although one of Strauss's intensivity tasks had equal volumes of water of different temperatures, none were as difficult to solve as MIXING LIQUIDS IV - i.e. different temperatures and different volumes.

Andersson (1980), reported pupil difficulty up to 15 years with the concept of fixed boiling point. His results are confirmed by present findings that many 12-14 year old pupils believed that an increased heat input would raise the boiling point.

The understanding that heat is an extensive quantity (the reverse side of the coin) seemed to be no more accessible. The framework embodying the idea that the amount of heat is related solely to temperature (and therefore the higher the temperature, the more heat energy) was well subscribed to in KETTLE AND BATH. Indeed, the contribution to this framework increased with age to over a third of the 16 year old group.

As to the nature of heat itself, elements of ideas identified by Albert (1978) in 4-9 year olds appear in the present results, particularly when pupils were asked in a completely open-ended way to define heat (DEFINITION OF HEAT). The 4-5 year olds in Albert's sample were unable to divorce the idea of heat from the hot object, yet this same explanation was still being used by 15% of 16 year olds. Albert proposed that egocentric descriptions of heat were typical of 6-7 year old thinking but 30% of 12 year olds in the interview sample offered the same type of description.

Molecular explanations of heat were rarely volunteered. This confirms results from a pressure Idea (MOLECULAR BOMBARDMENT) indicating that, although older pupils have some factual knowledge about the behaviour of molecules (e.g. that molecular speed increases as temperature rises) they do not readily apply this information in the explanation of phenomena.

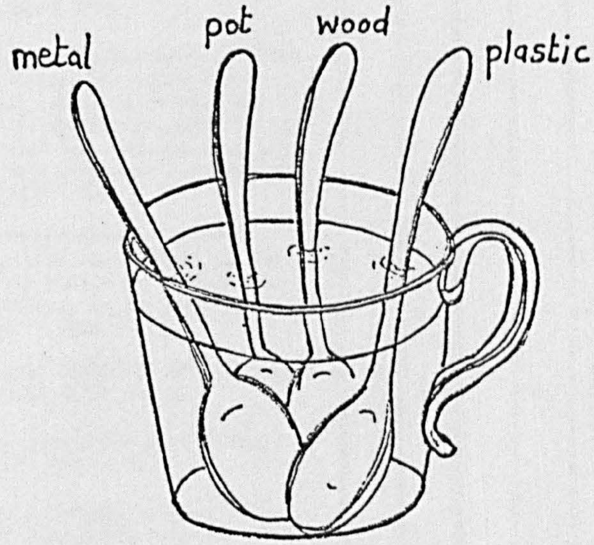
CONDUCTION OF HEAT

HEAT ENERGY TRAVELS THROUGH DIFFERENT MATERIALS AT DIFFERENT RATES

Two questions (PLATES and HANDLEBARS) test the Idea of heat conductivity in settings which ask for explanations of the sensation of cold. Another question (SPOONS) requires an explanation of the sensation of hotness.

Q.34. SPOONS

This question was given in the written test (see below) and repeated in interview. The apparatus as shown in the diagram was presented to pupils in interview and they were able to feel the spoon handles before giving their explanations.



Mary left some dirty spoons in a jug of hot water to soak.
She noticed that the handle of the metal spoon felt hotter sooner than the others.
Explain how this happens.

____

____

____

COMMENT ON RESULTS

There was a clear trend with age, showing an increased frequency of ordinal responses from about a quarter of 12 year olds to more than three quarters of 16 year olds. Few younger pupils, however, (and only 40% of 16 year olds) could explain what was meant by a good conductor in molecular terms. Most ordinal responses simply offered the factual information that metal was a good conductor of heat.

Many pupils were satisfied with the tautological statement that the metal spoon felt hotter because it got hotter quicker.

In addition, several interesting alternative frameworks were proposed, mostly by the 12 year old pupils. These included the

Q.34. SPOONS (contd.)

notion that metal heats up only on the surface (thereby concentrating the heat in this area) and the idea that metals attract heat, pull it towards them.

QUESTION 34 SPOONS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. MORE HEAT ENERGY TRANSFERRED BETWEEN PARTICLES IN METAL/ METAL PARTICLES VIBRATE MORE	0	0	1	3	7	23	8	28	13	54
"Metal conducts heat better . . . heat can travel through the metal better - it's absorbed. Metal particles are . . moving more at the bottom, and vibrating them further up. But as they get towards the top they aren't vibrating as much." (pupil 33)										
" . . . the molecules are speeded up . . they biff against each other, so the energy will be passed up through the moving particles. It happens faster in the metal." (pupil 62)										
B. METAL IS A GOOD CONDUCTOR OF HEAT/HEAT TRAVELS THROUGH METAL EASIER	8	27	12	41	12	40	14	48	7	29
" . . . heat energy can pass through it." (metal) (pupil 78)										
"It can travel through metal . . . it's sort of like a thermometer - the water touches the bottom of the spoon, and slowly the heat rises up so it touches the top of the spoon - the heat." (pupil 15)										
"Well, because metal is a conductor, it conducts the heat up into the metal . . it transfers heat . . . transfers heat along it." (pupil 64)										
TOTAL ORDINAL RESPONSES		27		45		63		76		83
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	3	10	1	3	1	3	1	3	1	4
N. METAL GETS HOTTER QUICKER	6	20	7	24	8	27	2	7	1	4
"I've been told that metal heats up faster than any of the other three." (pupil 46)										
"Metal takes heat in . . . and wood . . you can't really heat up wood with water." (pupil 34)										
"Well, metal does get hot and wood doesn't." (pupil 84)										
O. METAL HOLDS/STORES HEAT	1	3	1	3	0	0	0	0	1	4
"Metal holds heat . . . heat easily goes into it . . . wood doesn't hold heat." (pupil 83)										

Category set continued on next page.

QUESTION 34 SPOONS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	X12 n = 30 No.	X12 %	X14 n = 29 No.	X14 %	Y14 n = 30 No.	Y14 %	Y16 n = 29 No.	Y16 %	Z16 n = 24 No.	Z16 %
P. METAL ATTRACTS/PULLS IN/EXTRACTS HEAT *"I suppose it's a better conductor of heat than the other two . . . well heat . . . it'll be attracted to it . . like pulls the heat towards it . . . as if it was like a magnet."* (pupil 2) *" . . . a metal just pulls in heat - I can't remember the word . . . and it sucks it in and keeps the heat."* (pupil 26)	3	10	5	17	0	0	0	0	0	0
Q. METAL IS ONLY HOT ON THE SURFACE, WOOD IS HOT ALL THE WAY THROUGH *"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."* (pupil 6) *"I think it'd be hot on the outside mainly."* (pupil 30)	4	13	0	0	0	0	0	0	1	4
R. MISCELLANEOUS (i) The hotness soaks in (1 pupil) (ii) Particles of heat travel up metal (1 pupil) (iii) Metal conducts electricity, electricity carries heat (1 pupil) (iv) Metal expands and makes room for heat to travel up (1 pupil) (v) Hard substances heat up quicker than soft ones (1 pupil) (vi) Metal and pot spoons have been through fire in their manufacture (1 pupil) (vii) Heat rises - always goes upwards (if heat source at top, other end would <u>not</u> get hot) (1 pupil)	5	17	2	7	2	7	4	14	0	0
TOTAL ALTERNATIVE RESPONSES		73		55		37		24		17

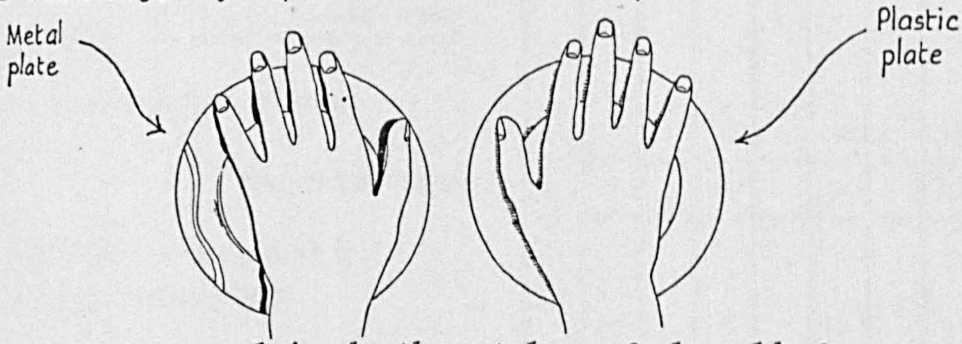
Q.35. PLATES - THERMOMETER READINGS

Q.36. PLATES

Pupils were told that the plastic and metal plates placed in front of them had been in the room overnight. They were then asked the following question:

Q.35. If you could put thermometers in close contact with these two plates would you expect to get any difference in the readings, or would they be the same?

Pupils were then asked to feel the plates with the palms of their hands and to comment on which plate, if either, felt colder. The vast majority reported that the metal plate felt colder.



Q.36. Can you explain why the metal one ***feels*** *colder?*

COMMENT ON RESULTS

Typically, responses to PLATES - THERMOMETER READINGS were inexplicit. There was no change in the percentage of ordinal responses with age for this question. About half of all responses indicated that the temperature of the metal plate would be lower, and a variety of reasons were suggested for this. For example, some pupils made the simple statement that metals are colder substances, some suggested that metals lose heat quicker and others proposed that metals were more responsive to cold air. Six pupils in the second round of interviews suggested that the metal plate was colder because cold travels through/is absorbed by metal. Since this response did not emerge in the first round, no category was already established, and these pupils had to be categorized as Miscellaneous.

Very few pupils gave a scientifically-correct response to PLATES. Only two pupils in the two younger age groups did so, though the figure rose to 19% for the 16 year olds. The large

Q.35. PLATES - THERMOMETER READINGS

Q.36. PLATES (contd.)

numbers of pupils in both the Uncodeable and Miscellaneous categories indicate the difficulty of categorizing this question and the wide range of responses offered. About a fifth of all responses indicated that the metal plate had lost its heat to the air whereas the plastic one retained heat and about the same number incorporated explanations which referred to some 'natural' property of metal. As with several other questions the notion of cold as a separate entity occurred.

QUESTION 35 PLATES - THERMOMETER READINGS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. SAME TEMPERATURE BECAUSE BOTH AT ROOM TEMPERATURE/IN SAME AIR *"With them being in the same room at a certain temperature . . . I suppose that can't get any warmer than that if it's in the same temperature."* (pupil 44)	4	13	5	17	3	10	5	17	3	13
B. SAME TEMPERATURE BECAUSE THERE IS NO HEAT SOURCE Same temperature *"because there's now't to warm it up."* (pupil 56) *"They'd be the same, because neither of them had collected any heat yet."* (pupil 7)	2	7	0	0	2	7	0	0	0	0
C. SAME TEMPERATURE, NO REASON	2	7	1	3	1	3	0	0	3	13
TOTAL ORDINAL RESPONSES		27		21		20		17		25
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	5	17	2	7	3	10	5	17	6	25
N. METAL IS COLDER/A COLD SUBSTANCE/ MATERIAL *" . . . because it's a cold material."* (pupil 6) Metal one colder *"because it's metal."* (pupil 53)	4	13	1	3	4	13	1	3	0	0
O. METAL COOLER, BECAUSE METAL COOLS QUICKER/LOSES HEAT QUICKER *"Well, it depends on the amount of time they've been left, because that would get colder quicker than the plastic one."* (pupil 39)	2	7	2	7	4	13	5	17	1	4
P. METAL PLATE MORE RESPONSIVE TO SURROUNDING AIR/COLD AIR EASILY GOES ON IT *" . . . the metal one . . . it would depend on the temperature of the room . . . the temperature would have more effect on that."* (pupil 32) Metal colder *"because air easily goes on it."* (pupil 20)	4	13	3	10	7	23	2	7	3	13
Q. METAL PLATE HOTTER BECAUSE METAL CONDUCTS HEAT/HEAT ATTRACTED TO METAL Metal would *"collect more heat than that one."* (pupil 46)	4	13	1	3	1	3	1	3	0	0
R. METAL COOLER, NO REASON	1	3	6	21	3	10	7	24	7	29

Category set continued on next page.

QUESTION 35 PLATES - THERMOMETER READINGS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
S. METAL HOTTER, NO REASON	0	0	2	7	1	3	1	3	1	4
T. MISCELLANEOUS	2	7	6	21	1	3	2	7	0	0
(i) Response refers back to the context of the SPOONS question (Q34) (2 pupils)										
(ii) Metals are hotter substances (1 pupil)										
TOTAL ALTERNATIVE RESPONSES		73		79		80		83		75

QUESTION 36 PLATES

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. METAL IS A BETTER CONDUCTOR THAN PLASTIC, THEREFORE CARRIES HEAT AWAY FROM THE HAND, THEREFORE IT FEELS COOLER *"Metal is a good conductor of heat and the plastic is not very good, and it takes away the heat from your hand quicker than the plastic does - and so the metal feels cold to the touch."* (pupil 75)	1	3	1	3	0	0	6	21	4	17
TOTAL ORDINAL RESPONSES		3		3		0		21		17
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	7	23	10	34	12	40	10	34	9	38
N. METAL FEELS COLDER BECAUSE LOST HEAT TO SURROUNDINGS/PLASTIC RETAINS HEAT *"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."* (pupil 48) *"Metal one is cooler because it'll lose the heat it's got."* (from the atmosphere) (pupil 66)	6	20	3	10	7	23	6	21	8	33
O. METAL FEELS COLDER BECAUSE CONDUCTS/ATTRACTS COLD/COLD AIR/METAL RESPONDS TO COLDNESS/DOES NOT ATTRACT THE HEAT *" . . . with it being metal any air collects around it making it colder . . plastic doesn't attract any heat or air around it."* (pupil 2) *"Metal colder because cold passes through it much quicker than the plastic."* (pupil 58)	1	3	6	21	3	10	2	7	0	0
P. METAL FEELS COLDER BECAUSE OF SOME OBSERVABLE OR 'NATURAL' PROPERTY OF METAL *"I just think it's the surface - it's a lot smoother."* (pupil 23) *"Cold air comes on to metal plate and goes through it because it's thin."* (pupil 28) *"Feels colder because it's metal."* (pupil 21) *" . . . it's metal and metal is cold."* (pupil 29)	11	37	7	24	5	17	4	14	0	0

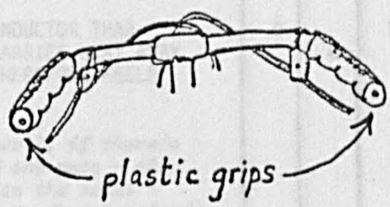
Category set continued on next page.

QUESTION 36 PLATES (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
M. MISCELLANEOUS	4	13	2	7	3	10	1	3	3	13
(i) Metal warmer because of properties of metal (colour and thickness) (2 pupils)										
(ii) Plastic better conductor of heat (1 pupil)										
(iii) Metal only 'reacts' if heated (1 pupil)										
(iv) Steel needs <u>more</u> heat to warm it than plastic (3 pupils)										
(v) Blood in the hand got used to coldness (1 pupil)										
(vi) Metal colder because it contracted (1 pupil)										
(vii) Metal colder because cold <u>on the outside</u> only (1 pupil)										
TOTAL ALTERNATIVE RESPONSES		97		97		100		79		83

Q.37. HANDLEBARS

The question below was given in the written test and repeated in interview.



On a frosty day, Sally noticed the metal part of the handle bars of a bicycle felt colder than the white plastic grips.

What is the reason for this?

____

____

____

APU item

COMMENT ON RESULTS

Only a single pupil from the two younger age groups offered a correct response, though about a fifth of 16 year olds did so. The idea of heat conduction from the person to the metal resulting in a sensation of coldness was clearly difficult to grasp.

There were some interesting alternative responses to this question. About a quarter of all responses attributed the coldness of the metal to the fact that metal attracts or conducts cold better than plastic. Others contained the idea that the two materials felt different because of some 'natural' observable property and still others indicated that metal was colder because it had lost its heat, whereas plastic retained heat.

The large numbers of responses in the Uncodeable and Miscellaneous categories indicate the wide variety of ideas (often muddled or nonsensical) which were proposed in response to this difficult question.

QUESTION 37 HANDLEBARS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. METAL IS A BETTER CONDUCTOR THAN PLASTIC, THEREFORE CARRIES HEAT AWAY FROM SALLY'S HAND, THEREFORE FEELS COLD *"Conductivity . . . well, if there's any heat around - if she puts - the heat in her hands - on the metal - will get conducted away from her hands, because it's a good conductor."* (pupil 76)	0	0	1	3	0	0	5	17	5	21
TOTAL ORDINAL RESPONSES		0		3		0		17		21
U. UNCODEABLE/DON'T KNOW *"Metal gets colder quicker than plastic again . . . don't know why."* (pupil 80)	6	20	4	14	7	23	9	31	5	21
N. METAL FEELS COLDER BECAUSE HEAT LOST TO SURROUNDINGS/ PLASTIC RETAINS HEAT (FROM AIR OR SALLY'S HANDS). *"Previously it was quite warm, so they both heated up, then it was cold this morning so the metal has lost its heat to the surroundings and the plastic has retained some of it - more than the metal. So the metal appears - is - cooler than the plastic."* (pupil 62)	3	10	3	10	3	10	4	14	6	25
O. METAL ATTRACTS/CONDUCTS/ABSORBS THE COLD/PLASTIC DOESN'T ATTRACT/RETAIN COLDNESS *"Metal is a harder substance and it takes the cold in much more quicker."* (pupil 9) *"Metal absorbs more cold than the plastic does."* (pupil 17)	7	23	13	45	7	23	8	28	5	21
P. METAL COOLS FASTER BECAUSE OF SOME OBSERVABLE OR 'NATURAL' PROPERTY OF METAL *"Plastic grips are softer so they feel warmer."* (pupil 12) *"The metal is much thinner . . . the cold air could stay on here."* (pupil 28) *"Steel is just colder I think . . . "* (pupil 13) *"Only that they're different materials."* (pupil 45)	6	20	3	10	8	27	2	7	0	0
Q. METAL FEELS COLDER BECAUSE UNPROTECTED/ PLASTIC COVERS METAL ON GRIPS, THEREFORE COLD CAN'T GET AT IT *"Because handlebars have got like something to cover them up and the metal hasn't."* (pupil 27)	4	13	2	7	1	3	0	0	1	4

Category set continued on next page.

QUESTION 37 HANDLEBARS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
R. MISCELLANEOUS	4	13	3	10	4	13	1	3	2	8
(i) Metal soaks up air better than plastic (2 pupils)										
(ii) Cold air sticks to metal, not to plastic (and freezes) (3 pupils)										
(iii) Cold is transferred from handlebar to hand (1 pupil)										
(iv) Metal is more responsive to weather than plastic (colder in cold weatner, hotter in hot). (4 pupils)										
TOTAL ALTERNATIVE RESPONSES		100		97		100		83		79

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understandings of CONDUCTION OF HEAT. The Table below lists the pupil frameworks identified for this Idea and gives their frequencies of occurrence.

TABLE 10 PUPIL FRAMEWORKS - CONDUCTION OF HEAT

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES								
		12 Yr (X12)			14 Yr (X14 & Y14)			16 Yr (Y16 & Z16)		
		Q34 (n=30) Spoons	Q36 (n=30) Plates	Q37 (n=30) Handle-bars	Q34 (n=59 Spoons	Q36 (n=59) Plates	Q37 (n=59) Handle-bars	Q34 (n=53) Spoons	Q36 (n=53) Plates	Q37 (n=53) Handle-bars
1. Different substances feel to be different because heat travels through them at different rates	34A,34B,36A,37A	27%	3%	0	54%	2%	2%	79%	19%	19%
2. Metal attracts/absorbs/conducts coldness	36O,37O	-	3%	23%	-	15%	34%	-	4%	25%
3. Conductivities of different materials depend on some observable property	34R(some),36P, 37P	3%	37%	20%	2%	20%	19%	0	8%	4%
4. Metals let heat in & out more easily	34N,34P,34R(some) 36N,37N	33%	20%	10%	36%	17%	10%	8%	26%	19%
5. Good conductors get hot on the periphery only, not all through	34Q,36Q(some)	13%	0	-	0	2%	-	2%	2%	-
No identifiable framework	34U,34O,34R(some) 36U,36Q(some)37U, 37Q,37R	23%	37%	47%	8%	44%	36%	11%	42%	34%

COMMENT ON PUPIL UNDERSTANDING OF CONDUCTION OF HEAT

It is obvious from these questions that the direction of heat conduction in relation to the pupil profoundly influences the answers they give. Problems about the different conductivities of varying materials elicited many more correct responses when the question asked for an explanation of the sensation of hotness (as in SPOONS) rather than coldness (as in PLATES and HANDLEBARS). Thus, SPOONS contributed considerable percentages of responses to the explanatory framework which links differing sensations of temperature with different heat conductivities (Framework 1), whereas PLATES and HANDLEBARS contributed few.

The pupil framework previously reported by Erickson (1979) that cold is an entity with, like heat, the properties of a material substance, suggests that some pupils do not perceive 'heat' and 'cold' as two poles of a single dimension. This was expressed explicitly in response to PLATES and HANDLEBARS, but seemed to be a general underlying assumption throughout the heat interview.

Concomitant with the idea that metals let heat in and out easier than other substances (Framework 4) is perhaps the notion of heat as a dynamic moving force (rather like that described for pressure identified from questions related to ATMOSPHERIC PRESSURE) Tiberghien (1980) comments that one of the pupils in her detailed study used the variable speed of movement of heat to explain different conductivities.

The rather low-level explanatory framework, drawing sometimes apparently randomly on 'natural' properties of the materials, such as colour, thickness and hardness to explain different conductivities (Framework 3) was quite well supported by the two younger age groups.

Only a few pupils contributed to the ingenious idea that metal conducts heat so well because heat concentrates exclusively on the surface and does not penetrate, but this was also reported by Tiberghien (1980).

The large numbers of responses contributing to 'No identifiable framework' are partly a reflection of the difficulty which pupils had with PLATES and HANDLEBARS, and the consequent big contributions to 'Uncodeable' and 'Miscellaneous' categories.

CHAPTER 6

PUPIL UNDERSTANDINGS OF EVOLUTION

Introduction:

The analytic procedures already established were perfectly adequate to accommodate the data for two of the Ideas on evolution (ACQUIRED CHARACTERISTICS and ADAPTATION) but one Idea (INHERITANCE) required slightly modified treatment. As before, interview results are reported at both question and Idea levels, and commentary is focussed on age-related trends within pupil groups. Only two written test items were used in this interview, so it was necessary to devise more additional questions for evolution. The data for the three Ideas are supplemented by a few general introductory questions which were administered at the beginning of the interview, and a short, multiple-choice quiz on biological adaptation which pupils had completed beforehand. Both these additional sources of information on pupil understanding are reported in this chapter.

INTRODUCTORY QUESTIONS

The following questions were designed to be a cue to pupils thinking about intra-specific variation and inheritance of characteristics. No category sets were generated, but salient characteristics in responses are noted below.

Q.38. ADULTS AND YOUNG (First round interviews only)

Pupils were presented with the photographs of adult and young animals (wild pigs, coots, baboons and emus) shown on p.178-9 and asked to match adults with corresponding young.

Q.39. ANIMAL VARIATION

Pupils were shown some black and white photographs of pure-bred beagles, shown on p.181 and asked, first, to comment on similarities and differences in the dogs, and then whether or not it is "normal and usual" to get variation like this among animals of the same kind.

Q.40. PLANT VARIATION

Following on from the previous question, pupils were asked whether the same thing (i.e. intra-specific variation) occurred in plants.

COMMENT ON RESULTS

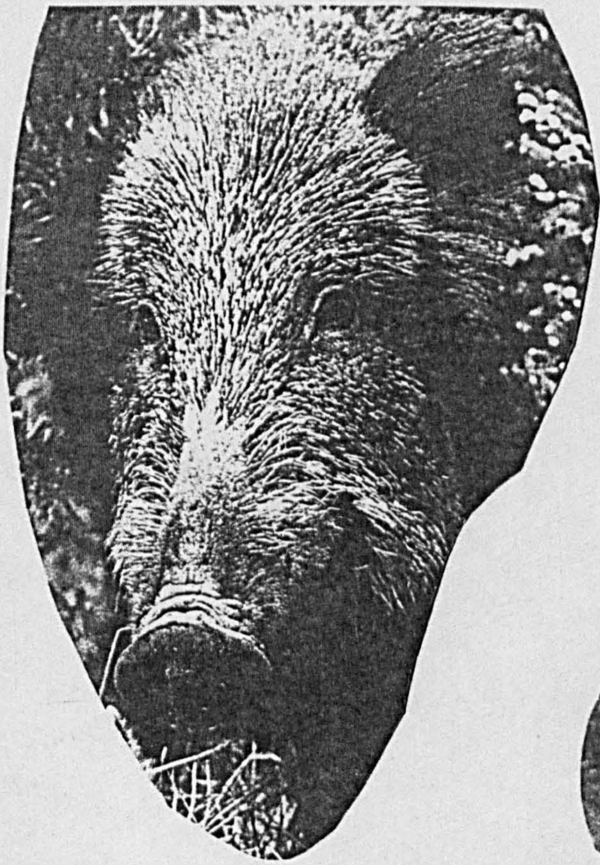
Not surprisingly, all pupils were able to match adults and young which suggests, perhaps, an intuitive idea that living things reproduce to give offspring of the same kind, with characteristics passed on.

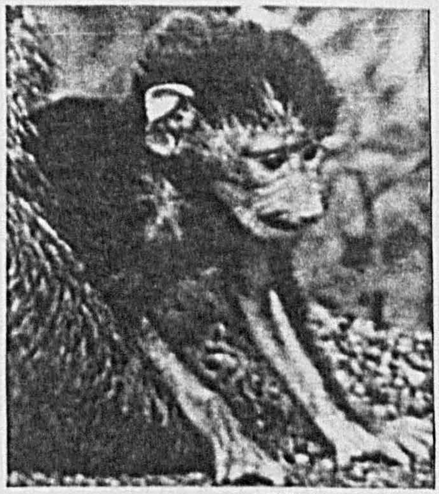
The majority of pupils (96% of all responses) recognized that variation among animals of the same species was quite 'normal', quite 'usual'. However, a sizeable proportion (17%) of responses indicated that variation in plants does not occur as a normal rule. This finding confirms an observation by Okeke and Wood-Robinson (1980) that 40% of their sample of 120 16-18 year olds did not seem to believe that plants were capable of sexual reproduction. Quotations from the present study include:

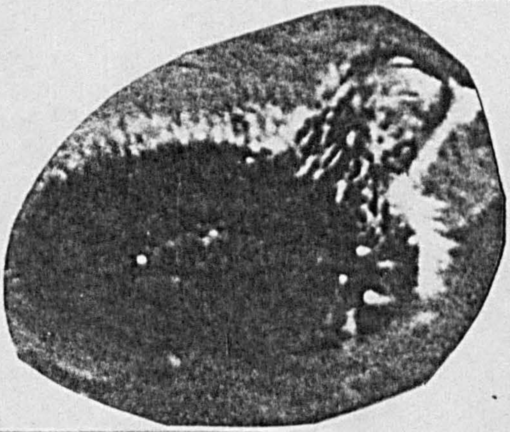
"*... well mostly in plants they're mostly the same ... they are from the same seed*

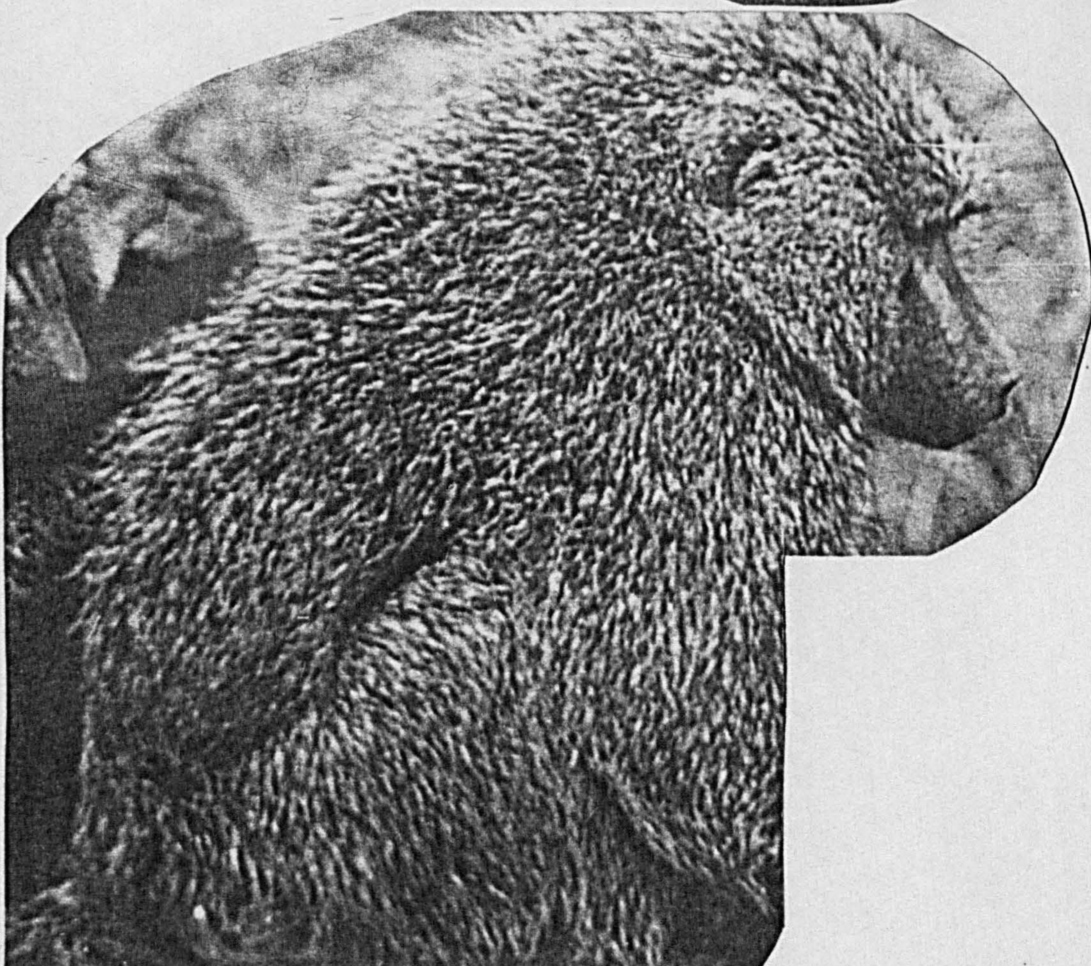
and the seeds are both like the same ...
one oak tree and another one, and if they're
both from one tree - the two seeds - well,
they'll grow like the same." (Pupil 22)

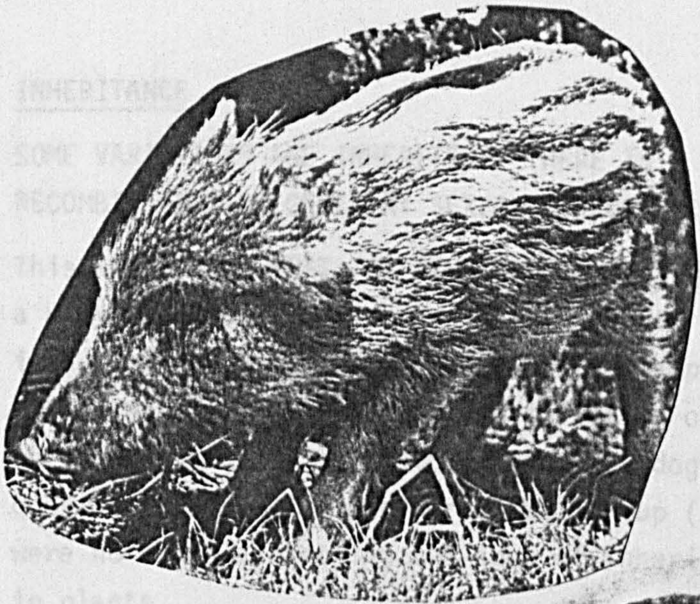
"No, probably all the same if they're the
same sort of plants". (Pupil 52)

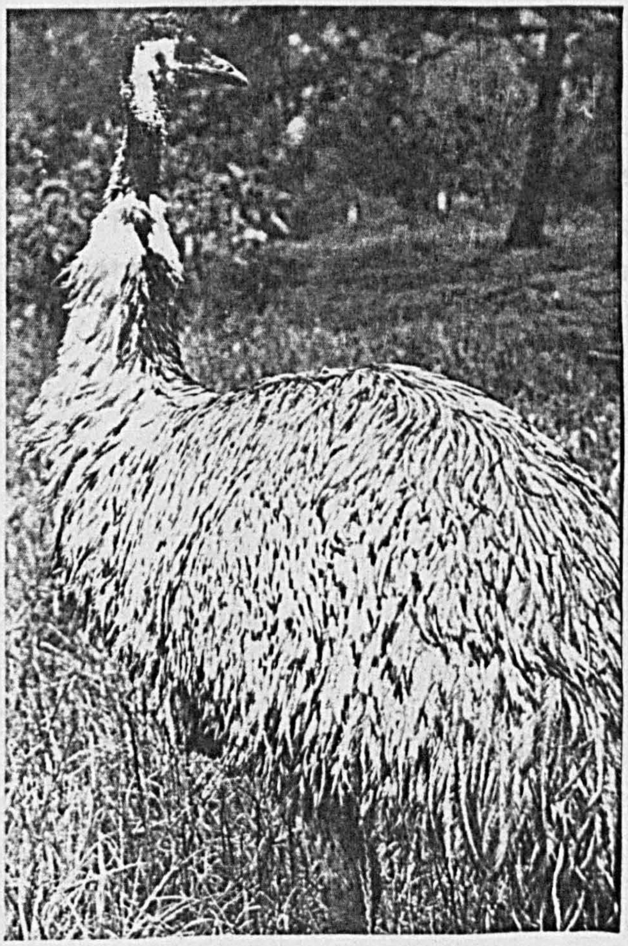












INHERITANCE

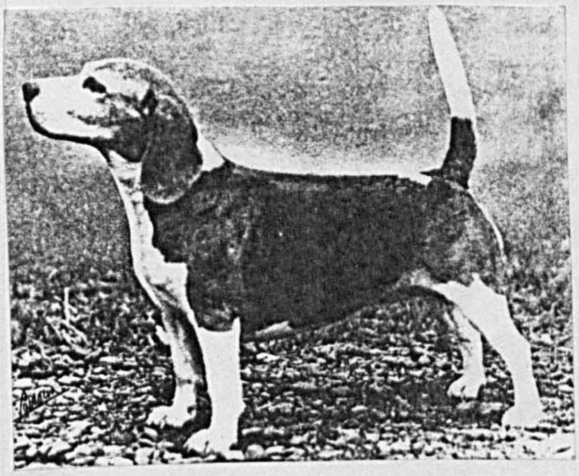
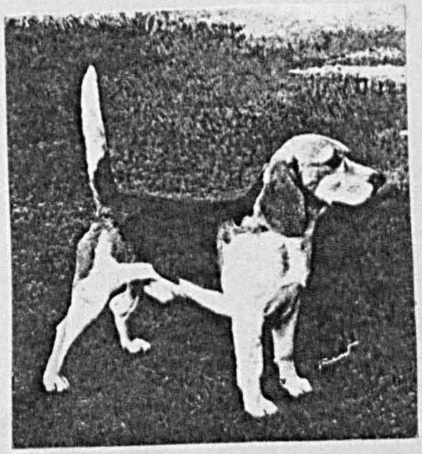
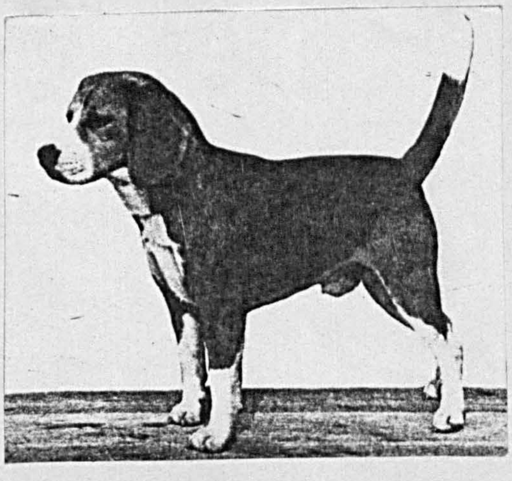
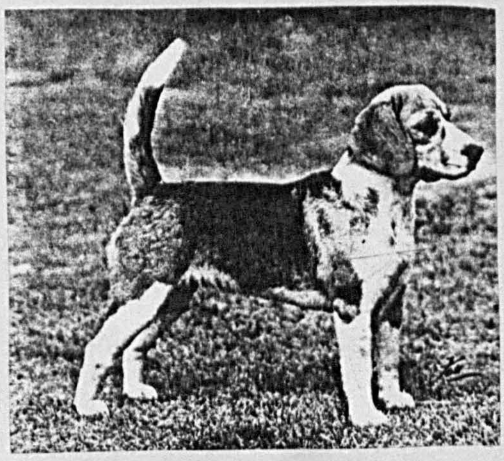
SOME VARIATIONS ARE INHERITED - THERE IS A GENETIC BASIS, WITH A RECOMBINATION OF GENES AT SEXUAL REPRODUCTION.

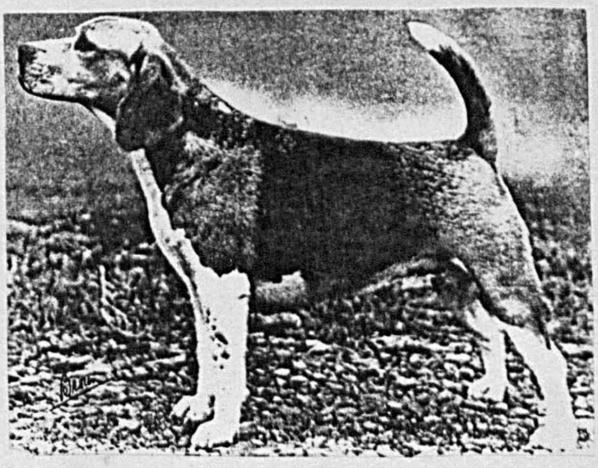
This Idea, like HEAT AND TEMPERATURE in the preceding chapter, is a very broad one. It was only possible to test pupils' ideas in a limited number of settings. For example, most of the questions which led to the identification of explanatory frameworks used mammals as examples (humans, dogs, mice). Only one question referred to another animal group (insects) and there were no examples testing the idea of inheritance of characteristics in plants.

Analysis of interview data feeding this Idea was problematic, partly because pupils found it an extremely difficult subject to talk about, particularly when they lacked the correct terminology and partly because some of the questions were insufficiently precise and pertinent to the Idea. Thus, although there are seven questions which inform understanding of the Idea, some of these do so rather obliquely. They are included in the question-by-question reporting because they yielded interesting alternative responses, or because they contributed in some other way to the general picture of pupil understanding. At Idea level some pupil frameworks are identified (though it is argued that, for this Idea, frequency counts would be inappropriate) and general commentary on pupil understanding is presented.

Q 41 DOGS' MARKINGS

Pupils were shown the photographs of beagles and the variation in coat colour and markings were discussed. The following question was then posed.



Can you explain how these variations arose?

Q.41. DOGS' MARKINGS (contd.)

COMMENT ON RESULTS

The results show a sharp increase in percentages of responses which made some link between variation and genetic make-up, from 7% in 12 year olds to 64% in 16 year olds.

About half the responses contained the suggestion (probably representing no more than a low-level understanding) that the coat markings were passed down from the parents.

No clear alternative response patterns emerged.

QUESTION 41 DOGS' MARKINGS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. GENETIC MAKE-UP OF DOGS DIFFERENT TO PARENTS' BECAUSE GENE COMBINATION HAS CHANGED/IS DIFFERENT *"Yes, each parent contributes something to the make-up of its children and, of course each parent has different colouring to begin with, so if you combine the genes of the two parents you get a sort of mixture which won't be exactly the same as either of the parents. That's how you get the differences."* (pupil 35)	0	0	0	0	2	7	3	10	5	21
B. GENETIC ENTITY CONTROLS MARKINGS AND CAUSES DIFFERENCES *"They receive some chromosomes from each parent so some of the characteristics of the parent are passed on."* (pupil 32) *"It's hormones from the mother and father . . . it's combining of hormones and sometimes they are stronger in one case than in another . . . it steers the colour of eyes and hair."* (pupil 31)	2	7	6	21	4	13	14	48	12	50
C. MARKINGS PASSED ON FROM PARENTS *"Well, say take these two for example . . . that one might have more of its mother's look - that might look more like the mother, and that might look more like the father."* (pupil 1)	19	63	19	66	18	60	10	34	6	25
TOTAL ORDINAL RESPONSES		70		86		80		93		96
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	7	23	3	10	4	13	2	7	1	4
N. MARKINGS PASSED ON FROM MOTHER *"They get it off their mother like, where they're patched."* (pupil 25) *"From the mothers and from their ancestors and all them."* (pupil 50)	2	7	0	0	1	3	0	0	0	0
O. MISCELLANEOUS Theological story (pupil 44)	0	0	1	3	1	3	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		30		14		20		7		4

Q.42. TWINS

Pupils were shown the photographs of identical twins below and asked the following question:

Can you explain why these two women look almost exactly the same?

COMMENT ON RESULTS

There was an increase in the overall number of correct responses between 14 and 16 years. Only a few younger pupils, though one third of 16 year olds, referred to a genetic explanation.

A substantial number of younger pupils gave the low-level tautological reply that the twins look alike because they were born at the same time.

Some alternative response categories seem to indicate a lack of pupil understanding of the equality of parental gene contribution.

QUESTION 42 TWINS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. FROM THE SAME GENES/DNA/CHROMOSOMES *"Well, they have the same genes."* (pupil 3) *"Because they have both got the same DNA . . . they both started out with the same cell, same nucleus, the same genes, and the same DNA."* (pupil 65)	2	7	4	14	3	10	8	28	9	38
B. FERTILIZED EGG SPLIT INTO TWO *"Because there's one egg is fertilized - when it splits in two you get twins who look exactly the same . . . because there's the kind of same person split in two. Made a double of."* (pupil 36)	10	33	9	31	8	27	5	17	2	8
C. EGG SPLITS/FROM ONE EGG *"'Cos' the egg split in two so they'll both be the same."* (After sperm joined or before?) *"Don't know."* (pupil 5)	1	3	0	0	2	7	1	3	4	17
TOTAL ORDINAL RESPONSES		43		45		43		48		63
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	9	30	6	21	8	27	8	28	4	17
N. BORN TOGETHER/AT THE SAME TIME/ DEVELOPED IN UTERO TOGETHER *"Because they were born exactly at the same time."* (pupil 6)	7	23	5	17	5	17	1	3	2	8
O. FROM ONE EGG, BUT TWO SPERM *" . . . usually only one sperm'll get through but sometimes two do get through, and then you end up with twins . . . I expect it's just because it's one egg."* (that they look alike) (pupil 54)	0	0	1	3	2	7	3	10	2	8
P. FROM TWO EGGS FERTILIZED BY TWO SPERM AT THE SAME TIME *"Is it because both eggs were fertilized at the same time . . . well their body chemistry I suppose would change at different intervals of time . . . of both parents."* (pupil 69)	0	0	2	7	1	3	2	7	1	4
Q. MISCELLANEOUS (i) Two eggs from the same ovary (pupil 23) (ii) Two eggs joined together inside the female, split at birth (pupil 55)	1	3	2	7	1	3	1	3	0	0
TOTAL ALTERNATIVE RESPONSES		57		55		57		52		37

Q.43. SIBLINGS

Pupils were shown the photographs of the brother and sister below, and we discussed sibling similarity. They were then asked:

Can you explain why it is that children in the same family frequently look like one another?

COMMENT ON RESULTS

Again the number of 16 year old pupils who offered a genetic explanation of the similarities was more than twice that for the other two age groups. In general a large number of pupils (40% of all responses) gave a low-level ordinal response which made no specific reference to a genetic explanation.

Interestingly, a few pupils indicated that they thought that the maternal contribution was more important and a few implied that all eggs or sperm released at the same time were genetically similar.

QUESTION 43 SIBLINGS

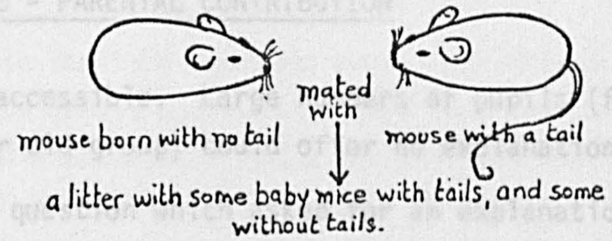
DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 23		X14 n = 29		Y14 n = 18		Y16 n = 29		Z16 n = 21	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. FROM SLIGHTLY DIFFERENT GENE COMBINATIONS/DIFFERENT COMBINATIONS OF DOMINANT AND RECESSIVE GENES/SOME GENES/LIKENESSES ARE THE SAME/SOME DIFFERENT *"Well if they have the same parents each time then each parent's genes - well, they remain the same, but they combine with one another in different ways so no two children, except identical twins of course, who were formed from the same genes, are identical."* (pupil 35) *"Well, it's the same parents and it's the same genetics that's been passed on."* (pupil 67) *"Because there might be a gene in family - a gene that comes out every time like nose or . . . "* (Do brother and sister have the same genes?) *"No, not exactly the same, but some are the same."* (pupil 11) *"Whereas the brother and sister are two totally different . . . eggs that were formed so there'll be slightly different changes in the way they've been fertilized . . . differently . . . they'll be . . . you know . . . receive slightly different information."* (pupil 81)	3	13	5	17	3	17	9	31	13	62
B. HAVE SAME PARENTS/FROM TWO DIFFERENT EGGS *"Both got the same parents."* (pupil 4) *"They . . . come from different ones . ."* (eggs) (pupil 83)	4	17	17	59	6	33	17	59	4	19
TOTAL ORDINAL RESPONSES		30		76		50		90		81
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	7	30	7	24	6	33	1	3	2	10
N. SAME MOTHER *"'Cos' we all come from the same mother - same person."* (pupil 17)	4	17	0	0	1	6	0	0	0	0
O. JUST BY CHANCE/JUST THE WAY THEY ARE BORN *"Just the way they are born."* (pupil 49)	2	9	0	0	1	6	1	3	0	0
P. BROUGHT UP IN SAME WAY/NOT BORN AT SAME TIME/DID NOT DEVELOP IN UTERO TOGETHER *"She might have been brought up the same as him . . . with her being born before him her mum might have done the same to him as she did to her and made them look the same."* (pupil 44)	2	9	0	0	1	6	0	0	1	5

Category set continued on next page.

QUESTION 43 SIBLINGS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 23		X14 n = 29		Y14 n = 18		Y16 n = 29		Z16 n = 21	
	No.	%	No.	%	No.	%	No.	%	No.	%
P. (continued) *"'Cos' we're not formed together, but we've still got a bit of likeness . . ."* (pupil 1) *"Because I were born before him - that's the only thing I can think of."* (pupil 13)										
Q. EGG OR SPERM RELEASE AT DIFFERENT TIMES MEANS NON-IDENTICAL - TIMING ESSENTIAL *"Well, it's just an egg from one ovary, and an egg from the same ovary but at different times."* (pupil 23) *" . . . perhaps . . . of the whole lot sperm that swim towards the egg all carry the same ingredients for a person . . . no, but with them* (the siblings), *they obviously would have been born with years in between them so . . . "* (pupil 72)	1	4	0	0	0	0	1	3	1	5
TOTAL ALTERNATIVE RESPONSES		70		24		50		10		19

Three questions were based on the written test item shown below.



Why was it that the mouse born with no tail produced tailless mice babies?

APU item

Q.45. TAILLESS MOUSE

One of the mice had been born with no tail - how did that come about, do you think?

Q.46. MICE-MIXED LITTER

When the tailless mouse was mated with a normal tailed mouse the litter was mixed - some babies had tails and some were tailless. Can you explain that?

Q.47. MICE-PARENTAL CONTRIBUTION

Would the tailless offspring have something passed down about tails from both parents or just from one? Can you explain?

COMMENT ON RESULTS

It was not possible to scale categories in response to TAILLESS MOUSE, because there are several possible explanations for the taillessness. They were therefore arranged on a single descriptive scale.

Few pupils used the idea of gene mutation (however expressed) to explain the sudden appearance of a tailless mouse, though the percentages for the 16 year old groups were somewhat higher. The notion of developmental defects to explain taillessness was clearly

Q.45. TAILLESS MOUSE
Q.46. MICE - MIXED LITTER (contd.)
Q.47. MICE - PARENTAL CONTRIBUTION

much more accessible. Large numbers of pupils (for example, half the 12 year old group) could offer no explanation at all.

The question which asked for an explanation of the mixed litter generated high percentages of ordinal responses in all age groups. These constitute some kind of hereditary explanation, though some ordinal responses were formulated in terms of phenotypic similarities only. But when pupils were asked specifically about the parental contribution to the phenotypic characteristic of tails/taillessness some interesting responses emerged. Only 14% of 16 year olds and none of the younger pupils could give a genetic explanation of the equality of parental contribution, though many more had an intuitive idea that both parents contributed something. Several alternative response categories incorporate the idea of a contribution for a given characteristic from one parent only. Approximately two thirds of both the 12 and 14 year old groups and one third of 16 year olds fell into these categories. Some of these pupils indicated a belief in the sole or disproportionate importance of either the mother or the father.

Some responses to MICE - MIXED LITTER referred to dominance and recessiveness of genes, though, finally, it was decided not to incorporate this aspect into the categorization. Nevertheless, one misconception is worthy of note. Four pupils (one 14 year old, and three 16 year olds) appeared to suggest that a given gene (e.g. for 'no tail') could be dominant in one offspring and recessive in another - a kind of floating dominance. For example:

> "*The genes from the tailless mouse - parent - would be dominant in some of the offspring and recessive in the others which will have had tails.*" *(Pupil 75)*

> "*Well, this mouse who had been born with no tail, his genes had said that he was to have no tail. He passed some of his genes on to combine with his mate's genes. Sometimes his genes were predominant*

Q.45. <u>TAILLESS MOUSE</u>

Q.46. <u>MICE - MIXED LITTER</u> (contd.)

Q.47. <u>MICE - PARENTAL CONTRIBUTION</u>

in the baby mice who were born without tails, in others his mate's genes were predominant when the mouse born had a tail." *(Pupil 35)*

QUESTION 45 TAILLESS MOUSE

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
H. THE GENETIC ENTITY HAS BEEN CHANGED *"Er . . . a slight abnormality in the chromosomes . . . some kind of abnormality . . . it might just occur naturally . . . there's about 21 chromosomes and anything can go wrong."* (pupil 3)	3	10	3	10	2	7	10	34	13	54
I. TAILLESS MOUSE RESULTS FROM TWO REGRESSIVE GENES *"Well, there'd be something wrong with the genetic material . . . a certain . . . er . . . genes that are recessive, which don't normally come out in normal fertilization. And this could produce slight variations . . . a recessive is a trait that is carried by the person but it doesn't . . . it doesn't come out as prominent as the dominant."* (pupil 69)	0	0	0	0	0	0	0	0	2	8
J. DEVELOPMENTAL DEFECT/DEFECT AT BIRTH *"Disfiguration at birth."* (pupil 39) *"That the mouse was deformed in some way - in the pregnency."* (pupil 47) *"Probably the mother might have had an illness or something wrong with her."* (pupil 23)	9	30	14	48	9	30	8	28	3	13
K. GRANDPARENTAL OR EARLIER GENERATION HAD TAILLESS MICE *" . . . like its grandparents you know - parents that belonged to his parents - that baby's parents - its grandparents, they might have had none."* (pupil 45)	1	3	1	3	1	3	4	14	0	0
L. NOT ENOUGH TIME TO DEVELOP A TAIL *"Well, it could have been that the mouse didn't have long enough to develop before it was born."* (pupil 22)	1	3	1	3	1	3	0	0	1	4
M. MISCELLANEOUS (i) incomplete fertilization (pupil 25) (ii) hormone deficiency (pupils 31 and 34)	1	3	2	7	2	7	2	7	0	0
U. UNCODEABLE/DON'T KNOW	15	50	8	28	15	50	5	17	5	21

QUESTION 46 MICE - MIXED LITTER

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. A GENETIC ENTITY PASSED DOWN FROM THE PARENT(S) DETERMINES WHETHER BABIES HAVE TAILS OR NOT *"Is it because the cells like . . . because he's been made from a wrongly-produced cell? All the cells that are inside it are the same - well, not all, but most. So some are born with tails and some without."* (pupil 3) *"This mouse had been born with a gene for no tail, so when it was mated with one with a tail, some of them would inherit this gene for not having a tail, and hence would not have a tail."* (pupil 62)	4	13	8	28	10	33	12	41	18	75
B. SOME OFFSPRING LOOK LIKE ONE PARENT/ SOME LIKE ANOTHER/TAILLESS BABY LOOKS LIKE TAILLESS PARENT *"Because some of the babies developed like the mouse with no tail and some developed like the mouse with a tail."* (pupil 1) *"Because that mouse* (one of the parents) *hasn't got a tail."* (pupil 4)	21	70	19	66	16	53	15	52	3	13
TOTAL ORDINAL RESPONSES		83		93		87		93		88
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	4	13	1	3	3	10	2	7	3	13
N. TAILLESS BABY RESULTS FROM DEFECTIVE DEVELOPMENT	1	3	1	3	1	3	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		17		7		13		7		7

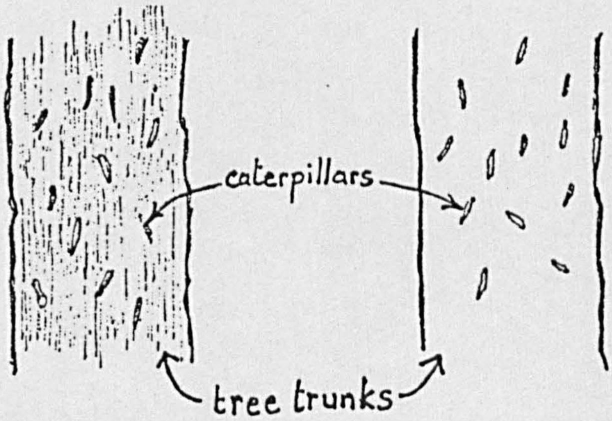
QUESTION 47 MICE - PARENTAL CONTRIBUTION

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 23		X14 n = 26		Y14 n = 27		Y16 n = 26		Z16 n = 18	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. FROM BOTH PARENTS, BUT IN HETEROZYGOUS INDIVIDUAL THE DOMINANT GENE DETERMINES THE PHENOTYPE *"Presumably . . . no tail we'll call ll and tail we'll call Ll - and therefore you mix the two together and you get Ll, Ll and Ll - and they'll all have big tails becuase they've got an L in them, and an ll."* (He agrees that he means that this would be the tailless baby) (pupil 68)	0	0	0	0	0	0	4	15	2	11
B. FROM BOTH PARENTS *"Well from both, but the strongest from the one without the tail."* (pupil 61) *"I think from both, but it just so happened that it got the tailless . . . thing."* (pupil 14)	9	39	3	12	11	41	10	38	10	56
TOTAL ORDINAL RESPONSES		39		12		41		54		67
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	4	3	12	2	7	4	15	1	6
N. FROM ONE PARENT/TAILLESS PARENT ONLY *"Probably from both - they'll probably look like the mother, but have no tail like the father."* (pupil 28) *"Well, they'll take after the father without a tail . . . I suppose it could have something passed down from the mother - you know if the mother had exceptionally large ears!"* (pupil 40)	11	48	19	73	11	41	7	27	5	28
O. ONLY OR MORE INFORMATION FROM THE MOTHER *"Probably just the mother."* (Nothing from the father?) *"No."* (pupil 59) *"Yes, I think it depends on the mother's side . . . from both but mainly the mother."* (pupil 57)	1	4	0	0	2	7	0	0	0	0
P. ONLY OR MORE INFORMATION FROM THE FATHER *"Because the father passed more . . . I can't think* (what they are called) *to some of his mouses."* (Did the mother pass any information?) *"Maybe a little but . . . "* (pupil 24)	1	4	0	0	1	4	0	0	0	0
Q. FROM EITHER PARENT	0	0	1	4	0	0	1	4	0	0
TOTAL ALTERNATIVE RESPONSES		61		88		59		46		33

Q.48. CATERPILLARS - PREDATORS

This question was based on the written test item shown below. After discussing camouflage and the advantage of this for the caterpillars, the following question was posed in interview.

Children were walking through a wood.
They noticed that one type of caterpillar lived on a certain type of tree. The tree trunk of this type of tree could be either pale or dark. They found that most of the caterpillars on the dark tree trunks were dark coloured and that most of the caterpillars on the pale trees were pale in colour.



(a) I think this is because__________________________________

____

What would you expect to happen if all the birds/predators that normally ate the dark caterpillars disappeared? If the children walked through the same wood the following week, and all the birds that normally ate the dark caterpillars had migrated, where would you expect they would find the dark caterpillars? Can you explain?

This question thus attempts to test understanding of the idea that this behavioural characteristic was inherited.

COMMENT ON RESULTS

Only 15% of the youngest age group, though nearly half the 16 year olds indicated either explicitly or implicitly that they understood that the behavioural characteristic was inherited.

The notions both of response to need created by environmental change and of biological adaptation as a conscious, deliberate process, which were popular here, occur as well with questions related to the Idea ADAPTATION and are therefore discussed later.

QUESTION 48 CATERPILLARS - PREDATORS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 26		X14 n = 27		Y14 n = 25		Y16 n = 26		Z16 n = 21	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. SAME TREE BECAUSE INHERITED THAT BEHAVIOURAL CHARACTERISTIC/JUST FROM HABIT/WOULD NOT REALIZE THAT THE BIRDS HAD GONE *"Probably on the same tree from habit of staying there."* (pupil 1) *" . . . possibly be some inherited characteristic that kept the black ones on the black trees, but that would slowly disappear if the birds disappeared . . . nothing's made clear to the caterpillars at all! They don't have any choice in the matter - if one is born with a gene which tells it to go on to a white tree and it does so, it wouldn't be under any disadvantage because it was on a white tree - because no-one was going to come along and eat it, so it would just survive and breed as well in those conditions."* (pupil 62)	4	15	12	44	7	28	12	46	10	48
B. SAME TREE BECAUSE THE FOOD SUPPLY IS THERE *"Well, still on the tree eating the normal food because once they've become acclimatized to that diet, they'll keep on eating it, even if there're no birds to catch them when they leave the camouflage of the tree."* (pupil 42)	1	4	0	0	1	4	1	4	0	0
C. SAME TREE, NO OR INCONSEQUENTIAL REASON *"I think they'll still be in the same place - it's not going to change . . . the . . . "* (pupil 37)	0	0	1	4	3	12	1	4	2	10
TOTAL ORDINAL RESPONSES		19		48		44		54		57
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	4	15	1	4	1	4	3	12	2	10
N. ANYWHERE, BECAUSE THE NEED FOR CAMOUFLAGE REMOVED *"On any tree. Oh . . . because if there was no birds going to eat them any more, it wouldn't matter . . . whether they could be easily seen or not - if there was no birds to eat them."* (pupil 2)	4	15	5	19	5	20	4	15	2	10
O. CATERPILLARS WOULD THINK BIRDS MAY RETURN/THEY HAD JUST BEEN LUCKY/MAY BE OTHER PREDATORS/THEY LIKE THE SAME TREE/WOULD REALIZE THE BIRDS HAD GONE/ THOUGHT THEY WERE SAFE *"On the dark trees still. Because if they're dark like they want to be on a dark colour . . . and so they don't bother like changing trees."* (Do they actually choose?) *"Yes."* (pupil 9)	13	50	8	30	7	28	4	15	4	19

Category set continued on next page.

QUESTION 48 CATERPILLARS - PREDATORS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 26		X14 n = 27		Y14 n = 25		Y16 n = 26		Z16 n = 21	
	No.	%	No.	%	No.	%	No.	%	No.	%
O. continued *"On the same tree. Because just if by chance the birds'd come back - they probably wouldn't risk that - being on the lighter-coloured tree there they'd be easier to get."* (pupil 16) *"Everywhere. Some pale ones might go on dark ones because they won't be frightened you know."* (pupil 50) *"I'd expect to find them on the same tree. Well, the caterpillars aren't to know that the birds have gone. The predators would probably creep up on them in a way that they couldn't see, so they would still be expecting them to be creeping around, looking for them."* (pupil 75)										
P. MISCELLANEOUS (i) Pale tree, no reason (pupil 59) (ii) Same place, because take too long to change colour (pupil 61)	0	0	0	0	1	4	1	4	1	5
TOTAL ALTERNATIVE RESPONSES		81		52		56		46		43

IDEA LEVEL

In order to help in the organization of this data at the Idea level another category set (GENETIC MATERIAL) was generated.

This set is rather different from those in the rest of the study. It represents, not an analysis of pupil responses to a single question, but an amalgamation of information from a number of questions on the evolution schedule (questions on animal variation, twins and siblings and mice). These questions provided much interesting, if diffuse, data on pupil ideas of the nature of genetic material which otherwise would be lost in the analysis. Since all the evolution interviews were transcribed it was possible to scan responses to several questions. The category set addresses the question:

Q.44. Do pupils use the idea of particulate genetic material in response to interview questions?

Categories are arranged on a single descriptive scale.

COMMENT ON RESULTS

Very few pupils of any age indicated a good understanding of the nature of gene function.

More than half the 16 year old pupils, but only one fifth of the two younger age groups advanced the notion of a genetic entity (of unspecified nature) being passed on at fertilization to determine phenotypic features.

A few pupils were explicit in indicating their belief in the transfer of likenesses during development of the embryo. Some of these pupils, at the same time, talked about sperm and a paternal contribution, apparently not perceiving the contradiction.

The most salient feature of this category set is perhaps the very large number of younger pupils (65% of all 12 and 14 year old responses) who made no mention of a genetic entity at all over several different question contexts. The 16 year old contribution to this category, however, was much smaller (15%).

QUESTION 44 GENETIC MATERIAL

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
H. THE CHEMICAL STRUCTURE OF GENES/ CHROMOSOMES CARRIES INFORMATION WHICH IS TRANSLATED BY THE CELL *". . . they're the building blocks of life . . . each of our cells has a genetic code message in it which, if you could take one cell from anybody, that's the basis of cloning as well, you could re-build an entire body from it. Genes give you the instructions what the being will be like. . . . they're the message which is being given."* (pupil 35)	2	7	2	7	1	3	1	3	3	13
I. GENETIC ENTITY PASSED ON AT FERTILIZATION DETERMINES FEATURES *"I don't know what they* (genes) *<u>are</u>, but they're what make up your body chemistry . . . and make you . . . make you look as you are . . . at fertilization."* (pupil 39) *" . . .* (chromosomes) *are fibres of the nucleus of cells which carry information about certain things should grow . . . at fertilization."* (pupil 69) *" . . . the two separate genes fight for what sort of sex and what colour of hair they'll have, and which ever gene wins, that's what you'll have."* (pupil 54)	2	7	4	14	12	40	17	59	13	54
J. GENETIC ENTITY/LIKENESSES PASSED ON DURING DEVELOPMENT OF EMBRYO/OF CHILD *"It's passed down in the genes . . . they have certain similarities, that's in't genes.* (What are genes?) *Like things that the parents have had and they pass on to the children . . . when the child's growing up* (they are passed on) *. . . when they're babies they don't look much like their mum or anything, but as they grow up they develop more like their mum."* (pupil 6) *" . . .* (genes are) *. . . cells which are passed on from the mother to the baby when the baby's inside . . . it's when the baby is developing."* (pupil 75)	2	7	4	14	0	0	5	17	2	8
K. MISCELLANEOUS (i) genes <u>are</u> features (pupils 11 and 67) (ii) genes are <u>not</u> something physical (pupil 76)	1	3	0	0	0	0	0	0	2	8
L. RESPONSES DO NOT MENTION GENETIC ENTITY	23	77	19	66	16	53	6	21	2	8
U. UNCODEABLE/DON'T KNOW	0	0	0	0	1	3	0	0	2	8

In this section information from the questions is collated to allow comment on pupil understandings of INHERITANCE. This Idea is broad in scope and the questions used here test different aspects of it. Consequently, problems arose with pupil framework identification. For example, frameworks of very different levels of generality arose. However, it was possible to identify three broad levels of understanding of the Idea as follows:

1. GENES RECOMBINE AT FERTILIZATION TO PRODUCE OFFSPRING WHICH ARE SIMILAR BUT NOT IDENTICAL TO THE PARENTS

   (In categories 41A, 43A, 47A)

2. GENETIC MATERIAL CONTROLS THE INHERITANCE OF CHARACTERISTICS

   (e.g. in categories 41B, 46A, 45H, 45I)

3. NO USE MADE OF THE IDEA OF GENETIC ENTITY

   (e.g. as in category 44L)

In addition, some other pupil viewpoints, covering subsumed ideas much narrower in scope, were identified and may be listed separately:

4. GENETIC MATERIAL IS PASSED ON DURING THE DEVELOPMENT OF THE EMBRYO OR CHILD

   (e.g. in categories 42N, 43P, 44J, 45J)

5. PARENTAL GENE CONTRIBUTION IS UNEQUAL

   (e.g. in categories 41N, 43N, 47N, 47O, 47P, 47Q)

6. ALL EGGS AND SPERM RELEASED AT THE SAME TIME GIVE RISE TO THE SAME PHENOTYPES

   (In categories 42P, 43Q)

Misleading impressions would emerge if these six frameworks were put together as a coherent group and tables of frequencies were drawn up as for the other Ideas. Their scientific significance is best handled descriptively, and this is done in the next section.

GENERAL COMMENT ON PUPIL UNDERSTANDING OF INHERITANCE

Pupils seemed to experience special difficulties in discussion of these questions. Firstly, some pupils, particularly the younger ones, were clearly embarrassed to talk about sexual reproduction with a stranger. Only a few interviews were adversely affected by this, but since it was clearly important to keep pupils relaxed and willing to talk, probing questions had often to be curtailed. More of the older pupils had access to the relevant terminology (though they did not necessarily use it correctly) and this helped them to describe their ideas with ease and confidence.

It was hoped to obtain some indication of pupil understanding of the inherited source of some intra-specific variation (that variation on which natural selection operates to result in biological adaptation and, ultimately, in evolutionary change). For most questions an increase in the number of good genetic explanations (Framework 1) appeared between 14 and 16 years. These did not necessarily comprise any detailed knowledge of the mechanism of gene action, but simply of the basic idea that characteristics are determined by a particulate genetic entity, which carries information translatable by the cell. Large numbers of pupils of all ages, however, were satisfied with low-level, naturalistic responses to these genetics questions. These were phrased in phenotypic terms, and perhaps reflect only vague notions of heredity. These pupils invoked no genetic explanations and made no mention of a genetic entity (Framework 3). Only one question (TAILLESS MOUSE) specifically tested the idea of mutations. The results indicated that very few children use this idea to explain the source of variation. Similarly, very few references to mutation were volunteered in response to questions on the Idea ADAPTATION, discussed later in this chapter. This confirms earlier findings (Deadman and Kelly, 1978; Brumby, 1979) that pupils and university students have few valid concepts concerning the source of variation.

Many pupils exhibited a lack of understanding of the equality of parental genetic contribution in sexual reproduction (Framework 5). This would seem to be a major block in understanding the mechanisms of inheritance. At a physiological level, for example there was the suggestion that identical twins resulted from one egg and two sperm. The idea of transfer of likeness from mother to embryo during development (Framework 4) was used in response to several questions, and is obviously another framework which at least implies this same lack of understanding. Some responses to questions on mice, dogs and humans indicated a belief in either unequal or exclusive parental gene contribution. Sometimes pupils argued explicitly that one parent contributed a gene for one characteristic and the other parent did so for another characteristic. Some fascinating suggestions were made - for example, that maternal contribution was more or even exclusively important (and, less commonly, that the same was true for paternal contribution), or that same-sex inheritance of characteristics (i.e. mother/daughter, father/son) was somehow stronger. These alternative frameworks were volunteered in interview and not tested for directly. It is interesting that both these misconceptions emerged similarly from the study by Kargbo, Hobbs and Erickson (1980).

The notion that all eggs and sperm released at the same time give rise to identical phenotypes arose within two question contexts with just a few pupils, but may represent a discrete and more widely-held viewpoint.

The suggestion that a given gene could be dominant in one offspring and recessive in another may represent genuine misunderstanding of the concept of dominance, or it may simply reflect linguistic difficulties with 'dominant' meaning 'showing up in the phenotype'.

Many of the pupil understandings emerging from the testing of this Idea could most usefully be studied further, using direct questioning set within simple contexts.

ACQUIRED CHARACTERISTICS

SOME VARIATIONS (THOSE ACQUIRED DURING AN ORGANISM'S LIFETIME) ARE NOT INHERITED.

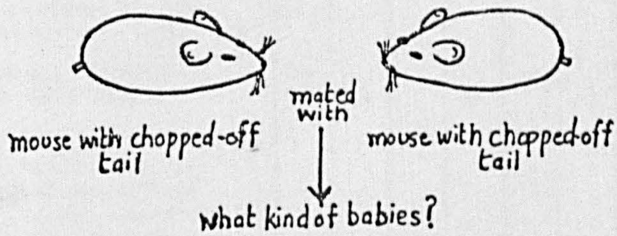
This Idea is tested using two examples of non-inherited characteristics in humans and one in mice. In two of these contexts the further question of the possibility of long-term inheritance of acquired characteristics was explored.

Q.49. MICE - CHOPPED-OFF TAILS

Q.50. MICE - CHOPPING OVER TIME

These two questions were based on the written test item below. The first is a simple reiteration of this question, and the second extended the problem.

> A scientist bred mice. In one litter he found that one of the baby mice had been born with no tail. When it was adult he mated this tailless mouse with a normal mouse and got some tailless babies in the litter. To see if he could get more tailless mice, he cut off the tails of some normal adult mice and bred them. When these mated, however, all their baby mice had tails.



> Do you think that if he bred the mice with the chopped-off tails again he would get tailless mice? Can you explain your answer?

APU item.

Q.50. What would happen if the scientists repeatedly chopped off the tails over several generations - what kind of babies would you end up with?

COMMENT ON RESULTS

No clear age trends emerged with either question - in fact, the percentages of ordinal responses remained remarkably stable over the age range.

Overall, a fifth of the responses indicated that there was at least some possibility of obtaining tailless mice after the first chopping, a further 44% indicated that tailless mice might result from the repeated chopping off of tails. Clearly, the idea of a gradual incorporation of acquired characteristics over a period of time is a plausible and appealing one.

QUESTION 49 MICE - CHOPPED-OFF TAILS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. MICE WITH TAILS BECAUSE THE GENETIC STRUCTURE CANNOT BE CHANGED *"Well, they'd still have tails because the chromosomes wouldn't have altered - it was just the tails that had been chopped off."* (pupil 3)	3	10	5	17	5	17	7	24	16	67
B. MICE WITH TAILS BECAUSE 'SOMETHING' INSIDE THEM CAN NOT BE CHANGED *"I think they'd get babies with tails. Because these mice can't just change their body structure . . . like how it is. But if you just have them chopped off - they'd have to change all the body feature of the mouse."* (pupil 22)	4	13	2	7	2	7	1	3	0	0
C. MICE WITH TAILS BECAUSE PARENTS HAVE HAD/WERE BORN WITH TAILS/BECAUSE UNNATURAL *"Mice with tails. Because they had tails until he chopped them off and it's . . . well . . . they were born with tails, so the other mice would be born with tails."* (pupil 14) *"Mice with just normal tails, because these chopped-off tails aren't natural so the babies will just . . .* (pupil 12)	15	50	17	59	13	43	15	52	3	13
D. MICE WITH TAILS, NO REASON/INCONSEQUENTIAL REASON/TAUTOLOGY *"I think he'd get baby mice with tails . . . because he's chopped them off himself."* (pupil 49)	0	0	2	7	2	7	1	3	1	4
TOTAL ORDINAL RESPONSES		73		90		73		83		83
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	0	0	1	3	0	0	1	4
N. MICE WITH TAILS IF STUMPS/ROOTS OF TAIL ARE LEFT *"I should think have tails. If he's chopped the tail off and there's a little bit showing . . . they're forced to have tails."* (pupil 84)	0	0	1	3	2	7	0	0	1	4
O. TAILLESS MICE, NO REASON/PARENTS HAD NO TAIL *"Babies with chopped-off tails. Because both the mice haven't got tails to start with, and when they mate you'd expect to get babies with chopped-off tails."* (pupil 13)	6	20	2	7	3	10	2	7	1	4

Category set continued on next page.

QUESTION 49 MICE - CHOPPED-OFF TAILS (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
P. TAILLESS MICE BECAUSE NO GENES FOR TAIL *"Ones with no tails. Because the genes that they inherit would be ones that didn't know anything about tails, so they just didn't have them."* (pupil 76)	0	0	0	0	1	3	1	3	1	4
Q. MISCELLANEOUS (i) a mixture of tailed and tailless mice (pupils 17 and 52) (ii) mice with medium-length tails (pupil 20)	2	7	0	0	1	3	2	7	0	0
TOTAL ALTERNATIVE RESPONSES		27		10		27		17		17

QUESTION 50 MICE - CHOPPING OVER TIME

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 24		X14 n = 27		Y14 n = 25		Y16 n = 24		Z16 n = 22	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. STILL MICE WITH TAILS (REASONS GIVEN IN ANSWER TO QUESTION 49) *"Mice with tails. Well, they're chopped off – they weren't not there naturally."* (pupil 4) *"Still mice with tails on."* (pupil 6)	13	54	16	59	13	52	13	54	13	59
TOTAL ORDINAL RESPONSES		54		59		52		54		59
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	4	3	11	0	0	0	0	0	0
N. MAY AT LEAST GET SOME TAILLESS MICE OVER TIME *"I think you would probably have ones with . . . after a time it might end up that babies don't have tails, if he keeps repeating it . . . it probably would happen, it's hard to say how many generations . . . well, probably after 4 or 5 generations they might start not to have tails."* (pupil 42) *" . . .* (long pause) *I suppose you'd still get normal ones . . . well, I thought it could have been . . . I mean it sounds a bit silly . . . but it could have been that, you know, they got used to the fact, with them being without a tail that the idea'd completely pass away or something like that . . . "* (pupil 41)	7	29	4	15	11	44	7	29	7	32
O. SOME TAILLESS MICE, BECAUSE MICE CONSCIOUSLY ADAPT *" . . . yes, then they probably wouldn't bother growing their tails any more if they knew they were just going to lose them."* (pupil 1)	1	4	3	11	0	0	2	8	1	5
P. GRADUAL SHORTENING OF TAILS AT LEAST A POSSIBILITY *"The tails would get shorter, but there'd still be some tails."* (pupil 69)	1	4	1	4	1	4	2	8	1	5
Q. MISCELLANEOUS (i) A range of tail lengths in the offspring *" . . . might be some with little tails and some with middle-sized."* (pupil 20)	1	4	0	0	0	0	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		46		41		48		46		41

Q.51. ATHLETES

Q.52. ATHLETES OVER TIME

After some discussion with pupils about the various factors which contribute to athletic prowess, the following two problems were posed in interview.

Q.51. Let's take as an example an athletic couple - a man and his wife - who had both become excellent runners. They had not been specially fast to begin with, but they had both trained hard and so become very good. Would their children be automatically excellent runners?

Q.52. If these children practised hard and their children did the same and so on, would the children be automatically fast runners in about 200 years?

COMMENT ON RESULTS

This example was chosen because it was thought that a sporting context would be appealing, but it turned out to be a difficult problem for some pupils to talk about. This is perhaps not surprising, since many genetic and environmental factors contribute to athleticism.

As with the questions on mice tails, no clear age trends emerged for either of these questions.

The majority of pupils of all ages thought that the effects of training would not be passed on to the first generation offspring, though only a few of these were able to offer a good explanation in terms of a distinction between inherited and non-inherited characteristics. However, as with the mice tails, the notion of a gradual incorporation of an acquired characteristic over time was clearly powerful, since nearly half the responses contained this idea.

QUESTION 51 ATHLETES

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. NO, BECAUSE TRAINING WOULD NOT AFFECT GENETIC MAKE-UP/CHILDREN WOULD NOT HAVE INHERITED THE REQUIRED ATTRIBUTES TO RUN FAST *"Not at the beginning, probably a bit faster because of the training . . . hang on . . . no, sorry, no, I wouldn't expect their kids to because, as I said earlier on, the DNA structure never changes. It would just be . . . probably a lot would depend on their health, if they were any good."* (pupil 8) *"No because it isn't a gene. It's like something what they've got into theirselves like mice with tails cut off."* (pupil 11)	2	7	4	14	4	13	5	17	8	33
B. NO, CHILDREN WOULD HAVE TO TRAIN THEMSELVES/CHILDREN WOULD HAVE TO BE INTERESTED/DETERMINED/PARENTS WERE NOT NATURALLY GOOD RUNNERS/PARENTAL ENCOURAGEMENT NEEDED *"I don't think so, because before they weren't really very good runners so the children might not be, 'cos' they were only trained to be good runners."* (pupil 12) *"No. It just counts if they were to train a lot like their parents."* (pupil 58)	20	67	18	62	14	47	12	41	12	50
C. NO, NO OR INCONSEQUENTIAL REASON *"No, I don't think so. It doesn't mean to say their children could run fast like they have."* (pupil 84)	3	10	4	14	6	20	8	28	2	8
TOTAL ORDINAL RESPONSES		83		90		80		86		92
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	1	3	1	3	1	3	0	0
N. YES, OR INCONSEQUENTIAL REASON *"Yes, well it just carries on from them like it does with foxes, and they get strength from the mothers and that, and they can run fast."* (pupil 50)	4	13	1	3	2	7	2	7	1	4
O. YES, IT WOULD WORK A BIT BUT THEY WOULD HAVE TO TRAIN AS WELL *"No, I think they'd have to train a little, but not as much as their parents did."* (pupil 57)	0	0	1	3	3	10	1	3	1	4
TOTAL ALTERNATIVE RESPONSES		17		10		20		14		8

QUESTION 52 ATHLETES OVER TIME

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 26		X14 n = 28		Y14 n = 25		Y16 n = 28		Z16 n = 22	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. NO, IT WOULD NOT WORK EVEN OVER TIME *"No, I wouldn't think so because it's the same sort of thing (as Question 51 . . . . . "* (pupil 41) *"No, I wouldn't say so, I'd say that it'd be something that was . . . because the parents weren't fast to start off with."* (pupil 47)	12	46	13	46	12	48	16	57	10	45
TOTAL ORDINAL RESPONSES		46		46		48		57		45
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	2	8	1	4	0	0	1	4	2	9
N. YES, IT MAY WORK, AT LEAST A BIT, OVER TIME, NO REASON OR INCONSEQUENTIAL REASON *"I suppose so if everyone before them were - I suppose eventually they'd all be good. Over a long time, I suppose."* (pupil 2) *"Yes. Because muscles get harder and harder."* (pupil 5)	11	42	13	46	11	44	8	29	8	36
O. YES, PRACTICE WOULD AFFECT GENETIC MAKE-UP OVER TIME *"Well, they might be slightly fast, but not automatically very fast. Well, it might be an inherited characteristic, sometimes."* (Which practice would have?) *"Brought out, sort of improved on."* (pupil 3) *"I think they'd be good to a certain extent, more than a normal person, because I think it'd be gradually carried on in the genes."* (pupil 76)	1	4	1	4	2	8	3	11	2	9
TOTAL ALTERNATIVE RESPONSES		54		54		52		43		55

Q.53. GARDENERS'CHILDREN

The following question was posed as a final example to probe pupils' ideas about the inheritance of acquired characteristics.

You know that gardeners sometimes develop rough patches of skin on their hands as a result of hard work in the garden. Would they pass these on to their children? Can you explain?

COMMENT ON RESULTS

Even for this very improbable (to adults) example, 11% of all responses indicated either that pupils were uncertain or that they thought that the characteristic of roughness would be passed on to the gardener's children.

QUESTION 53 GARDENERS' CHILDREN

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. NO, BECAUSE THE GENETIC MAKE-UP WOULD NOT BE AFFECTED/CHILDREN WOULD NOT INHERIT AN ACQUIRED CHARACTERISTIC *"No . . . well the gardener had to do the work to get the calluses . . .* (he) *wouldn't have inherited it through the chromosomes - he'd have to actually get it, and it wouldn't be passed on through the chromosomes because it was a sort of physical ailment."* (pupil 3)	3	10	2	7	2	7	5	17	6	25
B. NO, CHILDREN WOULD HAVE TO GARDEN THEMSELVES/PARENTS WERE NOT LIKE THAT FROM BIRTH/CAN BE REMEDIED/IS EXTERNAL/GOT ONLY THROUGH WORK *"No, well it's got there through a lot of years of work."* (pupil 4) *"No . . . probably because it's on the outside of the body."* (pupil 34) *"No . . . it'll probably depend whether the sons want to be gardeners as well."* (pupil 42)	21	70	19	66	20	67	16	55	14	58
C. NO, NO OR INCONSEQUENTIAL REASON	3	10	6	21	3	10	4	14	2	8
TOTAL ORDINAL RESPONSES		90		93		83		86		92
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	1	3	1	3	1	3	1	3	0	0
N. WOULD OR MIGHT BE PASSED ON *"Yes, I think so. Because . . . well if they get a lot of rough skin, I think it just carries on down through the families."* (Even though the children themselves might not garden?) *"Yes . . . just comes like."* (pupil 55)	1	3	0	0	1	3	2	7	0	0
O. NOT AT FIRST, BUT MIGHT OVER SEVERAL GENERATIONS/OVER TIME *" . . . Maybe . . . after a . . . after you know 50 years . . . if every one of their sons was a gardener, they might automatically get tougher hands. Take a long time though."* (pupil 39) *"No, I don't think so . . . over time if all his family were gardeners I suppose they might, because the Arctic fox I've just said developed thick fur."* (pupil 31)	1	3	1	3	3	10	1	3	2	8
TOTAL ALTERNATIVE RESPONSES		10		7		17		14		8

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understanding of ACQUIRED CHARACTERISTICS. The Table below lists the frameworks for this Idea and gives the frequencies of occurrence as percentages of subsamples of pupils.

TABLE 11 PUPIL FRAMEWORKS - ACQUIRED CHARACTERISTICS

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORK	FREQUENCIES														
		12 Yr (X12)					14 Yr (X14 and Y14)					16 Yr (Y16 and Z16)				
		Q49 (n=30) Mice	Q50 (n=24) Mice-time	Q51 (n=30) Athletes	Q52 (n=26) Athletes -time	Q53 (n=30) Gardener	Q49 (n=59) Mice	Q50 (n=52) Mice-time	Q51 (n=59) Athletes	Q52 (n=53) Athletes -time	Q53 (n=59) Gardener	Q49 (n=53) Mice	Q50 (n=46) Mice-time	Q51 (n=53) Athletes	Q52 (n=50) Athletes -time	Q53 (n=53) Gardener
1. Acquired characteristics are not inherited because there is no genetic change	49A,51A,53A	10%	-	7%	-	10%	17%	-	14%	-	7%	43%	-	25%	-	21%
2. Acquired characteristics are not inherited because it is "unnatural".	49B,49C,51B, 53B	63%	-	67%	-	70%	58%	-	54%	-	66%	36%	-	45%	-	57%
3. Acquired characteristics are inherited because phenotypic change affects the genes	49P,520	0	-	-	4%	-	2%	-	-	6%	-	4%	-	-	10%	-
4. Acquired characteristics are inherited by the first generation of offspring	490,49N,49Q, 51N,510,53N	27%	-	13%	-	3%	15%	-	12%	-	2%	11%	-	9%	-	4%
5. Acquired characteristics are not inherited immediately but they may be over several generations	50N,500,50P, 50Q,52N,530	-	42%	-	42%	3%	-	38%	-	45%	7%	-	43%	-	32%	6%
No identifiable framework	49D,49U,50A, 50U,51C,51U, 52A,52U,53C, 53U	0	58%	13%	54%	13%	8%	62%	20%	49%	19%	6%	57%	21%	58%	13%

GENERAL COMMENT ON PUPIL UNDERSTANDING OF ACQUIRED CHARACTERISTICS

These results are perhaps amongst the most interesting in the study because some of the pupil notions identified seem so highly improbable to adult ears. The findings of Brumby (1979) (whose subjects were university students) and Kargbo et al (1980) (who worked with young children) that the distinction between inherited and non-inherited changes is very confusing were confirmed. The belief in the inheritance of acquired characteristics, so clearly demonstrated by Kargbo et al in children below ten years, is also held by a sizeable proportion of the older children in this study.

Only small percentages of 12 and 14 year olds (though slightly more 16 year olds) could explain the non-inheritance of acquired characteristics in terms of lack of genetic change (Framework 1). Framework 2, on the other hand, is well supported, but represents only the most intuitive hunch that acquired characteristics are not inherited.

Significant numbers of responses in the 12 and 14 year old groups contain the idea of first generation inheritance of acquired characterestics (Framework 4), and a few even volunteered the explanation that phenotypic change affects genetic material (Framework 3), though this idea was not tested by direct questioning.

Two questions (MICE - CHOPPING OVER TIME and ATHLETES OVER TIME) were specifically designed to test pupils' understandings when the phenotypic change repeatedly occurs over several generations. It was very clear (and elements of this emerged in response to questions feeding the Idea ADAPTATION as well) that pupils find the idea of the influence of the passage of time on phenotypic change a compelling explanatory framework (Framework 5). Even pupils who gave good explanations for the initial non-inheritance of acquired characteristics were often unable to maintain that argument and succumbed to the notion that it would 'work in the end, given time'.

ADAPTATION

AS THE ENVIRONMENT CHANGES ORGANISMS WITH FAVOURABLE VARIATIONS SURVIVE, LEAVING MORE DESCENDANTS. WITHOUT THESE THEY DIE OUT.

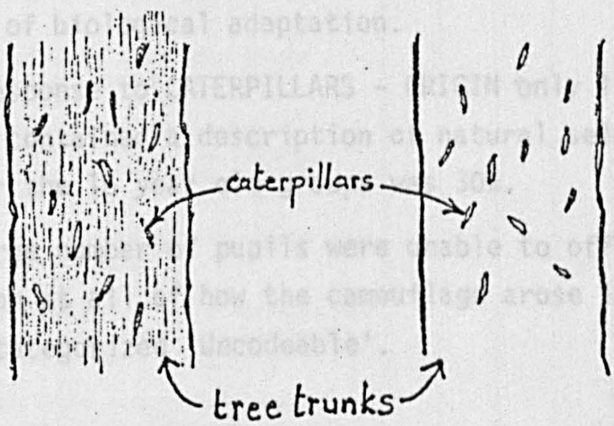
Previous questions and Ideas on variation and its sources which have been described in this chapter lead up to this key concept of biological adaptation and its role in evolution. Interview questioning was based on two examples of morphological adaptation camouflage in caterpillars and the thick-coatedness of Arctic-foxes. The results of the multiple-choice quiz on adaptation are presented separately.

Q.54. CATERPILLARS

Q.55. CATERPILLARS - ORIGIN

Pupils were reminded of the following written test item.

> Children were walking through a wood.
> They noticed that one type of caterpillar lived on a certain type of tree. The tree trunk of this type of tree could be either pale or dark. They found that most of the caterpillars on the dark tree trunks were dark coloured and that most of the caterpillars on the pale trees were pale in colour.



> I think this is because ______________________________
> ______________________________
> ______________________________

They were then asked this introductory question in interview.

Can you explain what is happening here? Why do you think that the children found most of the dark caterpillars on the dark trees and most of the pale ones on the pale trees?

and then:

How do you think that the arrangement came about in the first place?

COMMENT ON RESULTS

Responses to CATERPILLARS (arranged on one descriptive scale) provided some initial clues to pupils' thinking. Most pupils recognized that this was an example of camouflage. A distinction was made in categorization between responses which phrased this in the passive and those which indicated that this was a conscious, deliberate act on the part of the caterpillars. However, too much weight should

Q.54. CATERPILLARS
Q.55. CATERPILLARS - ORIGIN (contd.)

not be put on this linguistic distinction. It was undoubtedly easier (especially for younger pupils) to talk about the adaptation as an active, deliberate process. Not all pupils who expressed it in this way would necessarily believe it to be the case. However, as was demonstrated in response to the question on how the camouflage originated, many other pupils were firmly convinced, and very explicit, about the conscious and deliberate character of biological adaptation.

In response to CATERPILLARS - ORIGIN only 15% of all responses contained a description of natural selection, though the figure for the 16 year old groups was 30%.

A large number of pupils were unable to offer any coherent explanation at all of how the camouflage arose in the first place, and were categorized 'Uncodeable'.

QUESTION 54 CATERPILLARS

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
H. CATERPILLARS ARE CAMOUFLAGED AND PROTECTED *"Well, if there were any pale caterpillars on the dark tree the birds'd see them and eat them, so only the dark ones would survive on the dark trees - so there wouldn't be any light ones because the birds would get them all."* (pupil 3)	14	47	16	55	12	40	20	69	13	54
I. CATERPILLARS HAVE THEIR FOOD SUPPLY THERE/ECOLOGICAL NICHE *"It's probably their food, they probably feed on that tree, and they probably feed on other tree. They've got different feeds."* (pupil 60)	2	7	0	0	1	3	1	3	1	4
J. CATERPILLARS USE THE TREE FOR CAMOUFLAGE/ CAMOUFLAGE THEMSELVES *"The caterpillars are using the tree for camouflage . . . against the creatures that might eat them."* (pupil 1) *"Well, the light caterpillars might not like the dark so they try and find the lightest tree they can, and go on it . . . because if they go on the dark tree . . . like birds . . . they'd notice them easily and swoop down and pick them up."* (pupil 15)	12	40	11	38	14	47	6	21	7	29
K. CATERPILLARS ARE ATTRACTED TO THEIR OWN COLOUR *"I suppose the pale ones can see . . . notice that they are pale and that the tree's pale so they simply just go on it. I suppose it is* (a good arrangement for the caterpillars) *. . . meant that they are all together."* (pupil 44)	1	3	2	7	3	10	1	3	1	4
L. MISCELLANEOUS The colour of the tree influences the colour of the caterpillars (pupil 79)	0	0	0	0	0	0	0	0	1	4
U. UNCODEABLE/DON'T KNOW	1	3	0	0	0	0	1	3	1	4

QUESTION 55 CATERPILLARS - ORIGIN

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. NATURAL SELECTION OPERATING ON A MIXED CATERPILLAR POPULATION *"Natural selection. A caterpillar say developed . . . a mutant caterpillar . . yes, well, one caterpillar all of a sudden develops a strange gene and became white . . . and this gave it the ability to survive on white trees more than it did caterpillars on dark trees the ability to survive, and so one by one all the dark caterpillars got picked off and eaten by birds. All the white ones stayed where they were to carry on reproducing and making new generations of white caterpillars."* (pupil 65)	1	3	4	14	1	3	8	28	8	33
TOTAL ORDINAL RESPONSES		3		14		3		28		33
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	12	40	7	24	7	23	5	17	6	25
N. CHANGE OF COLOUR OVER TIME/NATURAL PROCESS/NO EXPLANATION *" . . . the moths have mated over a couple of years, and the caterpillars have adjusted to it over the years."* (How would they adjust?) *"Don't know . . . no idea."* (pupil 16)	2	7	3	10	4	13	5	17	3	13
O. INSTANT COLOUR CHANGE *"It's something to do with his skin - there's some animals can change their skin whatever . . . anything they're on. Like grasshoppers if they are in green grass they can make themselves green - if they're in brown grass they can make themselves brown."* (pupil 23)	2	7	2	7	0	0	0	0	0	0
P. DARK ONES ALWAYS BEEN ON DARK TREES - NO CHANGE/A NATURAL STATE OF AFFAIRS *"I think it's just followed down from generations."* (Always been like that?) *"Yes, yes I think so, yes."* (pupil 55) *"Always been the case."* (pupil 59)	0	0	2	7	5	17	5	17	0	0
Q. DARK CATERPILLARS DELIBERATELY MOVED TO DARK PLACES/BUTTERFLIES CONSCIOUSLY LAY EGGS IN PLACES WHICH OFFER PROTECTION/ LEARNT FROM EXPERIENCE THAT TREE OF OWN COLOUR OFFERS PROTECTION *"The butterflies probably laid their eggs on the branches of the dark trees, if they knew that their caterpillars would come out dark."* (pupil 1)	11	37	3	10	5	17	1	3	0	0

Category set continued on next page.

QUESTION 55 CATERPILLARS - ORIGIN (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 24	
	No.	%	No.	%	No.	%	No.	%	No.	%
Q. continued *"Well, the caterpillars might have just gone on to the dark tree and found that it was good because then the enemy couldn't get them."* (Realized that?) *"Yes."* (pupil 18)										
R. DELIBERATE/CONSCIOUS DEVELOPMENT OF CAMOUFLAGE/REALIZED HAD TO CHANGE COLOUR *" . . . the parents'd realize that they'd got to do something to protect themselves, so during the years they'd slowly become the same colour as the tree."* (pupil 38) *"Because at one time species'll be running out you know dying out so they knew that they'd got to change, and it'll have took a long time, but gradually they started to get darker and darker till eventually they were dark enough to survive like that."* (pupil 61)	1	3	8	28	3	10	4	14	3	13
S. COLOUR CHANGE FROM FOOD *" . . . maybe there's something on the trees which they eat."* (pupil 71)	0	0	0	0	2	7	1	3	1	4
T. MISCELLANEOUS (i) liked the colour of the tree (4 pupils) (ii) light attracted to dark tree and darkens caterpillars like sunburn (1 pupil) (iii) tree changes the colour of the caterpillars (1 pupil) (iv) God (1 pupil)	1	3	0	0	3	10	0	0	3	13
TOTAL ALTERNATIVE RESPONSES		97		86		97		72		67

Q.56. CATERPILLARS - PALE TREES

Pupils were shown the photograph of grey and white caterpillars on a leaf (see below) and asked the following, which is a supplementary question to the written test item CATERPILLARS just described.

What do you think might happen if the colour of the dark trees began to change over the years? It could, for example, become covered with a pale moss. What would happen to the dark caterpillars then?

If necessary, it was stressed again that the question asked about any possible long-term change. Thus, this question asks pupils to predict what will happen when the environment changes and to explain that prediction.

COMMENT ON RESULTS

Again, the percentages of correct responses rose significantly with the 16 year old groups, but there was no increase in understanding of natural selection from 12 to 14 years.

Nearly two-thirds of the 12 year old group subscribed to the notion that the caterpillars would take evasive action and move, either deliberately or unconsciously, to a more favourable environment.

QUESTION 56 CATERPILLARS - PALE TREES

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 26		X14 n = 27		Y14 n = 25		Y16 n = 26		Z16 n = 21	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. POPULATION OF BLACK CATERPILLARS WOULD DIE OUT, BECAUSE DISADVANTAGED AND FEW WHITE ONES WOULD SURVIVE AND PROSPER *"Well, natural selection would happen again. If a mutant was born that was a bit lighter . . . that were nearer to colour of tree that one wouldn't get eaten, and so it would breed and that one would be more successful . . . make a race of lighter ones."* (pupil 73)	0	0	3	11	1	4	7	27	6	29
B. BLACK CATERPILLARS WOULD DIE OUT/GET EATEN *"I suppose eventually because birds could see them they'd all get eaten."* (pupil 2)	2	8	1	4	1	4	2	8	0	0
C. COLOUR CHANGE WITHIN LIFE-SPAN OF INDIVIDUAL CATERPILLAR (EITHER BY EATING MOSS OR CHAMELEON CHANGE) *" . . . I think they'd change colour . . . just gradually, caterpillars breeding and eating the tree which is gradually changing colour - will gradually change the colour of them."* (pupil 40) *"They'd probably adapt to it and change their colour as well . . . make chemical changes in their body so that they could change their colour. There's a lizard - I can't remember what it's called, and that changes colour to stay on the scenery."* (pupil 1)	3	12	2	7	2	8	0	0	1	5
D. CHANGE COLOUR OVER TIME, NO EXPLANATION *"They'd adapt again to surroundings . . don't know* (how)." (How long would it take?) *"About four generations."* (pupil 6)	4	15	4	15	4	16	6	23	4	19
TOTAL ORDINAL RESPONSES		35		37		32		58		52
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	0	0	1	4	4	16	3	12	2	10
N. A CHANGE OF COLOUR OVER TIME, DELIBERATELY/CONSCIOUSLY EXECUTED *"Well the caterpillars would have to get lighter as well . . . well the caterpillars would be aware that their environment is changing and then they'd try to change by changing the pigment of their skin."* (pupil 54)	1	4	7	26	1	4	4	15	1	5

Category set continued on next page.

QUESTION 56 CATERPILLARS - PALE TREES (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 26		X14 n = 27		Y14 n = 25		Y16 n = 26		Z16 n = 21	
	No.	%	No.	%	No.	%	No.	%	No.	%
O. CATERPILLARS MOVE (EITHER DELIBERATELY OR UNCONSCIOUSLY FOR BETTER CAMOUFLAGE	16	62	9	33	12	48	3	12	7	33
"I think they'd just go and look for another darker tree, something dark." (a deliberate policy?) *"Yes, they've got to camouflage themselves or they're going to get eaten by birds."* (They would think that out?) *"Yes."* (pupil 55)										
"They'd probably stay under the bark (hide)." (pupil 78)										
"On another tree - they'd move on another dark tree. 'Cos they'd find out now that more are being killed off and the ones who are left say 'Well, its growing moss and its getting a lot paler, so we might as well move'." (pupil 26)										
"They'd have to move back to another tree - the dark tree." (pupil 7)										
"On other trees without moss." (pupil 39)										
P. MISCELLANEOUS	0	0	0	0	0	0	1	4	0	0
By cross-breeding with pale caterpillars										
TOTAL ALTERNATIVE RESPONSES		65		63		68		42		48

Q.57. ARCTIC FOX

This interview question was based on the multiple-choice quiz FOXES AND FLIES (see pp.230-33), which was administered to individual pupils 1-4 days before the evolution interview.

You did a quiz for me at the end of our last interview session, if you remember, called FOXES AND FLIES. I would like to go on to the example of the Arctic Fox. The thick coat is obviously extremely useful in the fox's survival in those very low temperatures - can you explain how you think this came about originally?

COMMENT ON RESULTS

Few pupils (11% of all responses) offered a Darwinian explanation of natural selection though 21% of 16 year olds fitted into this category.

More than one-third of the responses contained the idea that this adaptation is a response to a need created by the adverse environmental conditions.

Two other alternative response categories were very popular. About a fifth of all responses seemed to indicate a naive acceptance of biological stability as a natural state of affairs, whilst others, as with those from the CATERPILLAR questions, incorporated the notion of adaptation as a conscious, deliberate process.

QUESTION 57 ARCTIC FOX

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 23	
	No.	%	No.	%	No.	%	No.	%	No.	%
A. NATURAL SELECTION OPERATING ON ANIMALS, WITH INHERITED VARIATIONS IN THE POPULATION *"Well possibly there were some foxes with thin coats and some foxes with slightly thicker coats, but the foxes with thin coats would have frozen to death and the foxes with slightly thicker coats might have survived long enough to have more offspring with thick and thin coats, and the thin ones would die out, so the thicker-coated ones would survive more so they eventually ended up with very thick coats."* (pupil 3)	1	3	3	10	1	3	5	17	6	26
TOTAL ORDINAL RESPONSES		3		10		3		17		26
ALTERNATIVE RESPONSE CATEGORIES										
U. UNCODEABLE/DON'T KNOW	3	10	1	3	2	7	1	3	1	4
N. SELECTION DESCRIBED, SOME FOXES DEVELOPED THICK COATS, SOME DID NOT, NO REASON *"... well... they got it from their mothers and it just carried on from there... some might not have been all that thick,... some might... hair have been thinner...probably would have died if it had been really cold and they couldn't keep warm."* (How did thick coats come about in the first place?) *"I don't know, it was just ...like they wanted to wear a coat."* (pupil 50)	0	0	1	3	3	10	1	3	3	13
O. RESPONSE TO NEED IN INDIVIDUAL FOX'S LIFESPAN *"Well its just preparing itself to leave its mother and live in the cold itself...and when its old enough to leave it needs something to keep it warm, so it grows a thick coat, so it can keep warm while its out looking for food."* (pupil 10)	3	10	0	0	1	3	0	0	0	0
P. ARCTIC FOXES HAVE ALWAYS HAD THICK COATS/NO CHANGE/ A NATURAL STATE OF AFFAIRS *"I don't know really... probably since always... been born with thicker coats."* (pupil 59) *"The first one that was made was one with a coat... er. When animal's born and he's given certain things its made to go to a certain place."* (pupil 17)	4	13	8	28	5	17	9	31	2	9

Category set continued on next page.

QUESTION 57 ARCTIC FOX (continued)

DESCRIPTION OF CATEGORY AND EXAMPLES	SUBSAMPLE FREQUENCIES									
	X12 n = 30		X14 n = 29		Y14 n = 30		Y16 n = 29		Z16 n = 23	
	No.	%	No.	%	No.	%	No.	%	No.	%
Q. THICK-COATED FOXES MOVED TO NEW ENVIRONMENT WHERE BETTER SUITED *"There could have been a fox that had a thick coat but lived in quite a warm climate and it got hot because it had a thick coat so it moved up into a colder place and then carried on breeding... with thick fur coat."* (pupil 12)	1	3	0	0	0	0	0	0	0	0
R. DELIBERATE/CONSCIOUS DEVELOPMENT OF THICK COAT OVER TIME *"... because they got used to the cold so they thought that they'd better get the coats thicker, so it became thicker."* (a deliberate policy?) *"Yes."* (pupil 5) *"When it turned all cold the foxes fought to keep themselves alive and gradually they began to grow thicker coats until they were able to survive properly... yes, they were sort of determined to stay alive."* (pupil 14)	8	27	4	14	3	10	2	7	2	9
S. RESPONSE TO NEED (UNCONSCIOUS) IN POPULATION OVER TIME RESULTS IN GRADUAL THICKENING OF FUR FROM ONE GENERATION TO THE NEXT *"... and inside them when the baby was developing it might have just been a sort of natural instinct which made them grow thicker coats to stand up to the cold... it'd take time."* (pupil 15) *"... and they needed to survive so they passed it on through their generation to have thicker fur."* (pupil 39) *"Well, the colder it gets the more cold they'll get so they would have to start growing their fur... its a natural process, they can't will themselves to grow extra fur but it should happen over many years... they should start getting longer."* (pupil 54)	8	27	11	38	15	50	11	38	9	39
T. MISCELLANEOUS (i) inherited 'mistake', consciously taken advantage of (1 pupil) (ii) God (1 pupil)	2	7	1	3	0	0	0	0	0	0
TOTAL ALTERNATIVE RESPONSES		97		90		97		83		74

FOXES AND FLIES QUIZ

This short quiz (pp. 230 - 33) was designed to supplement data from the interview. It seemed likely that the use of teleological, naturalistic and anthropomorphic expressions in relation to adaptation (such as those offered in response to open-ended interview questions) may reflect linguistic difficulties in some cases as well as genuinely representing these interpretations in others. In order to distinguish the alternatives a number of clear-cut choices were presented to determine:
(a) whether pupils believed that the process of adaptation is done purposefully by organisms, as a response to environmental factors (b) whether pupils link the process to individual organisms or to whole populations (c) whether it is appreciated that the adaptive features which are significant from an evolutionary point of view are inherited. Two examples of animal adaptation (one morphological and one biochemical) were used with parallel choices offered for both. In Q.1 points (a) and (b) above are tested and in Q.2 points (c) and (b) are probed.

The results of the quiz are presented in the table:

TABLE 12 RESULTS OF QUIZ

TYPE OF EXPLANATION CHOSEN	QUESTION CHOICE	12 Yr (X12)		14 Yr (X14 & Y14)		16 Yr (Y16 & Z16)	
		Fox (n=30)	Flies (n=30)	Fox (n=59)	Flies (n=59)	Fox (n=53)	Flies (Q.1 n=53) (Q.2 n=52)
1. Natural selection operates on a varied population	Fox Q1 (b) Flies Q1 (c)	13%	37%	34%	46%	42%	42%
2. Teleological explanation, linked to individual organism	Fox Q1 (a) Flies Q1 (d)	43%	10%	25%	15%	9%	8%
3. Teleological explanation linked to populations	Fox Q1 (d) Flies Q1 (b)	43%	43%	41%	36%	47%	51%
4. Strongly teleological and anthropomorphic	Fox Q1 (c) Flies Q1 (a)	0	10%	0	3%	2%	0
5. Intra specific variations are inherited differences	Fox Q2 (c) Flies Q2 (d)	53%	60%	64%	59%	83%	73%
6. Adaptive feature is non-inherited and linked to individuals	Fox Q2 (b) Flies Q2 (c)	13%	20%	7%	15%	2%	12%
7. Adaptive feature is non-inherited and linked to populations	Fox Q2 (a) Flies Q2 (b)	10%	7%	12%	14%	6%	2%
8. Strongly and explicitly non-inherited adaptation	Fox Q2 (d) Flies Q2 (a)	23%	13%	17%	12%	9%	13%

FOXES and FLIES

This quiz is about the ways in which animals fit in specially well with where they live, and how both the animals and the conditions around them have changed. We talked earlier about how plants and animals do this. There are many different ideas on how all this happened, and scientists cannot be certain how it came about. I would like you to read the following, and then answer the quiz, giving in each case a tick beside the explanation which you think is best.

THE ARCTIC FOX

The Arctic Fox lives in extremely cold places and it can live perfectly well at very, very low temperatures. In fact, it doesn't even need to run around to keep warm when the air temperature is -50^{o}C. One way in which the fox does this is by having a very thick coat of fur.

I would like you to read the following explanation carefully and then put a tick ☑ beside the one you think is best. You will need to read all four through first, and think about them before you tick.

Question 1

(a) I think that each fox, as it grows and gets ready to leave its mother, makes some effort to survive the Arctic cold by growing a thick fur coat. ☐

(b) I think that long ago foxes with slightly thicker coats were more likely to survive the cold. Now Arctic foxes have thicker coats. ☐

(c) I think that the fox is likely to say something like this to himself - 'It's cold here. I'd better see if I can grow a warm coat'. ☐

(d) I think that long ago all the foxes that lived in the Arctic were cold - there was obviously a need to protect themselves from the weather, and the thick coats which they grew helped a lot. ☐

Here is another set of explanations about the Arctic Fox - again I would like you to pick out and tick ☑ the one you think is best.

Question 2

(a) Long ago foxes learnt that thick coats were useful in the cold. Each new generation of foxes has to learn the same thing. ☐

(b) If a fox grows a thick coat, he will live successfully in the cold, but he cannot pass this on to his young. ☐

(c) Long ago a few foxes had thicker coats. They passed this on to their young who in turn passed it on theirs and so on. ☐

(d) The thick fur of the Arctic Fox, which fits in so well with Arctic conditions, is not passed on from generation to generation. ☐

FLIES

Here is another example of an animal changing to suit its surroundings. Many insects (flies and mosquitoes) can be killed by a poisonous chemical called D.D.T. Since many insects carry disease, it was important for Man to try and kill off those insects which did carry serious diseases like malaria and typhoid. D.D.T. was used a lot and because it was such a good killer it was very helpful to Man. But about 30 years ago (when your parents were children) it was discovered that D.D.T. was not working so well - more and more flies were surviving even though they had been sprayed with the poisonous chemical. This is still true today. How do you think this came about? Read the following explanations carefully and then put a tick [✓] beside the one you think is best. You will need to read all four through first and think about them before you tick.

Question 1

(a) I think that the flies are likely to have thought something like this - 'We must do something otherwise we are all going to be killed off by the D.D.T. We must find a way of avoiding the chemical'. [ ]

(b) I think that 30 years ago, when all the flies that were sprayed were being killed by D.D.T., there was an obvious need for the flies to become resistant (to avoid being killed) and this is what happened. [ ]

(c) I think that there must always have been a few flies who were not killed off by D.D.T., even when it was first used, and these flies produced many more young. But those killed by the chemical may well have died before they had laid any eggs. [ ]

(d) I think that each fly made an effort to stay alive - and some succeeded and were not killed by the D.D.T. [ ]

Question 2

Here is another set of explanations about flies and D.D.T. Again I would like you to pick out and tick [✓] the one you think is best.

(a) The ability to resist, or not be killed by, D.D.T. is not passed on from one generation of flies to the next. ☐

(b) About 30 years ago flies learnt how to avoid the most harmful effects of D.D.T. Each new generation of flies has to learn the same thing. ☐

(c) If a fly makes a certain chemical change in his body he will live successfully even if sprayed with D.D.T., but he cannot pass this ability on to his young. ☐

(d) About 30 years ago some sprayed flies were not killed by D.D.T. This ability to survive D.D.T. was passed on to their young, who in turn passed it on to theirs and so on. ☐

Can you now please fill in the following:

NAME	AGE ....
SCHOOL	BOY OR GIRL ....
YEAR	TODAY'S DATE ....

IDEA LEVEL

In this section information from the questions is collated to allow comment on pupil understandings of ADAPTATION. The Table below lists the frameworks for this Idea and gives the frequencies of occurrence as percentages of subsamples of pupils.

TABLE 13 PUPIL FRAMEWORKS - ADAPTATION

FRAMEWORKS RELATING TO IDEA	CATEGORIES CONTRIBUTING TO FRAMEWORKS	FREQUENCIES								
		12 Yr (X12)			14 Yr (X14 & Y14)			16 Yr (Y16 & Z16)		
		Q55 (n=30) origin	Q56 (n=26) p.trees	Q57 (n=30) fox	Q55 (n=59) origin	Q56 (n=52) p.trees	Q57 (n=59) fox	Q55 (n=53) origin	Q56 (n=47) p.trees	Q57 (n=52) fox
1. Biological adaptation results from natural selection operating on a population	55A,56A,57A	3%	0	3%	8%	8%	7%	30%	28%	21%
2. Animals consciously effect physical change in response to a changed environ- environment	55R,56N,57R	3%	4%	27%	19%	15%	12%	13%	11%	8%
3. Animals adapt in response to a need for change	57O,57S	-	-	37%	-	-	46%	-	-	38%
4. Biological adaptation is a natural process	55N,56D,57N	7%	15%	0	12%	15%	7%	15%	21%	8%
5. Animals respond to a changed environment by seeking out a more favourable environment	55Q,56O,57Q	37%	62%	3%	14%	40%	0	2%	21%	0
No identifiable framework	55U,55O,55P,55S, 55T,56B,56C,56U, 56P,57U,57P,57T	50%	19%	30%	47%	21%	29%	40%	19%	25%

The symbol - in the above table indicates that there is no contribution to the Framework from that question.

Note: Since percentages are given only to the nearest 1%, the figures do not always add up exactly to 100%.

GENERAL COMMENT ON PUPILS UNDERSTANDING OF <u>ADAPTATION</u>

The interview results indicated that few pupils could explain biological adaptive processes. The framework indicating an understanding of natural selection (Framework 1) was poorly subscribed to, though there was a marked increase in percentage frequency with the 16 year old pupils. The percentages of pupils who opted for choices in the quiz which described natural selection operating on a varied population (Explanation 1) were somewhat higher, which is perhaps not surprising.

The distinction between adaptation as a process and adaptive features is emphasised in the literature. Maxwell (1978), for example, suggested that appreciation of adaptation as a process was much more difficult to grasp than the notion of an adaptive feature. In the quiz question 1 focusses on adaptation as a process and question 2 on adaptive features and, indeed, the percentages of pupils of all ages who chose the correct answer to question 2 were much higher than for question 1. Adaptation as a process is clearly a difficult and sophisticated concept.

Many responses in interview and in the quiz contained explanations with a teleological flavour. In question 1 of the quiz the majority of pupils opted for such explanations (Explanations 2, 3 and 4), though the crudely anthropomorphic expression of a teleological viewpoint (Explanation 4) was not popular.

In the interview analysis two of the frameworks (2 and 3) reflect an understanding of adaptation as a response to need, two others (2 and 5) contain the idea of it as a conscious, deliberate process i.e. a more subtle expression of anthropomorphism. This confirms earlier findings (e.g. Deadman, 1976; Jungwirth, 1977) that children's explanations frequently have a Lamarckian flavour, which is sometimes combined with anthropomorphism. Maxwell (1978) and Brumby (1979) reported that students tended to discuss adaptations with respect to individuals and not to populations. In question 1 of the quiz more pupils chose the explanations referring specifically to populations (Explanation 3) than to individual animals, though the percentages for the latter (Explanation 2) were also substantial.

In the quiz, substantial percentages of pupils of all ages chose Explanation 5, thereby indicating an understanding that the adaptive features which are significant from an evolutionary point of view are inherited. Even so, many pupils indicated a belief that adaptive features are non-inherited (Explanations 6, 7 and 8). The statements incorporating Explanation 8 were phrased in the strongest and most explicit terms; it is perhaps surprising therefore that so many pupils opted for this explanation.

Framework identification of interview data for this Idea indicates clearly how the context of the question influences pupil reasoning. The Arctic fox question for example, yielded large percentages of responses which drew on the notion of reaction to a generalised need (Framework 3), presumably because the image of a cold, adverse climate engendered this response. By contrast, this same response appeared in answer to only one of the caterpillar questions (CATERPILLARS - PREDATORS related to the Idea of INHERITANCE). For other caterpillar questions, on the other hand, large percentages of pupils suggested that the animals' response would be to move to a more favourable environment (Framework 5). Some of the categories contributing to 'No identifiable framework' constituted other context-dependent reasoning but it is very difficult, and not, I think, justifiable, to separate these categories from others such as Uncodeables in framework identification.

Results of the quiz also indicated how context influences the answers pupils give. The contributions of the 12 year old group to Explanations 1 (Natural selection) and 2 (Teleological explanation related to individual organism) were very different in the two question contexts.

CHAPTER 7

INDIVIDUAL PUPIL FRAMEWORKS

This chapter focusses on the responses of individual pupils rather than on pupil groups, and it addresses two research questions.

Firstly, it is clear that explanations of natural phenomena can be given on very different levels. There is evidence that the level and type of explanation is influenced by the way in which a problem is presented, by the specific context in which it is set. Responses will vary, for example, according to the pupils' familiarity with the phenomenon. The form in which the question is framed may also be crucial. So, responses will vary as well with the degree of open-endedness of the question. They will probably also depend on the kind of words used, for example questions including scientific terminology cue pupils into the idea that an answer in the scientific mode is expected.

Although explanations are always set within a context, it can be argued that some are bound to that particular context and do not extend from it, whereas others are less bound. The identification of pupil frameworks from question response categories represents a generalization, a characterization of scientific understanding which is at least partly distanced from the context of the question. It can be argued, therefore, that the presence of some degree of stability of response across different question contexts testing the same Idea would offer further support for the validity of pupil frameworks as firmly held ways of thinking. For the investigation of this issue it is essential to examine the responses of individuals.

Similarly, the second question, that of the development of children's scientific ideas over time, can be investigated best by an examination of the responses of individuals. Although cross-sectional methods (comparison of performances of groups of various ages) may provide valuable clues, only comparison of performances of the same individual will permit the detailed description of progress towards adult conceptions and of any points of arrest of this progress. Pedagogically, the question of stability of response over a period of time (and particularly of alternative ideas) is an interesting one. Is there any evidence, for example, that pupils' alternative frameworks, which are serviceable for them, are retained over time and resist further experience?

The procedures which have been used to tackle these two questions are outlined below, together with summaries of findings.

I INDIVIDUAL PUPIL FRAMEWORKS ACROSS DIFFERENT QUESTION CONTEXTS.

Procedures

It should be remembered that some frameworks are derived from response categories on the ordinal scale, whilst others are derived from alternative response categories. A distinction is now made between frameworks which were generated from pupil ideas which conformed to, or at least approached, the scientifically-acceptable one and those which were generated from pupils' alternative ways of thinking. Pupils who offered only predictions rather than explanations, together with those who were confused or uncertain, were grouped together under 'No Identifiable Framework' (NIF). Since these pupils did not demonstrate any clearly identifiable viewpoint about that particular scientific problem, it is not possible to comment on the stability of this group and it is kept distinct in the analysis. Thus, pupil frameworks were grouped into 'ordinal', 'alternative' and 'non-identifiable'. As reported in the preceding chapters frameworks are identified for these Ideas:

NATURE OF PRESSURE
MOLECULAR BOMBARDMENT
PRESSURE AND DEPTH
PRESSURE AND DIRECTION
ATMOSPHERIC PRESSURE
CONDUCTION OF HEAT
ACQUIRED CHARACTERISTICS
ADAPTATION

The following procedure was then adopted for each of these. Two questions were selected, each of which tested the same central aspect of the Idea but in different contexts. The type of response given by each pupil to the two questions was compared using the data from the first round of interviews only. For this comparison the question which was posed first in interview was designated as the initial categorization from which shifts or stability may be judged. The detailed results of the comparison across question contexts are presented for each of the above Ideas in Appendix 9. A summary of the analysis together with some general comment, is given below.

Results and Comment

Table 14 summarizes the results. The variability of response pattern across different Ideas is clearly a salient feature.

Some Ideas seem to confirm intuitions (e.g. NATURE OF PRESSURE, PRESSURE AND DEPTH) whilst others are counter-intuitive (e.g. MOLECULAR BOMBARDMENT, PRESSURE AND DIRECTION). This, of course, influences the difficulty of the question which in turn affects the number and type of categories and frameworks generated. The percentage of ordinal responses held stable over two contexts was high for some Ideas, such as PRESSURE AND DEPTH and ACQUIRED CHARACTERISTICS. Pupils apparently found these Ideas easy. However, it is interesting that in both these cases more stringent tests of the stability of ordinal frameworks produced a different result. So, for PRESSURE AND DEPTH more than two-thirds of the sample gave ordinal responses to both the goldfish and the submarine questions but of these fifty-eight pupils twenty abandoned this mode of thinking when responding to FISH TANKS and suggested that the total volume of water around the fish determined the pressure on it. Moreover, there was no clear age trend in this defection. Similarly, the apparently firmly-held notion of non-inheritance of acquired characteristics was abandoned by many pupils when the questions incorporated the extra dimension of inheritance over several generations.

For some apparently accessible Ideas the percentage of stable ordinal responses increased with age. This was true for example for NATURE OF PRESSURE, for MOLECULAR BOMBARDMENT, where twice as many 16 year olds as 14 year olds gave ordinal responses to both questions and for ADAPTATION, where few pupils gave ordinal responses to both questions but the figure increased with age to one quarter of the 16 year old group.

TABLE 14 Summary of Results Across Question Contexts

IDEA	QUESTION	BOTH ORDINAL %	ALT./NIF → ORDINAL and ORDINAL → ALT./NIF %	BOTH ALT. %	ALT. ↔ NIF and BOTH NIF %
NATURE OF PRESSURE $n = 60$	BOARDS AND WEIGHTS → SKIS	30	20	3	47
MOLECULAR BOMBARDMENT $n = 54$	TYRES → FOOTBALL	28	10	7	56
PRESSURE AND DEPTH $n = 84$	FISH → SUB.	69	17	7	7
PRESSURE AND DIRECTION $n = 83$	FRED → SUB	11	15	36	37
ATMOSPHERIC PRESSURE $n = 83$	STRAW → SYRINGE	19	23	5	53
ACQUIRED CHARACTERISTICS $n = 84$	MICE → ATHLETES	57	29	5	8
ACQUIRED CHAR. OVER TIME $n = 63$	MICE OVER TIME → ATHLETES OVER TIME	33	39	25	2
ADAPTATION $n = 83$	CATERPILLARS → FOX	10	4	31	55
CONDUCTION OF HEAT $n = 84$	PLATES → HANDLEBARS	5	2	30	63

It can be seen from the summary table that in general there was not much shifting between ordinal and non-ordinal frameworks, though for a few Ideas there was considerable movement (about a third of the sample moved between ordinal and non-ordinal frameworks for ACQUIRED CHARACTERISTICS and nearly a quarter of the sample shifted on the two questions testing ATMOSPHERIC PRESSURE).

Examination of the totals in the matrices in Appendix 9 indicate that similar patterns of response occur for most question pairs. But this was not a universal finding. For example, twice as many pupils offered ordinal responses for STRAW as for SYRINGE, possibly because the former was one of the few questions that cued pupils into a particular mode of thinking with the instruction 'Use the idea of atmospheric pressure' incorporated into the question.

For some Ideas with a large proportion of pupils subscribing to non-ordinal frameworks the figures for stable alternative frameworks were quite high. Alternative frameworks seemed to persist particularly for four Ideas (PRESSURE AND DIRECTION, ACQUIRED CHARACTERISTICS OVER TIME, ADAPTATION and CONDUCTION OF HEAT) where, in each case, between a quarter and a third of the total sample produced alternative frameworks in response to both questions. For the last two of these a range of alternative frameworks was generated and these Ideas therefore merited more in-depth analysis. The details of this are presented in Appendix 9 and reveal a very different picture for the two Ideas. In response to the CATERPILLARS and FOX questions, mapping on to ADAPTATION, only five out of the twenty-six pupils (19%) who gave two alternative responses gave the same one for the two questions. In this case it seems likely that many pupils did not perceive the two questions as probing the same phenomenon. So, for example, in the FOX question pupils' thinking was directed very much towards the animals' need to respond somehow to the adverse environmental conditions and this explanation was popular. However, in the CATERPILLARS question the animals' escape to a more favourable environment seemed to be viewed as a likely solution. By contrast, twenty-five pupils gave alternative responses to PLATES and HANDLEBARS, questions feeding CONDUCTION OF HEAT, and for sixteen of them (64%) this was the same alternative response. It is possible that here pupils found it easier to identify the common scientific problem embedded in these two similar question contexts, and that this might explain the higher level of stability of alternative frameworks for this Idea.

It is tentatively suggested, therefore, that stability may exist where questions are perceived as testing the same scientific notion in the same kind of context.

There were no clear age trends in the figures for stable alternative frameworks. For some Ideas the different age groups performed differently. So, for example, in PRESSURE and DIRECTION about one third of the sample held alternative frameworks stable, but the figure for 12 year olds (50%) was much higher than for 16 year olds (17%). However, for other Ideas, for example CONDUCTION OF HEAT, there were no such age differences.

For several Ideas, shifting from one non-ordinal framework to another was the dominant feature; this was the case for NATURE OF PRESSURE, MOLECULAR BOMBARDMENT, ATMOSPHERIC PRESSURE, ADAPTATION and CONDUCTION OF HEAT. For these Ideas many pupils clearly had available a range of alternative frameworks and different question contexts elicited different ones. This could be viewed as encouraging from a pedagogic point of view; if alternative frameworks are relatively unstable in this way, it is possible that pupils may find it easier to adopt more scientifically correct perspectives.

II TRENDS IN INDIVIDUAL PUPIL RESPONSES TO SELECTED QUESTIONS OVER TIME

Procedures

Developmental results were monitored for two ages (12 to 14 years and 14 to 16 years), for selected questions. The second round responses of pupils who had previously been categorized on the ordinal scale were recorded. Some offered the same response again, whilst others used a different ordinal response and yet others changed to an alternative or confused reply.

The second-round results of pupils who gave an alternative response in the first round were grouped in the same way. These comparisons allowed some assessment of the development of understanding (both improvement and deterioration) over time.

The method of data analysis was similar to that just described for the investigation of frameworks across question contexts. Pupil frameworks, previously identified for all the Ideas except HEAT AND TEMPERATURE and INHERITANCE, were again the basic unit of analysis. Pupils were assigned to a framework from both rounds of interviews for the same two key questions per Idea. It was then possible to monitor developmental trends for pupils in these selected questions. Frameworks were designated 'correct', 'partially correct', 'alternative' and 'non-identifiable'. For some of the Ideas both 'correct' and 'partially correct' frameworks were identified; the developmental analysis required more attention to shifts between these frameworks derived from response categories on the ordinal scale, compared to the previous analysis where 'correct' and 'partially correct' were amalgamated. Again the details of the results of these comparisons for each Idea are presented in Appendix 9, and a summary of the findings, together with comment, is given below.

Results and Comment

A summary of the developmental results is given in Table 15 but the figures should be interpreted with caution because no account is taken of the variable difficulty of the Ideas. However, the table is useful for an examination of general trends.

For some Ideas, such as PRESSURE AND DEPTH and PRESSURE AND DIRECTION the response patterns for the two selected questions were very similar. For others considerable variation occurred; the MICE and ATHLETES questions elicited different patterns for ACQUIRED CHARACTERISTICS for example, and, similarly, STRAW and SYRINGE gave a rather non-uniform pattern for ATMOSPHERIC PRESSURE.

The data indicate that once ordinal frameworks are employed they tend to remain stable over time which is an encouraging sign. The number of pupils who regressed over time,from ordinal to alternative or non-identifiable frameworks varied from Idea to

TABLE 15 Summary of Developmental Results

IDEA	KEY QUESTIONS	STABLE ORDINAL %		ALT./NIF → ORDINAL %		ORDINAL → ALT./NIF %		STABLE ALT. %		ALT. ↔ NIF & NIF %	
		X12–X14	*Y14–Y16*	*X12–X14*	*Y14–Y16*	*X12–X14*	*Y14–Y16*	*X12–X14*	*Y14–Y16*	*X12–X14*	*Y14–Y16*
NATURE OF PRESSURE	BOARDS & WEIGHTS	14	*41*	21	*14*	3	*7*	0	*0*	62	*38*
	SKIS	26	*58*	14	*10*	3	*0*	17	*3*	38	*28*
MOLECULAR BOMBARDMENT	TYRES	N/A	*24*	N/A	*21*	N/A	*0*	N/A	*17*	N/A	*38*
	FOOTBALL		*21*		*21*		*0*		*0*		*59*
PRESSURE AND DEPTH	FISH	48	*62*	7	*17*	14	*10*	10	*0*	21	*10*
	SUB	55	*76*	14	*7*	14	*14*	7	*0*	10	*3*
PRESSURE AND DIRECTION	FRED	7	*14*	7	*21*	7	*3*	34	*10*	45	*52*
	SUB	10	*10*	10	*28*	3	*7*	31	*10*	45	*45*
ATMOSPHERIC PRESSURE	STRAW	31	*21*	17	*17*	14	*10*	0	*0*	38	*52*
	SYRINGE	17	*11*	7	*11*	7	*0*	21	*18*	48	*61*
ACQUIRED CHARACTERISTICS	MICE	66	*62*	17	*17*	7	*3*	7	*7*	3	*10*
	ATHLETES	59	*38*	17	*21*	14	*24*	7	*3*	3	*14*
ACQUIRED CHAR. OVER TIME	MICE OVER TIME	52	*41*	4	*14*	4	*14*	30	*32*	9	*0*
	ATHLETES OVER TIME	24	*29*	28	*25*	20	*21*	20	*13*	8	*13*
ADAPTATION	CATERPILLARS	7	*3*	7	*24*	0	*0*	17	*3*	69	*69*
	FOX	3	*3*	7	*14*	0	*0*	24	*38*	66	*45*
CONDUCTION OF HEAT	PLATES	3	*0*	0	*21*	0	*0*	17	*14*	79	*66*
	HANDLEBARS	0	*0*	0	*17*	0	*0*	7	*24*	93	*59*

Note:

For most of the questions the pupil sample size was as follows X12 – X14 n = 29
Y14 – Y16 n = 29

The exceptions were: Y14 – Y16 SYRINGE n = 28
X12 – X14 MICE OVER TIME n = 23, ATHLETES OVER TIME n = 25
Y14 – Y16 MICE OVER TIME n = 22, ATHLETES OVER TIME n = 24

Idea over the 0-20% range. There was most regression on the responses to the questions mapping on to ACQUIRED CHARACTERISTICS. It is possible here that pupils experienced exceptional verbal difficulties both in understanding the complex ATHLETES question, for example, and also in adequately expressing their understanding of this Idea.

The overall figures for progress over time from alternative or non-identifiable to ordinal frameworks ranged from 5-25%. With the Ideas which pupils apparently found less accessible (PRESSURE AND DIRECTION, ADAPTATION, CONDUCTION OF HEAT) the older age group, not surprisingly, made more progress. Where two ordinal frameworks were identified these tended to represent an analytic understanding of the Idea and an understanding at an intuitive level, and for these Ideas a pupil's explanation frequently seemed to be arrested at the intuitive level. Thus, for NATURE OF PRESSURE many pupils stayed with a non-analytic explanation of pressure as a relationship between force and area. Similarly, for MOLECULAR BOMBARDMENT few pupils progressed from a knowledge of the relationship between temperature and molecular speed to an application of this to explain pressure change. This same stability of the partially correct framework over time was also apparent with ATMOSPHERIC PRESSURE and with ACQUIRED CHARACTERISTICS, where there was little movement from the explanation which represented a hunch that acquired characteristics are not inherited to a more elaborated genetic explanation of this.

The evidence on stability of alternative frameworks over time is equivocal. Thus for some Ideas (e.g. ACQUIRED CHARACTERISTICS OVER TIME) there were many stable alternative responses; for others such as PRESSURE AND DIRECTION large numbers of pupils in the 12-14 year group held alternative frameworks stable but this was not apparent in the older age group. For many of the Ideas, however, large numbers of pupils drew on different alternative or non-identifiable frameworks on the two separate occasions; this was the case for NATURE OF PRESSURE, MOLECULAR BOMBARDMENT, PRESSURE AND DIRECTION, ATMOSPHERIC PRESSURE, ADAPTATION and CONDUCTION OF HEAT. This instability over time remains a striking feature of these results.

III CONCLUDING REMARKS

Comparison of Tables 14 and 15 indicates that the same tasks elicit alternative frameworks which seem to be stable both across contexts and over time. Tasks mapping on to four Ideas - PRESSURE AND DIRECTION, ACQUIRED CHARACTERISTICS OVER TIME, ADAPTATION and CONDUCTION OF HEAT produced the highest numbers of alternative responses which were repeated across two question contexts and stable over time. Most shifting occurred between one alternative or non-identifiable framework and another, both across contexts and over time for the following five Ideas: NATURE OF PRESSURE, MOLECULAR BOMBARDMENT, ATMOSPHERIC PRESSURE, ADAPTATION and CONDUCTION OF HEAT. In both Tables performances on tasks mapping on to ACQUIRED CHARACTERISTICS, and particularly ACQUIRED CHARACTERISTICS OVER TIME, showed most movement between ordinal and other frameworks.

Finally, it is perhaps useful to recall that the scientific Ideas tested are very different in their scope. For example, PRESSURE AND DEPTH and PRESSURE AND DIRECTION are fairly narrow circumscribed notions, for which it is easy to design specific analogous questions (SUBMARINE and FISH). Other Ideas, such as ADAPTATION, ATMOSPHERIC PRESSURE and MOLECULAR BOMBARDMENT (which incorporates a basic understanding of kinetic theory) are much broader in scope. Questions mapping on to these Ideas tend to test slightly different aspects of the Idea. The breadth of the Idea will, of course, affect the breadth of the pupil frameworks generated for it. For these reasons the status of pupil frameworks, which are used as the basic unit of analysis reported in this Chapter, may not necessarily be the same from Idea to Idea. In the light of this, it is perhaps not surprising that there was great variability of response pattern from Idea to Idea.

It is possible that a more clear-cut picture would emerge from analyses of individual pupil frameworks if strictly circumscribed scientific notions were tested by questions which were perceived by pupils as being analogous.

CHAPTER 8

CONCLUSIONS AND THEIR SIGNIFICANCE FOR THE CLASSROOM

The chapter begins with a critical discussion of the methods used in this investigation. This is followed by a brief summary of the most significant empirical results obtained together with a review of the possible implications of this ideographic research for pedagogy.

I A reflection on method

It is assumed that individuals construct their own scientific meanings and that this is achieved as a result of interplay between sensory experiences on the one hand and pupils' own imaginative ideas and hypotheses on the other. Inevitably these constructions will rarely match the most sophisticated currently-accepted position held by scientists. It has been a basic tenet of this research that such constructions, or pupil frameworks, may profitably be viewed as staging posts on the way to a more complete understanding. Some may represent partial truths, stepping stones to further understanding; others may need explicit challenge, rather than circumvention, if further progress is to be made. It was therefore imperative that the methods adopted should avoid a notion of absolute correctness. In this respect the approach contrasts with that in studies which relate a Piagetian stage framework to children's scientific understanding. In the latter both partial understandings and alternative ways of thinking tend to be dismissed as inadequate or incorrect.

If it is accepted that meanings are internally constructed rather than received ready-made from the outside, it follows that the processes involved in their construction are likely to be individualized. Research methods adopted need therefore to respect the individual variability of understanding. This seems to create a major practical problem in the development of appropriate methodologies for ideographic research. In positivist research there is a strong expectancy of consistency; we do seem to find it difficult to look simultaneously for both consistency and variability. If pattern and consistency emerge then this should be reported without resort to the labelling of such patterns as typical performance levels. If no pattern emerges, this should be seen as equally valid; it should not disconcert the investigator.

In a sense the development of the method, which was not pre-determined but grounded in the data, was in itself, a significant result of the research. Its exploratory nature carried both advantages and disadvantages. Although data collection was based on very specific question contexts which tested the understanding of the application of scientific ideas, the interviews were sufficiently unstructured to allow pupils time to develop their ideas. This is a simple point, but an important one. There were many examples of exploratory talk, of pupils talking through their own ideas and reaching, at the end of an exchange, a more clearly formulated explanation. Consequently, the pacing of the interview constituted a major procedural problem for the interviewer.

Analysis of the data took place in several phases with super-ordinate groupings emerging from previously-identified ones (see Figure 4). So, categories at question level arose from individual responses, pupil frameworks were identified from an examination of categories across question contexts, and these were finally designated as 'correct', 'partially correct' and 'alternative'. These procedures represent a necessary reduction of the data. Much is lost in terms of the richness of individual variability; much is gained in terms of the manageability of the data. Decisions about the optimal level of reduction of data (that is, how generalized the final groupings are, how far quantitative treatments are to be substituted for qualitative etc.) are finally arbitrary. In similar studies pupil frameworks (that is, fairly general representations of pupil thinking) are often identified in a one-stage process, directly from transcriptions. It can be argued that there are advantages in staying with pupils' words for longer and that a multi-stage analytic process, with the criteria for each re-grouping made explicit in the reporting, makes the research more accountable. The fact that the interviews in this study comprised questions centred on specific tasks imposed

PUPILS' WORDS

Responses to requests for explanations of scientific phenomena set in everyday contexts.

↓ I (a) Establishment of categories
(b) Allocation of pupils' answers to categories

CATEGORIES OF RESPONSE

to individual interview questions

↓ II (c) Comparison of categories across two or more analogous questions

PUPIL FRAMEWORKS

Relating to the aspects of pressure, heat and evolution, investigated in the study:
These frameworks were then used as units of analysis for investigation of age trends, of stability of individual responses over different questions and of developmental trends.

FIG.4. STAGES IN ANALYSIS OF DATA

a ready-made structure on the analysis, in that responses to each question on the interview schedule were separately analysed as the first stage. This afforded some order to the process; it had the disadvantage that pupil ideas about aspects which were not directly tested for, but which were volunteered or referred to tangentially, were frequently not adequately explored. So, for example, the several interesting ideas about unequal parental contribution in the inheritance of characteristics were not extended as searchingly as they could have been.

A further problem arose, which also stemmed from the open and exploratory character of the method. Because categories and frameworks were not finally formulated until after the first round of data collection in the main study had been completed, it was sometimes difficult to make category assignments with confidence. Pupils' linguistic muddles were sometimes insufficiently clarified to make allocations surely, because the criterial distinctions between categories were not identified at the time of data collection. So, for example, it became clear that it was necessary to be certain what pupils meant when they used the word 'vacuum', and to establish whether the words 'heat' and 'temperature' were used synonymously or not. This kind of difficulty could only have been avoided by the inclusion of a full analysis, carried through to its more or less final form, at the pilot stage.

II Concluding Comments

It follows from Section I that generalised conclusions are difficult to make, and indeed may be inappropriate, when research is detailed and descriptive, rather than hypothesis-testing. Nevertheless, a few concluding remarks may be made.

The great variability of pupil response, indicated by the large numbers of categories generated for some questions, was a salient feature of the results. The data provides evidence that, at question level, the pupil frameworks identified are reproducible in terms both of general content and the frequency with which they occur in a population. However, it is also clear that predictions from this about the performance of individual pupils would be unjustified since, at the pupil level, different frameworks were frequently employed in response to different questions.

Generalizations about the developmental picture are difficult to make because there was little pattern discernible across Ideas. It can be said, however, that for some, e.g. ATMOSPHERIC PRESSURE there was little progress towards the accepted scientific notion over the 12-16 year age range.

Many of the Ideas tested were found to be difficult, even for 16 year old pupils, some of whom were at the end of their schooling. Amongst these are included: the application of molecular theory to the understanding of pressure; an understanding of the effects of the pressure of the atmosphere; the equality of pressure from different directions in fluids; the distinction between the extensive quantity of heat and the intensive quantity of temperature; the relationship between a particulate genetic entity and phenotypic characteristics; the relationship between intra-specific variation and natural selection; the mechanism of biological adaptation and the non-inheritance of acquired characteristics, even over a long period.

For these and other Ideas pupils sometimes offered suggestions which reflect analogies with historically-held ideas. Their descriptions of heat phenomena, for example, were reminiscent of those describing 'caloric' (Rumford, 1798) - that is, of heat as a kind of weightless, elastic, indestructible fluid which penetrates all bodies and flows from hot to cold. Historical notions of pressure (both in air and liquids) have evolved over the last 2000 years, and no sudden transition from ancient to modern ideas, corresponding to that in heat, can be identified. Up to the time of Galileo, at the beginning of the seventeenth century, all visible effects of air pressure were ascribed to an indefinite 'hatred' by nature for empty space - the so-called 'horror vacui'. The idea of a vacuum, and particularly of its strong sucking power, proved to be a useful explanatory framework for some pupils. In general, pupils were able to talk fairly competently about the effects of pressure, but not to explain <u>what</u> pressure is; to do this they had to have some idea of kinetic theory, and there was striking evidence that this area of school knowledge had not been integrated into pupils' thinking to enable them to apply it to physical phenomena. Again, this reflects the historical reluctance of scientists to accept the theory of the particulate nature of matter. But the predominance of historical notions is nowhere more striking than for evolution. Many of the pupils could well be taken for faithful disciples of Lamarck, since they expressed a belief in an inherent desire for improvement as the driving force of evolutionary change and a conviction that in time phenotypic changes (or acquired characteristics) will be inherited.

To note these similarities between children's ideas and the historical development of adult scientific thinking is not necessarily to subscribe to Piaget's recapitulationist argument, a position based on the fundamental hypothesis of genetic epistemology that there is a parallelism between the progress made in the organization of knowledge and the corresponding formative logical processes.

Because of the method of identification of pupil frameworks (e.g. the lack of any quantitative criterion for their establishment) variable validity is attached to them. The sample was relatively large compared to many ideographic studies, and so reasonable confidence may be placed in the generalizability of those frameworks which emerged from responses to direct interview questioning. However, other frameworks arose as a result of incidental responses, often as tangential comments made as asides in the interview discussion; these had correspondingly low frequencies of incidence. Further investigation of these frameworks is necessary in order to establish whether they have some general appeal, or were merely idiosyncratic responses. This could be checked by use of a cognitive preference test (see, for example, Erickson, 1980), in which the pupil frameworks identified from interviews were offered as alternatives in multiple-choice items. If these alternatives proved popular more credence could be given to them as established modes of thinking.

In the end, it was not possible to relate pupil understanding to coverage of the topics in school, though this had originally been intended. Attempts were made to collect information from the science departments of the schools involved about the ordering and specific nature of teaching related to the three concept areas. However, it proved to be an impossible task to collect this information because, not only did the three schools organise their science courses differently , but almost every child in the sample was following a distinct pattern of science teaching (because of the various systems of banding and streaming and because each class teacher in British schools is given so much autonomy in the ordering of material etc.).

Problems arising from the application of this work are discussed in the third section of this chapter. It is essential, I think, that results from several studies with different samples be compared and combined before any prescriptions for teaching or curricular development are even tentatively offered. The body of work on heat is perhaps reaching this stage. The findings presented here for both pressure and evolution need replication and extension.

III Implications for the classroom

The following discussion must, necessarily, be couched in general terms. This is because the body of ideographic research into children's scientific understandings is still small, and there are few examples available for evaluation of translation of research findings into specific recommendations for teaching. It should be stressed, however, that the identification of common belief patterns, even the tracing of developmental pathways in understanding is not a sufficient end-point for the educator. It is not obvious how this specific information may be used by teachers and the procedures whereby this evidence is integrated into the development of new curricula and teaching activities should perhaps themselves be subjects for classroom-based research by teachers. It is interesting that the Swedish Ministry of Education has sponsored a research programme (EKNA - Project under the directorship of Dr. B. Andersson) to investigate children's perceptions of phenomena across the physical sciences. The intention is to base the development of new teaching programmes on these findings. There is clearly a danger that ideographic research findings could be used prescriptively - for example, by producing checklists of possible pupil viewpoints. This restrictive application, analogous perhaps to the recommendations for inclusion and rejection of various topics in science curricula which emanate from some Piagetian studies, would be quite against the spirit of ideographic research.

Clearly, teachers cannot enquire in depth into the pre-existing knowledge of each pupil in the class every time a new topic is embarked upon. However, since some commonality of belief patterns emerges from ideographic research,[F] it has been suggested (Driver and Easley, 1978) that such studies could raise awareness of the possible perspectives pupils may bring to their scientific learning and to enable more effective classroom communication to take place.

F. A striking example of this commonality is provided by a series of cross-cultural studies on the 'Earth' concept (Nussbaum and Novak, 1976; Nussbaum 1979b; Mali and Howe, 1979), where very similar notions were identified in American, Israeli and Nepali children.

To achieve this effectively will demand some modification in teachers' assumptions about how learning best takes place in the classroom. It may be generally accepted that 'new' understanding rests on pre-existing forms of knowledge; that there are no blank spaces in children's minds to be filled by new facts, but rather that learning requires a novel re-organization of previously known information in the light of fresh experience. Yet Barnes (1977) and others have shown that many science teachers appear to short-circuit the necessary conciliation between intuition-based knowledge and formal school knowledge. Instead, new knowledge is frequently imposed by the teacher and there is evidence that this then becomes layered on top of intuitive knowledge which may be contradictory and which persists tenaciously, long after the school learning has been forgotten. It is true, of course, that pupils' constructions of meanings take time and that pupils' inexplicit and ponderous talk, as they work through their own ill-formed ideas, can be very inelegant. For the sake of efficiency, lessons are often strictly controlled by the teacher; her commitment to the material and its sequential presentation override any appreciation of the value of existing knowledge which her pupils present. Pupil contributions seem to be interpreted as a threat to the planned scheme, which need to be discarded as immature realizations of the teacher's own knowledge. The results of the present study and of ideographic research in general suggest that children carry a fund of ideas about topics which they have never encountered in school and that, although some of the frameworks are familiar, others are entirely unanticipated, even by experienced teachers. The message to teachers could then simply be: listen to your pupils. Yet teachers often only hear what they want to hear; they listen for the one 'correct' answer and cannot find 'wrong' responses relevant or useful.

Consistency and efficiency of lessons must not, of course, be completely sacrificed and I am not suggesting that children must have actual experience of everything that the teacher wishes to impart, or that pupils must individually 'discover' two hundred years of science for themselves. Far from it! Rather that teachers should value learners' existing knowledge, not for any sentimental reason, but because only in this way can the intellectual worlds of pupil and teacher meet and engage, rather than glide past one another. To this end Jung (1981) suggests that teachers should refrain from demanding that pupils be 'convinced' by the scientists' framework, and should instead be content with pupils knowing what that framework is like. Secondly, Jung proposes that the alternative frameworks which pupils employ in different contexts should be discussed in class in order to identify the advantages of each.

Ideographic research allows identification of alternative frameworks which may run counter to accepted scientific notions. The intuitive base underlying understanding is not immutable but there is some evidence (Rowell and Dawson, 1977) that intuitions can persist despite deliberate instructional attempts to refute them. It seems likely that something more subtle than counter examples are required; that pupils need to be given help to explore and confront their alternative ideas (which means they must talk about them) if the required learning is to occur.

It has been suggested (Driver, 1981; Deadman and Kelly, 1978) that new curricular developments should be based on the structure of thought of the child, rather than on the inherent structure of the discipline. Several studies show that the developmental path in conceptual understanding does not mirror exactly the logical ordering of ideas within a topic (Trowbridge, 1979; Hart, 1981). All teachers organise the material they present and this usually follows the 'logic' of what is being taught (at least in mathematics and the physical sciences). However, that logic is determined by experts who can see the topic as a whole and this may be an inappropriate order for a new learner.

Much lip service is paid to the need for individuals to trace for themselves the path from the familiar to the new. The results of this and similar studies offer further strong support for this necessity. Accumulations of evidence from different studies about the content of children's thought in specific concept areas should provide a valuable starting point for translating the exhortations into practice.

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APPENDIX 1 SHIPLEY TEST

NAME ______________________________

SCHOOL______________________________

YEAR ______________________________

In this test, whenever you see a dot there is one letter or number missed out. Write the missing letters or numbers just above the dots. Do as many questions as you can in 10 minutes. The first question is done for you.

1) A B C D E

2) 9 8 7 6 5 .

3) bad B sad S lad L had .

4) hot cold wet dry fast slow down ..

5) finger hand arm toe foot ...

6) peat pea note not bowl ...

7) no on ten net deer ....

8) January March May ....

9) 212 323 434 545 ...

10) she he sill ill slow ...

11) A Z B Y C X D W . .

12) great get tarry try blind bid chain ...

13) 864 753 642 531 ...

14) sloops pool unity tin zone ..

15) ABCD DABC CDAB ....

16) beneath bath swallow slow torrent ....

17) RZKT TRZK KTRZ ....

18) sheathe heath eat .

19) aBc bCd cDe ...

20) rain into tone .... atom

21) an can Dan am ram Sam at oat ...

22) ALZ DMX GNV JOT ...

23) 100 baa 201 cab 106 bag 543 ...

24) TOWN VQYP CITY ....

APPENDIX 2

SHIPLEY TEST & WRITTEN SCIENCE TEST SCORES FOR INTERVIEWEES

Pupil number	Sex	Shipley score	Science score
12 year olds		(out of 23)	(out of 42)
1	M	23	23
2	F	22	13
3	M	21	34
4	F	21	8
5	F	21	6
6	M	19	15
7	M	19	9
8	M	18	21
9	F	18	6
10	F	17	7
11	M	16	10
12	F	16	9
13	M	15	9
14	F	15	11
15	F	15	5
16	M	14	9
17	M	14	4
18	F	13	2
19	M	13	6
20	M	13	6
21	F	13	4
22	F	13	19
23	M	12	5
24	M	11	12
25	F	11	4
26	M	11	9
27	F	10	5
28	F	9	4
29	M	8	2
30	F	7	1
14 year olds			(out of 49)
31	M	23	25
32	M	23	19
33	F	22	26
34	M	22	14
35	F	22	31
36	F	21	18
37	F	20	20
38	F	19	14
39	M	19	21
40	M	19	18
41	F	18	19
42	M	18	24
43	M	18	14
44	M	17	12
45	F	16	6
46	M	15	6
47	F	15	8
48	M	15	22
49	F	14	2
50	F	14	4
51	M	14	10
52	F	14	3
53	F	12	9
54	M	11	18
55	M	10	13
56	M	10	8
57	F	10	10
58	F	8	1
59	F	7	2
60	M	6	10
16 year olds			(out of 51)
61	F	23	23
62	M	23	40
63	F	22	28
64	F	22	27
65	M	22	39
66	M	22	28
67	F	21	23
68	M	21	38
69	M	21	35
70	F	19	15
71	F	18	16
72	F	18	31
73	F	17	28
74	F	17	10
75	M	17	25
76	M	17	26
77	M	16	33
78	M	16	8
79	F	15	17
80	M	13	8
81	M	13	38
82	M	7	2
83	F	7	10
84	F	7	4

APPENDIX 3 INTERVIEW SCHEDULES

Please note: These interview schedules contain questions which were finally rejected at the analysis stage, and they are therefore not presented in Chapters 4, 5 and 6. The question numbers as they appear in the results chapters are given in brackets on the left hand margin of the schedules.

3(a) PRESSURE INTERVIEW SCHEDULE

Category Set Nos.		Question	Notes
	1	Show apparatus. Demonstrate indentations.	The boards are all the same weight
		(a) Can you pick out which board and weight would give you the deepest mark? Can you explain why you have chosen those?	Fill in response sheet
(1)		(b) Can you now pick out which board and weight would give you the shallowest mark? Can you explain why you have chosen those?	Fill in response sheet
	2	SKIS	1st & 3rd years only at first
		(a) What is it about the skis that keeps Mr X from sinking in?	
		(b) What would happen if he stood on one ski?	
(2)		(c) Why did Mr Y sink in up to his knees?	
(3)		(d) If you knew that Mr X weighed 200lbs and the total area of his two skis was 2 sq.ft., could you calculate what pressure he would exert standing on the snow?	Present pupil with response sheet. Don't linger if poor initial response
	3	FURNITURE	5th years only
		(a) This picture shows two bookcases - they are the same weight, but this one (A) rests on the carpet on two legs, and this one (B) has no legs and rests on its flat bottom. Which do you think makes the deepest mark in the carpet? Can you explain why?	
(4)		(b) The second picture shows these two tables of different weights - you are asked to work out which would make the deepest impression on the carpet. How would you do that? (What is the difficult part to work out?)	If poor response to this item, move quickly to SKIS with 5th years
	4	FLUID PRESSURE - FISH	
(8)		Present Fred and Goldie response sheet. (a) You are told that the water is exerting pressure on the fish. Which fish has more pressure on it? Can you explain why?	Fill in response sheet
(11)		(b) How does the pressure on Fred's back (drawn with a solid arrow) compare with that on his nose? (Drawn with a dotted arrow)? Is it the same, or more, or less?	Fill in response sheet
(9)		(c) If they are in these positions - how does the pressure on Fred compare with the pressure on Goldie now? Is it the same, or more, or less? Can you explain why?	Fill in response sheet
	5	SUBMARINE	
(12)		(a) The submersible craft in this question is on the sea bed, and you are told that there are 12 atmospheres of pressure here on the top of the craft. How much pressure would there be be here on the window at the side? Can you explain why?	
		(b) What would happen to a bubble of air given off from the craft? How will it change as it rises to the surface?	
(10)		(c) If the craft moves up from a depth of 100 metres to a depth of 50 metres, how will the pressure change?	
(13)		(d) We keep using the word 'atmospheres' of pressure, but do you know what an atmosphere is, as it is used in this question? Can you draw in on this diagram where you think 1 atmosphere of pressure is being exerted?	Present pupil with response sheet

PRESSURE INTERVIEW SCHEDULE (cont)

6 STRAW

(14) (a) You were told in this question to use the idea of atmospheric pressure. Can you explain then what
(15) happens when you drink squash through a straw? What about the pressure in the straw as you suck?

(b) Apparatus with bottle squash and bung. See how much squash you can get out of this. Try it. Can you explain why it is difficult to get a lot
(16) of squash out?

Present pupil with the apparatus then offer a drink of orange

7 SYRINGE

Demonstrate apparatus.
Depress plunger, finger over end, under water. Pull plunger upwards.
(17) What is inside the syringe now?
Remove finger. Water rushes in with force.
(18) What makes the water rush in like that?

8 WASHING UP

(a) You are told that John is washing up with hot water. What happens to the temperature of the air inside the cups after they have been sitting on the draining surface for a few minutes?

(b) (If say it cools down) Well, what happens to the air in the cups when the temperature falls?

(19) (c) Why are the cups difficult to lift off? What makes the 'pop'?

9 CONCLUSION

(5) If I asked you to say in a couple of sentences what pressure is, what would you say?

If a scientist were asked what pressure was, what do you think s/he would say?

3(b) HEAT INTERVIEW SCHEDULE

1 Heat electric kettle filled with cold water. Can you describe what is happening to the water in the kettle? What is the difference between hot water and cold water? What makes hot water hot?

Do not pursue, if initial response poor

2 KETTLE AND BATH

(a)Which of these contains the hotter water?

(22) (b)Which would cost the most to heat up the water electrically?/
(23) Which contains the most heat energy?

Ask about heat energy initially only if pupil mentions heat energy in 1.

(c)Kettle and bath response sheet - quantitative problem. Can you work out how much heat energy it will take to heat up the kettle and the bath in this problem?

Present only to selected 5th years (and possibly a very exceptional 3rd year)

3 POTATOES

In this question, both pans contain boiling water, but one has the gas turned up high, and the one on low is kept just on the boil.

Emphasise this at the beginning of the interview on this item

(31) (a)How does the temperature of the water in this pan compare to the temperature in this - is it the same, or higher or lower?

(32) (b)What does the cooking time of the potatoes depend on?

(33) (c)The cook thought that these potatoes would cook faster, and her friend thought that both pans of potatoes would be ready at the same time. Who do you think was right? Can you explain?

(d)The cook is using up more gas on this side (high)-what is happening to the extra heat?

If mention evaporation, pursue for change of state.

4 MIXING LIQUIDS

Do one practical mixing - using hot water from the kettle and a beaker of cold water.

(a)What is this?(condensation on the hot beaker) Where does it come from? Why is it on the hot beaker and not on the cold?

(28) (b)Could you fill this in for me?

Present pupil with response sheet (mixing problem-qualitative presentation)

(c)In this example how does the temperature of X compare with the temperature of Y - is it the same, or higher or lower? Can you explain why?

Same response sheet
Point out the second one (to give Y) contains twice as much hot water as the first

(d)Part 4 written APU item (water into syrup) Which do you think is the best answer of the alternatives offered? If say E - what other information would you need, then, to be able to answer the question?

(24)(25) (e)Can you fill these in for me please?
(26)(27) Can you explain your answers?

Present pupil with response sheet -mixing liquids-quantitative format

(29) (f)What is the difference between heat and temperature?

5 VISIBLE BREATH

(a)Why do you see your breath on a cold day, and not on a warm summer's day?

Emphasise that your breath contains water vapour

(b)What is the 'cloud' of breath?

(c)Does the 'cloud' stay around? What happens to it?

(d)Have you ever breathed on a cold mirror? Try it. Can you explain what happens? If you go on breathing on the same mirror, what happens? Do it. Can you explain?

Omit practical task with mirror if give full answers to 5(a) and (b)

HEAT INTERVIEW SCHEDULE (cont)

6 ICE

(a) Present ice melting response sheet.
Why is the thermometer still reading $0^{o}C$ here after 10 minutes of heating? What is happening to the heat from the bunsen burner?
Fill in response sheet

(b) Present ice cube response sheet.
Can you pick out the drawing you think is best? Can you explain why you have chosen that? What do you think these blobs are?
To 3rd and 5th years only. Not to 1st years

7 SPOONS

(34) (a) Can you explain why the handle of the metal spoon felt hotter first?
Ask pupils to feel and comment on spoons

(b) You are told that the pot spoon stayed hot longer after the spoons were taken out of the hot water. Can you explain why that was?

8 PLATES

(35) (a) Here are two plates - one metal and one plastic. If you put a thermometer in contact with the plates, would you get any difference in the readings or would they be the same?

(36) (b) Feel both the plates together. What do you feel? Can you explain why this is so?
Say that the plates have been sitting in the room for several hours

(37) (c) Have you ever noticed the same thing as Sally- that the metal handlebars of a bicycle feel colder than the plastic grips? Can you explain why this is so?

9 TYRES
3rd and 5th years only. Not 1st years

(a) What does it mean when it says 'The pressure in the car tyres increases' - what is pressure?
Stick to the word 'particles' in interview on this item - avoid 'molecules'.

(6) (b) Car tyres warm up during a long journey - have you ever felt that? Can you explain why the tyre pressure goes up after a journey?

(c) What happens to the particles of rubber and air after a journey?

10 FOOTBALL
3rd and 5th years only. Not 1st years

(a) You know when a football goes a bit soft you have to pump it up?
Present first football response sheet
Pupil fill in response sheet

(b) Present second football response sheet
Can you pick out the drawing you think is best? Can you explain why you have chosen that one? What do you think the blobs represent? What is in between the particles?
Pupil fill in response sheet

(c) We are told that the footballer pumped his ball up hard, and then the weather turned very much colder. The football was not leaking. Can you say what you think might happen to the molecules of air in the football when the temperature falls?
(20) (i) To the number of molecules?
(21) (ii) To the speed of the molecules?
(7) (iii) To the pressure in the football? Can you explain?

11 CONCLUSION

(30) If I asked you to say in a couple of sentences what heat is, what would you say?
If a scientist were asked what heat is, what do you think s/he would say?

3(c) EVOLUTION INTERVIEW SCHEDULE

1 DOGS

(a) I would like to begin by showing you some photos of dogs - they are all one breed, as you can see, but do you notice anything about them? (Well, are they all exactly the same in every detail?)

(39) (b) Do you think that it is quite normal for there to be slight differences like that between animals of the same kind?

(40) (c) (If say yes or maybe).Can you think of any other examples of that sort of slight variation within one kind of animal? Does the same thing happen in plants?

(d) (If say no - or refer to variation resulting from interference by man - i.e. breeding domestic animals). I have another example here of wild animals (zebras) - can you comment on these photographs?

(41) (e) Can you explain how these variations came about?

(f) (If advance only environmental reasons).Are there any other reasons for the variations?

(g) If these dogs were kept from birth under identical conditions, would you get these variations?

2 SIBLINGS AND TWINS

(38) (a) I have some photographs here of young and adult animals - can you match these up, putting the young with the right parent?

(b) Do you look like either of your parents? Do you know why that is? How does it come about?

(43) (c) These two are brother and sister - they look quite alike, don't they? Do you have brothers or sisters? Do any of you look alike? Can you explain why that is? (If say from same parents). At what point is the likeness passed on - is it when the egg is fertilized (when the baby is made) or when the baby is developing inside the mother, or at birth or is it something that happens as the child grows and develops?

(42) (d) What about these two - they are identical twins. Do you know why it is that they look almost exactly the same?

3 MICE

(45) (a) Do you remember that the scientist found that one of the mice had been born with no tail - how did that come about, do you think?

(46) (b) When he mated a tailless mouse with a normal one he got some tailless babies - can you explain that?
(47) Would the tailless mouse have something passed down (about tails) from both parents or just one?

(c) The scientist chopped the tails off some of his mice. (If grimace say - that was rather cruel and not a very good idea really, but he was trying to get more tailless mice quickly).
(49) He mates two mice with chopped off tails (as in drawing). What kind of babies would you expect? Can you explain your answer?

(50) (d) What would happen if the scientist repeatedly chopped off the tails over several generations - what kind of babies would you end up with?

(e) There was another part to this question, if you remember. Two boys were trying to breed a race of giant mice - how would they go about doing that? (If suggest pick out two large mice). Can you explain why you suggest that they should pick out two large parents?

4 CATERPILLARS

(54) (a) Can you explain what is happening here? Why do you think the children found most of the dark caterpillars on the dark tree, and most of the pale ones on the pale tree?

(55) (b) How did that arrangement come about in the first place? (Roughly how long does it take for these changes (adaptive change) which you are telling me about to occur?)

(c) What would you expect to happen if all the birds/predators that normally ate the dark caterpillars disappeared? If the children walked through the same wood the following week, and all the birds that normally ate dark caterpillars had migrated, where would you expect they would find the dark caterpillars?
(48) Can you explain your answer?

(d) What do you think might happen if the colour of the dark trees began to change
(56) over the years?(it could, for example, become covered with a pale moss).

(e) Here is a photograph of some caterpillars on a tree. You will notice that the caterpillars have slightly different markings. Do you think that some of them will be more easily seen by predators than others? What do you think will happen to those (the ones that fit in least well with the background) over the years? What do you think will happen to these (the ones best camouflaged) over the years?

EVOLUTION INTERVIEW SCHEDULE (cont)

5 ARCTIC FOX

You did a quiz for me at the end of our last interview session, if you remember, called Foxes and Flies. I would like to go on to the example of the Arctic Fox. The thick coat is obviously extremely useful in the fox's survival in those very low temperatures - can you explain how you
(57) think this came about originally? (Have there been Arctic Foxes with thick coats since the beginning of time? Well, how do you think it came about in the first place?)

6 ATHLETES

(a) Why do you think that some people are better runners than others?

(b) Is there any point in training?

(c) Could anyone in your class, say, be an Olympic runner, if they trained hard enough?

(d) If you take an athletic couple - a man and his wife - who had both
(51) become excellent runners - not so much because they were specially fast to begin with, but they had both trained hard and so become very good - would their children be automatically excellent runners?

(e) If these children practised hard, and their children did the same
(52) thing and so on, would the children, say in about 200 years time, be automatically fast runners?

(f) Let us talk about another example. You know that gardeners sometimes
(53) develop rough patches of skin (called calluses) on their hands, as a result of hard work in the garden. Would they pass these on to their children? Can you explain your answer?

APPENDIX 4 INTERVIEW TRANSCRIPTS

Pupils' words are given in italic script. Interviewer's probing questions (not verbatim) are given in brackets. The question numbers correspond to those in the interview schedules in Appendix 3, and the category set numbers (as in Chapters 4, 5 and 6) are given in brackets down the left hand margin.

(i) PRESSURE INTERVIEW (Pupil 28, 12 year old girl)

Cat. Set No.

(1) 1. (a) (b) *Because the smallest board and the heaviest weight ... with the board only being small the heavier the weight the further it'll go down. But as for this big green one here that one it wouldn't have gone down as far because there's a lot more area to cover. And to push down.*

(2) 2. (a) (c) *They are pieces of wood or they can be steel, and they just slide along the ice. And they're quite heavy so they can support the man's weight, but as there's snow and he's got nothing to support his weight - only the boots to keep his feet dry - and the weight, and with snow only being light - he'll just sink* (Mr. Y).

2. (b) *Well, if he had his foot in the snow well that'd sink down, but the other foot wouldn't ... Yes, he'd sink a bit more than he would on two skis, because the skis I don't think sink.*

2 (c) *Boots are just to keep your feet warm, and as for Mr. X he's got his boots on, then his skis - and the skis are quite heavy. Say the skis could - er - one ski could be half the weight of the man, and the other half ... And you can also get them different sizes - altogether if the man's weight was 10 stone - one ski would probably weight 5 and the other ski'd probably weigh 5, so they would be able to support the man's weight.*

(She then confirms that it is the <u>heaviness</u> of the skis which is important in support and offers no other factor).

(3) 2. (d) *Well, they'd only be small skis ... and he's 200 lbs. I'm not very good at this with lbs ... er ... how many stones in 200 lbs? ... well then he'd sink because the skis wouldn't be able to hold his weight, because they're only small skis and they wouldn't weigh very much.*

(8) 4. (a) *Well, I think they're both the same, because the pressure'd only hit the top of the water, and push the water down.*

(11) 4. (b) *The pressure coming down would be the more heavy. Because ... I've only known pressure to come down and not to the sides.*

(When you say you've only known it - where from?)

When I've been outside and if you've jumped - you've not gone to the sides - you've always come down after. You've never stayed up in the air!

(9) 4. (c) *The same. Because its the same amount of water and the same position. And the pressure coming down again will just push the water a bit down. And if they're both in the same place - well, they've both got the same pressure.*

(She agrees then that she means that the pressure is just on the surface of the water and just pressing down a little bit).

(12) 5. (a) *About 1, I should think.*

(b) *It'd go up to the top, then burst.* (How would it change?)*It'd get bigger, I should think. Because the pressure of the water coming down, and it's not the same pressure as what its come out of.* (How would the pressure change as it went up?) *It'll get more, I should think ... and as it goes up it'd burst because there'd be too much pressure ...* (She agrees that the pressure is on the outside of the bubble).

5. (b) contd.

And the pressure when it gets to the top of the water there'd be too much pressure on the bubble so it'd burst, cos its not used to that kind of pressure. It'd come out at, say, 12 and then it'd probably go into about 30 or 40 or even more.

(10) 5. (c) *Still about the same - 12. But as soon as it got to the top there'd be more pressure on it.*

(13) 5. (d) *No.*

(14) 6. (a) *The pressure is very little in the bottle and when you breathe up the orange juice - the pressure pushes down and the orange juice comes up the straw ...*

(When you say the pressure's very little in the bottle, where do you mean?)

Well there's more pressure on that (the bottle with no bung) *than there is on the one with the cap, because it can get in - it presses down ...* (When asked to show where it's pressing she indicates the surface of the orange, when asked what is pressing she answers 'pressure'). *And when you suck up the pressure pushes down and so you're able to suck the orange up.*

(Does the pressure press down on the orange juice when you're not sucking?)

Oh, yeah, it presses when you're not sucking and when you are.

(Why doesn't the orange juice just shoot up the straw anyway?)

Because you're sucking it up, and you're pulling pressure up like, with the straw. And that's pushing down and you're pushing it up and the straw's pulling it up as well.

(What about the pressure in the straw as you suck - is it changed?)

6. (a) contd.

(15) *Yes ... well, I think as it goes up it'll be more.*

(16) 6. (b) *Well, because there's no pressure in to push down ... I've tried this with my own drink ... there isn't any pressure in that to push down, so its very hard to get the pressure up if there isn't any in.*

(She agrees that she means it's very hard to get the pressure up the straw, if there isn't any in the bottle to begin with).

(She suggests that she could take the cork off the bottle with the bung to give herself a drink of orange juice). *Because again the air can get in - and with the tightly-fitting cork it can't get in.*

(17) 7. *Air. No air* (a correction) *Nothing.* (Finger off) *Well, the pressure in the water pushes up - its like a vacuum.* (Why such a force?) *Because the air has been sucked out, and its just the pressure left and the pressure is such a force that it shoves the water up.*

(there's only pressure left where?)

In the water ...

(Repeat the operation. This time she says there is 'nothing' in the syringe 'just a vacuum')

(Finger off) *Because the pressure at the bottom where the water is - with it being a vacuum - is sucking the water up and the pressure is pulling it up and the vacuum is sucking it, so it goes up even faster.* (She seems to think there are two factors involved - the vacuum and the pressure which is operating not on the surface, she says, but 'underneath'.)

8. (a) *It gets hotter.*

(19) 8 (c) *Because the pressure is pressing on your cup and the air inside the cup was ... couldn't get out because of the pressure. It needed more force of bringing*

8. (c) contd.

it up so the air could get out.

(Where is the pressure being exerted?) *All round the cup, especially on top of the cup* (on the outside) ... (She agrees that it is because of the pressure on the outside of the cup that he can't get it off) (What about the air inside the cup?). *Well, its only little and it can't get out because there's that much pressure pressing down on the cup ... there's more pressure pressing down on the cup than there is air inside the cup - so it can't get up.* (What about the air inside the cup?) *There's less air* (than normal) (What about the 'pop') *Because the air pressure and the ... the pressure and the air ... the air's getting out and the pressure's pushing down, and when you get it up - it seems to pop - probably they both - they meet. Like hot and cold air make thunder.*

(5) 9. *Pressure is a force pressing down and all around on to the surface of things.*

(ii) EVOLUTION INTERVIEW (Pupil 35, 14 year old girl)

Cat.
Set
No.

1. (a) *There are four dogs and the other three are bitches. They all seem to have white fore-legs ... and also white hind-legs, and a white tip to the tail.* (Exactly the same in every detail?) *No, they have basically the same colour scheme, but each one has different markings. They look similar but they aren't exactly the same.*

(41) 1. (b) *Yes, each parent contributes something to the make-up of its children and of course each parent has different colouring to begin with, so if you combine the genes of the two parents you get a sort of mixture which won't be exactly the same as either of the parents. That's how you get the differences.* (Same thing in plants?) *No. Well, not major differences as in colouring etc.* (Do you get inherited differences in plants?) *Not major ones. There would be slight differences between each plant but plants of a species don't change colour overnight. A rose is a rose, no matter where it's grown and who its parents were.*

1. (g) *Yes*

2 (b) *Yes, they do. Are these your children? Yes there's*
(c) *a similarity between you all. I don't look like my brothers but I look like my mum.*

(42) 2. (d) *Well if they have the same parents each time then each parent's genes - well they remain the same but they combine with one another in different ways so no two children, except identical twins who of course were formed from the same genes, are exactly the same. Your son was a different combination of genes than your daughter, but because the genes came from the same source they were basically similar and so leads to similarities in your children.*

2. (d) contd.

(Twins - same genes - explain?) *Well the egg was fertilized and split into two babies, but it happened at the same time - they weren't different children. They developed at the same time, the genes combined at the same moment - they weren't different sets of genes but of course each baby developed individually.* (Genes?) *Well they're basically formed from amino acids - they're the building blocks of life - each of us has a set of genes - I think its 28 or something - and we carry them inside us. Each of our cells has a genetic code message in it which if you take one cell from anybody - that's the basis of cloning as well - you could rebuild an entire body from it. Genes give you the instructions what the being will be like - they're the message which is given.*

(45) 3 (a) *There was a genetical fault. One of his parents had a faulty gene or a rogue gene which combined and it just so happened to be his misfortune that it was the gene that he got.* (How might the fault have arisen?) *Well, sometimes it's a hereditary fault. But of course genes aren't perfect and an occasional mistake is made - a faulty combination of amino acids or something like that.*

(46) 3 (b) *Well, this mouse who had been born with no tail, his genes had said that he was to have no tail. He passed some of his genes on to combine with his mate's genes. Sometimes his genes were predominant in the baby mice who were born without tails, in others his mate's genes were predominant when the mouse born had a tail.*

(49) 3. (c) *Mice with tails, because their genes haven't instructed their bodies to not build a tail - their genes say that they should still have a tail and as far as that mouse is concerned, apart from the fact that he's suffering pain because he's got a chopped-*

3 (c) contd.

off tail his body thinks he's still got one. So his genes will pass on the message that their children are to have tails.

(50) 3 (d) *I think he'd still get mice with tails. Its possible that they could learn to live without them after a very long period of time, but I should think that the babies would still go on having tails.*

3 (e) *Well, if they were to find two large mice and breed them together its possible that some of their children would also be large and in that case if they could breed another family of large mice, then they could start a clan off - of large mice. But the chances are that they wouldn't find two such large mice - they would find one large mouse and one small mouse - there might be a few large mice but there would also be small mice. I don't think they would succeed unless they went on breeding for thousands and thousands of years.*

(54) 4. (a) *Well, the caterpillars originally started off ...*

(55) (b) *long long ago they were the same species of caterpillar. One kind finally developed a liking for the sap or whatever it is of the dark tree. The other decided that it would prefer the pale tree. I presume they had different kinds of trees. So the ones who lived on the dark tree were probably pale-coloured as were the pale ones but - or they were some intermediate colour - they began - well, they were picked off at first by predators, and then naturally they developed a disguise - camouflage - to protect them from predators so that they became almost indistinguishable from the dark tree trunk. The pale caterpillars probably used the same scheme only they grew lighter in colour. It wasn't anything that they had conscious control of, it was just that the ones who had dark coats - maybe it was a fault or something, but some of them were born with dark coats on the*

4. (b) contd.

dark tree trunks - they survived, they passed that fault on to their children and so a breed established itself which had dark coats and the former breed was extinct because it had been picked off. However, on the other tree trunk, this happened - the ones with pale coats survived and the ones with darker coats didn't. (Is that what you meant when you said 'develop a disguise for camouflage'?) *Yes, they didn't have any conscious control over it - it was just natural selection - survival of the fittest.*

(48) 4. (c) *On both tree trunks, if they could get there. If there is no need for them to stay on the tree trunk one or two would eventually find their way to the pale tree trunk and they would lead the way for the rest. But I should expect that most of them would stay on their tree trunk because there's no reason for them to move. But in time they'd eventually spread out across the wood.* (Because you said there would be 'no need' for them to stay on the dark tree?) *Yes.* (And this need would be perceived in some way by the caterpillars?) *Well, I don't think they have any conscious thoughts - they don't think to themselves 'Ah, they've all gone, we can spread out now', but eventually one or two would find their way to a tree trunk that they'd perhaps been there before and one or two had been picked off, but eventually they would spread out. They'd just follow each other.*

(56) 4. (d) *I think the caterpillars would also change - either that or they'd move to a dark tree but I should think that they'd gradually change. The ones that had previously been picked off because they had a mossy-coloured coat would begin to survive and the same thing would happen all over again.* (So when you say they would change colour you don't mean that the individual caterpillars would change colour?) *No, the breed itself would begin to change colour.*

4. (e) *I think you would be able to see the lighter-coloured ones. They would probably become extinct.* (And the dark ones?) *I think they would survive - more of them would survive than the ones who are picked off because of their coloured coats.*

(57) 5. *Well, they didn't have any conscious thought thinking 'We've got to develop some sort of protection'. The ones who were born with naturally thicker coats survived more often than the others and they began to pass this on to the future generations of foxes, so developing a new breed which had originated from the old stock but had a slightly thicker coat.*

6. (a) *Some of them have a naturally stronger physique than others. Some of them are more mentally-disposed towards running - ... well, they're more naturally competitive than others and some of them like running better than others.*

6. (b) *If you really want to and your body will stand it then ... I should think its worth it, yes.*

6. (c) *Well, there's one boy - Richard Dukes - who couldn't make the Olympics today but he's a really good cross-country runner, but I don't think that we could really train that hard. I don't think so, but there are one or two of the boys who are strong enough to do it.*

(51) 6. (d) *No. Because they haven't changed their genes - they haven't changed the basic structure. They've changed themselves - outwardly - into becoming fast runners but that took a long time and it wasn't a process which nature had much of a hand in. So therefore, their genes will reproduce them as they were to begin with, and their children'll have to work hard to become fast runners.*

(52) 6. (e) *Well, they'd certainly be faster runners than the people who began, because their parents would be stronger and fitter every time, but I shouldn't think they were automatically fast runners.* (But you think that practice over time would have some effect?) *Yes, because the parents would become fitter, and more healthy and healthy parents give healthy children.*

(53) 6. (f) *I don't think so. Because its something that developed not as a direct result of the genetic message but as a direct result of existence and circumstance and of course each one of us goes through different circumstances, so each one of us has different things which develop in our bodies. Its like cancer - you don't pass cancer on - a cancer develops in each one. At least we don't think you can pass it on. And it isn't hereditary.*

APPENDIX 5 RESULTS OF INDEPENDENT CROSS-CHECKING OF CATEGORY DATA

Questions on the interview schedule (first round) were independently categorized for one quarter of the sample. Since this was done before the final selection of questions the check includes questions which do not appear in Chapters 4, 5 and 6 (these are marked with a * below). The pupils involved in the cross-checks are listed below under each concept area. Since all category data are given in Appendix 7, only the discrepant categorizations are reported here.

(a) PRESSURE (n=21)

Pupils 1, 7, 9, 13, 17, 21, 24, 28, 33, 38, 42, 46, 50, 54, 58, 62, 66, 70, 74, 78 and 81 were checked

QUESTION NUMBER AND NAME	DISCREPANT CATEGORIZATIONS		
	Pupil Number	First round categorization	Cross-check
Q1 Boards and weights	28	C	B
Q2 Skis	7	U	N
Q5 Definition of pressure	70	K	J
Q6 Tyres	33	0	A
Q8 Pressure on Fred and Goldie	21	A	P
Q14 Straw - open top	24	P	B
Q15 Straw - closed	38	U	N
Q18 Syringe	7	N	0
Q19 Washing up	33	N	0
	54	N	0
Q5(b) on interview schedule *	24,28,46,50		
Q5(d)i on interview schedule *	70		
Q8(a) on interview schedule *	58		

(b) HEAT (n=21)

Pupils 2, 6, 10, 14, 18, 22, 26, 30, 34, 39, 43, 47, 51, 55, 59, 61, 65, 71, 75, 79 and 83

QUESTION NUMBER AND NAME	DISCREPANT CATEGORIZATIONS		
	Pupil Number	First round categorization	Cross-check
Q22 Kettle and bath - cost	61	B	C
Q23 Kettle and bath	43	B	A
	75	Q	N
Q27 Mixing liquids IV	34	U	B
Q30 Definition of heat	18	L	M
	55	L	K
	59	J	K
	83	K	M
Q31 Potatoes - water temperature	39	A	N
Q32 Potatoes - cooking time	18	N	U
Q33 Potatoes	47	B	A
Q34 Spoons	34	N	P
	47	N	R
	61	A	B
	75	A	B
Q35 Plates - thermometer readings	34	P	R
	71	P	0
Q36 Plates	79	Q	N
Q37 Handlebars	2	0	Q
	14	R	N
	43	P	N
	61	R	0
	71	N	P
Q1 on interview schedule *	79		
Q4a on interview schedule *	26,39		
Q4d on interview schedule *	30,61		
Q5b on interview schedule *	10,14		
Q6a on interview schedule *	6,61		
Q6bi on interview schedule *	61		
Q6bii on interview schedule *	71		

APPENDIX 5 (cont)

(c) EVOLUTION (n = 21)

Pupils 3, 8, 12, 16, 20, 25, 29, 31, 35, 40, 44, 48, 52, 56, 60, 63, 67, 72, 76 80 and 84.

QUESTION NAME AND NUMBER		DISCREPANT CATEGORIES		
		Pupil Number	First round categorization	Cross-check
Q40	Variation in plants	56		
Q41	Dogs' markings	8	B	C
		76	B	C
Q42	Twins	76	U	A
Q43	Siblings +	8	-	O
		31	-	A
		63	A	B
Q44	Genetic material	3	H	I
		40	L	I
		67	K	I
Q46	Mice - mixed litter	8	A	U
Q47	Mice-parental contribution	63	B	A
Q48	Caterpillars - predators	8	A	C
		56	C	A
		80	A	O
Q49	Mice - chopped off tails	31	B	A
Q50	Mice - chopping over time	35	N	A
Q53	Gardeners' children	52	B	U
		67	B	A
Q54	Caterpillars	8	H	J
		40	H	L
		52	K	U
Q55	Caterpillars - origin	56	P	Q
Q56	Caterpillars - pale trees	8	B	D
Q57	Arctic Fox	48	R	O
		52	O	B
		76	S	O
		80	S	P
Q3c	on interview schedule *	67		

\+ Q43 Siblings
For two pupils there was disagreement as to whether they had given responses which could be categorised for this set.

APPENDIX 6 IDEAS GRIDS FOR PRESSURE, HEAT AND EVOLUTION

(a) PRESSURE

QUESTIONS	IDEAS				
	Nature of Pressure	Molecular Bombardment	Pressure & Depth	Pressure & Direction	Atmospheric Pressure
1 Boards and weights	✓				
2 Skis	✓				
3 Skis - quantitative	✓				
4 Furniture	✓				
5 Definition of pressure	✓				
6 Tyres		✓			
7 Football - pressure		✓			
8 Pressure on Fred & Goldie			✓		
9 Fish tanks			✓		
10 Sub. at 50m			✓		
11 Fred's back and nose				✓	
12 Sub. - hatch				✓	
13 One atmosphere					✓
14 Straw - open top					✓
15 Pressure in straw					✓
16 Straw - closed					✓
17 Syringe - what's inside?					✓
18 Syringe					✓
19 Washing up					✓
20 Football - molecular number		✓			
21 Football - molecular speed		✓			

(b) HEAT

QUESTIONS	IDEAS	
	Heat and temperature	Conduction of heat
22 Kettle and bath - cost	✓	
23 Kettle and bath	✓	
24 Mixing liquids I	✓	
25 Mixing liquids II	✓	
26 Mixing liquids III	✓	
27 Mixing liquids IV	✓	
28 Mixing liquids - qualitative	✓	
29 Heat and temperature	✓	
30 Definition of heat	✓	
31 Potatoes - water temperature	✓	
32 Potatoes - cooking time	✓	
33 Potatoes	✓	
34 Spoons		✓
35 Plates - thermometer readings		✓
36 Plates		✓
37 Handlebars		✓

(c) EVOLUTION

QUESTIONS	IDEAS		
	Inheritance	Acquired Character-istics	Adaptation
41 Dogs' markings	✓		
42 Twins	✓		
43 Siblings	✓		
44 Genetic material	✓		
45 Tailless mouse	✓		
46 Mice - mixed litter	✓		
47 Mice - parental contribution	✓		
48 Caterpillars - predators	✓		
49 Mice - chopped off tails		✓	
50 Mice - chopping over time		✓	
51 Athletes		✓	
52 Athletes over time		✓	
53 Gardeners' children		✓	
54 Caterpillars			✓
55 Caterpillars - origin			✓
56 Caterpillars - pale trees			✓
57 Arctic Fox			✓

APPENDIX 7

CATEGORY DATA

This appendix contains all the categorizations which were made from pupils' responses in interview.

Each question (category set numbers along the top of the grids) has a double column of results. The category in the left hand column is the one made from the first-round interviews and the one on the right from the second-round.

Category Set Nos.

Pupil No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	B A	A B	A A		J K	A	A	O A	O O	P B	O R	O B	A P	O N	O O	N C	B B	P P	R R	A	[illegible]
2	B B	B B	U A		J J	O	P	A P	N N	B B	S P	N B	N N	C C	O A	C C	B N	O C	P O	A	[illegible]
3	B A	A A	A A		H H	N	C	A A	A A	B B	U A	A A	A N	A A	A A	A B	A A	A A	A A	A	[illegible]
4	P B	C B	U U		U J	P	N	O O	P A	P O	R N	O N	A P	A B	A U	U B	B B	A A	B A	A	A
5	O P	Q B	U C		U J	U	N	O P	A O	P P	N A	N A	P P	P P	- O	O O	N N	N N	P P	A	[illegible]
6	C B	B B	U C		J I	P	N	A A	Q N	B C	T P	N P	N A	O O	O A	N N	N B	O C	P A	A	[illegible]
7	R Q	U U	U U		K J	P	Q	A P	N U	B B	A T	A R	N N	P O	- O	N B	N N	N N	R U	A	[illegible]
8	B Q	B A	A A		H U	P	B	A A	A A	B B	O O	O N	A P	A P	A A	A A	B B	P A	N A	A	B
9	O C	U N	U U		J J	O	O	P P	O N	B B	P B	N U	P P	O U	U U	O U	B N	O U	R U	N	B
10	C B	N C	U U		K J	U	C	N U	U U	P U	N R	O N	N N	B B	U N	B B	B B	B C	O O	A	B
11	C B	C A	C A		J J	B	A	A A	N N	B B	A A	A A	N A	O B	O O	C C	O B	O C	N N	A	B
12	O C	C R	U U		J J	O	B	A A	N N	B B	Q U	Q U	P P	O C	U O	C B	N U	O O	Q Q	A	A
13	C C	C B	B N		J K	N	Q	A A	P O	B B	R T	U O	N N	B B	O N	C B	B B	A B	P A	A	B
14	P -	C -	U -		J -	-	-	P -	B -	N -	B -	B -	P -	O -	U -	O -	B -	P -	N -	-	-
15	C C	B C	N N		J H	O	Q	A A	A N	B B	T P	O B	O O	O O	U O	N N	N N	N N	O O	P	O
16	C B	B B	B B		J U	N	Q	A A	A N	B B	S T	N U	N N	C C	O O	B C	N B	O P	U N	A	B
17	O C	Q P	U U		K J	U	U	O P	N N	B C	S T	R B	N N	U N	- U	N C	B B	P P	O N	Q	U
18	C C	P N	N C		J U	P	O	N N	P O	B B	N R	N A	O P	O O	O O	N N	N N	N N	P P	N	P
19	C C	U C	U U		J J	N	O	A A	B N	C O	N O	N O	N N	O B	N N	B B	N B	O C	O R	N	U
20	C C	C C	U C		J J	P	U	A A	N O	B B	B N	P N	N N	U A	A A	U B	N B	O P	Q P	U	P
21	Q Q	Q N	U U		U U	U	U	A P	N N	U B	B R	N U	A O	O O	U U	O B	N N	N N	- O	A	U
22	N C	P C	U U		K K	N	Q	A P	P P	B B	R R	O O	N N	A P	A U	A B	B B	B B	B A	O	U
23	C B	P C	A U		J J	N	P	A A	A P	B B	A R	B A	P P	B B	O U	B B	B B	Q B	A U	O	B
24	B B	B B	C C		J J	U	P	A A	A A	B B	A A	A A	O N	P N	O O	B C	B B	B P	B N	A	B
25	U C	C C	U U		K U	U	N	P P	O A	P B	O O	N O	N P	B B	O N	B B	N N	O U	U U	A	O
26	P C	B B	B U		J K	B	B	A A	U N	B B	R U	O U	P N	A B	A A	B U	B B	A B	U A	A	B
27	N C	O P	U U		J J	U	N	O O	A B	B N	B B	B N	Q Q	O C	N N	C C	N N	O O	Q Q	A	P
28	C U	O C	U U		H J	P	U	N A	P A	N B	O O	N O	Q N	B U	O O	B B	B O	Q O	B U	A	N
29	C C	C N	U O		K J	U	N	P P	B N	C C	B B	O N	P P	U U	- O	N O	N B	N U	P P	U	N
30	P C	C C	U U		J J	U	C	A A	O O	B O	R O	N N	O P	B O	O N	B P	N N	O O	Q P	A	N

Pupil No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
31	B A	B B	A A	- B	J I	N A	B A	A A	A A	B B	B O	B A	N N	P A	- A	U A	B A	P A	Q A	A A	B A
32	B B	B B	A A	- A	J H	A A	A A	A A	A A	B B	A A	A A	N A	A A	A A	U A	B U	A A	A Q	A A	B A
33	C B	B B	U C	- A	K J	O O	C B	A A	O N	B B	B A	A B	N N	B B	O O	U B	B B	C C	Q N	A A	B B
34	B B	B B	U O	- B	J H	B A	P A	A A	N N	B B	P T	A B	A N	N O	A O	O C	B B	P P	N O	A A	B B
35	B A	B A	P A	- A	H H	A A	A A	A A	A A	B B	A A	A A	A A	A A	A A	B A	- A	- A	A A	A A	B A
36	P B	P B	C U	- N	J J	O A	Q B	N A	O O	B B	R B	N A	O P	O O	O O	C P	B B	C P	P R	P A	B A
37	B B	B B	U U	- N	J J	N A	O A	N A	O B	P B	R A	R B	P N	O O	O O	B C	O B	O O	P Q	O A	B B
38	B B	B B	B C	- N	J K	O P	Q C	A A	N N	B B	N R	N B	N N	O O	U O	U N	N N	O N	R O	A A	B A
39	B A	B B	U A	- A	I H	A A	A A	A A	A A	B B	A A	B A	N N	B A	U A	B A	B A	A A	A U	A A	B B
40	C B	C B	A A	- P	K J	N A	C A	A A	A A	B B	S B	N B	N N	O B	A A	A B	B B	P C	U U	O A	U B
41	B B	B B	C O	- P	U J	B B	A B	A A	O O	B B	B A	O A	P O	B O	O N	B C	B B	A A	U U	A A	B B
42	B B	B B	A A	- A	J J	B A	B B	A A	A A	B B	S A	N A	N N	B A	A A	B A	N B	Q A	P Q	A A	B B
43	C -	B -	U -	- -	J -	P -	N -	A -	A -	B -	N -	N -	N -	O -	O -	C -	N -	N -	Q -	N -	B -
44	C C	C C	U U	- N	J J	P N	N P	A A	O O	B B	O O	Q N	P P	B O	U O	B B	B O	O P	U Q	A A	B A
45	C C	U P	O U	- U	J J	O P	C N	A A	A N	B B	U A	B B	O P	O O	U U	P O	N N	U U	U P	A A	U B
46	B C	B B	U U	- N	J J	O B	N N	N P	O O	B N	N N	N A	O O	O B	N A	P O	N N	N N	Q A	A A	B B
47	C C	B B	U U	- U	J H	O O	N N	O A	N N	B B	T A	N N	O P	O O	O O	C C	O N	Q O	P P	A N	N N
48	B B	B B	A C	- N	J H	A B	Q Q	A A	A N	B B	T S	N U	P N	B B	O O	B B	B B	P C	N Q	A O	B B
49	C C	U U	U U	- N	K U	P U	C U	A P	A N	B B	N B	B O	O N	O O	O O	O C	N B	O U	P U	A U	U U
50	U U	U P	U N	- B	J J	U U	O N	P N	O O	B P	N U	B N	N O	O O	N N	O O	N N	N N	P P	A N	U U
51	Q C	A B	O U	- B	J J	N N	Q C	A A	A N	B B	N P	N B	N N	O C	O U	C C	B B	P P	U O	A O	N B
52	R C	N Q	U U	- U	U U	U U	N C	U O	O O	O U	B T	O A	Q Q	U O	A A	U U	N N	O U	U U	A N	B B
53	U C	C Q	U U	- U	K J	P U	C P	A P	O U	B U	N T	N U	N P	O O	O U	P P	O N	U U	P U	O O	O B
54	B B	B B	A C	- U	J H	N N	P Q	A A	A B	B B	A A	A A	N N	O N	A U	P C	B B	P C	Q N	A O	N A
55	B C	P B	U U	- N	K J	O U	Q U	O A	O A	B B	T B	R B	A P	O O	U N	N N	O O	O O	Q P	N N	B U
56	B B	B B	A B	- -	J K	P N	Q O	A A	A A	B B	N U	N A	P P	O O	- N	P C	B B	U A	R O	N U	B B
57	C Q	B B	C N	- B	J J	U O	C C	O A	O N	B B	N P	N N	N Q	O O	O O	N P	N N	O U	P P	N N	B B
58	Q C	U U	U U	- -	J U	U U	Q C	A A	N B	B U	N U	N B	O P	O O	O O	N P	N N	N O	P U	A U	N U
59	C B	U C	U U	- -	J J	U U	C Q	A O	O O	P B	B N	N N	O P	C O	O U	U B	N N	U U	U U	P A	O N
60	P C	N P	U U	- U	K J	N B	N B	A A	O O	B B	A N	B U	P P	O B	O O	N P	N B	O Q	Q Q	N A	B B

Pupil No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
61	C			N	J	O	N	A	O	B	A	B	Q	B	N	B	B	C	N	A	B
62	B			A	I	A	A	A	B	B	A	A	A	A	A	A	A	A	A	A	A
63	B			B	H	A	A	A	A	B	R	B	N	A	A	B	B	U	A	A	B
64	B			N	J	A	B	A	A	B	S	A	N	B	A	B	B	P	N	A	B
65	B			A	J	A	A	A	A	B	B	B	A	A	A	A	B	A	A	A	B
66	B			A	J	B	C	A	A	B	B	A	A	B	U	B	B	B	U	A	B
67	P			U	J	N	C	A	N	B	B	B	A	B	U	B	N	O	N	N	U
68	A			A	H	A	A	A	A	B	U	A	A	A	A	A	A	A	A	A	B
69	B			A	J	A	B	A	A	B	A	B	A	A	A	A	B	A	U	A	A
70	C			N	K	U	C	A	A	B	O	N	N	O	A	C	B	O	R	N	B
71	B			N	J	O	C	A	A	B	P	U	A	O	-	O	N	N	U	N	O
72	B			B	J	A	A	A	B	B	B	B	A	B	U	C	B	P	N	A	B
73	B			P	K	A	B	A	A	B	O	O	N	U	A	C	B	P	N	A	B
74	C			N	K	P	N	A	A	B	O	O	N	O	U	C	B	C	Q	P	N
75	B			B	J	N	P	A	N	B	T	B	Q	B	O	U	B	P	N	A	U
76	B			B	J	P	C	A	A	B	A	A	A	A	A	B	B	B	O	N	B
77	C			P	J	A	A	A	N	B	B	A	N	N	A	A	B	P	O	A	A
78	B			N	K	U	B	A	A	B	O	B	N	N	-	B	B	C	N	A	B
79	B			P	U	O	C	A	N	B	T	N	N	O	O	P	N	N	Q	N	B
80	C			N	U	N	Q	A	O	B	A	A	A	O	A	C	N	O	R	N	P
81	B			A	H	A	A	A	A	B	A	B	A	A	A	A	A	B	A	A	B
82	Q			O	U	U	N	O	B	C	N	N	Q	O	N	N	N	U	U	A	U
83	C			N	U	U	N	O	B	B	-	N	U	O	N	P	N	O	U	N	N
84	N			O	U	U	U	O	A	P	B	B	P	O	N	N	N	U	P	N	B

Pupil No.	22		23		24		25		26		27		29		30		31		32		33		34		35		36		37	
1	B	B	Q	U	A	A	A	A	P	P	Q	O	L	L	N	I	N	N	A	U	U	A	B	B	O	T	N	O	N	O
2	B	B	B	B	A	A	A	A	P	P	B	P	K	J	J	J	A	N	A	A	A	A	P	P	Q	R	O	U	O	N
3	B	A	A	A	A	A	A	A	P	A	B	B	M	I	I	H	A	A	A	A	A	A	B	B	O	A	A	A	N	A
4	B	B	B	A	A	A	A	A	N	P	N	B	J	L	U	U	A	A	A	O	A	A	Q	A	T	A	U	O	P	O
5	N	B	R	N	A	A	A	A	N	N	U	N	L	L	M	M	N	A	N	A	O	A	R	N	P	P	U	U	U	O
6	B	B	N	B	N	A	P	A	P	P	Q	N	L	K	M	J	A	A	A	O	A	U	Q	O	N	R	P	P	U	P
7	B	B	B	N	N	A	N	A	N	P	N	P	L	K	L	U	B	B	U	A	U	B	N	N	B	N	P	P	P	P
8	B	N	A	P	A	A	A	A	B	A	B	B	H	I	I	I	N	A	A	A	O	A	B	B	P	P	N	N	Q	N
9	P	B	C	B	N	N	N	N	N	N	N	N	K	U	U	I	N	N	N	N	O	O	R	N	A	R	U	U	O	U
10	B	B	C	B	A	A	U	A	B	P	U	P	K	K	U	L	B	N	N	N	O	B	N	B	A	C	U	U	U	O
11	B	B	B	A	A	A	U	A	B	B	U	R	H	J	L	H	N	A	N	U	N	B	B	R	Q	Q	U	U	O	O
12	B	B	R	U	A	A	A	A	Q	Q	R	P	U	U	L	U	N	A	N	A	O	O	N	N	N	R	P	U	P	U
13	N	B	N	N	A	A	A	A	B	P	U	P	L	K	L	U	N	N	N	A	O	P	O	U	U	T	Q	O	P	O
14	B	-	N	-	A	-	A	-	B	-	C	-	J	-	K	-	N	-	A	-	U	-	B	-	N	-	P	-	R	-
15	B	B	N	P	N	N	N	P	N	N	N	U	J	L	L	M	N	N	N	U	B	B	B	B	A	R	Q	P	O	R
16	B	U	B	A	N	A	Q	A	N	Q	S	R	M	J	M	N	N	N	N	U	O	O	B	B	U	U	N	P	U	U
17	O	U	N	U	O	N	O	U	O	U	O	U	M	U	L	M	N	N	N	N	O	O	R	B	U	T	P	O	O	P
18	B	B	N	O	O	A	O	A	O	N	O	N	J	J	L	K	O	O	N	A	N	N	N	N	R	S	P	P	Q	O
19	P	B	Q	S	A	N	U	N	U	N	U	N	K	K	L	N	U	N	U	O	P	O	R	B	N	T	U	P	U	U
20	B	B	B	B	U	A	U	A	U	B	U	C	U	U	J	U	A	A	A	U	A	A	N	P	P	P	N	O	R	O
21	B	C	R	C	O	U	O	U	O	U	O	U	K	K	L	L	N	N	O	O	A	O	U	N	B	A	P	P	R	O
22	P	B	N	P	A	A	A	A	P	P	B	P	M	J	I	N	N	A	N	N	O	B	R	B	P	T	Q	N	O	O
23	B	C	Q	N	N	A	P	A	N	A	Q	P	H	L	N	U	A	A	U	N	O	A	B	B	A	U	P	Q	O	R
24	A	B	B	A	A	A	A	A	N	P	S	P	I	I	J	I	A	A	A	U	A	A	P	N	Q	T	N	O	N	O
25	B	P	R	C	U	N	U	P	U	N	U	U	K	U	K	U	A	N	N	O	A	O	U	R	Q	R	N	U	R	O
26	B	B	B	N	A	A	A	A	B	P	P	P	J	J	K	K	A	A	A	A	A	O	P	B	C	O	U	N	Q	N
27	B	P	R	C	O	N	O	N	O	N	O	N	K	K	M	M	B	N	U	O	B	B	U	P	C	A	Q	U	Q	Q
28	B	B	O	N	N	A	N	A	P	P	P	B	K	K	J	L	A	A	A	U	U	O	Q	B	U	S	P	Q	P	Q
29	O	P	N	C	U	N	U	N	U	N	U	N	L	L	M	M	N	N	U	U	O	N	N	P	T	O	P	U	U	O
30	O	B	O	U	N	A	U	A	N	N	N	N	L	K	J	J	N	N	O	U	B	O	Q	P	U	A	P	U	P	R

Pupil No.	22		23		24		25		26		27		29		30		31		32		33		34		35		36		37	
31	B	A	B	A	A	A	A	A	P	Q	U	R	I	I	K	H	A	A	A	A	A	A	A	A	N	O	U	A	O	A
32	B	A	B	A	A	A	A	A	A	A	B	A	L	H	I	I	A	A	A	A	A	A	A	A	P	O	P	N	O	N
33	B	B	Q	Q	A	A	A	A	B	B	B	R	I	I	I	I	A	A	U	A	A	A	A	A	P	T	U	U	O	O
34	B	A	B	N	A	A	A	A	P	P	U	U	I	I	I	I	B	A	A	A	A	A	N	B	P	A	U	A	P	A
35	-	A	B	B	A	A	A	A	A	A	C	C	I	I	I	H	A	A	A	A	A	A	A	A	A	U	N	N	N	N
36	O	B	O	C	A	A	A	A	P	Q	P	C	J	I	K	I	A	A	U	A	A	A	B	B	U	U	O	A	O	O
37	B	B	A	N	N	A	N	A	N	B	N	B	M	K	K	J	N	A	U	A	U	A	N	B	N	A	Q	U	P	U
38	B	B	N	N	A	A	P	A	N	N	N	P	I	J	K	U	N	A	A	U	N	A	A	A	O	T	N	A	U	A
39	-	A	Q	N	A	A	A	A	P	P	U	P	-	I	H	H	A	A	A	A	U	A	A	A	O	R	N	N	N	N
40	B	B	N	B	A	A	A	A	P	B	Q	U	K	U	N	I	P	A	A	A	N	A	B	U	U	P	P	P	P	R
41	A	B	N	N	A	A	A	A	B	P	Q	P	M	M	H	I	N	A	N	O	O	A	B	B	P	R	O	U	P	O
42	B	A	A	A	A	A	A	A	A	A	B	C	J	I	H	I	A	A	A	A	A	A	A	B	R	O	P	A	R	A
43	B	-	B	-	A	-	A	-	B	-	B	-	U	-	J	-	N	-	A	-	O	-	U	-	O	-	N	-	P	-
44	-	B	B	N	A	A	A	A	Q	B	N	B	J	K	I	U	A	A	A	A	A	A	B	A	A	R	U	A	Q	A
45	P	B	U	N	U	A	U	U	U	U	U	U	U	U	J	M	B	A	U	U	N	N	R	B	C	R	U	U	P	U
46	B	P	P	N	N	A	U	P	N	Q	N	R	K	K	K	U	A	A	O	A	A	A	N	B	Q	A	Q	U	P	U
47	B	B	B	N	N	N	N	N	N	N	N	N	K	U	N	U	N	U	N	A	B	O	N	R	N	N	P	U	O	O
48	B	B	N	N	A	A	A	A	N	P	N	P	K	U	N	N	N	A	U	A	O	A	R	R	P	O	N	N	N	N
49	B	B	S	C	N	N	Q	N	N	N	S	N	K	K	L	L	B	A	U	U	A	A	N	R	O	R	U	U	P	U
50	C	C	P	P	A	A	N	P	N	N	N	S	M	M	K	K	O	O	N	U	N	N	N	R	P	P	U	O	R	O
51	B	B	N	A	A	A	A	A	U	B	U	U	J	I	N	I	N	U	N	A	O	B	B	B	P	R	U	P	U	U
52	B	C	P	Q	N	N	N	N	N	N	N	N	U	L	M	L	N	N	N	N	O	O	N	N	U	S	U	U	U	U
53	C	B	B	U	A	N	U	N	Q	N	R	N	M	U	I	K	U	A	A	U	B	B	B	B	N	U	Q	O	U	O
54	B	B	N	N	A	A	A	A	B	N	B	N	J	M	I	I	A	A	A	A	A	A	B	B	A	A	N	U	O	O
55	P	B	R	S	A	A	A	A	N	N	N	S	M	J	L	K	B	A	U	A	B	A	B	B	R	U	N	P	R	U
56	P	B	N	S	A	A	A	A	Q	P	R	P	K	K	K	J	O	O	U	A	N	N	B	B	B	U	U	P	O	P
57	P	U	P	O	N	N	N	P	N	N	N	Q	U	L	U	U	N	A	N	O	B	A	B	A	T	O	U	N	R	U
58	C	C	C	O	A	A	A	A	N	U	N	U	K	K	J	J	N	N	N	U	O	B	B	B	R	Q	O	U	U	O
59	B	P	S	C	N	N	Q	N	N	N	U	U	K	U	J	J	N	B	U	A	U	B	N	N	S	R	U	Q	U	U
60	B	B	B	N	N	N	N	P	N	N	U	N	J	K	I	J	N	N	N	U	U	B	B	B	B	A	P	N	U	P

Pupil No.	23	24	25	26	27	29	30	31	32	33	34	35	36	37
61	B	A	A	B	U	K	I	B	A	A	A	P	U	R
62	B	A	A	A	A	M	I	A	A	A	A	C	N	N
63	B	A	P	A	Q	J	I	B	U	A	A	R	A	A
64	N	A	A	B	C	J	J	A	A	A	B	A	U	O
65	A	A	A	A	B	M	I	A	A	A	A	C	N	N
66	A	A	P	A	Q	M	I	A	O	A	B	A	N	O
67	R	N	U	N	U	M	N	N	U	B	B	R	U	O
68	B	A	A	A	C	I	I	B	U	A	A	R	A	A
69	B	A	A	P	P	I	H	A	A	A	A	R	N	O
70	N	A	A	B	U	U	I	B	A	B	A	P	N	N
71	N	A	A	N	N	K	K	N	N	U	B	P	N	N
72	C	A	A	A	U	U	H	A	A	A	A	R	U	R
73	P	A	A	B	U	L	I	N	A	O	B	R	Q	N
74	U	A	A	P	P	M	L	A	U	N	A	U	U	U
75	Q	N	N	N	N	I	I	B	U	A	A	O	A	A
76	B	A	A	B	C	I	I	B	U	O	A	U	N	A
77	N	A	A	P	R	I	I	A	U	A	A	U	Q	O
78	B	A	A	A	C	K	I	N	U	N	B	R	U	Q
79	N	A	A	B	R	M	I	B	A	A	Q	U	Q	U
80	N	A	A	P	P	K	J	A	N	A	B	U	N	U
81	A	A	A	P	U	U	N	B	U	A	A	A	A	A
82	N	N	U	N	N	K	J	B	U	B	U	C	U	N
83	N	N	N	N	P	K	K	N	N	O	O	U	U	U
84	-	O	O	O	O	U	L	N	N	U	N	S	U	U

Pupil No.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
1	C B	N A	P A	L I	J J	B A	N N	A C	C C	O O	B B	A N	B B	J H	Q R	C D	R S
2	C C	B B	- B	I I	H H	A A	N U	N N	B C	A A	B B	N N	O C	H H	T U	B N	R S
3	C B	A A	A B	H H	H H	A A	N N	U N	A A	A A	B A	O A	A A	H H	A A	O B	A A
4	C C	U P	B B	L L	U U	B B	B N	- O	C C	A A	B B	N A	B B	U H	U A	- A	O A
5	C C	C B	B B	L L	U M	U B	- N	U O	O C	- A	B B	N A	B B	H J	U U	D O	R S
6	C C	N U	A U	J J	J J	B A	B N	O N	C C	A A	N N	- -	C C	J H	U R	D N	S R
7	C C	B B	- U	L L	U J	B B	N N	N N	C N	A U	N B	- N	B B	J J	R R	O N	R S
8	B B	A A	- A	H H	H H	A A	U U	A A	A A	A A	A B	A A	A U	H H	N A	B A	S A
9	U C	N U	N B	L L	U U	B B	N Q	O -	C C	A A	C B	U N	B C	J K	U U	O -	P P
10	U U	B B	U B	L L	U K	B B	- N	N N	C D	U U	B C	A N	C C	J H	Q U	O D	O S
11	B B	U Q	A A	K I	K J	A A	B N	A A	A A	N O	A A	N N	B B	H J	Q Q	O O	T S
12	C C	B N	B B	L L	U J	B B	B N	O A	C C	N N	B B	N N	B B	H J	Q Q	O N	Q S
13	U C	B B	P B	L L	U M	U B	- N	U O	O D	- N	N B	- N	3 B	H H	Q R	O C	S S
14	C -	B -	- -	L -	U -	B -	B -	O -	C -	N -	B -	A -	B -	H -	O -	C -	R -
15	U C	U O	N U	L J	J U	B B	O N	O A	C B	N N	B C	N N	B B	J J	Q O	N N	S S
16	C B	N A	U A	L I	J J	B A	B N	O O	C A	A A	N O	- O	B O	J H	N N	D D	S S
17	U C	B U	N B	L L	J J	N B	- U	O A	Q C	N N	B B	A A	B C	H H	U P	O O	P P
18	U C	U N	U B	L L	U J	B B	N N	O O	C C	N U	B B	N A	B B	J J	Q R	O D	R R
19	C O	N N	B B	L L	J U	B N	B -	O A	O B	- A	B B	A A	B C	H J	U R	O O	P P
20	C B	U U	N A	L J	U U	B A	N N	O O	Q A	Q A	C A	N A	B A	J J	U Q	O O	R T
21	U U	U U	- U	L L	U U	U B	- -	- A	C C	A A	B B	A A	B B	I H	U U	- U	U U
22	C C	B B	U B	L J	L J	B B	B B	N A	B C	N P	B B	N A	B B	H J	U N	D N	S R
23	C C	Q P	Q B	L L	J L	B B	N N	O A	C C	A A	B C	A A	B B	H J	O O	C C	T S
24	C C	U B	U U	J L	J J	B B	P N	A O	B C	P O	B B	A N	A B	H H	Q R	O N	R R
25	N U	U U	U U	L L	M J	B U	B -	U A	O C	- A	B C	N A	U B	J H	U U	O O	U P
26	C C	U B	- B	L L	U U	U B	- B	B A	C C	A A	B B	A N	N B	J H	Q A	O A	O N
27	C C	N N	O B	L L	J U	B B	N B	- -	O O	- -	B B	N N	C B	I K	U P	- -	U P
28	N C	N Q	U B	L L	U J	B B	N N	O O	B C	A A	C B	A N	B B	J J	Q R	O O	S P
29	C C	B N	O U	L L	U J	B B	- N	O U	O O	- -	U U	U U	B B	H H	Q U	O O	P P
30	C C	B B	- B	I L	U J	B B	N N	- A	C C	A A	B A	A A	B B	K H	U N	- O	S P
31	B B	C A	- A	I I	M H	A A	N A	A A	B A	A O	A A	A N	O A	H H	N A	U A	N A
32	B B	U A	- A	I I	H H	A A	B B	N N	C C	N O	B B	N A	O C	H H	Q N	D D	S S
33	B B	A A	- A	I I	U H	A A	N B	A A	A A	A A	A B	A A	B B	J H	N A	D A	S A
34	U B	N B	U A	L I	M H	B A	N A	N A	N A	- A	O A	- O	B A	H H	U A	O U	S S
35	A A	A A	A A	H H	H H	A A	- A	N N	A A	N P	A A	N N	A A	H H	A A	A A	A A
36	C B	B A	A A	I I	J J	A B	N B	O O	C C	P P	A B	A O	B B	J J	R R	D N	R R
37	B B	B A	U A	I J	U K	A A	B B	C A	C C	A A	B B	N A	B A	J J	U Q	O O	S P
38	C A	C B	- A	I I	L H	B A	N A	O A	B A	A A	C A	A A	A A	J H	R A	C A	S S
39	A C	P P	A B	I I	J M	A B	B U	O A	A C	N N	O N	- -	O C	J H	Q N	O D	S S
40	C B	B A	B B	L I	U H	B A	N B	A N	C A	A A	B A	N A	B B	H H	S A	C A	R A
41	C B	U Q	- A	I I	J U	B A	B N	A B	A Q	N -	C C	A N	B B	H H	P A	O A	S S
42	C B	B A	- Q	I I	J H	B A	N Q	B A	C B	N N	B O	O N	B O	H H	N S	O N	S S
43	C -	A -	- -	I -	U -	A -	N -	- -	A -	A -	C -	N -	C -	J -	S -	- -	N -
44	O B	N B	P U	L I	J H	U A	U N	- -	C A	A A	B C	N A	C B	K I	U U	- -	P S
45	C C	O O	U B	L L	K J	B B	B N	N N	C C	A A	C B	A A	B B	H H	Q R	O U	U P
46	C A	U U	- B	U I	J K	A B	P B	U A	O P	- -	B C	N A	B N	J H	P P	O O	S S
47	C C	U O	B B	L L	J J	B B	B B	A C	C C	A A	B C	A A	B B	H H	Q P	O B	P U
48	C C	B N	N B	L J	U J	B B	N U	O U	O O	- -	U N	N O	B B	J J	T R	U N	R P
49	U U	N U	O B	L L	J U	U B	B -	- -	D C	A A	N C	- A	B C	K U	U U	- -	P P
50	N B	U P	U B	L I	U M	B B	B B	O O	O D	- N	N C	- A	B N	H J	U N	O U	N N
51	C C	B B	B B	I J	U U	B B	N U	A U	U C	N A	C B	N U	B B	J H	N U	O D	U P
52	U U	U U	U B	L L	U J	N B	- B	- -	Q Q	N -	B B	N N	B B	K K	U U	- -	O S
53	C B	U U	B B	L I	U U	B B	B B	O A	C C	N A	B B	A A	B B	J H	T U	B D	P P
54	C B	O O	- B	I I	U H	A A	U N	A A	P O	- -	B C	O A	B B	J J	R A	N A	S A
55	C C	Q U	U B	L J	U U	B B	N -	C O	N C	A A	B B	A A	N B	J H	P P	O P	S P
56	C C	N U	B B	L L	J J	B U	B N	C A	C C	A N	B C	A A	B B	H H	P N	O D	S S
57	C B	B U	- B	L I	U K	B B	O U	N P	C C	N A	O B	- A	B B	J H	T P	O D	S P
58	U C	B C	- B	L J	U J	B B	B N	O O	D C	N N	B B	A N	U C	H H	Q N	U B	S R
59	C C	U U	- O	L L	U K	B U	O -	P U	C C	N N	C B	N N	C U	J J	P P	U O	P P
60	C C	N B	B B	L I	U J	U B	- N	- A	C C	A N	B U	A N	B B	I H	U R	- N	S S
61	B	A	A	I	H	A	B	P	A	N	B	N	B	H	R	O	R
62	B	A	A	H	H	A	B	A	A	A	A	A	A	H	A	A	A
63	C	O	A	I	I	A	B	A	A	A	A	A	A	H	U	D	S
64	C	A	-	H	H	A	N	U	A	A	B	N	B	H	A	O	A
65	B	A	B	H	H	A	A	U	A	A	B	U	B	H	A	A	A
66	B	C	A	I	H	A	B	A	A	A	B	A	B	H	A	A	N
67	B	U	A	K	U	U	-	A	A	A	B	A	B	J	U	O	P
68	B	A	A	I	H	A	A	N	A	A	A	A	A	H	A	-	A
69	B	P	-	I	I	A	B	O	C	P	A	N	B	J	R	D	N
70	A	B	B	I	H	A	B	O	A	A	A	N	O	H	N	D	S
71	A	A	A	I	H	A	B	A	A	A	B	A	B	H	S	N	S
72	C	U	Q	I	H	A	U	A	U	N	B	N	O	H	A	A	N
73	A	O	A	I	H	A	B	A	A	N	A	A	B	H	A	A	A
74	B	C	A	I	H	A	N	O	A	A	B	U	B	H	R	C	S
75	B	C	A	J	J	A	-	O	A	A	B	A	B	J	U	O	S
76	B	U	P	K	J	A	B	A	P	-	A	O	A	J	N	O	S
77	A	A	A	I	H	A	B	N	A	A	B	N	B	H	N	U	S
78	C	C	-	L	L	B	N	A	C	A	O	-	C	J	T	O	S
79	B	A	A	I	J	A	-	-	A	O	A	N	B	L	T	D	R
80	C	N	B	U	U	B	N	A	C	N	B	A	B	J	T	U	S
81	A	A	A	I	H	A	-	C	A	N	B	O	A	J	A	A	A
82	C	U	U	L	U	U	-	-	D	N	C	A	B	I	U	-	-
83	B	B	B	J	U	U	-	C	O	-	N	-	A	U	U	O	P
84	U	N	U	U	U	B	N	-	N	N	C	N	C	K	U	-	U

APPENDIX 8

NOTES ON INTERPRETATION OF CATEGORY SETS

The questions below are arranged in the same order as they appeared in Chapters 4, 5 and 6.

Q1 BOARDS AND WEIGHTS

(a) Inconsistent responses to the two parts of the question

In these few cases, if a pupil gave a category A or B response for either part, the pupil was categorized thus. But if a pupil gave a category C response for one part and an alternative response to the other, the pupil was categorized in the appropriate alternative response.

(b) Category C

The position of category C on the ordinal scale needs justification. The apparatus was presented to the pupils as being of different weights and sizes of boards, so the two variables were pointed out. But pupils had to make two choices, and I think it can be argued that correct choices together with a reiteration of the importance of the two variables represents some intuitive understanding of the nature of pressure.

(c) Distinction between categories B and C

Responses must contain some suggestion of spread/distribution (i.e. some idea of the relationship between force and area) to merit a B categorization.

Q2 SKIS

(a) Category B Responses contained some idea of spread/distribution/concentration - i.e. some idea of the relationship between weight and area.

(b) Category P Responses emphasised various properties of skis.

(c) Category Q Respondents seem to accept that skis have 'magical properties.'

Q3 SKIS - QUANTITATIVE

No interpretative notes.

Q4 FURNITURE

(a) Category P Responses were described as 'Mathematical juggling' because the pupils began by doing just that - juggling numbers - and not with the expressed idea that, for example, pressure = area/weight, or pressure = area x weight.

Q5 DEFINITION OF PRESSURE

No interpretative notes.

APPENDIX 8 (cont)

Q6 TYRES

(a)Category A To fit into this category pupils had to say something about the force on the tyre wall, but it did not have to be phrased formally as 'molecular bombardment'.

(b)Category B Pupils in category B knew that there was some connection between increased molecular speed and increased pressure, but did not know exactly what it was.

(c)Category N The idea of expansion is essential to category N.

(d)Category O Respondents emphasised that wheel movement/rotation caused an increase in pressure.

Q20 FOOTBALL - MOLECULAR NUMBER

No interpretative notes

Q21 FOOTBALL - MOLECULAR SPEED

No interpretative notes

Q7 FOOTBALL - PRESSURE

No interpretative notes

Q8 PRESSURE ON FRED AND GOLDIE

(a)Just occasionally it was necessary to use information gleaned from Q11 as well. For example, pupil 37 was categorized N rather than O because, in answer to Q11 she specifically mentions the pressure of air on the water surface, though her response to Q8 could have been either.

Q9 FISH TANKS

No interpretative notes

Q10 SUBMARINE AT 50m

No interpretative notes

Q11 FRED'S BACK AND NOSE

(a)Category A This in fact includes responses that are more sophisticated than the descriptor - i.e. that the pressure on Fred's nose is slightly greater than the pressure on his back because it is a little deeper.

Q12 SUBMARINE - HATCH

(a)Category A As with Q11 above, this category contains the more sophisticated response - that pressure on the hatch would be slightly more because it is slightly deeper down.

APPENDIX 8 (cont)

Q13 ONE ATMOSPHERE

(a)Category N Most pupils in this category specified that one atmosphere would be 1/12 way down from the surface to the sea-bed.

Q14 STRAW - OPEN TOP

(a)Categories A and B The essential difference between these two is that category A responses contained some understanding of the importance of the pressure difference, whereas B responses contained an idea of air pressure in the bottle.

(b)Category C Category C responses contained the notion that air in the bottle is somehow responsible for the orange going up the straw, but there was no description of the air pressing on the surface of the orange.

Q15 PRESSURE IN STRAW

(a)Pupils occasionally offered the information that there was a pressure change in the straw in response to Q14 - in which case they were categorized on that.

(b)Category U Category U includes responses where the question was misunderstood, and they referred to direction of pressure e.g. 'upwards'.

Q16 STRAW - CLOSED

(a)There were many changes of mind after the practical demonstration. Many pupils gave the initial response that the straw would not reach the orange, but then changed their response after the demonstration. In all cases of convinced changes of mind the last response was categorized.

(b)Categories B & C The distinction between B and C was not always easy to sustain. The essence of category B is that non-entry of air into the bottle is important because of the reduction of pressure of air in the bottle. The difficulty was that this was sometimes implied and not stated explicitly.

Q17 SYRINGE - WHAT'S INSIDE

(a)Again, there were many changes of mind recorded - both after the in-rush of water and, on reflection, after answering Q18.

(b)Responses to Q17 were not inferred from answers to Q18, although of course, sometimes the responses to the two parts of the syringe question did not match.

Q18 SYRINGE

(a)Use of the word 'sucks' was not automatically taken as an indication of a category P response. It is very difficult to describe what is happening in this question and there were several examples of pupils saying that the water is going to 'suck up' into the space and then giving a category A response - i.e. indicate by what they subsequently said that they did not really think that any active sucking was taking place.

APPENDIX 8 (cont)

Q18 (cont)

(b)Category C This contains the simple notion of water going in to fill the space. It differs from category N which contains the idea of air rushing out when the finger is removed from the end of the syringe, and then the water going in.

(c)Category O Incorporates the idea of pressure as an active agent.

Q19 WASHING UP

(a)Category O Pupils were categorized O if this was the only explanation they offered. Pupils sometimes added the idea of a soapy seal to another explanation - e.g. to a category N response - in these cases they would be categorized N.

Q22 KETTLE AND BATH -COST

Q23 KETTLE AND BATH

Categories A, B, C, U, N, O and P are the same for these two questions.

(a)Category A Differences in both volume and temperature had to be mentioned for this categorization, but figures were not always put on it, and the comparison of temperatures was sometimes implied rather than explicitly stated.

(c)Category O These responses contain the idea that the directness of the electricity is important, though this, again, was sometimes implied and not made very explicit.

Q24 MIXING LIQUIDS I

Q25 MIXING LIQUIDS II

Q26 MIXING LIQUIDS III

Q27 MIXING LIQUIDS IV

(a)In all these questions it was important to look not just at the final answer, but to probe the thinking behind it. So, for example, an answer of 60°C for Q25 was not automatically categorized N - it was essential to know how the answer was arrived at.

Q29 HEAT AND TEMPERATURE

No interpretative notes

Q30 DEFINITION OF HEAT

(a)Category J The essence of this category is that something heating up is used to describe what heat is. Heat and "hot air" were frequently equated.

(b)Category K Responses emphasised that heat is given off from something.

(c)Category L Responses here were phrased in an egocentric way.

APPENDIX 8 (cont)

Q31 POTATOES - WATER TEMPERATURE

No interpretative notes

Q32 POTATOES - COOKING TIME

(a)Distinction between categories A & N Because pupils sometimes use the words "heat" and "temperature" synonymously categorization of responses such as "It depends on the amount of heat you've got" (pupil 22) is problematic. In this case it was possible to categorize this pupil as N by referring to her response to Q31. However, the very similar response by pupil 23 "How much heat there is" had to be coded uncodeable (category U) since this pupil's other answers across the POTATOES questions were inconsistent, and gave no clue.

(b)Category O This contains all the responses which mentioned only the size or variety of potato, the volume of water, etc.

Q33 POTATOES

No interpretative notes

Q34 SPOONS

(a)Use of the word "conduction" per se was an insufficient indicator. For example, four pupils who went on to describe conduction satisfactorily used the wrong word initially in the first round of interviews (three used 'convection' and one 'contraction'). Conversely, some pupils used the correct word but went on to indicate that they did not understand its meaning - e.g. "Because all particles of heat travel up metal, because it conducts it." (pupil 48).

(b)Category B Responses contained some idea of heat moving through metal. Most pupils used the words "conduct" or "travel". The word "rise" on its own was not adequate since one pupil thought that heat would only travel in an upwards direction.

(c)Category P Responses contained the idea of an active force.

Q35 PLATES - THERMOMETER READINGS

No interpretative notes

Q36 PLATES

(a)Some cross-referencing with Q35 was necessary in categorization of this question.

(b)Category N Responses imply that the pupil thinks the metal actually is colder, but this is not advanced as the main explanation.

(c)Category O The essence is the existence of 'cold' as an entity, and/or that metal attracts the cold.

(d)Category P Responses offer either an observable property of metal as the main explanation or, simply, the fact that metals are cold substances.

APPENDIX 8 (cont)

Q37 HANDLEBARS

(a)Categories A, U, N, O and P are the same as for Q36 PLATES, and the notes on categories N, O and P above apply here as well.

Q38 ADULTS AND YOUNG

No interpretative notes

Q39 ANIMAL VARIATION

No interpretative notes

Q40 PLANT VARIATION

No interpretative notes

Q41 DOGS' MARKINGS

(a) Category A The essence of category A is that the gene combination is different.

(b)Category B 'Genetic entity' in this category can be variously described - genes, hormones, etc. A general decision was made that the correct word was not essential - sometimes pupils clearly could not think of the correct word, and yet they adequately describe particulate genetic information. In the examples given on the category sheet, pupil 31 uses the word 'hormones'. but goes on to describe them as genetic entities. The converse of the argument - that correct words can be used without understanding - is particularly pertinent to the area of inheritance. There is evidence from the interviews that the word 'gene' is bandied about without the least understanding. So, it was decided that use of the correct word without elaboration would not qualify a response as an ordinal response, and that use of an incorrect word would not automatically disqualify a response from the ordinal scale.

Q42 TWINS

(a)Category B Responses gave no indication why a split fertilized egg made the twins look identical.

Q43 SIBLINGS

(a)Some cross-referencing with Q42 was necessary in categorization of this question. Some pupils answered the questions 'Why do the siblings look similar', but others seemed to be answering the question 'Why do siblings, unlike the twins, look non-identical'? An attempt was made to combine the responses to these in one category set, but some of the category descriptors look rather strange. For example, in category B 'Have same parents' is an explanation of why the siblings look similar, whereas 'From two different eggs' is an explanation of why they are not identical like the twins.

APPENDIX 8 (cont)

Q44 GENETIC MATERIAL

This category set is a synthesis from responses to all the questions on variation and genetics on the schedule. Since pupils addressed themselves to different aspects of genetic material, scaling was impossible, and a single descriptive scale was more appropriate.

(a)Category H The essence of this is that the genetic information is translated by the cell.

(b)Category I Responses here relate genetic entity (which can be variously described - see notes on Q41) to features. A particulate genetic entity must be indicated. So "likeness passed on at fertilization" would not merit Cat. I on its own because likenesses were sometimes used just to mean 'brown hair/blue eyes' etc. On the other hand, "something in the egg" would be enough to merit this categorization.

Q45 TAILLESS MOUSE

(a)Categories are arranged on a single scale, because there could, in fact, have been several valid explanations for the sudden appearance of a tailless mouse. As with other questions 'genetic entity' (Cat. H) is generously interpreted (see notes on Q41).

Q46 MICE - MIXED LITTER

No interpretative notes

Q47 MICE - PARENTAL CONTRIBUTION

(a)Categories O & P Sometimes, in discussing the mating between the tailed and tailless mouse, pupils made an arbitrary designation of one as the mother and one as the father (they are not told which is which in the question and they seemed to feel that it is easier to talk about if they decide which is the mother and which is the father). Pupils had to do more than make this arbitrary designation to be assigned to Cats. O and P. Pupils in Cat. O gave the overall impression in Q47 that they considered the mother's contribution to be much more important than the father's, whereas pupils in Cat. P considered the father's to be more important than the mother's.

Q48 CATERPILLARS - PREDATORS

(a)The sample for this question excludes those pupils who did not mention camouflage in response to the initial question on CATERPILLARS (Q54). Although the question specifically asked what the children would find the next week, some pupils insisted on giving only a long-term prognosis. These responses were put into 'Uncodeable' (Cat.U).

(b)Category O Respondents in this category may say either that the caterpillars would stay on the same tree or that they would move anywhere. The essence is that the caterpillars are thinking things out and controlling their own destiny!

APPENDIX 8 (cont)

Q49 MICE - CHOPPED OFF TAILS

(a)It was sometimes necessary to refer back to responses to Qs 45 and 46 for this categorization.

(b)Category A Responses in this category contained the idea of particulate genetic material, but, again, the wrong words may be used (see notes to Q41). Responses must correctly describe either the nature/location of genes or make some correct reference to timing - i.e. at fertilization.

(c)Category B Responses here contain vaguer references to 'something' in the mouse's body, with no clear indication of what or where it is.

Q50 MICE - CHOPPING OVER TIME

The sample for this set obviously excludes those pupils who suggested that the first chopping (Q49) would result in tailless offspring.

(a)Category A Three pupils who said that you may get the odd tailless mouse due to chance/mutations/recessive genes were included here.

(b)Category N Some of the responses in this category were very tentatively phrased - pupils merely considered the possibility that some tailless mice may appear over time. I decided that it was interesting to include all pupils who had seriously considered the possibility that the experiment may work over time in this category. Most responses were hedged around with numerous 'probablys'.

Q51 ATHLETES

(a)Occasionally, cross-referencing with Q52 was necessary. For example, some pupils offered no explanation to Q51, but then incorporated one in their response to Q52. These cases were appropriately categorized here.

(b)Category B These responses included a wide variety of low-level reasons for thinking that the effects of training would not be passed on to the children.

Q52 ATHLETES OVER TIME

The sample for this question obviously excludes those pupils who said that the training would work with the first generation of offspring.

Q53 GARDENERS' CHILDREN

No interpretative notes

Q54 CATERPILLARS

(a)Categories H & J The distinction between these categories represents an attempt to separate anthropomorphic responses (Cat.J) from other descriptions of camouflage (Cat.H).

APPENDIX 8 (cont)

Q55 CATERPILLARS - ORIGIN

(a)Category A Responses must include mention of both selection and variation.

Q56 CATERPILLARS - PALE TREES

The sample for this set excludes those pupils who did not mention camouflage in answer to Q54.

(a)Scaling categories was problematic. Category C must be counted as a theoretical possibility.

Q57 ARCTIC FOX

(a)Category A Responses must include mention of both selection and variation.

APPENDIX 9. RESULTS OF ANALYSIS OF INDIVIDUAL PUPIL FRAMEWORKS (a) ACROSS QUESTION CONTEXTS (b) OVER TIME

NATURE OF PRESSURE

The following frameworks provide the basis for the analysis:

'Ordinal'

1) Pressure = force acting on a unit area

2) Pressure involves distribution of force over area

'Alternative'

3) Pressure involves only one variable - either weight or area.

'Non-identifiable' (N.I.F.)

4) Context-dependent reasoning applied.

5) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to BOARDS AND WEIGHTS (Q.1.) and SKIS (Q.2.). Not all 16 year old pupils answered SKIS, so this age group is excluded from the matrix.

Second question (Q.2.) SKIS	First question (Q.1.) BOARDS AND WEIGHTS			
	ORDINAL (Frameworks 1 & 2)	ALTERNATIVE (Framework 3)	N.I.F. (Frameworks 4 & (5))	TOTALS
ORDINAL (Frameworks 1 and 2)	*18 (30%)* 5 (17%) 13 (43%)	*0* 0 0	*11 (18%)* 6 (20%) 5 (17%)	29
ALTERNATIVE (Framework 3)	*0* 0 0	*2 (3%)* 2 (7%) 0	*11 (18%)* 6 (20%) 5 (17%)	13
N.I.F. (Frameworks 4 and(5))	*1 (2%)* 0 1 (3%)	*5 (8%)* 5 (17%) 0	*12 (20%)* 6 (20%) 6 (20%)	18
TOTALS	19	7	34	60

Total n = 60. In each cell figures are given in italics for the first-round sample and then, turn left to right, the figures for 12 year olds (n = 30) and 14 year olds (n = 30).

(b) Over time

Developmental results for the same two key questions (Q.1. BOARDS AND WEIGHTS and Q.2 SKIS) are presented below. For the purpose of this analysis the ordinal frameworks are separated into

Framework 1 - correct
Framework 2 - partially correct

Comparison of Individual Responses over time to BOARDS AND WEIGHTS (Q.1) and SKIS (Q.2)

	SAME CORRECT FRAMEWORK		SAME PARTIALLY-CORRECT FRAMEWORK		PARTIALLY-CORRECT → CORRECT		CORRECT → PARTIALLY-CORRECT		ALTERNATIVE/ N.I.F. → CORRECT/ PARTIALLY-CORRECT		CORRECT/ PARTIALLY-CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN ALTERNATIVE AND N.I.F.		BOTH 'NON IDENTIFIABLE'	
	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2
X12 to Y14 n=29	0	3%(1)	7%(2)	17%(5)	3%(1)	3%(1)	3%(1)	3%(1)	21%(6)	14%(4)	3%(1)	3%(1)	0	17%(5)	21%(6)	28%(8)	41%(12)	10%(3)
Y14 to Y16 n=29	0	0	31%(9)	52%(15)	10%(3)	3%(1)	0	3%(1)	14%(4)	10%(3)	7%(2)	0	0	3%(1)	0	14%(4)	38%(11)	14%(4)

APPENDIX 9 (contd.)

MOLECULAR BOMBARDMENT

The following frameworks provide the basis for the analyses:

'Ordinal'

1) Pressure as molecular bombardment

2) Relationship between temperature and molecular speed recognized, but no link made with pressure.

'Alternative'

3) Variations on incorrect use of kinetic theory.

'Non-identifiable' (N.I.F.)

4) No use of kinetic theory made in application to pressure.

5) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to TYRES (Q.6.) and FOOTBALL (Q.7.); both these questions tested the link between temperature change in a gas and change in pressure. Twelve-year old pupils were not asked questions about molecules.

Second question (Q.7.) FOOTBALL	First question (Q.6.) TYRES			
	ORDINAL (Frameworks 1 & 2)	ALTERNATIVE (Framework 3)	N.I.F. (Frameworks 4 & (5))	TOTALS
ORDINAL (Frameworks 1 and 2)	*15 (28%)* 5 (17%) 10 (42%)	*2 (4%)* 1 (3%) 1 (4%)	*1 (2%)* 0 1 (4%)	18
ALTERNATIVE (Framework 3)	*2 (4%)* 2 (7%) 0	*4 (7%)* 3 (10%) 1 (4%)	*1 (2%)* 1 (3%) 0	7
N.I.F. (Frameworks 4 and (5))	*0* 0 0	*16 (30%)* 10 (33%) 6 (25%)	*13 (24%)* 8 (27%) 5 (21%)	29
TOTALS	17	22	15	54

Total n = 54. In each cell figures are given in italics for the first-round sample and then, from left to right, the figures for 14 year olds (n = 30) and 16 year olds (n = 24).

(b) Over time

Developmental results for the same two key questions (Q.6. TYRES and Q.7. FOOTBALL) are presented below. For this analysis the ordinal frameworks are separated into

Framework 1 - correct

Framework 2 - partially correct.

Comparison of Individual Responses over time to TYRES(Q.6.) and FOOTBALL (Q.7.)

	SAME CORRECT FRAMEWORK		SAME PARTIALLY-CORRECT FRAMEWORK		PARTIALLY-CORRECT → CORRECT		CORRECT → PARTIALLY-CORRECT		ALTERNATIVE/ N.I.F. → CORRECT/ PARTIALLY CORRECT		CORRECT/ PARTIALLY-CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN ALTERNATIVE AND N.I.F.		BOTH 'NON-IDENTIFIABLE'	
	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7	Q.6	Q.7
Y14 to Y16 n=29	10%(3)	10%(3)	3%(1)	3%(1)	7%(2)	3%(1)	3%(1)	3%(1)	21%(6)	21%(6)	0	0	17%(5)	0	17%(5)	24%(7)	21%(6)	34%(10)

APPENDIX 9 (contd.)

PRESSURE AND DEPTH

The following frameworks provide the basis for the analyses:

'Ordinal'

1) Pressure increases with depth

'Alternative'

2) Pressure in a liquid depends on the pressure of the atmosphere.

3) Pressure decreases with depth

'Non-identifiable' (N.I.F.)

4) No identifiable framework.

The matrix below gives the results of comparison between pupil responses to PRESSURE ON FRED AND GOLDIE (Q.8.) and SUBMARINE AT 50m (Q.10).

a) Across Question Contexts.

Second question (Q.10) SUBMARINE AT 50m	First question (Q.8.) PRESSURE ON FRED AND GOLDIE			
	ORDINAL (Framework 1)	ALTERNATIVE (Frameworks 2 and 3)	N.I.F. (Framework (4))	TOTALS
ORDINAL (Framework 1)	*58(69%)* 16(53%) 21(70%) 21(88%)	*9(11%)* 3(10%) 5(17%) 1(4%)	*2(2%)* 1(3%) 1(3%) 0	69
ALTERNATIVE (Frameworks 2 and 3)	*1(1%)* 0 1(3%) 0	*6(7%)* 4(13%) 1(3%) 1(4%)	*2(2%)* 1(3%) 1(3%) 0	9
N.I.F. (Framework (4))	*2(2%)* 2(7%) 0 0	*2(2%)* 1(3%) 0 1(4%)	*2(2%)* 2(7%) 0 0	6
TOTALS	61	17	6	84

Total n = 84. In each cell figures are given in italics for the first-round sample and then, from left to right the figures for 12 year olds (n = 30), 14 year olds (n = 30) and 16 year olds (n = 24).

(b) Over time

Developmental results for the same two key questions (Q.8 PRESSURE ON FRED AND GOLDIE and Q.10 SUBMARINE at 50m) are presented below.

Comparison of Individual Responses over time to FISH (Q.8.) and SUBMARINE (Q.10)

	SAME CORRECT FRAMEWORK		ALTERNATIVE/ N.I.F. → CORRECT		CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN Frs. 2,3, and (4)		BOTH 'NON-IDENTIFIABLE'	
.	Q.8	Q.10	Q.8	Q.10	Q.8	Q.10	Q.8	Q.10	Q.8	Q.10	Q.8	Q.10
X12 to X14 n=29	48%*(14)*	55%*(16)*	7%*(2)*	14%*(4)*	14%*(4)*	14%*(4)*	10%*(3)*	7% *(2)*	10%*(3)*	7%*(2)*	10%*(3)*	3%*(1)*
Y14 to Y16 n=29	62%*(18)*	76%*(22)*	17%*(5)*	7%*(2)*	10%*(3)*	14%*(4)*	0	0	10%*(3)*	3%*(1)*	0	0

APPENDIX 9 (Contd.)

PRESSURE AND DIRECTION

The following frameworks provide the basis for the analyses:

'Ordinal'

1) Pressure acts equally in all directions.

'Alternative'

2) Pressure downwards is greater than pressure across.

3) Pressure in different directions depends on distance to containing surface.

'Non-identifiable' (N.I.F.)

4) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to FRED'S BACK AND NOSE (Q.11.) and SUBMARINE-HATCH (Q.12.).

Second question (Q.12.) SUBMARINE-HATCH	First question (Q.11.) FRED'S BACK AND NOSE			
	ORDINAL	ALTERNATIVE	N.I.F.	TOTALS
ORDINAL	*9(11%)* 3(10%)3(10%)3(13%)	*2(2%)* 0 1(3%)1(4%)	*5(6%)* 1(3%)1(3%)3(13%)	16
ALTERNATIVE	*0* 0 0 0	*30(36%)* 15(50%)11(37%)4(17%)	*11(13%)* 5(17%)5(17%)1(4%)	41
N.I.F.	*6(7%)* 1(3%)2(7%)3(13%)	*9(11%)* 2(7%)4(13%)3(13%)	*11(13%)* 3(10%)3(10%)5(22%)	26
TOTALS	15	41	27	83

Total n = 83. In each cell figures are given in italics for the first-round sample and then, from left to right, the figures for 12 year olds (n = 30), 14 year olds (n = 30), and 16 year olds (n = 23).

(b) <u>Over time</u>

Developmental results for the same two key questions (Q.11 FRED'S BACK AND NOSE and Q.12 SUBMARINE - HATCH) are presented below.

Comparison of Individual Responses over time to FRED (Q.11.) and SUBMARINE (Q.12)

	SAME CORRECT FRAMEWORK		ALTERNATIVE/ N.I.F. ⟶ CORRECT		CORRECT ⟶ ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN FRS. 2,3, and (4)		BOTH 'NON-IDENTIFIABLE'	
	Q.11	Q.12	Q.11	Q.12	Q.11	Q.12	Q.11	Q.12	Q.11	Q.12	Q.11	Q.12
X12 to X14 n=29	7%*(2)*	10%*(3)*	7%*(2)*	10%*(3)*	7%*(2)*	3%*(1)*	34%*(10)*	31%*(9)*	31%*(9)*	38%*(11)*	14%*(4)*	7%*(2)*
Y14 to Y16 n=29	14%*(4)*	10%*(3)*	21%*(6)*	28%*(8)*	3%*(1)*	7%*(2)*	10%*(3)*	10%*(3)*	45%*(13)*	31%*(9)*	7%*(2)*	14%*(4)*

APPENDIX 9 (contd.)

ATMOSPHERIC PRESSURE

The following frameworks provide the basis for the analyses:

'Ordinal'

1) The atmosphere exerts a pressure which is observable only when there is a pressure difference.

2) The atmosphere exerts a pressure on surfaces.

'Alternative'

3) Vacuums suck or exert pressure

4) Pressure is an active agent

5) Spaces must be filled.

'Non-identifiable' (N.I.F.)

6) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to STRAW-OPEN TOP (Q.14.) and SYRINGE (Q.18.)

Second question (Q.18.) SYRINGE	First question (Q.14.) STRAW			
	ORDINAL (Frameworks 1 & 2)	ALTERNATIVE (Frameworks 3, 4, 5)	N.I.F. (Framework (6))	TOTALS
ORDINAL (Frameworks 1 and 2)	*16(19%)* 6(20%) 3(10%) 7(29%)	*0* 0 0 0	*1(1%)* 1(3%) 0 0	17
ALTERNATIVE (Frameworks 3, 4, 5)	*13(16%)* 5(17%) 3(10%) 5(21%)	*4(5%)* 0 2(7%) 2(8%)	*26(31%)* 10(33%) 11(38%) 5(21%)	43
N.I.F. (Framework (6))	*5(6%)* 2(7%) 2(7%) 1(4%)	*0* 0 0 0	*18(22%)* 6(20%) 8(28%) 4(14%)	23
TOTALS	34	4	45	83

Total n = 83. In each cell figures are given in italics for the first-round sample and then, from left to right, the figures for 12 year olds (n = 30), 14 year olds (n = 29) and 16 year olds (n = 24).

(b) Over time

Developmental results for the same two key questions (Q.14 STRAW - OPEN TOP and Q.18 SYRINGE) are presented below. For this analysis the ordinal frameworks are separated into

Framework 1 - correct
Framework 2 - partially correct

Comparison of Individual Responses over time to STRAW (Q.14) and SYRINGE (Q.18.)

	SAME CORRECT FRAMEWORK		SAME PARTIALLY-CORRECT FRAMEWORK		PARTIALLY-CORRECT → CORRECT		CORRECT → PARTIALLY-CORRECT		ALTERNATIVE/ N.I.F. → CORRECT/ PARTIALLY-CORRECT		CORRECT/ PARTIALLY-CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN FRS. 3,4,5 and (6)		BOTH 'NON-IDENTIFIABLE'	
	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18	Q.14	Q.18
X12 to X14 n=29	3%(1)	7%(2)	21%(6)	3%(1)	0	0	7%(2)	7%(2)	17%(5)	7%(2)	14%(4)	7%(2)	0	21%(6)	10%(3)	28%(8)	28%(8)	21%(6)
Y14 to Y16 Q14=29 Q18=28	7%(2)	11%(3)	7%(2)	0	7%(2)	0	0	0	17%(5)	11%(3)	10%(3)	0	0	18%(5)	7%(2)	43%(12)	45%(13)	18%(5)

APPENDIX 9 (contd.)

CONDUCTION OF HEAT

The following frameworks provide the basis for the analysis:

'Ordinal'

1) Different substances feel to be different because heat travels through them at different rates.

'Alternative'

2) Metal attracts/absorbs/conducts coldness.

3) Conductivities of different materials depend on some observable property.

4) Metals let heat in and out more easily.

5) Good conductors get hot on the periphery only, not all through.

'Non-identifiable' (N.I.F.)

6) No identifiable framework

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to PLATES (Q.36.) and HANDLEBARS (Q.37.).

Second question (Q.37.) HANDLEBARS	First question (Q.36.) PLATES			
	ORDINAL (Framework 1)	ALTERNATIVE (Frameworks 2, 3, 4, 5)	N.I.F. (Framework (6))	TOTALS
ORDINAL (Framework 1)	*4(5%)* 0 0 4(17%)	*1(1%)* 0 0 1(4%)	*0* 0 0 0	5
ALTERNATIVE (Frameworks 2, 3, 4, 5)	*1(1%)* 1(3%) 0 0	*25(30%)* 9(30%)10(33%)6(25%)	*19(23%)* 6(20%)8(27%)5(21%)	45
N.I.F. (Framework (6))	*0* 0 0 0	*16(19%)* 9(30%)5(17%)2(8%)	*18(21%)* 5(17%)7(23%)6(25%)	34
TOTALS	5	42	37	84

Total n = 84. In each cell figures are given in italics for the first-round sample and then, from left to right, the figures for 12 year olds (n = 30), 14 year olds (n = 30), and 16 year olds (n = 24).

CONDUCTION OF HEAT - ALTERNATIVE FRAMEWORKS

The above analysis indicates that 25 pupils advanced alternative explanations in response to both questions. The matrix below gives the detailed distribution of the responses of these pupils within the alternative framework group (Frameworks 2, 3, 4, & 5).

HANDLEBARS (Q.37)	PLATES (Q.36) Fr.2	Fr.3	Fr.4	Fr.5	TOTALS
Fr.2	2	4	3	0	*9*
Fr.3	1	5	1	0	*7*
Fr.4	0	0	9	0	*9*
Fr.5	0	0	0	0	*0*
TOTALS	*3*	*9*	*13*	*0*	*25*

(b) Over time

Developmental results for the same two key questions (Q.36 PLATES and Q.37 HANDLEBARS) are presented below.

Comparison of Individual Responses over time to PLATES (Q.36) and HANDLEBARS (Q.37)

	SAME CORRECT FRAMEWORK		ALTERNATIVE/ N.I.F. ⟶ CORRECT		CORRECT ⟶ ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN FRS. 2,3, 4,5,(6)		BOTH 'NON IDENTIFIABLE'	
	Q.36	Q.37	Q.36	Q.37	Q.36	Q.37	Q.36	Q.37	Q.36	Q.37	Q.36	Q.37
X12 to X14 n=29	3%*(1)*	0	0	0	0	0	17%*(5)*	7%*(2)*	62%*(18)*	76%*(22)*	17%*(5)*	17%*(5)*
Y14 to Y16 n=29	0	0	21%*(6)*	17%*(5)*	0	0	14%*(4)*	24%*(7)*	41%*(12)*	41%*(12)*	24%*(7)*	17%*(5)*

APPENDIX 9 (contd.)

ACQUIRED CHARACTERISTICS

The identification of frameworks for this Idea was described in Chapter 6. This set of frameworks was split for the present purposes to allow separate analysis of two issues.

(i) the possibility of the inheritance of acquired characteristics.
(ii) the possibility of the inheritance over time of acquired characteristics.

(i) The following frameworks provide the basis for the analyses of the first issue:

'Ordinal'

1) Acquired characteristics are not inherited because there is no genetic change.

2) Acquired characteristics are not inherited because it is 'unnatural'.

'Alternative'

3) Acquired characteristics are inherited because phenotypic change affects the genes.

4) Acquired characteristics are inherited by the first generation of offspring.

'Non-identifiable' (N.I.F.)

5) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to MICE - CHOPPED OFF TAILS (Q.49.) and ATHLETES (Q.51.).

Second question (Q.51.) ATHLETES	First question (Q.49.) CHOPPED OFF TAILS: ORDINAL (Frameworks 1 & 2)	ALTERNATIVE (Frameworks 3 & 4)	N.I.F. Framework (5))	TOTALS
ORDINAL (Frameworks 1 and 2)	*48(57%)* 17(57%)13(43%)18(75%)	*10(12%)* 5(17%)4(13%)1(4%)	*2(2%)* 0 1(3%)1(4%)	60
ALTERNATIVE (Frameworks 3 and 4)	*6(7%)* 3(10%)2(7%)1(4%)	*4(5%)* 1(3%)2(7%)1(4%)	*1(1%)* 0 1(3%)0	11
N.I.F. (Framework (5)	*7(8%)* 2(7%)5(17%)0	*4(5%)* 2(7%)1(3%)1(4%)	*2(2%)* 0 1(3%)1(4%)	13
TOTALS	61	18	5	84

Total n = 84. In each cell figures are given in italics for the first-round sample and then, from left to right, the figures for 12 year olds (n = 30), 14 year olds (n = 30) and 16 year olds (n = 24).

(b) Over time

Developmental results for the same two key questions MICE - CHOPPED OFF TAILS (Q.49) and ATHLETES (Q.51) are presented below. For this analysis the ordinal frameworks are separated into

Framework 1 - correct

Framework 2 - partially correct.

Comparison of Individual Responses to MICE (Q.49) and ATHLETES (Q.51)

	SAME CORRECT FRAMEWORK		SAME PARTIALLY-CORRECT FRAMEWORK		PARTIALLY-CORRECT → CORRECT		CORRECT → PARTIALLY-CORRECT		ALTERNATIVE/ N.I.F. → CORRECT/ PARTIALLY-CORRECT		CORRECT/ PARTIALLY-CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN FRS. 3,4,(5)		BOTH 'NON-IDENTIFIABLE'	
	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51	Q.49	Q.51
X12 to X14 n = 29	10%(3)	3%(1)	52%(15)	41%(12)	3%(1)	7%(2)	0	7%(2)	17%(5)	17%(5)	7%(2)	14%(4)	7%(2)	7%(2)	3%(1)	0	0	3%(1)
Y14 to Y16 n=29	7%(2)	7%(2)	38%(11)	21%(6)	14%(4)	3%(1)	3%(1)	7%(2)	17%(5)	21%(6)	3%(1)	24%(7)	7%(2)	3%(1)	10%(3)	10%(3)	0	3%(1)

APPENDIX 9 (contd.)

(ii) The following frameworks provide the basis for the analyses of the second issue of inheritance of acquired characteristics over time:

'Ordinal'

1) Acquired characteristics are not inherited, even over time.

'Alternative'

2) Acquired characteristics are not inherited immediately but they may be over several generations.

'Non-identifiable'(N.I.F.)

3) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to MICE - CHOPPING OVER TIME (Q.50.) and ATHLETES OVER TIME (Q.52.).

Second question (Q.52.) ATHLETES OVER TIME	First question (Q.50.) MICE - CHOPPING OVER TIME			
	ORDINAL (Framework 1)	ALTERNATIVE (Framework 2)	N.I.F. (Framework (3))	TOTALS
ORDINAL (Framework 1)	*21(33%)* 6(29%)8(38%)7(33%)	*10(16%)* 4(19%)4(19%)2(10%)	*1(2%)* 1(5%) 0 0	32
ALTERNATIVE (Framework 2)	*10(16%)* 2(10%)4(19%)4(19%)	*16(25%)* 6(29%)5(24%)5(24%)	*0* 0 0 0	26
N.I.F. (Framework (3))	*4(6%)* 2(10%)0 2(10%)	*1(2%)* 0 0 1(5%)	*0* 0 0 0	5
TOTALS	35	27	1	63

Total n = 63. In each cell figures are given in italics for pupils who were asked this question in the first round, and then, from left to right, the figures for 12 year olds (n = 21), 14 year olds (n = 21) and 16 year olds (n = 21).

(b) Over time

Developmental results for the same two key questions (Q.50 MICE - CHOPPING OFF OVER TIME and Q.52 ATHLETES OVER TIME) are presented below.

Comparison of Individual Responses over time to MICE (Q.50) and ATHLETES (Q.52)

	SAME CORRECT FRAMEWORK		ALTERNATIVE/ N.I.F. → CORRECT		CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN ALTERNATIVE AND N.I.F.		BOTH 'NON-IDENTIFIABLE'	
	Q.50	Q.52	Q.50	Q.52	Q.50	Q.52	Q.50	Q.52	Q.50	Q.52	Q.50	Q.52
X12 to X14 Q50n=23 Q52n=25	52%*(12)*	24%*(6)*	4%*(1)*	28%*(7)*	4%*(1)*	20%*(5)*	30%*(7)*	20%*(5)*	4%*(1)*	4%*(1)*	4%*(1)*	4%*(1)*
Y14 to Y16 Q50n=22 Q52n=24	41%*(9)*	29%*(7)*	14%*(3)*	25%*(6)*	14%*(3)*	21%*(5)*	32%*(7)*	13%*(3)*	0	13%*(3)*	0	0

APPENDIX 9 (contd.)

ADAPTATION

The following *frameworks* provide the basis for the analysis:

'Ordinal'

1) Biological adaptation results from natural selection operating on a population.

'Alternative'

2) Animals consciously effect physical change in response to a changed environment.

3) Animals adapt in response to a need for change.

4) Biological adaptation is a natural process.

5) Animals respond to a changed environment by seeking out a more favourable environment.

'Non-identifiable' (N.I.F.)

6) No identifiable framework.

a) Across Question Contexts

The matrix below gives the results of comparison between pupil responses to CATERPILLARS - ORIGIN (Q.55.) and ARCTIC FOX (Q.57.).

Second question (Q.57.) ARCTIC FOX	First question (Q.55.) CATERPILLARS - ORIGIN			
	ORDINAL (Framework 1)	ALTERNATIVE Frameworks 2, 3, 4, 5)	N.I.F. (Framework (6))	TOTALS
ORDINAL (Framework 1)	*8(10%)* 1(3%)1(3%)6(26%)	*0* 0 0 0	*0* 0 0 0	8
ALTERNATIVE (Frameworks 2, 3, 4, 5)	*3(4%)* 1(3%)0 2(9%)	*26(31%)* 12(40%)8(27%)6(26%)	*27(33%)* 7(23%)14(47%)6(26%)	56
N.I.F. (Framework (6))	*0* 0 0 0	*4(5%)* 1(3%)3(10%) 0	*15(18%)* 8(27%)4(13%)3(13%)	19
TOTALS	11	30	42	83

Total n = 83 In each cell figures are given in italics for the first-round sample and then, from left to right, the figures for 12 year olds (n = 30), 14 year olds (n = 30), and 16 year olds (n = 23).

ADAPTATION - ALTERNATIVE FRAMEWORKS

The above analysis indicates that 26 pupils advanced alternative explanations in response to both questions. The matrix below gives the detailed distribution of the responses of these pupils within the alternative framework group (Frameworks 2, 3, 4 and 5).

	CATERPILLARS (Q.55)				
FOX (Q.57)	Fr.2	Fr.3	Fr.4	Fr.5	TOTALS
Fr.2	3	0	0	3	*6*
Fr.3	5	0	8	5	*18*
Fr.4	0	0	1	0	*1*
Fr.5	0	0	0	1	*1*
TOTALS	*8*	*0*	*9*	*9*	*26*

(b) Over time

Developmental results for the same two key questions (Q.55 CATERPILLARS - ORIGIN and Q.57 ARCTIC FOX) are presented below.

Comparison of Individual Responses over time to CATERPILLARS (Q.55) and FOX (Q.57)

	SAME CORRECT FRAMEWORK		ALTERNATIVE/ N.I.F. → CORRECT		CORRECT → ALTERNATIVE OR N.I.F.		SAME ALTERNATIVE FRAMEWORK		SHIFTS BETWEEN FRS. 2,3, 4,5 (6)		BOTH 'NON-IDENTIFIABLE'	
	Q.55	Q.57	Q.55	Q.57	Q.55	Q.57	Q.55	Q.57	Q.55	Q.57	Q.55	Q.57
X12 to X14 n=29	7% *(2)*	3% *(1)*	7% *(2)*	7% *(2)*	0	0	17% *(5)*	24% *(7)*	41% *(12)*	41% *(12)*	28% *(8)*	24% *(7)*
Y14 to Y16 n=29	3% *(1)*	3% *(1)*	24% *(7)*	14% *(4)*	0	0	3% *(1)*	38% *(11)*	41% *(12)*	24% *(7)*	28% *(8)*	21% *(6)*