Investigation of Schoolchildren's Understanding of the Process of Dissolving with Special Reference to the Conservation of Matter and the Development of Atomistic Ideas

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ABSTRACT

The study is set in a constructivist framework within which children are regarded as actively engaged in constructing and re-structuring their knowledge of the 'physical' world. The overall purpose of the research is to describe the development of children's conceptions about the nature of matter as disclosed by their ideas concerning the dissolving process.

Information about children's ideas concerning various aspects of the dissolving process was obtained through individual interviews with a representative sample of pupils between the ages of seven and seventeen selected from school year groups 3,5,7,10 and 12. In addition a survey was conducted in which a further representative sample of 588 pupils were given group administered tasks relating to the same phenomena. In both the interview and the survey, pupils were required to make predictions, observations and explanations which were subsequently categorised to reflect recurrent features in their responses. These categories were coded and entered on a computer for further analysis.

Aspects of children's conceptions as they related to atomistic ideas and to the conservation of matter, weight and volume formed the focus of the research. Most of the pupils in all five year-group conserved substance but a considerable number did not conserve its weight/mass and/or its volume. A U-shaped trend was found in the development of weight/mass conservation. This is interpreted in terms of the developing complexity of children's conceptions making schema selection and co-ordination more problematic. The development of 'dissolved volume' conservation started with few pupils in the early years and progressed in an almost linear fashion. There is evidence of a complex relationship between the development of volume displacement and the way matter is modelled.

The findings about atomism indicated that whereas a major proportion of pupils in each year-group spontaneously imagined an atomistic view of matter, few of them used such a conception to explain weight/mass or volume conservation. It appears that early atomism is based on the view of matter being broken down into 'bits'. The way this interacts with conservation reasoning is described.

Educational implications of the findings are discussed together with suggestions for further research.

To

JEAN

and

RUTH, ANDREW, DAVID, SHARON & SARAH

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CHAPTER 1

BACKGROUND AND PURPOSE OF THE STUDY

1.1 Area of study

This study is located in the growing area of enquiry concerned with schoolchildren's personal understanding of the physical world. At present, there is particular educational interest, not only in the nature and origin of children's constructs, but also in their modification and, sometimes, radical change during school years. The topic area chosen for study was that of children's ideas about the nature of matter. The particular context used to elicit these ideas was that of the dissolution of a 'solute' in a 'solvent' to form a 'solution'. Children's discourse about 'dissolving' reveals a variety of understandings that are different from the science meanings which underlie the 'terms' used in the previous sentence. This study elicited children's understanding of 'dissolving', whether and how they conserved dissolved matter. In addition it explored the possibility of spontaneous atomistic thinking about dissolved and undissolved matter.

1.2 Development, importance and justification

The study originated from a desire to further an approach to science education that assists children to construct science knowledge for themselves. A pedagogy that aspires to such an aim has to take account of the nature of knowledge and how knowledge development may be related to psychological development. Furthermore, it would seem appropriate to study these matters in a restricted topic area so that specific questions may be addressed. Thus, this study has its roots in philosophical and psychological concerns and, hopefully its fruits in pedagogical and curricular concerns. We shall now explain how each of these concerns relates to the development, importance and justification of the study.

1.2.1 Philosophical assumptions and considerations

The primary assumption of this study is an epistemological one, namely, that knowledge is the outcome of a pupil's constructive activity and cannot be acquired in 'ready-made' form from a teacher or a supposed ontological world. This premise influences the way in which pupil's responses are interpreted. Thus, children's statements and diagrams are not 'seen' as having a degree of correspondence with some pre-conceived 'reality', but rather as their endeavour to depict the world 'as-they-perceive-it'. Since the researcher's findings are also a 'construction' there are similar philosophical implications for the status of those findings.

The traditional philosophical approach to questions about the nature of the world was to rely solely on reflective thought. One notion that aroused considerable philosophical interest in recorded history, was an atomistic view of matter. In modern times, this has become a science curriculum goal that many children find difficult. The roots of the idea that 'substance' is composed of 'particles' goes back to the philosopher Democritus (ca. 400 B.C.[1]). The genetic epistemologist, Jean Piaget investigated the possible occurence of this idea in children's thinking.

> Studying the quantification of qualities through the construction of the physical principles of conservation and through the child's gradual and spontaneous elaboration of atomism raises the wider problem of the relations between mind and objects, or rather of the interactions between mental activity and experience. (Piaget,1940/74,p.viii)

As the last phrase of the quotation shows, Piaget considered that spontaneous 'atomistic thinking' had far reaching epistemological implications.

The question of atomistic thinking raises a further philosophical problem that has intrigued mankind, namely, the relationship between 'parts' and 'wholes' - in this study the relation between 'bulk substance' (e.g. a crystal) and its 'atoms'. An example would be whether the whole was equal to the sum of the parts in terms of volume (i.e. no 'void'). Another example would be whether properties of parts (e.g. physical state) are similar to the whole or whether the whole has properties over and above those of the parts.

In sum, philosophical assumptions and considerations play a fundamental role in the development of this study.

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1. Democritus thinks the nature of the eternal entities consists of small substances infinite in number; as a place for them he supposes something else infinite in size, and to this he applies the names 'void', 'nothing', and 'the infinite', while to each of the substances he applies the names 'thing', 'solid', and 'real'. He thinks the substances are so small as to escape our senses, but have all sorts of shapes and figures, and differences of size. From these substances, as from elements, are generated and compounded visible and sensible masses... (Aristotle, quoted in Ross,1952,p.148)

1.2.2 Psychological development issues

The psychological importance of this study lies in an attempt to model several ways in which children construct ideas about 'dissolving' and, possibly, re-construct them at some later time. As a consequence of the epistemological stance, outlined in the previous section, it is assumed that children actively organise sense data and construct a 'reality'. In attempting to model children's knowledge of 'reality' it was found useful to conceive of existing knowledge as composed of dynamic system of 'schemes' that are built-up through particular experiences over time. Having adopted such a conception of knowledge, inferences are made about which schemes are generated, and, possibly, how they are interrelated, used and changed. We shall now illustrate this point.

A substantial part of knowledge building is the construction and maintainence of invariances. In chemistry, for example, the construction of conservation of mass is regarded as an essential foundation for building-up many other ideas. Piaget made extensive studies of children's construction of conservation. He did not regard this ability as innate. He laid down the principle that children could not be credited with the ability to conserve an 'object' unless they had experienced that 'object' being transformed in some way[1].

In this study the 'object' was crystalline sugar transformed by dissolution in water. An individual utilizing an 'atomistic' and 'gravitational' scheme may predict that sugar substance (i.e. its constituent molecules) and the sugar weight[2] (i.e. the force with which the earth attracts these molecules) remain invariant during the disappearance of dissolving sugar. This study attempts to infer alternative schemes that children use to conserve (or not conserve) sugar between the ages of seven and seventeen. Study of the ways in which pupils conserve dissolved substance, its weight and its volume is particularly complex as it appears to involve the convergence of schemes (or systems of schemes). That is, it embraces schemes about

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1. 'Conservation is generally regarded as the invariance of a characteristic despite transformations of the object or a collection of objects possessing this characteristic'. (1968, p.978)
2. Scientists do not agree on a definition of weight (Sears, 1963; King, 1962; Iona, 1965). This accords with a constructivist view that although physicists may reach a degree of consensus each has a different way of 'putting together' features of the weight property that, in their experience, relates to a conception of weight.

'substance' and what happens to 'substance' when it dissolves, as well as schemes about 'weight' and about 'volume'.

Further, it is possible to make conjectures about how children's perceptions of a phenomenon interact with their existing schemes. This may throw more light on some features of children's understanding within the theoretical framework outlined.

1.2.3 Pedagogical justification

There are several ways in which this study of children's ideas may be important for designing a pedagogy that can assist pupils to engage in further knowledge construction.

Knowledge of children's ideas may reveal 'where-they-are' in relation to some learning objective. Such information may inform a teacher's thinking about appropriate learning activities that are likely to establish, modify or radically challenge held ideas.

Also, children sometimes have novel ways of constructing ideas that other pupils could find helpful. Such an exchange of ideas could be undertaken in classroom discussion.

A further application of information about pupil's ideas is in assessing readiness for further study that is conceptually related to 'dissolving' (e.g. osmotic pressure and vapour pressure of solutions).

Again, a different pedagogical use of pupils' diverse ideas may be to have them defend their alternative ideas with a view to illustrating the 'progress' of science (Layton, 1973). This study provides a number of ideas that could be so used.

Finally, alternative ideas, revealed in the study, are a constant reminder that, although certain notions may be readily comprehensible to teachers, many of them pose considerable conceptual problems for the pupils. Though teachers cannot directly transfer their conceptual structures they may be able to provide activities through which pupils may develop viable structures for themselves.

1.2.4 Science curricular relevance

A science curriculum may be structured in many different ways depending on the age of the children, their perceived needs, the school tradition, the needs of the catchment area, and so forth. In the case of younger children there is a tendency to organise the curriculum around activities and children's interests, whereas in the case of older pupils, traditional subject structures or conceptual themes may dominate the curriculum design.

So far as activities and interests are concerned there are several ways in which this study may assist curriculum development. The proportion of nil-responses to the eliciting tasks may be taken as an indicator of their curricular suitability by a particular age-group. Also, particular features of the responses may suggest other 'follow-up' curricular activities. With regard to children's interests, the topic itself is wideranging in its relatedness to daily-life experiences.

In regard to 'traditionally structured' and 'conceptually structured' curricula, the study may show the extent to which such school curricula have influenced children's thinking about solutions and about matter in various physical states.

As a further outcome of the study it should be possible to structure a curriculum around the development of atomistic ideas that is set in the context of dissolution. Such a structure may be devised on the basis of data about atomistic ideas in various year-groups.

Finally, the study may assist in the sequencing of topics having a similar conceptual framework.

1.3 Purpose of the study

A survey of the literature had indicated that though some small scale enquiries had been undertaken, a more comprehensive survey of children's ideas about solutions would usefully extend the range of empirical data. It was, therefore, decided to attempt such a survey and at the same time facilitate the interpretation of data by carrying out individual interviews of a more 'open' character than those previously undertaken. As an outcome some answers to the following questions were pursued:

a. What are the major ideas that children offer about 'dissolving'; the weight of, and space taken-up by, dissolved substance; and, the 'inner constitution' of both a solution and a solute?

b. How does the prevalence of ideas change through the school-years?

c. What inferences may be made about ways in which children construct the conservation of substance, weight, and space taken-up by dissolved sugar?

d. What is the nature and extent of children's atomistic ideas about dissolved and undissolved substance?

e. What are the implications of the findings of this study for classroom practice, science curricula and cognitive psychology?

By attempting to answer these questions it is intended to build models of children's understanding that should encourage teachers to engage in imaginative ways of assisting pupils to construct science knowledge for themselves.

CHAPTER 2

THEORETICAL FRAMEWORK

2.1 Introduction

Children's 'knowledge' about aspects of the nature of matter is the focus of this enquiry. It is appropriate therefore to review prevalent ideas, held by psychologists, philosophers and scientists, regarding the acquisition of 'knowledge' of the physical world.

Ideas about how knowledge may be acquired range from an empiricist view on the one hand to a radical constructivist one on the other. Supporters of the former stance affirm that it is merely necessary to observe the 'real world' to obtain knowledge about it, whereas constructivists maintain that we have no direct access to the world as-it-really-is. Any knowledge that we have, they claim, has been actively built up over time. Thus the 'world-as-we-know-it' is regarded as one viable model of reality based on experience and not as discovery of 'what is'. One of the first scientists involved in the development of modern physics, Erwin Schrödinger (1887-1961) expressed this view as follows:

> ...every man's world picture is and always remains a construct of his mind and cannot be proved to have any other existence. (1956, p.44)

Schrodinger's subjective picture of the world may be contrasted with an empiricist view that was frequently maintained by scientists prior to his time:

> In physics we are dealing with those sensations which are mediated in the inanimate nature through our senses and find their expression in more or less exact observations and measurements. The content of what we see, hear, feel, is the immediate given, hence untouchable reality. (Planck, 1965, quoted in Roth (1980) p.45)

This empiricist view that the mind passively acquires knowledge of reality has been analysed by Piaget:

> Empiricism is primarily a certain conception of experience and its action. On the one hand, it tends to consider experience as imposing itself without the subject's having to organise it, that is to say, as impressing itself directly on the organism without activity of the subject being necessary to constitute it. On the other hand, and as a result, empiricism regards experience as existing by itself and either owing its value to a system of externally ready-made 'things' and of given relations between those things (meta-physical empiricism), or consisting in a system of self sufficient habits and associations (phenomenalism). (1936, p.362)

Doubts about the empiricist view and its 'certainty' were also raised by Heisenburg's Uncertainty Principle which he annunciated in 1926. It led to a lack of confidence in the idea that physical concepts (e.g. position, velocity, mass) have an objective reality.

George Kelly recognised that there was an epistemological problem in acquiring any direct knowledge of 'things-as-they-are' in the real world:

> Neither our constructs nor our construing systems come to us from nature. It must be noted that this philosophical position of constructive alternativism has much more powerful epistemological implications than one might at first suppose. We cannot say that constructs are essences distilled by the mind out of available reality. They are imposed upon events, not abstracted from them. There is only one place they come from; that is from the person who is to use them. He devises them. (1970, p.13)

To summarise, constructivists reject both the need for pre-supposing the existence of objective structures in 'reality' and the possibility of obtaining a copy of (supposed) ontological structures. Such presuppositions, they claim, overlook the problem of how such structures may cross the interface between 'reality' and the experiential field of the individual. They regard the organisation and structure of 'reality' as unknowable (as it really is) and make no assumptions about the real world other than that it 'exists'. That itself is a construction. Knowledge, they claim, can only be built up from elements that are within the subjective experience of an individual, simply because they are the only available 'raw materials'.

Furthermore, the constructivist approach holds out the interesting possibility of exploring the varied mental operations that individuals may use to construct their ideas of the world. Such information about children's ideas could be of particular value for teachers and curriculum developers - if they regard learning as a 'constructive activity'.

2.2 Epistemological positions of constructivist researchers into children's understandings

The various stances, regarding the origin and nature of knowledge as 'seen' by several constructivists, are outlined below.

2.2.1 Piaget's constructivist epistemology

In Piaget's terms his, genetic epistemology purports,

> ...to study the origins of various kinds of knowledge starting with their most elementary forms, and to follow their development to later levels up to and including scientific thought. (Piaget, 1970/72, p.15)

Jean Piaget was foremost among epistemologists who rejected the view that knowledge could be passively received from an ontologically independent real world. As an outcome of his work with infants and children he became convinced that knowledge of the 'external world' was constructed in the mind and that this knowledge was not to be regarded as a reflection of ontological reality. He insisted that:

> Knowledge is not a copy of reality. To know an object, to know an event, is not simply to look at it and make a mental copy or image of it. To know an object is to act on it. To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed. (Piaget,1964, p.176)

He postulated that, underlying the knowledge building process was the 'activity' of the young knower:

> All knowledge is tied to action and knowing an object or an event is to use it by assimilating it into an action scheme...this is true on the most elementary sensory-motor level and all the way up to the highest logical mathematical operations. (Piaget,1967, p.14)

Indeed, he assumed that the child at birth already possessed some 'fixed action patterns' as a result of genetic disposition. From then on 'activity' is regarded as the underlying factor that assists 'knowledge growth'. He suggested that in the first eighteen months a substructure of practical knowledge develops, during which time conceptions of 'object', 'space', 'causality' and 'time' are constructed.

During this period of 'sensory-motor assimilation' children construct their 'world'; then at the end of this time they begin to experience it as though it is a world external to themselves. Piaget describes this 'minature Copernican revolution' as follows:

> At the starting point of this development the neonite grasps everything to himself...whereas at the termination of this period...he is for all practical purposes but one element or entity among others in a universe that he has gradually constructed for himself, and which hereafter he will experience as external to himself. (1964/67,p.9)

After the sensory-motor stage an ability develops to re-present practical knowledge gained hitherto. Imitations, play and signs are used to re-present situations that are 'non-present'. This so-called pre-operational stage is regarded as a preparation for later 'operational' stages. It is also characterised by the beginning of language, lack of reversibility and non-conservation.

The activity of building up knowledge in later stages he called 'operating' - a process that has already been defined in the quotation above (Piaget, 1964). In his view, operational schemes have four characteristics: they can be internalised, they are reversible, they suppose some conservation and they are always linked to other operations. As a result, he saw knowledge as a growing organic whole rather than as an accumulation of fragments. The earliest 'operations' he called 'concrete' because they related to activities on objects, rather than on hypotheses. Later 'operations' that utilized hypotheses he called 'formal'. At this stage of development, knowledge may be generated through reasoning-on-hypotheses.

He suggested that four factors could explain the development of knowledge from one set of structures to another. These were: maturation, experience of the physical environment, social transmission and equilibration (or self regulation). Of these four, he regarded equilibration as the fundamental factor:

> It is that in the act of knowing, the subject is active and consequently, faced with an external disturbance, he will react in order to compensate and consequently he will tend towards equilibrium...equilibration, as I understand it, is thus an active process. It is a process of self-regulation. (Piaget,1964, p.181)

To summarise, knowledge building amounted to the construction of successively more viable schemes at progressively higher levels of abstraction. The main driving factor, he claimed was equilibration or a process of self-regulation:

> I think that this self-regulation is a fundamental factor in development. I use this term in the sense in which it is used in cybernetics...of processes which regulate themselves by a progressive compensation of systems. (Piaget, 1964,p.181)

It is clear that in his view, knowledge does not consist of a passively received internal picture of an 'external world', rather it is the active construction of invariants, regularities and viable schemes. It must be said, however, that not all interpreters of Piaget regard him as radical in his constructivism, for example Kitchener (1986) maintains that Piaget's constructivism is not completely subjective:

> ...for the environment (or reality) plays a decisive role in delimiting possible constructions and setting out constraints on an adequate construction. This entails the view that form (or structure) resides in reality as much as in the subject and hence (contra Kant) that form is not exclusively the product of the subject. Structures of reality must be assumed to exist in order to explain why knowledge progresses the way it does. Hence, Piaget's constructivism must be committed to some kind of realism. Talk of organisms constructing reality is, therefore, a solecism. (Kitchener, 1986,p. 121)

Von Glasersfeld does not agree with this. He summarises Piaget's epistemological position in the following lengthy but precise way:

> The radical constructivist's interpretation of Piaget's Genetic Epistemology, then, consists in this: The organism's representation of his environment, his knowledge of the world, is under all circumstances the result of his own cognitive activity. The raw material of his construction is 'sense data', but by this the constructivist intends 'particles of experience'; that is to say, items which do not entail any specific 'interaction' or causation on the part of an already structured 'reality' that lies beyond the organism's experiential interface. As a cognitive construct, this 'interface' is a corollary of the organism's externalization of his constructs, an operation manifestly inherent in every act of self-consciousness or experiential awareness. Though externalization is a necessary condition for what we call 'reality', this reality is wholly our construct and can in no sense be considered to reflect or represent what philosophers would call an 'objective' reality; for no organism can have cognitive access to structures that are not of his own making. (1974, p.22)

Both interpreters of Piaget admit that there are difficulties in obtaining, from Piaget's writings, a consistent epistemological position - sometimes Piaget appears a moderate constructivist and other times a radical. His 'real' position must remain an open question. A moderate constructivist view would maintain that, although 'knowers' construct their own structures, they utilize (structured) 'raw material' provided by the (external) environment. Radical constructivists, on the other hand, cannot 'see' any rational way in which (external) environmental 'structures' can cross the experiential interface and become structural material in the mind of a knower. Instead they regard the environment as an unknown and hold that we construct an experiential world from sense data registered within the knower's experience. That is the construction is wholely subjective from the 'firing of neurons' (Hebb,1958,p.461) onwards.

2.2.2 von Glasersfeld's constructivist epistemology

Closely related to Piaget's constructivism, but more clearly and consistently expressed, are the views of knowledge held by the psychologist Ernst von Glasersfeld. His version of constructivist psychology has been called 'radical' because it departs from common-sense views of knowledge acquisition. Describing his perspective on constructivism, von Glasersfeld affirms that:

> ...it embodies not only the view that cognition must be considered a process of subjective construction on the part of the experiencing organism rather than a discovering of ontological reality, but also the belief that there can be no rational access to any world as it might be, prior to, and independent of, our experience. (von Glasersfeld, 1975,p.109)

He rejects not only a behaviourist view that knowledge acquisition is a passive process, but, also, what he called a 'trivial constructivist' approach that does not face up to the epistemological implications of the nature of constructed knowledge. He argues that a 'genuine' constructivism must make explicit the relation between constructed knowledge and 'the reality of the traditionally presumed ontological world' (von Glasersfeld,1985, p.92). Furthermore, he suggests that many psychologists may be unwilling to make the effort of decentration required to change their position from a 'common-sense' view to a 'radical' view of the acquisition of knowledge.

Von Glasersfeld claims that constructivism is not a new approach to epistemology. He traces its beginnings to the pre-Socratics and its re-emergence to the seventeenth century skeptics[1]. Gassendi the philosopher and scientist, some of whose constructions about solutions will be discussed in chapter five, opposed the dogmatists of his time. However, the first clear exposition of constructivism, so von Glasersfeld claims, was offered by Giambattista Vico (1710)[2] in his treatise on epistemology. Commenting on Vico's writings, von Glasersfeld remarks:

> According to him (Vico), the only way of 'knowing' a thing is to have made it, for only then do we know what its components are and how they were put together. (1974,p. 28).

The frequent use of 'active' verbs (making, putting together) and the noun 'operation' was apparent in Vico's writings - according to von Glasersfeld. Also, Vico expressed the limitations of human cognition:

> Man cannot know the things that are in the world because their component elements lie <u>outside</u> man's <u>mind</u>, and man, therefore has no access to them <u>and cannot</u> build up true knowledge. (von Glasersfeld, 1975, p.94)

In addition to Vico's work, the constructivist 'heritage' includes the writings of Berkeley, Dewey, Bridgman, Cecatto and Piaget - claims von Glasersfeld.

One of the most important components of von Glasersfeld's constructivism is the relation between knowledge and reality. He emphasises that constructed knowledge does <u>not</u> claim to <u>match</u> reality

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1. Skeptics are primarily those who make a habitual distinction between...'appearances', or what things seem to be, and...'the truth', or what things are, and who swear they will raise no quarrel concerning the appearance of things, but only concerning their truth...they engage in dispute with dogmatics only over the claim they make to know not only how things appear but also what they are like in themselves, or what their inner nature is like. (Gassendi 1658/1972, p.304).
2. As God's truth is what God comes to know as he creates and assembles it, so human truth is what man comes to know as he builds it, shaping it by his actions. Therefore science (scientia) is the knowledge (cognito) of origins, of the ways and the manner how things are made. (Vico, 1710). This and other quotations from Vico's work are taken from von Glasersfeld. (1984 & 1985)

by providing an iconic correspondence with it. The way in which von Glasersfeld 'sees' knowledge acquisition is:

> ...something that the organism builds-up in the attempt to order the as such amorphous flow of experiences and relatively reliable relations between them. (1984, p.39)

This construction of 'order' requires two assumptions. First, that the knower's activity is 'goal-directed' and performs within his/her experiential world. Goals are a consequence of the propensity of individuals to evaluate their experience, tending to repeat certain ones and avoid others. Second, he assumes that it is possible for individuals to establish regularities in their own experience. He quotes Hume in this respect:

> For all Inferences from Experience suppose, as their Foundation, that the future will resemble the past...If there be any suspicion, that the Course of Nature may change, and that the past may be no Rule for the future, all Experience becomes useless and can give rise to no Inferences or Conclusions. (1963, p.47)

He also argues that, in order to establish regularity, consistency or invariance, it is necessary to make comparisons. This necessitates putting one-experience-in-relation-to-another and then deciding whether they are the same or equivalent in some way(s). (Thus concepts of identity and equivalence also have to be constructed). Furthermore, in order to be capable of repeated perceptions, an individual needs the prior capacity to represent the objects and events in question and place them 'into a space that is independent of the subject's own motion and into a time independent of the subject's own stream of experience'. Also, he asserts that an individual checks his comparisons of repeated experiences by using the principles of assimilation and accommodation as suggested by Piaget. Von Glasersfeld also points out that:

> ...all concepts that involve repetition are dependent on a particular point of view, namely, what is being considered, and with respect to what sameness is demanded. Given that the raw material of the experiential world is sufficiently rich, an assimilating consciousness can construct regularities and order even in a chaotic world. The extent to which this will succeed depends far more on the goals and the already constructed starting points than on what might be given in a so-called 'reality'. (1984, p.37)

He concludes that what we come to know is necessarily 'built up of our <u>own building blocks</u> and can be explained in no other way than in terms of <u>our ways and means of building'.</u> (Ibid,p.47)

As the subjects of this study are <u>schoolchildren</u> some consideration of social construction of knowledge, from his perspective, is appropriate. Von Glasersfeld (1985) has suggested that this process may be traced back to the construction of 'Others' where the 'cognizing organism begins to discriminate certain experiential objects which, eventually, will be considered 'alive' (Ibid.,p.98) [1]. This may take place by tentative attributions of perceptual capabilities modelled after those attributed to self. Then, as the model of others grows, they will 'come to be thought of as possessing cognitive structures and ways of operating that are similar to but not identical' with one's self. He cautions that the process of constructing others' ideas is necessarily limited by one's own conceptions:

> ...to take another's point of view, therefore, can only mean rearranging one's conceptual structures in a way in which one does not usually arrange them in one's own operating, no effort of decentering can draw on material one does not already possess in some form or fashion. (Ibid.,p.98)

He acknowledges that a considerable proportion of communication is linguistic, and warns against the assumption that successful interaction is necessarily a consequence of similar 'fixed' and 'external' word meanings.

To summarise, von Glasersfeld regards knowledge as the product of construing personal experience that 'has been cut up into pieces, compared, categorised, and built into schemes' for he emphasises 'unless we cut, compare, and establish equivalences and identities, we can have no elements, relations, structures, or schemes and we can have no inferences of any kind'. Overall, he 'sees' the 'knower' as an active, purposeful constructor of personal knowledge who assembles a viable model of the world from the 'stuff' of experience and prior constructions. He claims an historical heritage for constructivism and embraces the notions of some of the founders of constructivist thought. In particular, he has found Piaget's conceptions of adaptation, assimilation, accommodation, equilibration, reflective abstraction and the cybernetic metaphor particularly useful in assembling his epistemology.

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1. It is, of course, possible to go further back still - to earlier constructions, but these are assumed for the purpose of this particular discussion.

2.2.3 Gilbert and Pope's constructivist epistemology

The conceptual framework, adopted by Gilbert and Pope is a philosophy of constructive alternativism originally developed by George Kelly (1955). Although Kelly evolved his theory in the area of clinical psychology, Gilbert and Pope consider that it has potential for illuminating the construction and development of personal knowledge of the world by scientists, philosophers, teachers, children and others. (Pope and Gilbert,1983)

Like Piaget, Gilbert and Pope view the 'person' as an active constructor of reality, but do not share the limitations that stage-theory placed on personal construction. Instead, they affirm that any limits on the constructive process are imposed by the 'person' (who is regarded as fully responsible for his/her system of constructs[1]).

Gilbert (1982) regards each person's representational model of the world as composed of 'a series of interrelated personal constructs or tentative hypotheses',(p.13). This view of personal knowledge contrasts with the Osborne and Wittrock view, to be discussed later, that regards the knower as a processing system made up of several parts (perceptual, cognitive, and memory units). Gilbert and Pope's view is closer to that of Piaget and von Glasersfeld's idea of a complex network of inter-connected, personally made schemes. Gilbert and Pope consider that individuals use their constructs as tentative hypotheses in a similar way to scientists:

> ...the construction of reality is a subjective, personal, active, creative, rational and emotional affair. If we are to believe modern philosophers of science then similar adjectives can be applied to scientific theorising and methodology. (Pope & Gilbert, 1983, p.3)

Gilbert and Pope also share with Kelly a relativistic view of knowledge and, like Piaget, regard reality as mind-constructed. They agree with von Glasersfeld that many people find it difficult to accept that:

> ...personal models are not the world as it is but are constructed realities and that they are not soundly based in absolute truths...that it is <u>they</u> that construct their own world views. (Ibid.,p.4)

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1. In describing his idea of construct systems, Kelly wrote, 'Man looks at his world through transparent patterns or templets which he creates and then attempts to fit over the realities of which the world is composed...Let us give the name constructs to these patterns that are tentatively tried on for size. (Kelly, p.8/9)

The corollaries that Kelly put forward as elaborations of his fundamental postulate, are appropriated by Gilbert and Pope as applicable to knowledge construction bv children and others. For instance, the organisation corollary [1] is adapted to describe a hierarchical structure of constructs:

> Kelly...saw perceptual development as an evolutionary process which involved the progressive differentiation of conceptual structures (groups of constructs) into independently organised substructures and the hierarchic integration of these substructures at progressively higher levels of abstraction. (Ibid.,p.6)

Also, his fragmentation corollary [2] originally designed to describe constructs that for some 'good' reason did not appear to be consistent with the rest, is applied to hypothesis testing.

The person-as-scientist may:

> ...test out new hypotheses without having just to discard the old hypotheses/constructs. As constructs are hypotheses, we can hold on to constructs which are incompatible - Kelly saw this as a feature of human thought which was especially noted in children.(Ibid.,p.6)

The range corollary [3] is adapted to illustrate how science teachers may extend children's personal experience as a means of assisting them to construct formal knowledge. (Ibid,p.9)

The modulation corollary [4] is applied to illustrate the limitations on change of construct that persons are prepared to make.

Permeable construct systems allow new data to be assimilated and thereby enable the construct system to change. (Ibid.,p.6)

The commonality corollary [5] is used to account for the progression 'from the personal construction of individual scientists...towards some consensus construing of a topic by a community of scientists' (Ibid.,p. 12).

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1. Organisation Corollary: Each person characteristically evolves, for his convenience in anticipating events, a construction system embracing ordinal relationship between constructs (Kelly, 1955,p.56)
2. Fragmentation Corollary: A person may successively employ a variety of construction subsystems which are inferentially incompatible with each other (Kelly, 1955, p.83)
3. Range Corollary: A construct is convenient for the anticipation of a finite range of events only (Kelly, 1955, p. 68)
4. Modulation Corollary: The variation in a person's construction system is limited by the permeablity of the constructs within whose ranges of convenience the variants lie (Kelly, 1955, p.77)
5. Commonality Corollary: To the extent that one person employs a construction of experience which is similar to that employed by another, his psychological processes are similar to those of the other person. (Kelly,1955, p.90)

To summarise, Gilbert and Pope apply Kelly's constructivist framework to knowledge development in 'persons', 'scientists' and 'children'. Their central theme is the metaphor, person-the-scientist. As scientists have invented a variety of hypotheses, so children construct 'alternative conceptions' that are regarded as the bedrock (Gilbert,1985) on which further knowledge may be built-up.

2.2.4 Driver's constructivist epistemology

Driver's constructivism derives from Piaget's epistemology, particularly from his view that children impose their individual meanings on events, situations, tasks and the like. However, in her view, the content of a task is 'at least as important as its logical structure' in pupil's problem solving ability (Driver, 1982b,p.354). Indeed, she regards the nature of the conceptual structures themselves to be content dependent. In her view children (and adults) are the 'architects' of their own knowledge. Many studies of children's ideas about science topics have revealed a wide range of 'informal notions' that she has called 'alternative frameworks' (Driver and Easley,1978). Children's self-constructed knowledge owes its origin to everyday experience and is therefore likely to persist in spite of exposure to formal science (Driver,1982a). Driver does not agree with Piaget that 'by experience alone children will come to develop the conceptual framework of accepted science'. (Driver,1980,p.355)

In regard to the construction of new knowledge, the main factor, in her opinion is:

> ...the existence of a learner's conceptual schemes and the application of these in responding to and making sense of new situations, (Driver,1982b, p.74)

However, other factors such as personal processing capacity, physical environment, cultural mileau and the individual's purposes may limit the construction process. (Driver,1986)

In Driver's view, the 'schemes' that constitute existing knowledge are different in character from Piaget's schemes, in that they relate to contextually specific domains of experience. The relevant hypothesis adopted is that:

> ...information is stored in memory in various forms and that everything we say and do depends on the elements or groups of elements of this stored information. Such elements or groups of elements have been called 'schemes'. A scheme may concern an individual's knowledge about a specific phenomenon...or a more complex reasoning structure...These 'schemes' also influence the way a person may behave and interact with the environment,

> and in turn may be influenced by feedback from the environment. (Driver et al, 1985,p.4)

Further, the schemes are 'organised among themselves to form a structure' and groups of schemes may be linked to other groups of schemes. Such an organisation of schemes, that is different for each individual, is thought to account for the diversity of conceptual frameworks. The observation that several contradictory ideas are sometimes offered by a student may be explained by supposing:

> ...different schemes are brought into play; these ideas may all be stable in so far as the schemes leading to them are integrated into structures, and to change any one of them may require the modification of a structure not merely an element of that structure.(Ibid., p.5)

In regard to the nature of the knowledge constructed by individuals Driver (1986) agrees with von Glasersfeld that:

> ...to know something does not involve the correspondence between our conceptual schemes and what they represent 'out there'; we have no direct access to the 'real world'. (p.5)

She also agrees with Piaget and von Glasersfeld that the urge to generate new knowledge is in essence an adaptive process for both the individual and the species:

> ...we learn in order to produce a better 'fit' between our internal representations and sensory input. (Ibid.,p.4)

Also Driver makes explicit the view that knowledge is not only personally constructed but also socially constructed 'by communication with others through language and the physical and cultural environment'. (Ibid.,p.5)

To summarise, Driver 'sees' knowledge as both personally and socially constructed rather than 'given' or 'transferred'. A major feature of her epistemology is the set of conceptual schemes, or ways of seeing the world, that individuals bring to potentially knowledge-building-situations. In such situations, Driver regards human beings as 'purposive, active, adaptive, knowing, self-aware, social organisims' capable of generating new conceptual schemes.

<u>2.2.5 Osborne and Wittrock's constructivist epistemology</u>

These researchers designed a model of human learning that placed 'full recognition on the importance of what pupils bring with them to any learning experience' (Osborne & Wittrock, 1983,p.492). It is claimed that they bring prior knowledge, memories and experience with them and the model shows how children generate perceptions and meanings that are consistent with prior learning (Wittrock 1974).

The model [1] is essentially an information processing one that illustrates the brain as three units: long-term memory (LTM), short-term memory and sensed experience. This 'brain model' is said to represent an active constructor of information, that can interpret information and draw inferences. Within the brain, interaction was considered to take place between sensory information from the environment, information processing strategies, and memory. The construction of meaning, they suggest, begins with selective attention to an experience - influenced by 'aspects of LTM and cognitive processes'(p.494). Selective perception results from selective attention. To make sense of the sensory information, links with the LTM are generated. At first, tentative links lead to tentative meaning construction. These are checked for consistency before the final meaning is constructed. 'Finally and most importantly', it is claimed, 'this evaluation of the tentative meaning against sensed experience may lead to the re-structuring of knowledge in the LTM'.

It appears that Osborne and Wittrock regard knowledge, stored in the memory, as a composite of: inferences, models of reality, and a variety of conceptualisations. This 'knowledge' may be modified through interaction with sensory information, tentative hypothesising about its meaning and testing against sensed experience.

Osborne and Wittrock suggest that the 'drive' to generate meaning, through the pathways outlined above, is more intrinsic (intentions, plans and previous experience) than extrinsic (environmental stimulation). They consider that a major motivator is students' acceptance of responsibility for their own learning.

2.2.6 Novak's constructivist epistemology

It would appear that Novak's constructivism originates from his interest in the manner that scientists (and students of science) apply concepts to their observations of physical phenomena. He comments that although the history of science may be regarded as a succession of scientist's constructions of conceptual schemes, science teaching does not reflect such a characteristic. In general, he finds that science teaching is positivistic in its approach to knowledge and that efforts to teach the 'right' concepts prove to be largely unsuccessful in

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1. See Appendix 1.1.

changing students' personal ideas. (Novak,1984)

In order to help students to construct knowledge, Novak, in collaboration with Gowin, invented a heuristic that:

> ...can be used by students to help them understand the constructed nature of knowledge and the key role that concepts play in observing and interpreting events or objects.(Ibid.,pp.3,4)

Gowin's Epistomological Vee[1] distinguishes theoretical/conceptual elements from methodological ones while at the same time manifesting their interdependence.

In addition, Novak draws upon the theory of Ausubel (1963,1968) that establishes the importance of the construction of meaning during the acquisition of new knowledge. He particularly stresses the contribution of student's pre-existing knowledge - in particular, the anchorage that pre-existing knowledge can provide for new knowledge. Like Piaget, he provides evidence that children, from a very early age, perceive regularities in their experience and generate concepts. Moreover, he denotes 'faulty' perceptions of regularities as 'misconceptions'. The latter he considers to be somewhat resistant to modification. Further he judges that, from an information processing perspective, human knowledge construction is limited by the processing capacity of the human brain. Thus he argues for the breaking down of 'material-to-be-constructed' into small segments so that construction of meaning may be made easier. Persuaded by Ausubel's ideas, he advocates concept mapping as a means of learning; for he believes that the mind hierarchically subsumes new concepts under pre-existing ones. He claims that students having a constructivist commitment are more adept at modifying inadequate conceptions than those having a more positivistic outlook. Moreover, he holds that a constructivist approach produces positive feelings which in turn promote positive attitudes to learning.

To summarise, Novak's epistemological views have been influenced by the new philosophy of science, by Ausubel's work on prior knowledge and meaningful learning, and by Gowin's view of the 'structure of knowledge'.

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1. See Appendix 1.2.

So far as Novak is concerned, concepts[1] play a vital role in knowledge acquisition for he regards the perception of regularities in experience as an innate quality of Homo Sapiens. He also regards new knowledge as the elaboration of concepts leading to new linkages between concepts thereby 'modifying a whole matrix of interconnected concepts'. (1978,p.6)

2.2.7 Resnick's constructivist epistemology

Resnick has formulated an epistemology that has been influenced by research findings in cognitive science. In her view, knowledge is 'stored in clusters' and 'organised into schemata' (Resnick, 1983,p.477). The latter are used by the knower to interpret familiar situations and to reason about new ones. In order to acquire new information a knower must be able to link it into existing knowledge. This is a key point in her view of knowledge construction. She holds that individuals construct understanding rather than 'simply mirror what they are told or what they read' (Ibid.,p.477).

In her view students perceive regularity and order in the world and this leads to the construction of naive theories about it. Such theories, she claims, are tenacious and often interfere with taught ideas. Furthermore when taught ideas are presented quickly and abstractly, they do not connect with existing knowledge. Consequently, they are not retained. She suggests that in order to understand complex learning it is necessary to study 'how people learn particular subject matters' rather than study 'disembodied processes of thinking', because, in her view, knowledge growth 'depends intimately on the kind of knowledge that the person has about the particular situation in question' (Ibid.,p.478).

To summarise, Resnick regards individuals as constructors of knowledge in that they have the innate capacity to find regularities in events and build theories about them. Such construction happens on particular contexts and is worth investigation. She adopts the hypotheses that constructed knowledge is organised into schemata and that the acquisition of new knowledge depends on making links with prior knowledge.

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1. 'We define concept as a regularity in events or objects designated by some label'. (Novak, 1984, p.4)

2.3 Similarities and differences in constructivist epistemologies

This survey of the ways in which constructivist researchers view knowledge and its acquisition demonstrates that all of them regard children as active constructors of knowledge. Also, they place responsibility, for 'what' knowledge is built-up and 'how' it is assembled, with the constructor. Furthermore, they share the view that prior knowledge is an important factor influencing 'whether' and 'what' further construction takes place.

Driver, Gilbert, Piaget and von Glasersfeld are explicit about the relation between personally constructed knowledge and the 'real world' that is hypothesised to exist 'out there'. They regard constructed knowledge, not as a copy of reality, but as one viable model that can operate within the range of experience of the constructor. However, Novak, Osborne and Wittrock do not appear to comment on this relationship.

In other respects there are a number of differences between the approaches of the constructivist researchers. First, there is the problem of the source of constructed knowledge. Is knowledge construction partly or completely dependent on the mind? In other words, is any contribution made by the environment?

According to von Glasersfeld, the 'environment' is the product of the knower's activity and in that sense 'exists' in the knower's mind. Both the constructor and the 'environment' are 'parts of his/her own experiential field' (1984,p.120). He 'sees' no rational way of constructing from 'external' elements, and holds the view that the origin of 'raw material' is 'internal'; that is 'reality-as-we-know-it' is wholely mind-constructed.

Piaget held a similar view, he regarded knowledge as the product of 'acting on' and 'not copying' objects.

> The transformational structures of which knowledge consists are not copies of the transformations in reality; they are simply possible isomorphic models among which experience enables us to choose. (Piaget,1970,p.15)

Some other researchers appear to suggest that something 'external' contributes to knowledge.

This appears to be the case in Resnick's notion of construction when she writes:

> We assume that learning occurs as a result of mental constructions of the learner. These constructions respond to information and stimuli in the environment but they do not copy or mirror them. (Resnick,1981, quoted in Driver,1986,p.3)

In this quotation the implied stimulus-response schema, 'underplays' (Piaget,1964), the 'active assimilation' on the part of the knower. Radical constructivism regards the knower, not as a passive receiver of stimuli but as an active experiencer (von Glasersfeld,1979). The knower, already in possession of certain schemes, is active in modifying current experiences to fit those schemes, and so construction procedes (within the experiential field of the knower). Mischel explains:

> ...what he responds to is his construal of the external intrusion, and he is also the one who interprets the outcome of his compensatory activities. (1971,p.324)

Second, there is the problem of the constitution of constructed knowledge i.e. the structure and organisation of knowledge.

So far as Piaget was concerned, physical and mental actions resulted in the development of 'schemes' that were generalised by repetition. Also particular schemes were held to be operative in analagous situations. Further, schemes were not isolated but co-ordinated into higher order schemes. In Piaget's view, schemes of acting and schemes of operating constituted 'knowledge'. Because schemes were regarded as only relatively permanent they could be changed to accommodate new elements of experience, i.e. knowledge was regarded as being in a state of constant construction. Thus it seems that the kind of knowledge, Piaget postulated, had dispositional character; it provided the capacity to act in a certain way.

Apart from von Glasersfeld, who regarded Piaget's ideas as the most plausible he had encountered, other researchers present a less detailed view of the constitution of knowledge. Generally, they regard it as having a conceptual nature that is built up from the knower's recognition of regularities in his/her experience of the world. Driver and Resnick suggest that individuals store conceptual schemes in the memory. Like Piaget's schemes, they are structured. However, they are associated with particular physical domains tending to be more content and less dispositionally oriented. Osborne and Wittrock consider that the memory store includes memories of inferences, models of reality and a variety of conceptualisations.

Gilbert and Pope adopt the Kellian view of the constitution of knowledge, namely, that each person has an evolving system of personal constructs; these are deemed to be structured into hierarchies. Novak regards concepts as the primary building units of knowledge and they too are hierarchically structured.

Third, there is the problem of how knowledge grows. Piaget and von Glasersfeld are the only researchers who attempt to trace the development of knowledge from early childhood. For Piaget, knowledge growth could be regarded as a spiral of development through successive stages, each stage being dependent on the previous one. Both researchers argue that individuals have to construct all the elements of their experience - even objects are not 'given'. Both begin with an assumed amorphous experience (of an infant child) and build-up a developmental model of knowledge growth through the hypothesised and interwoven processes of adaptation, equilibration, reflective abstraction and decentration.

Gilbert, Pope, Osborne and Wittrock's ideas of knowledge growth are less age-related and focus mainly on the making and testing of hypotheses (or constructs) by the knower.

Driver, Novak and Resnick's views of knowledge growth centre particularly on the conceptual schemes children already possess and the possibility of making links (to new information) that may bring about conceptual change in existing schemes. In general, it would appear that researchers hypothesise that knowledge grows by the multiplication of schemes, or constructs or hypotheses or conceptual schemes. Schemes can be co-ordinated to give new schemes, these in turn can co-ordinate with others and so on. Schemes generate further schemes (e.g. Flavell,1963,p.109).

Fourth, there is the problem of motivation or drive towards construction of new knowledge. For Piaget, development was essentially a self-controlled system in which each stage gave place to a further one, because the latter was more equilibrated:

> We do not act unless we are momentarily in disequilibrium...(which manifests itself as) awareness of a need. Conduct ends when the need is satisfied: the return to equilibrium is thus marked by a feeling of satisfaction. This schema is very general: no nutrition without alimentary needs; no work without needs; no act of intelligence without a question, that is without a felt lacuna, therefore without disequilibrium, therefore without need (Piaget, 1954, quoted in Mischel, p.327).

In his view, anything that could not be assimilated to existing schemes stirred-up cognitive conflict or disequilibrium. Acknowledgement of this conflict could motivate a child to accommodate his/her schemes. Thus the motivator is the 'need' to establish consistency between the schemes one currently possesses and whatever factor that has produced disequilibrium. Further, the feeling of satisfaction that marks the return to equilibrium would be likely to influence future handling of disequilibrium.

Other researchers seem to make an assumption that something is built into the nature of Homo-Sapiens which invests the species with the 'drive' to construct knowledge. Each researcher had a particular emphasis in this respect; for von Glasersfeld it is the evaluation of experience (1983,p.47); for Gilbert and Pope it is Kellian anticipation, based on previous experience (1982, p.12); for Driver it is purposiveness (1986, p.3); for Osborne and Wittrock it is intention tied to personal responsibility (1983,p.494), and for Novak, it is the 'positive emotional experience' that is said to be the outcome of meaningful learning (1984, p.103).

Thus, in general, the drive towards the construction of knowledge would seem to depend on an individual's expectations, and the evaluation of previous experience. Piaget would probably add the drive for an internal consistency of schemes, though strictly he had the notion that it is:

> ...not necessary for us to have recourse to separate factors of motivation...because they are included from the start in the global conception of assimilation (Piaget,1959, as quoted in Mischel,1971, p.330).

2.4 Constructivism and the philosophy of science

In recent years there have been a number of attempts to gain an insight into how knowledge may develop through studies of the history of science (e.g. Kuhn,1970; Toulmin,1972; Lakatos,1978). According to Popper(1968), 'the growth of knowledge can be studied best by studying the growth of scientific knowledge' (p.15). As a result of such studies, varied philosophical perspectives have emerged but they have some common features. These, together with their impact on psychology have been summarised by Manicas and Secord (1983).

In connection with this study, it is of interest that the new philosophies of science are compatible with constructivist ideas. For example, the influence of the knowledge (concepts, theories, etc) scientists already possess, in determining what they perceive, means that their observations are theory-laden and so called 'facts' bear a relation to some theory. Piaget recognised that inordinate claims were sometimes made about 'facts', for instance:

> In psychology as in physics there are no pure 'facts', if by 'facts' are meant phenomena presented nakedly to the mind itself, independent respectively of hypotheses by means of which the mind examines them, of principles governing the interpretation of experience, and of the systematic framework of existing judgements into which the observer pigeonholes every new observation. (1926/73,p.33)

From arguments of this kind it is clear that 'facts' do not represent what is 'there' in an absolute sense. Such considerations interlink with the importance that constructivists assign to prior-knowledge as a determinant of the nature of the new knowledge that is to be constructed.

Also, there has been a change in the way that many philosophers and scientists think about the process of 'deriving' theory from 'facts'. For example Hempel (1966) argued:

> The transition from data to theory requires creative imagination. Scientific hypotheses and theories are not derived from observed facts, but are invented in order to account for them. (p.15)

This is consistent with the constructivist view that schemes, conceptions, theories and the like, are personal interpretations of experience rather than logically derived outcomes. However, the feeling that they 'work' often creates the impression that theories correspond with reality. Such a position, however, is to ignore the possibility of further experience (i.e. experimental data) or, the feasibility of other theories.

Further, Kuhn (1970) has shown that frequently, in the history of science, there has been resistance to the change of 'working theories'. This parallels constructivist thinking about the tenacity of children's intuitive ideas. When ideas have 'worked' for some time, their influence on other operating schemes may have become so far-reaching that a massive effort would be required to restructure the conceptual system. Restating this another way, the investment required, and, temporary loss of security envisaged, may endorse the status quo. Evidence that scientists (and children) have problems with restructuring long held ideas would appear to support the constructivist hypothesis.

A notion that science will eventually lead to absolute truth has pervaded the discipline for some considerable time and still exists. This, also, may be an illustration of the resistance to change discussed above. The possibility of obtaining 'ontological reality' rather than a 'mind-constructed reality' has been exemplified by the statement:

> What we are seeking, in science, are true theories, true statements, true descriptions of certain structural properties of the world we live in. These theories or systems of statements may have their instrumental use; yet what we are seeking in science is not so much usefulness as truth: approximations to truth; explanatory power, and the power of solving problems; and thus, understanding. (Popper, 1982,p.42)

On the other hand some scientists have expressed the notion that 'reality' may be created by scientific thought:

> The reality created by modern physics is indeed, far removed from the reality of the early days...Without the belief that it is possible to grasp the reality with our theoretical constructions, without the belief in the inner harmony of our world, there could be no science. (Einstein and Infield,1978,p.296)

This latter statement is somewhat reminiscent of one by an early constructivist, many years ago:

> Human science, thus, is no more nor less than an effort to bring things into pleasing relations to one another. (Vico,1710/1858. Quoted in von Glasersfeld, 1985,p.94)

Not many scientists (originally designated natural philosophers) doubted that their work was indeed answering the ontological question as to 'what is'. However, the radical conceptual changes introduced by physicists, such as Einstein, Heisenburg and Schrödinger, have provided convincing evidence that the 'world-as-seen' by scientists is a mind-created reality rather than a copy of the world as-it-really-is.

Although it makes sense rationally, constructivism has been slow to permeate the thinking of educators. There are a number of reasons for this. First, there is a traditional form of thought; which, as has been explained, is difficult to replace. Second, there is our language which conveys the impression that our ideas are 'out-there' e.g. useful text-books, clear diagrams, infuriating children etc. Third, there is the difficulty of not externalising one's conceptions and models to the point where one believes they are 'true' - particularly if they appear to 'fit'. As von Glasersfeld and Smock (1974) have said, 'The (constructivist) approach is neither easy nor comfortable' and probably demands the greatest act of decentration we may ever have to make. Thus it is unlikely to court popularity.

2.5 The epistemological framework of this inquiry

As the reader will have observed, there is some variation in what constitutes 'constructivism' among researchers in the field. The view of knowledge and its construction taken in this enquiry will now be presented.

'Reality' and knowledge

At one time, the 'knowledge' that schoolchildren have about physical phenomena and the 'knowledge' that the researcher has about children's ideas may have been classified as different 'kinds' of knowing, i.e. as 'physical-science' and 'social-science' knowledge respectively. The data associated with physical-science were regarded as objective and its theories logically derived, whereas social-science data and theories were taken to be subjective and open to a variety of interpretations. However, the act of knowing, as we have seen, involves the <u>person</u> who registers, assembles and interprets data of <u>any</u> kind. Thus the knowledge outcome of an experiment or experience depends on the personal characteristics of 'knower' for s/he governs 'what' and 'how' data are observed, recorded, classified, interpreted etc. The personally constructed character of knowledge, as outlined, carries with it a corollary about 'what-cannot-be-known', namely 'things-in-themselves' that are independent of a human 'act of knowing'. The view taken in this inquiry is that each person constructs a 'reality' and 'what-is-constructed' is just one viable model of 'what is'.

From this perspective, the knowledge that the children have of each aspect of 'dissolving' is regarded as a personal construction and school-science knowledge is taken to be an inter-subjective (consensus) construction agreed by various individuals. Similarly, the different theories of solutions held by different scientists are not regarded as mirrors of ontological reality, but as mind-constructed. Also, the researcher's knowledge of children's ideas is regarded as a personal construction[1].

'Activity' and knowledge

It is clear from the above paragraph that a 'passive-reception-of-knowledge' is rejected. Rather, children are regarded as actively engaged generating ideas about 'objects' and 'processes' within their experiential field. Instead of regarding knowledge as directly received from reality, it is 'seen' as the product of physical and mental activity in which sensory experience interacts with existing ideas. This may be contrasted with a view that the activity which builds knowledge is an interaction between a child's (cognitive) structures and supposed real structures in the environment.

'Environment' and knowledge

From a constructivist viewpoint, once an environment is sensed by an individual, it is not regarded as being 'out-there'; instead the environment becomes a conceptual model in the 'head' of the knower. Thus the 'reality' of the environment is regarded as a construction. The environment is taken to be 'as a person perceived it' - just that.

'Observation' and knowledge

That which is observed (influenced by prior-knowledge) is regarded as being within the experiential field of the observer. Thus, the 'observe-action' is regarded as taking place between 'elements' of sensory perception and conceptual schemes the individual already possesses. Both are within the 'head' of the individual. Thus observations are not assumed to refer to 'the-way-things-are-out-there'.

'Development' and knowledge

The words 'activity' and 'build' in the previous paragraph suggest that personal knowledge is not static, but subject to change and growth. In this study, the view is taken that because experience of 'objects' and 'processes' is ongoing, fresh aspects may be sensed and further interaction with existing ideas can ensue. As a result, existing ideas can be adjusted (equilibrated) to take account of fresh perceptions and thereby new ideas may result. Further experience may

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1. This is to emphasise that the researcher accepts final responsibility for what he has constructed and to deny that he is claiming ontological reality. However, he accepts that the ways of obtaining and interpreting data had some intersubjective character in they were shared by and with other researchers.

lead to a further cycle (of assimilation or accommodation) and so on. No end is seen to this equilibration process (within a lifetime). Any particular course taken during a particular cycle of adjustment of ideas is noted with interest.

'Personal responsibility' and knowledge

From a constructivist perspective a 'knower' is regarded as one who actively relates new experiences to existing knowledge. As this process takes place only in the head of the 'knower', no one else may directly participate, so 'knowers' are necessarily responsible for the outcome of their constructs. In addition, individuals are regarded as having their own purposes when they engage cognitive activity so in this sense also they are responsible for whatever they construct.

'Linguistic communicability' and knowledge

Much of the research reported here is concerned with linguistic communication between the researcher and the researched. From a realist viewpoint, knowledge generated in the 'head' of 'person A' (e.g. a child) is transferred 'as-it-is' to the 'head' of 'person B' (e.g. researcher). Although words may be expected to convey 'knowledge' from one 'head' to another what is actually conveyed is a set of associations (attributed to those words) by 'person A' to another set of associations (attributed to those words) by 'person B'. Hence, from a constructivist viewpoint the researcher's knowledge of a child's ideas must necessarily be regarded as just one viable interpretation of the child's words.

'Schemes' and knowledge

Individual 'ways of seeing' the physical world are, in this study, interpreted by supposing that individuals construct regularities and invariances in objects and events. Thereby, they invent 'working' hypotheses or schemes about them. Supposed 'schemes' vary considerably in complexity and as a result are notoriously difficult to describe[1]. Furthermore, they are deemed to co-ordinate thereby producing larger schemes or structures. Also, it is probable that many of the supposed schemes children generate may be derived, by abstraction, from early physical actions. Also, it is possible that existing schemes may co-

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1. See for example the wide-ranging attributes used by Rumelhart (1977,p.33-58). Piaget also presents his view of schemes a variety of ways.

ordinate to form new ones.

To summarise, constructivist epistemology links knowledge to the 'person' who either implicitly or explicitly is regarded as its originator. Knowledge is and remains a personal construction. Even though the person may be unaware that constructive 'acts' are proceeding, it is considered necessary to postulate construction because there is no rational way in which persons can get into the objects of knowledge and examine their structures; nor can supposed structures of the object enter into personal cognitive structures. Moreover, there is no rational way of checking the validity of our knowledge against ontological reality. Futhermore intersubjective checks may merely corroborate one's own construction.

From infancy a person is regarded as being physically and mentally active, creating a 'reality' of its own from an initially formless stream of experience.

This pre-supposes an innate propensity to cut apart one's experience, to compare and contrast its parts, and to re-present previous experience so that it may be be juxtaposed with the present. Given these propensities, the conceptions of sameness, equivalence and difference may be built-up and imposed on (constructed) 'objects', 'events', 'processes' etc. As a result regularities and relationships between parts or entities of experience may be invented. Thus conceptions about one's experiential entities and relationships between them may emerge. These conceptions are subject to change as they interact with further entities of experience. Although conceptions may be externalised, i.e. projected outside our experiencial world, they are not given ontological status.

Although personal 'working' knowledge appears to 'fit' objects, situations, processes etc, it is still regarded as just one viable description or explanation - one way of putting the 'entities' together. Although others appear to share similar conceptions, this does not confer ontological status either. Scientific conceptions and theories are regarded as shared inter-subjective knowledge, agreed by a community of scientists. Other communities of scientists may well hold different ideas about experimental data; it is not only conceptually selected but also subject to a variety of interpretations.

In the history of science, new imaginative ways of interpreting experiments or experience have led to changes in ways of 'seeing' the 'world'. Constructivists would predict that this is a never-ending process.

CHAPTER 3

REVIEW OF THE RESEARCH LITERATURE CONCERNING CHILDREN'S UNDERSTANDING OF DISSOLVING

3.1 Introduction

Investigations of the development of children's understanding of the process of dissolving, reported in the literature, have tended to be part of broader research inquiries or else studies which have been restricted to narrow age bands. These are summarised in Appendix 2.1.

Possibly the earliest relevant investigation was undertaken by Piaget and Inhelder (1941/74). For them 'dissolving' was one phenomenon through which they could study a child's construction of material quantities. They enquired into children's understanding of the conservation aspect of dissolving since they claimed that conservation was both a condition and also a result of quantification. As a consequence of his work Piaget hypothesised a stage theory for children's development of conservation of substance, weight and volume in that sequence.

He also considered the possibility that there exists an 'instrument of conservation and quantification', namely atomism. He postulated that the appearance of atomistic ideas was a spontaneous process at a certain stage of development.

There have been four main responses to Piaget's work in this field:

a. An appropriation of Piaget's analysis of children's development followed by the use of a dissolving task to assess stages of children's cognitive development. (Shayer & Wharrey, 1974; Adey, 1976).
b. a questioning of Piaget's sequence of conservation development. (Beard, 1962).
c. a questioning of Piaget's assertion that atomism develops spontaneously in children. (Selley, 1977; Pfundt, 1981).
d. many inquiries into the range of children's ideas about various aspects of dissolving.

Since Piaget's work was seminal in this field of research, his methodology, findings and theories deserve special consideration, and will be considered first.

3.2 Piaget's study of children's construction of the dissolving of sugar

3.2.1 Methodology and findings

Piaget and Inhelder interviewed more than one hundred children, aged four to twelve, about expected and observed changes in weight and volume when lumps of sugar were added to water. Essentially, the interview followed a series of cycles, each cycle included a prediction, an experiment and/or observation, and an explanation from each child.

By this process Piaget was able to obtain both the expectations children brought to the phenomena and their comments on his experiments. Thus he was able to document their intuitive ideas, their perceptions about experimental observations and any interaction between them.

Extensive extracts of interview transcripts were reproduced in Piaget and Inhelder (1941/74) but no statistical data was given. Prior to this investigation he had enquired into children's thinking about the clay ball conservation problem. He claimed that children followed a similar conservation sequence in the case of the dissolution of sugar and he postulated a four stage development towards total conservation.

Stage	Corresponding mental construction
I Absence of conservation (4-7 years)	Unable to conserve because visual perception dominates their thinking.
II Conserves substance (7-9 years)	A substance must be responsible for the lasting taste.
III Conserves weight (9-12 years)	Weight independent of the form or position of an object. Child visualises division into parts and recomposition to a whole.
IV Conserves volume (12+ years)	Displacement of water indicates that volume is preserved during decompression (loosening) and compression (tightening).

He claimed that a major driving force for the development of conservation was the construction of atomistic schema. It is therefore considered appropriate to discuss Piaget's concept of atomism at this point.

3.2.2 Hypothesised atomism

Atomism, in the context of the dissolution of sugar in water, is simply a child's belief that the disintegration of a lump of sugar into smaller pieces eventually leads to a multitude of minute invisible particles. Further, if these particles (corpuscles or compositional elements) are subsequently brought together, then they reconstitute the lump. In addition to its particulate and reversible features his concept of atomism has other features worth noting.

First, atomism is based on mental constructs rather than sense perception (p. 79 op.cit.). At an early age, children may interpret this experience of dissolving as the spontaneous disintegration of sugar that leads to the destruction of the sugar. However, when the child is able to operate on the process i.e. interiorise the separation and subsequent joining together again of the 'tiny bits', then s/he is liberated from 'egocentric phenomenalism' and is in possession of a useful reasoning tool.

Second, the process of dissolution may be modelled by the child's experience of dust and powders - an idea that Piaget culled from Bachelard (1933). This, he claimed, may assist the acquisition of atomistic ideas by providing a 'picture' of matter - particularly if they have already appropriated the idea that 'scattered material may be recovered'.

Third, atomism is a possible agent of conservation (p.132 op.cit.). When children construct a 'particulate' hypothesis about matter then they can understand that the sum of the scattered parts is equal to the whole lump. It then follows that conservation of weight is a logical necessity or $W=\Sigma w_i$ = constant, when W = total weight and w_i = weight of one part or particle.

Fourth, a child's interpretation of data from measuring instruments plays a vital role in the acquisition of atomism (p.viii,op.cit.). Piaget observed that when children, who had denied conservation, were faced with conservation evidence - as from a balance, for example - they then adopted an atomistic schema. That is, they recognised the weight of the tiny bits as an inherent quality rather than something that varied with form and position.

Nevertheless he maintained, evidence obtained from measuring devices fails to convince children who are still imprisoned by 'egocentric phenomenalism'.

To summarise this section it may be helpful to summarise the course of development of atomistic ideas from the Piagetian perspective.

Initially, there is a pre-atomistic stage at which children believe that sugar ceases to exist once it has dissolved. Contradictory evidence, such as persistance of taste or unchanged weight, is explained away since it is no match for the direct interpretation of their visual experience.

It is claimed that a primitive atomism appears when the persistence of taste so impresses children that it becomes the springboard of the new construction, namely, that a substance must persist and be responsible for the taste. At this stage the form of the substance is unknown and its parts, if conceived, are considered too small to possess weight or volume. However, when children are then confronted with evidence for unchanged weight they no longer deny it.

Further development of atomistic ideas ensues when children realise that the tiny grains of sugar are responsible for this unchanged weight and, consequently, they conclude that the sum of the weights of these tiny particles is equal to the weight of the lump. The final stage is a realisation that the volume of the tiny grains is preserved and the schema of displacement is constructed; the water 'stays up' because each 'tiny bit' has a volume and the sum of the individual volumes is equal to the volume of the lump.

3.2.3 Some comments regarding Piaget's atomism

Few would deny that Piaget's work in this area is perceptive, original and fascinating, nevertheless, on taking another look at his transcripts, one is left wondering what exactly is the nature of the atomistic ideas supposedly possessed by some of the children he interviewed. Children's atomistic ideas are of particular interest to those who teach atomism, and, it would be useful for them to know whether the hypothesised spontaneous atomism refers to particles of similar size and weight or to heteromorphic 'bits' of continuous sugar. If children have constructed 'tiny unseen bits' of (continuous) sugar that may be reconstituted to the original whole, then they have made a useful step forward that may be built upon. Further it would be advantageous to know whether children have atomistic ideas about water. Piaget was silent on the latter point. Also, he did not mention the possibility that a cube of sugar, because of its agglomerate character, could cue atomistic ideas.

A further criticism, that could be levelled, is the use of lump sugar in the volume task. It complicated the issue by, in effect, asking the children to think about three different 'volumes': the volume of the agglomerate of granules with its air spaces, the volume of the individual granules, and the volume of the hypothesised 'atoms'.

3.3 Research on children's ideas about dissolution that adopted Piaget's theory of development

3.3.1 Shayer and Wharrey's contribution

Shayer and Wharrey (1974) adapted Piaget's dissolving task, amongst others, for testing a whole class at one time. Their purpose was to obtain a developmental profile of a class of pupils. Shayer had previously suspected a mis-match between the cognitive demand of Nuffield Science Curricula and schoolchildren's cognitive level. Consequently, he needed a valid and reliable instrument that would measure the 'levels of thinking' that were considered to characterise individual pupils.

Amongst the various tasks used for the purpose, the dissolving task was labelled 'Task 7'. Wharrey administered this to a class of thirty-five pupils. They were provided with worksheets, without diagrams, containing questions with spaces for answers. Pupils were required to write short sentences to describe what happened to sugar when it dissolved in water.

The researcher claimed that:

> "The answers to questions posed during the demonstration both about the place of the sugar itself when it apparently had disappeared and about the volume changes pointed out during the process of solution offer a clear <u>indication of the developmental stage</u> and the child's <u>use of the atomism concept in his treatment of</u> chemistry". (p. 452, op.cit. - underlining added.)

The dissolving task, among others, was regarded as diagnostic in relation to the matters underlined in the quotation. On the basis of the responses to this task, it was felt that decisions could be made about the suitability of certain curricular topic areas for particular children.

3.3.2 Adey's contribution

Adey (1976) also used children's responses to questions about the dissolution of sugar, together with another task, to test Caribbean children for the attainment of conservation. As a result he hoped to obtain an 'accurate fix on each child's position on the developmental scale'. Although conservation was only one of many important science concepts, Adey argued that:

> ..the evidence from Piaget's own analysis of thinking strategies, and from replication studies is that there is overall a strong positive correlation amongst the ages of attainment of a particular stage across all concept areas. (p.116, op.cit.)

His Piagetian stance was also illustrated in his justification for the validity of the tasks:

> It is most important to realise that their validity rests in the last resort on Piaget's own analysis of the thinking strategies required to solve certain practical problems, and on his interpretation of the child's responses to these problems. This is an analysis of the logical structure of knowledge, and as such it is as universal as logic itself. (p.116,op.cit.)

This justification for the validity of the procedure suggests an underlying view of knowledge that does not allow individuals to 'see' matter, weight, volume etc, in different ways and to relate these to one another.

Questions, about the dissolution of sugar, culled from Piaget's interviews, were arranged in the form of a written test. Expected responses to the questions were assigned to categories that corresponded to Piaget's hypothesised developmental stages. This categorisation was based upon the interpretations offered in Piaget and Inhelder (1970). The tests were administered to 527 children between the ages of 11 and 15. Teachers administered the tests to groups of children. Also, teachers were allowed to explain the test items and the testing lasted for about one hour.

Adey claimed that the dissolving test correlated well with the other reasoning tests mentioned in para. 3.3.1. The exception to this was the volume task. (This correlation refered to the extent to which the various tests agreed on the so called 'stages of development').

Adey's work also led him to draw the following conclusion regarding the prevalence of children's atomistic ideas:

> ...no consistent pattern emerged which suggested that pupils naturally begin to conserve weight and volume because they see matter as made up of particles. When prompts are provided, many pupils refer to grains, atoms and even molecules, but since many of them will have heard talk about atoms.....such reference reveals nothing about the supposed genetic development of atomistic concepts. (p. 125, op.cit.) (Comment on CSSC trial of Task 7 - dissolving task.)

Adey concluded that if the dissolving task was used in conjunction with another 'volume and heaviness task', then those tasks could be relied upon for the assessment of stages of cognitive development. He believed that those tests would be a powerful tool for both cognitive development investigations and curriculum development planning.

3.4 Research that challenged Piaget's suggested sequence of concept development

Beard's contribution

Beard (1962) questioned Piaget's proposal that there was an 'inevitable' order of achievement of the concepts of the conservation of quantity, namely: substance, weight and volume. Piaget had claimed that conservation of substance was realised about two years before conservation of weight and that conservation of volume was always achieved later than weight. Piaget believed that it was necessary for children to distinguish the roles of weight and size before they could conserve volume. Baird, on the other hand, claimed that weight was irrelevant to understanding that two apparently identical bodies of very different weight made water rise by the same amount. In Beard's view, realisation of these things came through doing the experiment of immersion. If children had this experience then, she claims, conservation of volume would be understood as soon as conservation of substance was achieved.

Although Beard and her team investigated children's ability to conserve substance (or mass), weight and volume in a variety of contexts, only one of these involved dissolution. It was designed to test ability to conserve the volume of salt dissolved in water. 140 children between the ages of five and ten were questioned as follows:

> "If we put a tablespoon of salt into the water what will happen to the water?...Will it go up?... Now suppose we stir the salt, what will happen?.... When the salt has all dissolved so that we can't see any of it will the water still stay up where it was? Tell me why you think so." (p. 231, op.cit.)

Beard's inquiry did not include the weighing of soluble materials before and after dissolving.

The test was administered in various parts of Britain by student-teachers on school practice under the supervision of their mathematics lecturers.

The results obtained are reported as percentages of pupils who were able to conserve the volume of salt (i.e. predict that the water would rise[1]).

Age:	4.10-5.9 (N = 35)	6.10-7.9 (N = 42)	7.10-8.9 (N = 31)	8.10- (N = 32)
% Cnsr:	30.0	53.0	20.7	48.4

No difference in the percentage of success was observed between children rated bright, average or dull. The only consistent difference was that between the sexes:

Girls: 32.8% Boys: 43.0% (conservers)

Because there was no progress with age and no difference due to intelligence, Beard decided that the most probable explanation was 'lack of experience with water'. She believed that the substantial difference between the sexes confirmed this view. She also thought it very 'improbable that the children were consciously, if at all, separating the roles of weight and size mentally, as Piaget suggests....'. (p.235,op.cit.)

Overall, she found that Piaget's order of achievement of concepts was not borne out in the case of substance and weight. She attributed the later achievement of conservation of volume to lack of 'relevant experiences'.

3.5 Research that challenges the theory of spontaneous development of atomism

3.5.1 Selley's contribution

'Another Look at Piaget's Atomism' was the title of a part of the appendix to Selley's investigation into how scientific models and theories are taught in schools (Selley, 1979). He was engaged in curriculum development and the possibility of nascent atomism, held out by Piaget, excited him. A 'gradual and spontaneous elaboration of

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1. In the actual experiment (with salt and water) the water does not rise, but as in Piaget's interviews, Beard considered that 'logical reasoning' would lead the child to expect the water to rise. Possibily, she thought that 'experience with water' would generate a displacement scheme.

atomism' appeared to constitute a valuable foundation upon which teachers could not only build but also use to interpret phenomena in physics and chemistry.

Selley cast the possible relationship between conservation and atomism in the form of a testable hypothesis:

> Atomism and the conservation of quantities invariably develop in conjunction with one another. (p.A-2,op.cit.)

He argued that this hypothesis would be refuted if it could be demonstrated that some pupils show full conservation of weight and volume during dissolution but still reject the particle model.

He designed a test in order to reveal children's tendency to conserve substance, weight and volume during dissolution. It was administered to groups of eight to twelve children at one time. He described the children as being at three distinctly different stages of cognitive development but did not say how this information was obtained. The test was administered as follows:

> Each question was given orally, with expansion and clarification, before the subjects wrote their responses; no spoken answers were allowed at this stage...after the papers had been completed and collected, the questions were reconsidered in turn, and the answers and suggested explanations were discussed fully. The proceedings were recorded. All the experiments were demonstrated, thereby making the occasion a teaching situation (p. A-8, op.cit.).

His results are shown in the table below.

	Group I Age 11 Junior Mixed unselected	Group II Age 13 middle mixed unselected	Group IIIA Age 14 selective boys avge ability	Group IIIB Age 15 selective boys high ability
Conservers (with dissolved sugar)	7*	3	11	9
Partial conservers	8*	4	13	17
Non-conservers	9	10	0	0
	N = 24	N = 17	N = 24	N = 26

Partial conservers generally conserved weight but not volume.

* This sign indicates the categories of the only two children in groups I and II who mentioned particles in the discussion

In general he found little evidence that children used atomistic ideas. In group I only two pupils mentioned particles when pressed to explain their predictions. Throughout the test and discussions no pupils in group II mentioned particles or grains. In groups IIIA and IIIB seventeen out of twenty-four and twenty-two out of twenty-six, respectively, made mention of particles in the first two items of another test. Also a surprising number of able students failed to conserve the volume of sugar on its dissolution.

He made a statistical comparison of children's visible conservation (clay ball deformation) and invisible conservation (dissolving) and reported that:

> No clear pattern could be seen in the individual scores....for when each ability was graded on a four point scale the resultant grid showed $\chi^2 = 15.55$ (9 degrees of freedom) which is almost a significant lack of correlation. There were signs of a hierarchical relationship (no conservation on invisible unless on visible), but with at least two exceptions.(p.A-9,op.cit.)

Selley obtained additional evidence by administering 'Task 7' of the Shayer (1976) tasks. He found that a considerable number of pupils and adults were able to conserve weight and volume without admitting to a belief in grains and many who were knowledgeable about molecules still failed to conserve the volume of sugar.

Selley concluded that his findings provided no support for Piaget's ideas about the spontaneous development of atomism. However, he added, in view of the fact that many pupils showed conservation and atomism together, at various stages of development, there 'may be some probabilistic relationship which it would take a more extensive study to demonstrate'. He also commented that:

> Few pupils reach the stage of confidence in the mental separation and rearrangement of molecules of constant size before the picture is completed by variations in molecular spacing due to bonding, hydration etc. (p. A-12,op.cit.)

3.5.2 Grutzmann and Pfundt's contribution

Pfundt (1981) investigated children's ideas about dissolving and recystallising because she wanted to know whether children regarded the atom (or molecule) as the final product of the disintegration process. If children did indeed regard this final product as a preformed building block of matter, then dissolving might be one learning experience for introducing precise atomistic ideas. Pfundt was sceptical about the conclusion that Piaget had drawn:

> When some children to justify an invariance of weight and volume postulate the conservation of minute, invisible sugar particles, it can certainly not be concluded that these

> children also assume sugar to be made up of such - preformed - granules. The children's answers provided by PIAGET and INHELDER give no indication of whether the children think that the invisible particles presumed to be in the solution are also presumed to be contained separately in the granular lump of sugar. (p. 10, op.cit.)

Pfundt interviewed fourteen schoolchildren, ages 11-14, and Grutzmann (1980) interviewed forty-nine children ages 13-15, fourteen of which had already used the particle model to explain the melting process; the remainder had not yet encountered the particle model at school.

Each child was interviewed three times. The first occasion had to do with evaporation and condensation of water. (This will not be discussed further as it is not directly relevant to dissolving). On the second occasion the interview focussed on a crystal of copper sulphate dissolving in a petri-dish of water. Other small crystals were added later. In the third interview attention was drawn to crystals that had appeared in the petri-dish a few days after the second interview.

Each interview had essentially five components and their sequence was mainly guided by promising comménts supplied by the pupil. The five phases were as follows:

a. pupils perform an experiment and make observations;
b. pupils comment freely: describe observations, make comparisons with familiar processes, interpret and question;
c. pupils select from provided comparisons and give reasons for their choice;
d. pupils draw, explain drawings and select from provided drawings giving reasons for their choice;
e. pupils select interpretations from those provided and give reasons for their choice.

Response categories were based on pupil comments and were stated to imply three speculations about dissolving matter:

(i) a continuum which can be thinned;
(ii) a continuum which can be broken down into not preformed particles;
(iii) a discontinuum which can be decomposed into its preformed particles.

Only four out of fourty-nine pupils interpreted the dissolution of copper sulphate using the conception of preformed particles. Also only four pupils used this conception of crystallisation. Only one pupil used this conception of both dissolving and crystallising, but he did not use this conception of evaporation and condensation.

A 'great number' of pupils were inconsistent in their reasoning across tasks, for instance they would use the thinning of a continuum to explain solution but a few days later would assume that small granules united in the solution in order to explain crystallisation.

Two interesting conceptions of the colour of copper sulphate were observed by the researchers. Some imagined a blue colour without a 'carrier' substance; others associated the blue colour with the carrier substance but this carrier substance was something apart from the actual substance of the copper sulphate - which was assumed to be colourless. Some imagined the blue carrier substance to thin continuously and melt with the water.

The main conclusions from this work were summarised as follows:

> Only a small number of pupils decide to use the conception of particles, preformed in the substances, in some degree of consistency to explain some of the observed phenomena. The majority of the pupils reason more or less consistently using the conception of substances as continua which either thin continuously or which are broken down into not preformed particles. (p.20, op.cit.)

It was hypothesised that pupil inconsistency was due to their not having developed conceptions prior to the interview - that is they were formed during the interview.

Pfundt's work is of particular interest to teachers who attempt to develop atomistic ideas in children via the sequential breakdown of macro material (e.g. dissolving). Such an approach can create a number of misconceptions such as:

a. the fracture positions are ill-defined; they are different each time you break it - atomic boundaries are imprecise;

b. the shape of the resultant atom, molecule or ion is precisely that of the starting material or irregular bits of it;

c. there is no space between the particles - space is in no way necessary - the material must fit together.

3.5.3 Anderson's contribution

Anderson was interested in the ability of children, confronted with a physical phenomenon, to construct a mental model. He believed that such research would be a useful contribution to the curriculum development of the sixties when there was extensive interest in the use of models.

Anderson (1956) interviewed one hundred and fifty children between the ages of nine and twelve about five physical phenomena, and one 'mechanical' model of a mixture of alcohol and water.

The phenomenon relevant to dissolving was: 'a mixture of alcohol and water occupies less space than the sum of their separate volumes'. After he had demonstrated this phenomenon, he asked the key question, "What is water like so this happens?". In this way he hoped to elicit an explanation of the event in terms of the nature of water itself, that is, the child was expected to invent a model of water that would explain its behaviour.

Anderson did not tape-record the responses; instead he wrote the children's responses on paper during the interview and consulted with each child on the wording to be used. He selected children at random from four schools and classified them by age, I.Q., grade level and sex.

He categorised the children's models as atomistic, non-atomistic, magical, animistic or no model. Among those classified as atomistic were included: molecules, little pieces, atoms, particles and cells (non living). The percentage of models in this category system was not given. However, when pupils who gave this type of model were asked whether they meant that the liquid was made up entirely of these particles or of these 'particles' together with something else, 95% indicated the latter.

Anderson also reported that subsequent to observing the mechanical model of the alcohol-water mixture, the percentage of pupils giving an atomistic model increased from thirteen to thirty.

Anderson concluded that children were able to form mental models - an ability that increased with age and I.Q. He also found that the consistency of explanations across tasks increased with age.

3.6 Research that has elicited a range of children's ideas about dissolution in various contexts

3.6.1 Dow, Auld and Wilson's contribution

Part of an extensive study of secondary pupils' concepts of solids, liquids and gases was devoted to concepts of solutions. The survey was principally concerned with particulate ideas of matter. (Dow, Auld and Wilson,1978).

The authors do not report how ideas were elicited from pupils. However, it would appear that a combination of written tests, drawing tasks and interviews was used.

With regard to the dissolution process, it was found that about half the first year secondary pupils could visualise the disintegration of solid matter into molecules but some were uncertain as to whether the 'parts' were of the same size and shape, or differed in these ways. There were many ways in which the solute was thought to change: melting, penetration by water before dissolving (adequate space between solute molecules), no increase in molecular spacing of solvent, solute changes from a cubical shape to a shapeless mass, and no appreciation that dissolution is a surface phenomenon until the fourth year. There was an understanding of saturated solutions at the macro-level but they could not be explained in molecular terms by pupils or teachers. It was most surprising that many teachers believed that molecules of solvent were so far apart that there was no change in volume on adding solid solute. The researchers believed that pupils' inability to expain osmosis at a later stage was a direct result of the previous misconception about solvents. They suggest that teachers clarify the situation by using diagrams (p. 4.44,op.cit.).

3.6.2 Inagaki and Hatano's contribution

Some indication of the extent of conservation through the dissolution process shown by Japanese children is revealed in a paper by Inagaki and Hatano (1977). Although this data was incidental to their main study it is of interest from the cross-cultural point of view.

Two randonly selected groups of pupils (age 9-10 years) were required for their main study. They were randomly drawn from six classes in two elementary schools. Both groups were asked whether the combined weights of sugar and water would increase, decrease or remain the same after dissolving. They were classified as conservers or non-conservers according to their response.

	First Group (N = 101)	Second Group (N = 102)
No of conservers	56	53
No of non-conservers	45	49

These figures are quoted so that the reader may compare the proportions of conservers with those of British children of the same age.

3.6.3 Cosgrove and Osborne's contribution

Part of an enquiry into children's ideas about physical changes, by Cosgrove and Osborne (1981), included the dissolution process.

An interview-about-event procedure was used to elicit ideas from forty-three pupils aged between eight and seventeen.
The event used was:

> "Hot water is poured into a cup and a teaspoonful of sugar is dissolved in it, with stirring",

and the question asked:

> "What has happened to the sugar?"

Further questions were asked to elicit the pupils' ideas.

Sample student responses were documented in a working paper and some categories were extracted. These are listed below:

Category	No. of responses
Sugar melts	15
Sugar is broken up; gets smaller and smaller; fades; disappers	11
Sugar dissolves; makes a solution	27
Particles are involved	14
Heat breaks it down	9

- The categories were not mutually exclusive

Cosgrove and Osborne concluded that few pupils had a picture of the dissolving process at the microscopic level. In general they found that the particle model 'appeared to be a rather abstract model to many children, hardly, if at all, related to reality.

3.6.4 Driver and Russell's contribution

Part of an investigation into children's ideas about 'change of state', by Driver and Russell (1982), contained a section on dissolving. This took the enquiry into pupils' ideas a step further because they were given the opportunity to quantify the extent of their belief in the conservation or non-conservation of dissolved sugar.

Three task sheets were prepared that contained alternative responses that had been collected from children of a similar age group. The tasks were based around the following three questions:

> "What happens to the sugar?
> (Five alternative choices provided)
>
> "What will the contents of the beaker weigh after sugar has been added?"
> (Four alternative choices provided)
>
> "What will the contents of the beaker weigh when the sugar cannot be seen any more?"
> (Four alternative choices provided)

The tasks were administered to 324 pupils aged between eight and fourteen.

On the first task the number of conserving responses increased with age and the word 'melt' was used more frequently than dissolve. However, it was acknowledged that this was possibily a semantic rather than a conceptual problem.

So far as the other tasks were concerned, children frequently predicted a loss of mass of sugar, especially after dissolving it. The data also showed signs of a 'U' shaped development with age; this was interpreted as a change of problem solving strategy with age. The early numerical/additive strategy is not adopted so readily at the next stage where children appear to be swayed in their judgement by the apparent visual contradiction. Older children, who understood conservation, overcame this seeming conflict.

3.6.5. Friedman's contribution

A section of Friedman's enquiry into pupils' ideas about selected chemistry concepts was concerned with dissolving various substances.

Friedman (1982) used the interview-about-events method with thirty-four Australian pupils between the ages of thirteen and eighteen. They observed various substances (sugar, salt, ice-cream, ice, oil, disprin and copper sulphate) placed in water.

"Does the ____________ dissolve?",

followed by:

"Why did you say that?".

The responses were categorised and some examples are listed below.

Solute	Category	Percentage
Sugar/salt	Dissolving related to own experience	30%
	Melting (N.B. hot tea/water used)	20%
	Heat explains dissolving	30%
	Solute disappears - not there	20%
Disprin	Dissolving and particles (can be seen)	25%
	Not dissolving - not clear	20%
Copper sulphate	Colour mentioned	25%
	Solution clear	35%
	Solute not there	25%

Friedman reported that younger children responded with descriptive answers, whereas the older ones tended to give a particle explanation. However no percentages were quoted.

3.6.6 Longden's contribution

Longden (1984) inquired into children's understanding of the 'concept' of dissolving by presenting them with exemplars and non-exemplars of dissolving culled from daily-life experience.

The main investigation took the form of interviews-about-instances with twenty children in the first year of secondary education, aged eleven to twelve years. The task involved: recognising when dissolving occurred, giving reasons for their decisions and making explicit their thoughts about concepts related to dissolving. There was in addition a secondary investigation in which 81 children of a similar age were asked to write a sentence that expressed their understanding of the word 'dissolving'.

Longden reported a 'surprising' variety of understandings of 'dissolve' evidenced by different categorisations of events, reasons and explanations. He tentatively suggested a number of 'barriers to understanding':

* recognising that it is the solid which disperses and disappears into the liquid and not the colour which should disappear;
* recognising that colour spreading from a material is a substance dissolving;
* recognising that dissolving is part of an overall change (p. 82)

Longden found that children had not previously thought about everyday events as instances of dissolving in the sense of 'spreading out and mixing up' but rather in the everyday sense, i.e. disappearing. The latter was a much stronger association and an example of compartmentalising 'school' and 'out-of-school' knowledge. He also found that the use of scientific terms was rare.

3.7 Summary

It would appear that there are two major controversial issues that arise from the literature survey:

* whether at some point in children's development there is a spontaneous genesis of atomistic ideas and, in particular, whether this occurs along with the construction of conservation of a soluble substance such as sugar;

* whether, in the context of dissolution, the development of conservation of dissolved substance, its weight and its volume, take place in the order stated.

A brief summary of the position of each of these issues and, also the extent to which this study of children's ideas might shed some light upon them, follows.

First, the hypothesised spontaneous development of atomistic ideas. This is an issue of particular interest to science teachers - particularly if they wish to adopt a purposeful teaching strategy of modifying, or reconstructing children's prior knowledge. According to Piaget, atomism (and conservation) are constructed by a combination of experience and reason. He argued from the premise that older children know two things: sugar taste lasts, and the level of coffee remains constant after it has been sugared. He continued:

> Finally though the dissolved sugar is transparent and its molecules invisible, it nevertheless remains a fact that once he has adopted atomism the child extends it to the vanishing sugar grains. For all that, it is clear that our experiment would not have led him to complete conservation or to atomistic compositions had deductive factors not helped to structure and complete the perceptible data. (p.113, underlining added)

Although Piaget found that 'conservers' - we are not told what proportion - used words having atomistic connotations[1], other researchers, such as Selley (1977), Pfundt (1981) and Adey (1976) found that only very small proportions of 'conservers' used words of this kind and yet managed to conserve matter. Could it be that they by-passed the atomistic scheme when constructing conservation, or did they hold the atomistic scheme implicitly and were unable, or felt it unnecessary to declare their atomistic ideas? It would seem that some investigation which attempts to uncover the possible existence of 'implicit-atomism' would be a useful approach to solving the current 'spontaneous atomism' controversy between researchers. As we indicated, Anderson found some evidence for atomistic modelling but he did not state the proportion of children who responded in this way. Chapter nine will describe a task that attempts to uncover implicit atomism.

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1. Words such as: crumbs, grains, bits etc.

Second, the hypothesised sequential development of conservation of substance, weight and volume is another controversial issue among researchers. Piaget has suggested an inevitable sequence that is summarised in the following quotation:

> There are first of all notions on which the child bases his predictions: absence of all conservation, followed by the conservation of substance, the conservation of weight, and finally the conservation of volume, everyone of these invariants becoming integrated with preceding ones until there is the total conservation characteristic of the final phase of this development, (Piaget et al,1941/74, p.112)

Beard challenged this 'inevitable sequence' on the ground that many children, of the ages she investigated, had not differentiated the concepts of substance, weight and volume anyway. So, she argued, how could one be built upon another? She explained her findings by stating that children, by virtue of their experience, know 'what' happens rather than 'why' it happens. In her view, success in these tasks was related to familiarity with the materials and the event. It should be borne in mind that Beard's investigations were class tasks in which there was little or no opportunity to probe children's meanings of substance, weight and volume so that there was no check in their concept differentiation ability. In the interviews, outlined in this study, some effort was made to check out children's meanings before, during or after they performed their tasks. In that way the differentiation issue mentioned above was at least partially overcome. In addition, children's reasons for making conservation or non-conservation statements were elicited so that their ways of 'seeing' matter, weight and volume could be ascertained, at least, to some extent. Also familiar materials were used throughout, so that lack of familiarity would not be an additional variable.

Finally, the literature survey indicates that conceptions of 'dissolving' are a promising area of inquiry into the nature, prevalence and mode of construction of children's ideas. It would appear that pupils bring a variety of ideas about this phenomenon to the classroom and it is proposed to follow any changes these ideas undergo during the school-years. As a result it may be possible to speculate about the thinking processes that could underlie the development of children's ideas.

CHAPTER 4

DESIGN OF THE INVESTIGATION AND METHODOLOGY

4.1 Introduction

Before describing the methodology used in this study, the major assumptions on which it is based will be reviewed. As indicated in the second chapter, learners are regarded as active constructors of their knowledge of physical phenomena, rather than passive receivers of ready-made knowledge (Resnick,1983). Further, it is proposed that this knowledge is built up through the development of schemes. Over time, it is suggested that schemes become integrated and possibly subsume under other schemes to form more complex structures.

In general children are not aware of the substantial amount of knowledge up they have built up over time. Consequently an eliciting methodology is required to disclose their ideas. From these, underlying schemes may be inferred. In the light of this approach, some promising contexts for eliciting children's ideas may be:

* revisiting activities in which children may have generated ideas;
* engaging in new activities where their ideas may be applied; and
* anticipating the outcomes of certain activities and justifying their predictions.

The resulting conversations or written responses may then become the focus for reflection by the researcher with a view to making inferences about underlying schemes.

4.2 The overall strategies employed

As implied in the introduction, some promising strategies for eliciting individual 'knowledge' include, making observations of phenomena and giving supporting explanations, or making predictions and giving supporting reasons. Indeed, it is sometimes possible to combine these in the sequence: prediction, reason, observation and explanation. Such strategies were employed in the tasks described in the sixth, seventh and eighth chapters. Another approach was an attempt to raise the imagination level by asking children to pretend they had a special vision (e.g. X-ray eyes) and then invite them to describe or draw what they would expect to see. This kind of strategy was used in the task described in the ninth chapter where children's ideas about internal composition of a solution are reported.

Researchers in the field of children's knowledge have used a variety of eliciting techniques and these have been reviewed and summarised

(Driver and Erikson,1983; Gilbert and Watts,1983). In this study, it was decided that one appropriate technique would be the clinical interview since it held out the possibility of simultaneously probing children's meanings. The technique was developed and described by Piaget(1929) as follows:

> The clinical method...which is an art, the art of questioning, does not confine itself to superficial observations, but aims at capturing what is hidden behind the immediate appearance of things. It analyses down to its ultimate constituents the least little remark made by the young subjects. (Piaget,1926, p. xiv)

As the review articles, mentioned at the beginning of this paragraph, show, the clinical method has been used extensively in the last decade to explore children's conceptions and some inter-relationships perceived to exist between them. The procedure of interviewing, transcribing and analysing tape recordings of interviews is very time consuming. In this study a small sample was interviewed and the resulting data were supplemented with a written survey on the same tasks but given to a larger sample. In this way it was hoped to make the findings more generalisable, though it was recognised that the survey gave less detail and insight into children's meanings. Thus, the interview technique was chosen to assist construction of children's meanings and the survey was undertaken to provide an estimate of the prevalence of their ideas. Taken together the two techniques also provided a 'triangulation' check on findings, insofar as the limitations of both are borne in mind. (Cohen and Manion, 1982).

Because the researcher was interested in developmental aspects of children's understanding, he decided upon a cross-sectional study of the pupil population. There are disadvantages of such a study compared with a cohort study (Cohen and Manion, 1982). However, the constraints of time necessitated the choice of a cross-sectional study in this case.

4.3 Selection of schools and pupils

The study was carried out in a total of 15 schools with a range of catchment areas, (four Junior, three Middle and eight High schools).

The year-groups were chosen to cover the range from Junior-1-class to the Sixth-form (and at the same time, avoid disruption to examination year-groups). Headteachers were requested to select for interview six pupils (three girls and three boys) from each year-group in such a way that there was equal representation of high, average and low ability pupils[1]. This selection is illustrated in Table 4.1 below. Altogether, 90 pupils were interviewed in 13 schools.

TABLE 4.1 INTERVIEW SAMPLE CHARACTERISTICS

Year group	Age	Number of girls 'ability' high	middle	low	Number of boys 'ability' high	middle	low	Total
3	7/8	3	3	3	3	3	3	18
5	9/10	3	3	3	3	3	3	18
7	11/12	3	3	3	3	3	3	18
10	14/15	3	3	3	3	3	3	18
12	16/17	3	3	3	3	3	3	18
Total	-	15	15	15	15	15	15	90

Written surveys were administered to a total of 588 pupils in 12 schools. Headteachers were requested to select, for survey tasks, classes that either singly, or together, represented the whole ability range. The outcome of this selection is illustrated in Table 4.2 below. These were different children from those included in the interview sample.

TABLE 4.2 SURVEY SAMPLE CHARACTERISTICS

Year group	Age	Number of Boys	Number of Girls	Number of Pupils in year-group
3	7/8	64	48	112
5	9/10	56	53	109
7	11/12	75	52	127
10	14/15	81	73	154
12	16/17	43	43	86
Totals	-	319	269	588

In most of the schools there were mixed ability classes in which the pupils had been randomly selected. Where this was not the case, two or three classes that represented the whole ability range were surveyed. It so happened that the number of boys usually exceeded the number of girls in each year-group but this situation was accepted as representative of the year-groups in the school sampled.

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1. This selection was frequently delegated to a Head-of-year.

Pupil identification numbers. Each pupil in a particular year-group was identified by the last three figures in the I.D. Nos. listed in Appendices 3.9 and 3.10. Examples of children's responses found in subsequent chapters of this thesis contain this number preceded by a decimal point and the school year-group (as specified in Tables 4.1 and 4.2). The child's gender is also indicated : b - boy and g - girl.

4.4 Trialling and development of the eliciting tasks

Similar tasks were used in both interview and survey procedures. They were formulated after a period involving design, trialling and modification during the months of January to July 1984.

The trials were made in two Junior Schools, one Middle School and two High Schools in the Leeds area. Trial interviews were carried out with six or more pupils in each of the year-groups to be used in the study. Pupils of both sexes were selected from the whole ability range. Altogether 46 interviews were conducted with a view to developing interview technique[1], improving the interview schedule, trialling different task equipment, varying task sequences and adapting the interview to a wide age-range. The final form of the interview schedule is shown in Appendix 3.1. In Appendix 3.2, are example transcripts of interviews with pupils in each of the year-groups.

Survey tasks were also trialled during this period - using whole classes of pupils. At this time possible 'cue-words' were removed from early survey drafts; tasks were set in a context that was familiar to children[2]; cartoon pictures of two children, Liz and Rob, performing each task were included; also, Super-Rob was introduced as having the ability to see the detail 'inside' objects. Further, it was decided to limit the amount of eliciting material on each page by having one task per page. An important criterion in the trial period was the extent to which the youngest age group could understand what was required of them and the modifications outlined above proved to be satisfactory. The final form of the survey task, together with example

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1. I am indebted to Dr. Rosalind Driver and Professor Jack Easley for their helpful criticism of the tapes and transcripts during this period of 'learning to learn' from children.
2. An approach recommended by Donaldson(1978). This counters Bronfenbrenner's charge against some kinds of developmental psychology as 'the science of the strange behaviour of children in strange situations with strange adults for the briefest possible periods of time' (1977, p.19)

task-sheets completed by pupils in each year-group, are shown in Appendices 3.3 and 3.4 respectively.

4.5 Data collection

In July 1984 letters requesting permission to both interview and survey pupils were sent to headteachers. A copy of the letter is included in Appendix 3.5. In those cases where permission for the research study was granted, further arrangements were made to visit the school and discuss necessary details with the Headteacher and/or a delegated teacher. Details regarding arrangements for times and rooms were frequently made difficult by teachers' action and the loss of rooms due to asbestos removal. As a result the data collection period was somewhat prolonged and took place between October 1984 and May 1985. The teachers involved were told that the inquiry would focus on children's ideas about some science topic areas but were not told which particular areas. In order to cause minimum disruption to the school routine, survey tasks and interviews were fitted into lesson periods. This entailed the setting up of apparatus beforehand.

Because 1984/5 was a particularly difficult time for research in schools, not only because of teacher's action and loss of teaching time through other causes but, also, because of assaults on young children, less than ideal interview conditions had to be accepted. For such reasons, at various times, the researcher was given: an alcove at the back of a 'working' classroom, the head's room with either the head or the secretary present; the library and other 'public' places. (While the 'public' character of the arrangements protected the security of the child and the reputation of the researcher, background noise made tape transcription particularly difficult.)

Headteachers requested that pupil's names should not be identified in any research report; accordingly pseudonyms or abbreviated names are used in this thesis. The researcher was informed that any arrangements were subject to teacher action and was advised to telephone and check the school situation before setting out. In most cases research had to stop before lunch-hour as schools were locked at that time. Despite the difficulties most school staff were co-operative, within the constraints put upon them, and the researcher was grateful for their assistance.

4.5.1 Survey task administration

At a time when the classroom was vacant (e.g. during assembly, break-time, or lunch-hour) a demonstration table was prepared at the front of the classroom. All the necessary apparatus, listed in Appendix 3.6 was set out in task order. The apparatus was covered with a cloth so that it would not be a topic of conversation during the settling down period when the class arrived. (It so happened that the cloth-cover also raised the level of curiosity about the tasks.) While the room was vacant, pencils, task sheets and large sugar crystals were set out on numbered individual tables. The layout of the room was recorded so that any apparent evidence of idea-sharing could be located and such response sheets could be discarded later. (This was a very rare occurrence).

When pupils entered the room they were asked to sit down where there was a paper and pencil. Then the researcher explained his presence and purposes in the manner outlined in Appendix 3.7. After a brief conversation about children's collecting hobbies, the researcher said that he too was a collector, but he was collecting children's ideas rather than things. Pupils were encouraged to write down their own ideas. It was emphasised that this was not a test and they were not to worry if they did not have, or could not explain, ideas about some of the tasks. Further, they were to be involved in a story about the activities of two children, Liz and Rob, and the researcher would demonstrate the things they did. (Older pupils were asked to appreciate that much younger children had to be given the same tasks and, though the presentation might appear elementary, they, i.e. older pupils, were expected to offer their 'current' ideas about the tasks.) After being given the opportunity to ask questions, pupils were encouraged, by the researcher, to join with him in reading the survey task story. Where there was an activity, he paused, showed the apparatus and demonstrated the activity. The researcher thanked the pupils for their ideas when each task had been completed (i.e. at the end of each page). The pupils were also asked for personal information such as age, gender, seat number and, if appropriate, the science options they had chosen.

4.5.2 Interview task procedure

The materials shown in the checklist in Appendix 3.8 were assembled. After arrival at the school, before the interviews began, permission was requested to meet the interviewees collectively. The researcher explained his presence and discussed 'collecting hobbies' in much the same way as that outlined in the preceding section. As a result the pupils did not find the researcher to be a complete stranger when they were called for interview.

After a location for the interviews had been given, a period of about 5-10 minutes was requested before the first interviewee appeared, so that the equipment could be set out. A small table, preferably facing a wall (with a power point), was arranged to have two chairs on the same side of the table and facing the wall. (The wall reduced the possibility of distractions from other people, events and so forth in the surroundings. The arrangement of chairs on the same side of the table helped the interviewee to focus on the phenomena rather than on the researcher). The materials in the 'general' checklist were set out in appropriate positions on the table and boxes, containing materials related to the various phases of the interview, were placed in order on the table. A list of children's fore-names was obtained from the teacher and the first interviewee was welcomed by name.

The interview opened with a continuation of the conversation about collecting hobbies that had taken place with the interviewees collectively, unless some other more immediate event was considered to be a useful focus for conversation. Having established some rapport, the researcher explained that he had brought a few things 'to talk about together'. The interviewees were told that the researcher would be very interested in any ideas they had about some of the things on the table, like 'what they were made of' and 'what made them the way they were'. The researcher then followed the interview schedule outlined in Appendix 3.1. The sequence was sometimes allowed to vary to follow the natural flow of ideas introduced by the child. The researcher attempted to maintain a conversational style when probing responses. He also expressed interest in responses but tried to be neutral in relation to their content. The main focus of the procedure was to elicit <u>pupil's</u> ways of 'seeing' the materials and the changes presented to them. Professor Easley had advised the researcher that the focus of the interview as follows: 'It is unreasonable for the children to possess scientific theories, they must have something else, what is it?'. At the close of the interview the pupils were asked what they had found interesting or surprising and finally they were thanked for their conversation.

4.5.3 Intersection of task content and school-science

Subsequent to the data gathering, teachers of children involved were asked for information regarding curriculum content insofar as it overlapped with the interview and survey tasks. Specifically, teachers were requested to comment on the pupils' familiarity with relevant:

* terminology (solvent, solute, solution, dissolving, melting, crystallising, weight, mass, volume, atom, molecule and particle);
* weight, mass and volume measurement (i.e. balance and measuring cylinder);
* diagrammatic particulate representations of solids, liquids, solutions, melting and dissolving; and,
* experimental work on recovery of a solid from a solution, separation of soluble and insoluble substances, and conservation of mass.

The questionnaire, completed by teachers, is shown in Appendix 3.11. Many teachers were able to respond, but owing to school organisational matters (such as recent teacher replacement, syllabus changes and the like) the curriculum picture was not quite complete. However, the following generalisations would appear to be a reasonable summary.

a. In the third and fifth school-years there was little attempt to undertake a formal approach to the above matters apart from some weighing and occasional volume measurement.

b. In the seventh school-year there was increasing familiarity with terms such as solvent, solution, solute, dissolving, melting, weight, and volume in a more formal way. Acquaintance with atomistic ideas was rare.

c. By the tenth school-year most of the pupils had been acquainted with the terminology, methods of measurement and experimental work listed above. Almost all had received instruction regarding particle representations of physical states but few had been acquainted with a similar approach to either 'melting' or 'dissolving'.

4.6 Methods of analysis used in this study

Because several types of responses were requested in the various tasks (e.g. imagining change, explaining change, selecting predictions presented in a multiple choice format, justifying those predictions, drawing pictures of imagined change, drawing pictures of imagined constituent parts etc) the detailed procedures for analysis are described in the chapters that set out the results of analysis. The general analytical procedure used was to develop categories of response based in the data. This process began by reviewing the aims of a particular eliciting task and then 'heading' each of several sheets of paper with a specific kind of information to be abstracted, such as: reason for prediction, inferred conceptual scheme,atomistic ideas, perceptual cues focussed upon, 'telling' words used, and apparent meanings attached etc. A margin was used for recording identification numbers and a right hand column was added for coding purposes. Each response (written, drawn, or transcribed) was considered in turn, then information was abstracted according to the system indicated above and further points of interest were noted. The abstracted responses were compared and contrasted, then grouped into categories of perceived similarity and coded. If the categories showed some perceived general trend in character or complexity, they were arranged in a trend order. The specific procedures used may be found in sections 6.5, 7.5, 8.5, 9.3.3 and 9.4.3. The same categories were used for both interview and survey data and the results were entered on a computer for further analysis. The SPSS-X Batch System was used to sort and display the data by year-group. It was also used for recoding variables and for statistical analysis. Coded interview data may be found in Appendix 3.9 and that for survey data in Appendix 3.10.

4.7 Limitations of this study

There were two kinds of limitations on the methodology and findings of this study, namely, what was possible 'practically' and what was possible 'within the theoretical/epistemological framework of the study'.

Beginning with the practical procedures, outlined in this chapter, it would appear that they were limited, first by the effectiveness of the survey questions and interview questions in eliciting the children's ideas about particular topics of interest to the researcher. As indicated in para. 9.3.2, for example, the alternatives were a narrowness of question focus that might cue a response and an open eliciting style that might invite responses which could side-step the issues of interest to the researcher. The limitations of either course of action just had to be accepted. Second, and related to the first, was the skill of the interviewer in both probing responses and also in maintaining a position of both neutrality towards the content and yet showing interest. A third limitation lay in the attitude and expressive skills of the pupils. A lot depended on how much the pupils were prepared to offer in terms of ideas and what conceptions they were able to express verbally, or by non-verbal signals, or by diagrams. A fourth limitation lay in how the researcher interpreted the pupils' meaning when he categorised the responses. Because pupils were often imprecise in their use of words and may not have differentiated accepted meanings of several of their response words, there was bound to be some uncertainty or ambiguity in categorisation. A fifth limitation was the 'environmental effect' and it included the influence of researcher (and other occupants) of the 'research-room', the tape recorder, the apparatus used, the 'school', even the school-bell that sometimes interfered with the child's punch-line! Examples of all five types of limitations will be illustrated in later chapters as well as in other parts of this chapter. Having recognised that these limitations were present in the study, it must also be stressed that every effort was made to reduce their influence on the outcomes, so it may be claimed that most of the findings should be, at least, recognisable in school classes. The sampling, should enable generalisations to be made to school year-groups corresponding to those investigated in this study.

The limitations of the study 'seen' from an epistemological viewpoint relate to the heavy dependence of the study on linguistic communicability. Constructivist philosophers regard the linguistic communicability of knowledge as an illusion (von Glasersfeld,1986). They suggest that, because we often interact successfully with others we get the impression that ideas or knowledge can be transmitted by words. Von Glaserfeld argues:

> But ideas and knowledge are formed in people's heads and have no way of existing outside the heads that have formed them. The power of words, indeed, consists in evoking experiences or conceptual structures, in the language user's head; but in order to be called up, these experiences and conceptual structures must be already in the language user's head. They are associated with words, but they don't travel from one person to another with the sounds which the persons recognise as words. Associations, be they emotive or semantic, are subjective in the sense that they must be made by each individual in his or her own experience. (1986, p.2)

Because the researcher cannot uncover the associations between children's words and their conceptual structures any more than the child can uncover the associations between the researcher's words and his conceptual structures, the research findings are limited to being viable models of children's 'real' constructs.

4.8 Reliability and validity issues in this study

The central question that is addressed in this section is how, or to what extent (or even whether) the concepts of reliability and validity, as traditionally conceived, may be applied to this piece of qualitative research. The discussion begins by outlining the two current approaches to this topic and summarises the philosophical base that underlies each of them. The discussion continues by reviewing the methodology of this study from both perspectives so that the reader may make some assessment of the internal 'reliability' and 'validity' of this study together with an appreciation of the problem associated with establishing its external 'reliability' and 'validity'.

4.8.1 An approach derived from quantitative methodology

The first approach is one outcome of an attempt, in recent years, to offer specific procedures to qualitative researchers that are considered to promote the trustworthiness of their findings, see, for example, Guba (1981), LeCompte and Goetz (1982), Miles and Huberman (1984). The work of LeCompte and Goetz will be taken as an example of this approach towards achieving reliability and validity through the use of recommended procedures. This perspective starts with the definitions and methods of quantitative research and, in a systematic fashion, asks how each of these may be applied in the area of qualitative inquiry. The result is a thoroughly derived set of procedures that are intended to guard researchers against any supposed 'threats' to the credibility and accuracy of their work. Such an approach leaves the concepts of reliability and validity, drawn from a quantitative 'setting', largely unchanged. Procedural details will be considered later.

4.8.2 An approach derived from epistemological assumptions

The idea of taking procedures from a form of enquiry, that has different epistemological foundations, has been questioned by Smith (1983) and Smith and Heshusius (1986). They object to such direct transfer of procedures because they believe that such procedures carry with them the realist epistemology that underlies them. For example, LeCompte and Goetz (1982) assert:

> Validity necessitates demonstration that the propositions generated, refined or tested match the casual conditions which obtain in human life. There are two questions involved in matching scientific explanations of the world with actual conditions in it. First, do scientific researchers actually observe or measure what they think they are measuring? This is the problem for internal validity. Secondly to what extent are the abstract concepts and postulates ... applicable across groups. This addresses the issue of external validity... (p.43).

It would appear from the underlined words that the researcher is required to produce research results that correspond to how people, out there, in an independently existing 'world', actually construct their 'world'. Smith argues that in qualitative enquiry there must be a different conception of validity - one based on epistemological assumptions such as: reality being regarded as mind-dependent, truth regarded as agreement between interpretations, and the impossibility of separating facts from values. He rejects the view that certain procedures are necessary to establish a correspondence of our words with an independently existing reality' (p.9). Such correspondence, it is asserted, 'requires independent access to both domains of mind and an independently existing reality' (p.10). According to this view validity cannot be conceived in terms of 'correspondence'.

Since both of the approaches, outlined above, are current in social science research, the validity and reliability of the 'dissolving' study will be reviewed from both perspectives.

4.8.3 Implications of the first approach for this study

The procedural details for making an inquiry trustworthy, according to LeCompte and Goetz (1982) arose when they asked: how are the 'tenets of reliability and validity translated and made relevant for researchers in qualitative, ethnographic or phenomenological traditions'? (p.31). In their view:

> External reliability addresses the issue of whether independent researchers would discover the same phenomena or generate the same constructs in the same or similar settings. Internal

> reliability refers to the degree to which other researchers, given a set of previously generated constructs, would match them with data in the same way as the original researcher. (p.32)

In general then, reliability amounts to the 'extent to which research studies can be replicated' (p.35). That being so, a measure of the reliability of the 'dissolving' study could be obtained by having an independent researcher conduct the same inquiry using the same procedures in similar settings. After that, one would have to enquire as to the extent to which this independent researcher obtained the same findings. As LeCompte and Goetz comment: 'this poses a herculean problem' (p.35), for an independent researcher would be a different person, interviewing different children in different surroundings. Different children would need be involved because an interview is a learning situation. Watts (1984) recounted his interview experience as follows:

> It is clear from the comments they (pupils) make before, during and after the sessions that their ideas are themselves affected by the discussions...From this point of view it is highly unlikely that had I returned to reinterview Colin with the same questions that I would have elicited the same responses. Pilot attempts at reinterviewing in this way made the point convincingly. (p.13).

It could hardly be expected that a different interviewer, in different surroundings with different (and limited number of) children would obtain precisely the same sets of responses.

Indeed, it is not unknown for different researchers to 'interact' with <u>inanimate</u> matter under laboratory conditions and obtain several different outcomes. How much more likely are there to be different outcomes[1] in interpersonal interactions.

Because replication makes insurmountable demands, LeCompte and Goetz have suggested that qualitative research should attempt to <u>approach</u> rather than attain reliability. In their view, such a need arises from factors such as 'uniqueness or complexity of phenomena and the individualistic and personalistic nature of the ethographic process' (p.37). They suggest that in order to 'approach' reliability attention should be paid to five features of the research situation: researcher status position, informant choices, social situations and conditions,

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1. From a constructivist perspective, such differences and apparent 'unreliability' (- a realist viewpoint) does not devalue varied researcher-pupil dialogue. Rather it uncovers a wider range of hitherto untapped personal knowledge. What would reduce the authenticity of the inquiry would be a lack of interest, commitment or eliciting competence on the part of the researcher.

analytic constructs, and, methods of data collection and analysis. Each of these features will now be reviewed in relation to the methodology of the dissolving study.

The influence of researcher status position is important in attempts to replicate inquiry. Similar perspectives are likely to be obtained only if an independent researcher assumes a comparable role to that of the original researcher i.e. a person who has attempted to assume a learner role in relation to children's knowledge.

The second feature, informant choices, refers to the description of pupils to be chosen for interview and the decisions that led to their selection. In order to 'approach' a replication of this study, an independent researcher should ask a headteacher to select two high ability, two average ability and two low ability pupils from each year-group, each pair to include a boy and a girl. The choice of six pupils from a large year-group depends on teacher assessment of 'ability' and personal qualities of the children. For example, teachers are unlikely to select pupils who for some reason would find it difficult to talk to a comparative stranger. (It was felt that during the interview phase, when teacher action was particularly strong, a demand for random selection together with more time for ability testing would have been unacceptable.)

The third feature to be considered in relation to reliability is social situation and conditions. So far as the physical and social context for interview is concerned, research in schools is dependent on the availability of rooms such as: headteacher's study, library, staff room, preparation room, a corridor, a laboratory etc. Frequently, there were spectators such as headteachers, curious members of staff and pupils. As 'guests' in schools, researchers have to accept the wider physical and social context but have some control in providing a pleasant, open and accepting researcher-pupil relationship. Any researcher attempting replication would have to work under variable conditions as indicated above.

The fourth issue concerns the analytic constructs and premises to be used by the replicating researcher. LeCompte and Goetz suggest that the same assumptions and metatheories should be used as those employed in the original study. In this study it was assumed that the pupils actively constructed ideas (about matter and the process of dissolving) as a result of daily life experience and social interaction. Children's responses were valued as an expression of their current personal conceptions. It was also assumed that pupils could be assisted towards a greater awareness of their personal knowledge in an interview situation. Insofar as other researchers share these assumptions and values they may be able to 'approach' replication. However, analytical constructs are more difficult to replicate, for although they 'arise from the data', different researchers may focus on slightly different elements of the pupils' responses, simply because they have different personal conceptual schemes and values. Consequently the sets of categories that emerge may differ in some respects.

The fifth, and last, feature that has to be addressed when seeking to establish inter-researcher reliability is the <u>method of data collection and analysis.</u> So far as the 'dissolving' study is concerned these methods are laid out in detail at the beginning of each data chapter i.e. Chapters 6,7,8 and 9. Methods of data collection, interview and survey, could be followed since sufficient procedural steps are specified. However some differences could arise from probing interview responses as these are difficult to predict in a precise way. The extent to which the methods of analysis may be followed by another researcher will depend on the degree to which conceptual schemes are shared with the original researcher.

Having reviewed procedures that should, according to LeCompte and Goetz, enhance reliability procedures will be considered that are claimed to make research 'valid'. Procedures, used in the dissolving study will be reviewed in the light of the recommended procedures. While admitting that there are many problems with reliability, LeCompte and Goetz suggest that validity may be the major strength of qualitative research because:

* long periods are spent with the participants during which data collection and analysis may be refined; also matching between categories and participant reality may be ensured;
* informant interviewing is a less abstract data source than instruments used in quantitative research designs;

* participant observation occurs in natural settings as opposed to contrived settings.
* the researcher undergoes self-monitoring - that open the research activity to continual questioning and re-evaluation.

In order to reduce 'threats' to the validity of ethnographic inquiry, they suggest that researchers take account of: history and maturation, observer effects, selection and regression, morality and spurious conclusions. Each of these will now be considered insofar as they may influence this study.

Because an extended time of researcher-pupil contact is involved in qualitative research, it is considered important to consider history and maturation effects i.e. which data remains constant over time and which changes. So far as this study was concerned, the interview period gave the pupils more opportunity to change their minds as they thought through the implications of their ideas. The extra time, over that taken for the survey task, made it possible for them to consider alternatives and in that sense make a more considered judgement. Another time-related effect was the development of 'response-probing' skills as the researcher gained experience over the period of the study. This effect was reduced by conducting several pilot interviews.

Observer effects refer to the possible influence of his/her very presence. In order to minimise the possibility of some children being overawed on the one hand or, being out-to-impress on the other, the researcher chatted informally with the interviewees at morning registration. This dialogue was continued at the outset of each interview to enhance rapport and create conditions under which the child's perspective on presented phenomena could be elicited. Accordingly, the child's own words were taken up and used by the researcher where it was thought that such an approach would help to keep the communication at the pupil's language 'level'.

Selection effects refers to the possibility of distortion of data as a result of lack of diversity of types of participants in the study. Because of the immense amount of time involved in setting up, conducting and analysing interviews it was necessary to restrict the sample of interviewees. Careful selection was required to sample a representative sample of the population. In this study, schools were chosen that represented the broadest range of catchment areas and, within schools, pupils were sampled from the whole ability range.

Mortality effects did not arise in this study since there was insufficient time for loss or gain of participant group members during the period of study.

Spurious conclusions sometimes arise in research when relationships (e.g. cause-effect, covariation etc) are presumed or postulated. A possible source of spurious data, in this study, was to presume that the words children used had lexical meanings. Attempts were continually made to elicit word meanings and if these could not be expressed, associated situations, in which the word was used, were elicited.

4.8.4 Implications of the second approach for this study

The conceptions of reliability and validity as defined in the first approach are not compatible with the assumptions made by constructivist epistemologists. They find it impossible to conceive that any (research) situation can be replicated because the researcher and participants will have modified their conceptions, in some way(s), as a result of the first enquiry. They claim that it is not possible to separate the investigator and the investigated, (Smith and Heshusius,1986). Consequently, reliability as conceived in realist terms is non-existent. They also contend that research findings cannot be matched to an external reality since 'independent access to both our minds and an independently existing, uninterpreted reality' is not possible. Thus they cannot accept the realist's view of validity. Smith and Heshusius claim philosophical support for this view from Goodman,1978; Putnam,1982 and Rorty,1979.

If 'reliability' is inconceivable and 'validity' not possible, what assessment can be made of the trustworthiness of research findings? From the constructivist viewpoint, research findings are interpretations and 'validating' is interpreting the interpretations of others. As Smith and Meshusius summarised the position:

> Quantitative inquiry aspires certitude to the idea that our descriptions can match actual conditions in the world and that we can know when this matching occurs and when it does not. This certitude is achieved primarily through an adherence to proper techniques. For the qualitative perspective, inquiry is a never ending process (hermeneutical) of interpreting the interpretations of others. All that can be done is to match descriptions to other descriptions, choosing to honour some as

> valid because they "make sense", given one's interests and purposes. There is no rule book of procedures to follow. (p.9)

The concept of interpretation is therefore a key issue in the conceptualisation of 'validity' from a constructivist viewpoint.

How such a view relates to the 'validity' of interpretations of pupil's responses will now be examined. A framework for an analysis of the interpretative process has been suggested by von Glasersfeld (1983). It will be adapted for the purposes of this discussion. He says that when we make a statement such as: "R interprets X" we have in mind the following elements:

(i) an active researcher (R, the interpreter);

(ii) a pupil's response (X), which is experienced by R;

(iii) a specific activity (interpreting) carried out by R;

(iv) the activity's result (I), an interpretation which is not part of R's immediate experience of X but is linked to X by some relation known to R.

We may also assume that an originator or pupil(P) produced the response X to convey an intended meaning (M). Neither the meaning M, nor the interpretation I, is a constituent part of the response X. M is the result of an act of association on the part of P, and is in P's head. I is the result of R's interpretative activity and is therefore in I's head. There is no way of comparing M and I for 'match' - a requirement that realist's expect when they define 'validity'. Von Glasersfeld summarises the position as follows:

> The requirement that an interpretation of X, in order to be considered a correct interpretation, must <u>match</u> the meaning an originator has associated with X, is just <u>another</u> manifestation of the epistemological ingenuousness that leads realists to the unwarrented belief that what we experience should in some way <u>correspond</u> to an ontological reality, and that if only we try <u>hard enough</u>, we shall finally have a "true picture" of the world as it is. (p.208)

To return to the application of constructivist perspectives to the children's responses in this study, fig 5.1 illustrates a sequence of interpretative processes. Prior to process 1., in the diagram, there would be some observed phenomenon such as 'dissolving' that is not shown in the diagram. The child's overt response (X) to the phenomenon is the result of a personal act of construction that took place in the child's head.

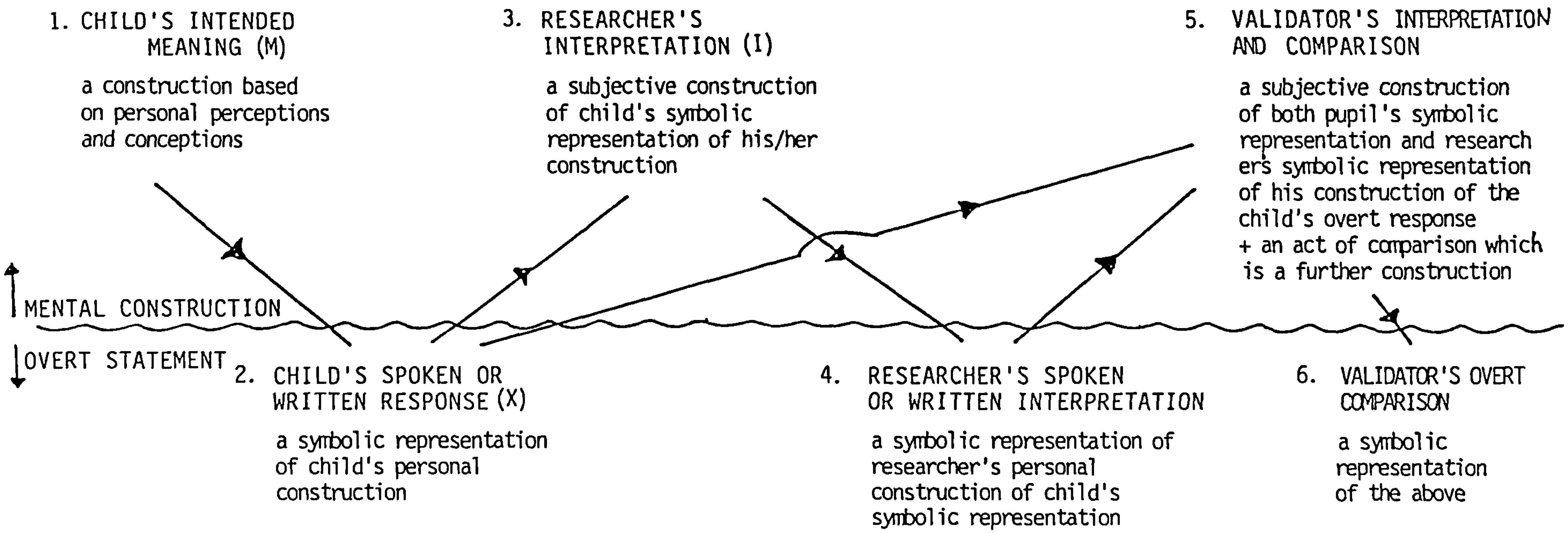

Fig. 4. 1 A diagrammatic representation of a sequence of interpretation processes. (Its sole function is to illustrate the rational inaccessibily of ontological reality - in this case <u>replicating</u> the child's intended meaning).

The child's intended meaning (M) was located there also and hence was inaccessibile to the researcher. The researcher had to interpret a spoken or written expression of the child's meaning. The language used in the child's response may be regarded as the product of a child's 'life-story of associations' of words with particular personal and social experiences. However, the researcher had to attribute a meaning to the child's language and this activity took place in the head of the researcher. However, he was unable to compare and contrast his (subjective) construction of the child's meaning with the child's (intended) meaning because the latter was formulated in the child's head. Not only did he have that limitation but he also expressed his interpretation in a form of words behind which lay the researcher's 'life-story of associations' of words with personal and social experiences.

Let us suppose a 'validator' is brought into the situation with the task of confirming or refuting the researcher's interpretations. Then, according to the constructivist view, he may undertake a similar, but distinctly personal enquiry to that of the researcher (as he reflects on the child's overt expressed response). Also he will endeavour to construct an interpretation that he can compare and contrast with his interpretation of the researcher's construction of the child's response. In other words the 'validation' involves two further acts of personal construction beyond those the researcher has made. The 'validator' would also bring to his work personal (and necessarily somewhat different) conceptions and language meanings. Some differences in these matters might be diminished as a result of reflecting on all the responses (rather than a sample) and by employing a consensus meaning system to that used by the researcher. However, in view of the subjective character of all that the exercise involves, and, the inaccessibility of both the child's mental processes and those of the researcher, differences of interpretation are almost inevitable. Agreement depends on the degree to which all parties share meaning, values and interests.

Let us suppose that a validator compared children's responses with researcher's interpretations. We have already argued that one cannot confirm whether the researcher has represented the 'actual' ideas held by pupils. If it was felt reasonable to disregard personal differences in the experience, knowledge and language meanings of the child, researcher and validator, then it is, possibly, conceivable that the researcher's interpretations could be tested for 'harmony' or 'mutual fit' with the overt responses of the pupils. That is, one could consider whether the interpretations are models of the responses. It might be necessary to modify a particular model given more cases (pupils' responses). Since, constructivism precludes the knowing of 'reality' or 'actuality', modelling is the most that validation can achieve but still at a considerable price in terms of subjective differences which are disregarded.

4.8.5 The position taken in this study

Although the conventional structures for 'good' practice have, as already explained, been observed, the researcher is convinced that these do not, of themselves, guarantee reliability and validity as traditionally defined. This is because constructivist assumptions about the nature of knowledge preclude any claims about reliability (traditionally viewed as replicability) or validity (traditionally viewed as correspondence with an independent ontological reality). According to the constructivist approach there are at least three reasons for the position just stated.

First, both the ideas that pupil's offered and the interpretations the researcher placed upon them were constructed in the heads of the pupils and the researcher respectively. As such, it was not possible for anyone to have an (omniscient) 'God's eye view' (Putnam,1981,p.74) of either of these mind-constructions, in order to establish their correspondence or otherwise.

Second, the categorisation and interpretation of pupil's responses were a function of the researcher's conceptions, interests, values, skills etc., as indeed were some of the outcomes of the interviews. That is, separation of both the researched and the analytic procedure from the researcher was not possible.

Third, the language in which children's responses were expressed (or indeed that of the researcher) may not have been an adequate representation of 'intended' meaning. Again we have a mind-dependent factor that could not be verified without a 'God's eye view'.

In view of these epistemological considerations, we shall now layout what claims can be made about findings of this study.

First, this study has been undertaken in consultation with experienced researchers[1] in this field of study and, where practicable, their comments have been valued and assimilated. Further, conventional approaches to research, culled from the literature, have been adopted or adapted in this study. Thus it has not been an entirely idiosyncratic exercise. There is evidence, therefore, that the constructions of the data are communicable.

Second, it is held that the findings of this study represent a 'picture' or 'model' of expressed and interpreted children's ideas (though not necessarily their intended meanings) as 'seen' by the researcher (with his current set of conceptions, values, interests, knowledge, etc). From a constructivist viewpoint, this study, like any piece of carefully designed and executed research, has the status of just one viable model of reality - not claiming ontological status. However, it does claim to model recurrent sets of features in children's thinking about dissolving. It is anticipated that readers may recognise many of these patterns. Moreover, similar frequency patterns were found in the responses obtained from both interview and survey samples of the school population. Such findings would appear to approach confirmation of the researcher's construction of reality (though not, of 'reality' itself). It is further expected that teachers could find the response patterns a useful starting point for planning classroom interaction.

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1. Helpful comments and advice have been taken from: Dr. R. Driver, Professor D. Layton, Dr. D. Shorrocks, Professor R. White, Professor J.A.Easley Jr., Dr. B. Andersson, Dr. A.E.Wheeler, Professor P. Guidoni, Dr. W.Dierks, Professor S. Strauss and others. However, the researcher takes full responsibility for the procedures taken and the outcomes recorded.

CHAPTER 5

SOME SIGNIFICANT CHANGES IN THE THEORY OF DISSOLUTION IN THE HISTORY OF SCIENCE

5.1 Introduction

Many theories about the dissolution process have been generated throughout the history of science. Several of these theories are included in this chapter for a number of reasons. In the first place, such a study has human interest value in that it relates to personal and social knowledge construction. In Chapter 2 it was noted that some constructivists have put forward metaphors such as 'person-the-scientist' to describe aspects of human behaviour. The history of solution theories provides examples of, and an insight into, some of the ways in which scientists operate. (It will be of interest, in later chapters, to observe how children interpret similar phenomena, to what extent they generate invisible constituent entities and how general are their theoretical conceptions).

In the second place, the evolution of ideas about solutions may be of interest to anyone who is engaged in the study of conceptual change. So far as constructivist teachers and researchers are concerned the ways in which children's ideas are modified or re-structured are a current focus for enquiry. For instance, interest may centre on the difficulties encountered by children who attempt to construct current science models for themselves. Some similar difficulties may have been expressed in the past and overcome in ways that have pedagogical usefulness. If teachers are aware of the influences that challenged historical research programmes they may be better equipped to facilitate changes in pupils' conceptions about solutions.

In the third place, the theoretical constructs of 'eminent' scientists may be used to advantage in a 'constructivist' classroom. Sometimes, classroom situations arise in which children are embarrassed by the realisation that they have proffered an idea that is not the generally accepted one. Teachers, familiar with historical conceptions, may be able to put children at ease by telling them that famous scientists had similar ideas. The suggestion that the children are in eminent company may not only check embarrassment but also prepare the way for questions about subsequent change of scientific ideas. This, in turn, may lead children to a better understanding of the nature of science. Bent (1971, p.133) has listed a number of useful examples of 'misconceptions' held by many 'chiefs' of science in previous centuries.

Thus historical conceptions of solutions may be of interest to both cognitive development researchers and teacher-researchers. For the former group there is a theoretical interest in conceptual change, and, for the latter group, there is material that is likely to motivate interest, facilitate conceptual change and encourage pupil-teacher discussion/interaction.

5.2 Some noteworthy theories of dissolution

It would appear to be a human characteristic that, when presented with a phenomenon, diverse ideas about its origin, effects or function are generated. This would certainly seem to apply to conceptions of dissolving and to solution properties. In effect, it is as though philosophers and scientists have put a question such as, 'What entities and organisations are likely to underlie sense impressions such as the disappearance of solute, transparency of solution, constancy of mass, modification of volume, alteration in temperature, and eventual saturation?', and then proceded to generate several possible ideas. As we shall observe, some of these ideas survived for a considerable period before being superceded. However, according to Lakatos (1978), research programmes that are most successful should not only have explanatory value, but also predictive value. Unless predictions are fulfilled, programmes are likely to be replaced. As in other sectors of science, change and movement characterise the history of solution theory. Views as to the prevailing conditions that support change in science conceptions have been suggested by Strike and Posner (1985,p.340):

* there is dissatisfaction with existing conceptions;
* a new conception must be minimally understood;
* a new conception must appear initially plausible;
* a new conception should suggest the possibility of a fruitful research programme.

The conceptual changes that are evident in the history of solution outlined below may bear out some of these pre-conditions.

5.2.1 An interstitial atomistic model

It is possible that the earliest recorded model of a solution was the one constructed by Plato (427-347 B.C.). He built upon the notion attributed to Democritus (ca.400 B.C.), that matter consists of 'atoms' and 'the void'. He reasoned that if there are empty interstices between atoms of one substance then they could be entered by the atoms of another substance (Arrhenius, 1916). Thus by a process of interpenetration of 'atoms', Plato explained the dissolving process and accounted for the disappearance of the solute.

5.2.2 A continuous model

Aristotle rejected the conception of a 'void' put forward by Democritus. He supported a continuous view of matter. As Solmsen (1952) comments:

> For Aristotle the void is simply not there; though he nowhere says in so many words that all cosmic space is filled with body, he evidently cannot envisage the possibility that the void could arise anywhere in the world, be it only for a moment. (p.142)

Because of Aristotle's widely recognised authority in natural philosophy, it would appear that atomistic ideas about solutions were held back for many centuries.

5.2.3 The (pre-shaped) pore model

The revival of Democitan atomism was led by the French philosopher, mathematician and scientist Pierre Gassendi[1] (1592-1655). He made a general plea that philosophy should be freed from the domination of Aristotelian perspectives, indeed he regarded the philosophers of his time as 'prisoners in Aristotle's cage' (Jones, 1981). Among the fruits of this newly found philosophical freedom were Gassendi's atomistic ideas about matter. For example, one of his conjectures was that common salt crystals were composed of very small particles, called corpuscles, and, that they, like the (visible) crystals were cube shaped. He made a further conjecture that water contained empty cube-shaped pores. He explained dissolving process as though cube shaped salt corpuscles entered the cube shaped pores of water. According to his view, when all the cube-shaped pores had been filled, no more salt could 'dissolve'. In this way saturation was explained.

Moreover, Gassendi had noticed that a saturated solution of common salt could dissolve alum crystals (or other substances). He explained this observation by suggesting that water contained 'pores' that were

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1. It is worth noting that Gassendi had constructivist leanings in that he took the view that the 'human mind cannot hope to penetrate the inner secrets of nature and must be content with probable conjectures - to claim more ... is presumption' (op.cit.). Thus, he took the view that the human mind, through science, for example, cannot take the wrappers off reality.

octahedral - the shape of alum crystals - and, as he thought the shape of alum corpuscles also. He also held the view that common salt corpuscles were forbidden entry into octahedral 'pores', i.e. in the dissolution process the shape of the 'corpuscles' had to match the shape of the 'pores'.

Gassendi's assumption that the shape of a corpuscle of a substance was similar to that of the parent crystal, followed from his maxim: 'What is true of the whole is also true of the part' (see Canon XVI, op.cit., p. 116). It will be shown in Chapter 9 that children frequently have a similar idea about crystals and their 'parts'.

Robert Boyle (1627-1691), the English chemist and natural philosopher, who had a 'research programme' on the properties of gases, adopted Gassendi's corpuscular view of matter. Later he developed this view of matter to fit in with his chemical ideas of elements and compounds. The French physician and chemistry textbook[1] writer, Nicholas Lemery (1645-1715) also developed Gassendi's 'atomistic' views in the domain of acids and bases. Having observered that the usual crystal form of acids was 'needle-shaped' (i.e. sharp and pointed) he conjectured that acid corpuscles were similarly shaped - an example of 'part-resembles-whole' reasoning. The 'sharp' taste of acids was attributed to their 'needle-shaped' corpuscles. The ability of acids to dissolve metals was attributed to the penetrating power of the 'needle-shaped' acid corpuscles. He explained the neutralisation of acids by suggesting that alkalis contained 'pores' in which the sharp ends of acid particles broke off, and hence lost their acid properties.

In time, the number of different crystal shapes, known to scientists, became so large that the postulated number of 'pore' shapes seemed implausible. Consequently, the pre-occupation of theory-makers with 'shape' led this particular corpuscular theory to loose its credibility. Furthermore, analogies from Isaac Newton's current 'research programme' on the planets ('seen' as large corpuscles) had both explanatory and predictive power, and, appeared to contain the seeds of a promising alternative theory of solutions.

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1. He published 'Cours de Chymie' in 1675.

5.2.4 The gravitational-forces-between-particles model

After his success in explaining planetary motion in terms of the attraction of 'great bodies' at a distance, Newton (1643-1727) proposed the existence of 'certain kinds of forces whereby minute bodies attract or dispell (sic) one another at little distances'. He tentatively stated:

> The truth of this hypothesis I assert not, because I cannot prove it, but I think it very probable because a great part of the phenomena of nature do flow from it which seem otherwise inexplicable; such as are chymical solutions, precipitations,... (Reprinted in Cohen, 1980,p.180)

As a corollary of this theory Newton alleged that a salt can dissolve in water if the salt particles have a greater (gravitational) attraction for water molecules than they have for each other.

The concept of interaction between particles appeared to have a greater explanatory power than previous theories. There were immediate efforts to calculate these forces and relate them to solubilities. However, no relationship was found between the masses of the (supposedly) interacting 'bodies' and solubility. As a result conjectures were made about some force other than (or additional to) gravitational interaction. Before leaving Newton's major postulation of interaction between 'minute bodies', it is interesting to note that, after observing the rapid dispersal of dissolved material he generated the idea that repulsive forces between 'minute bodies' could be responsible for that effect. Thus, in his view, a combination of attractive and repulsive forces were involved in 'dissolving'.

5.2.5 The 'like-dissolves-like' model

Conjectures about some cause of interaction between 'minute bodies' of solute and solvent had their beginnings in the work of the French naturalist Georges-Louis Buffon (1707-1788). His own work sometimes involved the mixing of a variety of solutes and solvents such as water, salts, oils, fats, etc. He postulated that the form of the (supposedly) interacting 'minute bodies' would be important if they were to come into close proximity and 'dissolve'. He hypothesised that substances having similar characteristics would be made up of 'bodies' of similar form and so fulfil the stated requirement. He supported his view with the general observation that, in his experience, mutually soluble substances appeared to have a similar (physico-chemical) characteristics. A general rule seemed to apply: 'like dissolves like' (similia similibus solvuntur). (Modern chemists have a similar rule of thumb: 'polar-liquids dissolve polar-solids' and 'non-polar liquids dissolve non-polar solids'). However, Buffon was unable to speculate on the nature of the interactive forces between solutes and solvents. Theories about that subject became an important field for investigation and much controversy in the next century.

5.2.6 The solute-solvent chemical combination model

The French chemist Claude-Lois Betholl et (1749-1822) maintained Newton's proposition that all forces of 'affinity' that brought about change were, in essence, modified gravitational attraction. He also held the view that substances reacted in all proportions. As a result he did not clearly distinguish between compounds and solutions. He believed that 'real chemical changes' accompanied the dissolving of some substances in water. Such changes did not, in his view, take place between constant proportions of 'reacting' substances. Berthollet disagreed with the chemist Joseph Proust (1754-1826) that: 'a compound is a substance to which Nature assigns fixed ratios ... a being which Nature never creats other than balance in hand'. Proust was uncertain about the nature of the forces of a attraction in the dissolution of sugar but was convinced about the definite composition of sugar itself:

> The attraction which causes sugar to dissolve in water may or may not be the same as that which makes a fixed quantity of carbon and of hydrogen dissolve in another fixed quantity of oxygen to form the sugar of plants but what we do clearly perceive is that two kinds of attraction are so different in their results that it is impossible to confound them. (Partington,1951,p.157)

This controversy was taking place at a time when scientists were attempting to classify 'change' as either physical or chemical. They also tried to clarify the criteria for each type of change. Some support for Berthollet's 'chemical affinity' between solute and solvent continued for the next half century. For example, Griffin supposed that the overall decrease in volume that often occurs on dissolution was a manifestation of an 'immense external pressure' bringing already condensed phases into closer (chemical) combination. Further support came from Berthollet who attributed the heat changes that accompany solution to chemical combination. Meanwhile another (related) theory was gaining acceptance.

5.2.7 The 'hydrate' model

Between 1860 and 1880 the eminent Russian chemist Dmitry Ivanavich Mendeleyev proposed the idea of solution hydrates (i.e. compounds of solutes and water that have a definite composition). His work greatly interested English chemists and close co-operation in solution chemistry followed. The major theory during that period was known as the hydrate theory which contained the proposition:

> when a salt (or any solute) dissolves in water, the solvent first forms hydrates which are then dispersed throughout the liquid. (Dolby, 1976,p.327)

Summarising the status of the theory, during that period, Dolby states:

> The hydrate theory of solution was the most plausible method of explaining the physical changes resembling the manifestations of chemical combination that accompany the formation of a solution. (Ibid,p.302)

5.2.8 The 'mutual interaction' model

Despite the popularity of the hydrate theory, the physical chemist William Nichol, began, in 1883, to challenge it. He rejected the idea that water molecules are chemically united to the solute in the same manner as they are in 'water of crystallisation'. His theory of dissolution was based on mutual interaction between solvent and solute molecules. Thus, he hypothesised that a solution is formed when the attraction of molecules of water for molecules of solute is greater than the attraction of molecules of solute for one another (Dolby, 1976). He produced what he considered to be experimental evidence in support of his theory. For example, he claimed that his theory explained the contraction in total volume observed when many salts are dissolved in water. (It will be recalled from para. 5.2.6 that Griffin had used similar experimental data to support the chemical combination model).

5.2.9 The kinetic-energetic model

Kinetic aspects of the theory of solutions were slow to develop. As far back as the seventeenth century the physicist, Robert Hooke (1635-1703), suggested that the properties of matter, especially gases, would be better explained if the constituent corpuscles were considered to be in motion. However, he did not have the mathematical ability to develop his ideas. It was left to those who had this ability to develop a kinetic theory of gases. However it was not until the second half of the nineteenth century that kinetic theory applied to solutions. As far as some theorists were concerned, the motion of solute particles was 'seen' as analagous to the motion of gas particles.

In 1827 a botanist, Robert Brown (1773-1858) observed that particles from within (and hence much smaller than) pollen grains, suspended in water, executed a characteristic motion (Layton,1965,p.367). Brown and others examined various suspensions and concluded that this motion increased if the particles were smaller or if the medium was more fluid or if the temperature was higher. Brownian motion was regarded as analagous to that of molecules. However, evidence for the motion of 'molecules' within a solution (as opposed to a colloid or suspension) had to await the discovery of radioactivity and the work of Svedburg in 1923.

5.2.10 Mathematical modelling of kinetic - molecular ideas about solutions

Since the latter part of the nineteenth century there has been a considerable amount of experimental investigation of the properties of solutions as well as mathematical modelling of its many aspects. For example, the German physicist, Albert Einstein (1879-1955), developed a mathematical model of Brownian motion and the French physicist, Jean-Baptiste Perrin (1870-1942) did a tremendous amount of related experimental work. Perrin (1910) made it his mission to convince scientists of what he called 'molecular reality' and wrote a book having that title. He collated 'evidence for molecules' from about nine different investigations - much of it from solution science. He also made a plea that scientists would unite atomistic ideas with kinetic/energetic ideas in the further development of their theories. His book ended as follows:

> I think it impossible that a mind free from all preconception, can reflect upon the extreme diversity of the phenomena which thus converge to the same result, without experiencing a very strong impression, and I think that it will henceforth be difficult to defend by rational arguements a hostile attitude to the molecular hypothesis, which, one after another, carry conviction, and to which at least as much confidence will be accorded as to the principles of energetics. As is well understood, there is no need to oppose these two great principles, the one against the other and the union of Atomistics and Energetics will perpetuate their dual triumph. (Perrin,1910).

Leaving on one side a discussion of the possibility of having 'a mind free from preconceptions', ideas about the energy of solution particles certainly underlie modern conceptions of solution phenomena.

Since 1910, many new theories about dissolution have been generated. They have had to take account of a growing body of extensive experimental data and, also, of many changing conceptions of atoms, molecules and ions that are regarded as the theoretical interacting entities in a solution. If, as a constructivist standpoint suggests, the human mind is limited to structuring its own experience of the world, and not an ontological reality itself, then the theory making process is likely to continue.

5.3 Conclusion

Having surveyed a variety of theories that 'scientists' generated about a single phenomenon, namely dissolution, it is tempting to draw conclusions about the mode of generation of these theories and, also, the qualities attributed to the theoretical entities that are conceived to be the component parts of solutions.

The point made above, that several theories are held about a single phenomenon, would suggest that there is no single rational route from the making of an observation to formulating a theory. Close examination of the theories indicates that each scientist brought his own experience and knowledge to the phenomenon of dissolution. For instance, from what we know of Gassendi and his theory it may be inferred that some of the experience that underlay his observation and theory included: the (cubic) appearance of common salt crystals, his mental image of 'pores'[1]; acquaintance with early Greek atomism; and the maxims that formed part of his philosophy. Thus it could be argued that his conjectures were influenced by specific perceptual 'elements' (from his 'observations'), conceptual 'elements' (from his prior knowledge) together with links that were made between these 'elements'. If we assume that different personal experiences determine the character of the various 'elements' mentioned and, also, the diverse ways in which they may be assembled, then alternative theories of solutions may be expected. (Because experience is an ongoing process, the 'elements' ought not to be considered static or, for that

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1. Both Gassendi and Newton used ideas based on a conception of 'pores'. Gassendi on another occaision used skin 'pores' to illustrate the idea that certain things which are hidden from the senses nevertheless exist. The presence of pores, he said, may be inferred from the appearance of sweat. He then added a similar argument for the existance of a void: 'if there were no void, there would be no motion , which the senses do, in fact perceive'. (Jones 1981,p.XLV) For Newton's use of 'pores', see Newton 1952, p. 268.

matter, the ways of connecting them. However, if particular combinations of the various 'elements' ensue in a viable explanation, then it is likely that these will be utilised again and become 'established' as working 'schemes'.

Such a view of the activity of scientists was summarised by von Glasersfeld as:

> What a scientist finds or concludes is under all circumstances determined by the way in which he sees, the way in which he observes, and the way in which he conceptually relates the elements he carves out of his experience. (1985, p. 93)

It will be recalled that Griffin and Nicol had different ways of interpreting the overall volume change that often occurs on dissolution. Each of them used the same observation to support quite different theories. It may be argued that each scientist mentioned in our survey was, according to this perspective, (mentally) operating upon perceptual and conceptual components of his experience and not on the 'real/actual/inner' processes of dissolution. Accordingly, their theories would appear to be their way of linking elements of a dissolution process that they had constructed. If their theories seemed successful it merely meant that they were 'viable up to that point' (Glasersfeld,1975) i.e. within the limits of known experience.

Attribution of properties to theoretical entities of a solution

The attribution of properties to unseen entities is an intriguing feature of the work of the early scientists. (Modern scientists often avoid a 'physical' type of model, instead they tend to model in mathematical terms that may not allow physical interpretation).

The major principle underlying the attribution of particle properties by early scientists was to endow the atomistic 'parts' with the similar characteristics to the 'whole'. For instance, they conjectured the similar shape - e.g. cubic salt 'atoms' (Gassendi's part/whole maxim); and the same capability e.g. penetrating power of 'sharp' particles (Lemery's view of acids). Newton, however, took account of (his view of) matter having 'pores' or holes and postulated that component particles would be 'incomparably harder and so very hard as to never wear out', i.e. he enhanced the macroscopic property of matter to fit in with his theory about microscopic particles. Modern science is less explicit about such particle characteristics - indeed it would seem that, in the view of modern science, the smaller particles are, the less 'material-like' they seem to be, and, that the 'parts' bear progressively less resemblance to the whole.

Attribution of 'force' between solution particles

A landmark in the history of solution chemistry was Newton's attribution of a 'force' between small particles. Having successfully explained celestial phenomena in terms of gravitational forces, he attributed an 'attractive force' that could reach 'but a small distance' from the particles and, he said, 'where attraction ceases there a repulsive virtue ought to succeed' (Newton,p.395). This had the effect of moving chemical thinking towards some understanding of the reasons for 'affinity' between certain substances. 'Interaction conceptions' underpinned the numerous theories that followed.

Attribution of 'motion' to solution particles

The attribution of unceasing movement to the molecules in a solution seems to have been a very slowly developing idea and its acceptance comparatively late in time. Its advent seems to have originated from the 'Brownian movement' analogy. This provided a 'picture' that could counter the sense perceived static appearance of a solution, and also take account of other known properties.

In sum, it has been noted that, as a result of speculating about what underlies the dissolving process, scientists have constructed ideas about constituent entities (of matter) that are beyond the reach of the senses and that stretch the limits of the imagination. They have also attributed specific kinds of behaviour to these theoretical entities that are thought to constitute a solution. Moreover, the theoretical ideas, located in their models of solutions, were part of a more general theory of matter. In subsequent chapters, ways in which pupils interpret their experiences of 'dissolving' and the extent to which they generate 'invisible entities' will be discussed.

CHAPTER 6

SCHOOLCHILDREN'S UNDERSTANDING OF THE DISSOLUTION PROCESS

6.1 Introduction

Children of all ages are fascinated by the phenomenon of dissolution. They gaze engrosed as a hard glassy crystal of sugar slowly and silently disappears without apparent trace in still, clear water - the otherwise unyielding (permanent) object vanishes in water. The young mind is intrigued. What secret hiding places has sugar found? What disguises has sugar adopted? What invisible abrasive has worn the sugar away? What unseen blows have broken the sugar down? Does it dematerialise to sweetness? Will it ever re-appear? Personal queries like these appear to stir children to wonder about what happens, why it happens and how it happens. As a result, various schemes may be invoked, conceptions built up and individual theories generated. For some, sense experience may provide an adequate basis for answers to their quest, but, others may distrust immediate sense perceptions and may generate several mental constructions about the fate of the dissolved sugar. This chapter aims to explore the ideas pupils develop about 'dissolving', and how their conceptions relate to those taught in school science.

6.2 A School-science view of the dissolving process

Pupils may be introduced to the terms 'dissolve' and 'solution' in both junior school and early secondary school through simple experiments that relate to mixtures and the separation of mixtures. Textbooks such as 'Science from the beginning' (Hampson and Evans,1980) and 'Science 2000' (Mee, Boyd and Ritche,1980) present these terms in this way. They introduce the pupil to solutions such as salt in water, and, subsequently, contrast them with suspensions. Later the terminology is extended to include words such as solvent, solute, soluble, insoluble, filtrate, evaporate etc.

When pupils have been introduced to atomic theory and ionic theory, they are expected to think about dissolving and solutions in terms of molecular or ionic particles. It may be assumed that the transition from continuous to molecular thinking is a straight-forward step - and, that a few experiments at the macroscopic level should suffice to illustrate the ideas. See, for example, Hall, Mowl and Bausor,1973.

It is worth noting, at this point, the extent of the difference between visual experience and conceptual ideas of dissolution in the space of two or three pages of some texts (e.g. Hall, Mowl and Bausor, 1973, pp. 18-21). Instead of seeing a solitary crystal of sugar in placid water, pupils are required to imagine an ordered, strongly bonded array of many millions of molecules of sugar, surrounded by many millions of mobile, loosely bonded water molecules. Further they have to imagine that the interaction of the surface molecules of the crystal with the randomly moving water molecules, demolishes the crystal architecture without, at this stage, their having any picture of the nature of the interaction.

6.3 The eliciting tasks

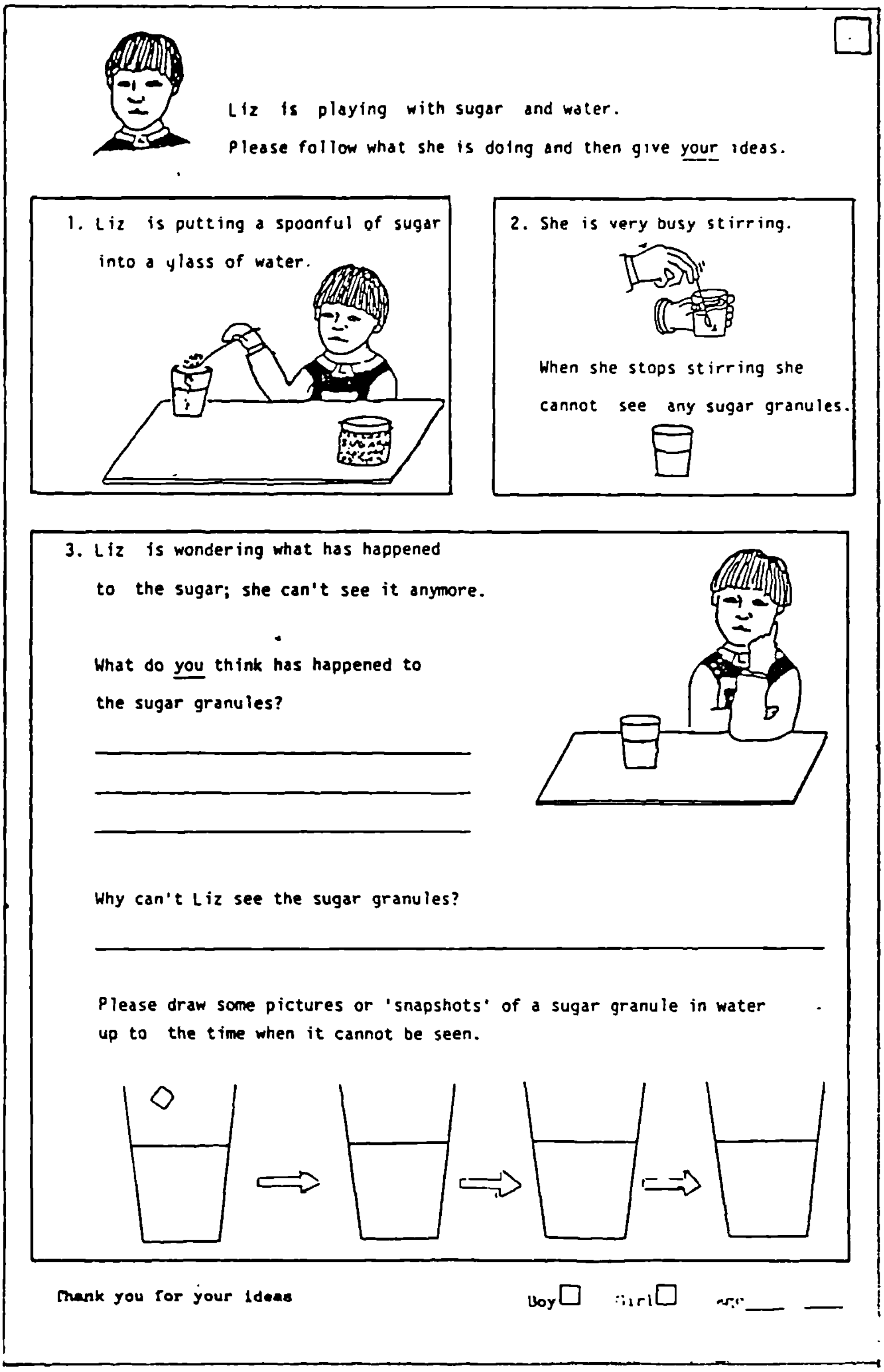
The interview task

The interview began with a conversation intended to put pupils at ease. Following this, the researcher presented some large sugar crystals and asked each pupil to handle one of them. After eliciting comments on features that interested them, pupils were asked to place the crystal in a small dish containing cold (but previously boiled) water. The interview continued as the immersed crystal dissolved. Meanwhile, pupils viewed granulated sugar under a magnifying glass and noted the similarity to the large crystals. Then, they placed about half a teaspoonful of granulated sugar into a clear plastic tumbler containing cold (boiled) water. (It had been found, during pilot trials, that pupils' observation of (dissolved) air, released when sugar dissolves in tap water, aroused considerable interest. However, it sometimes became a distraction from the main issues being probed. Consequently, boiled water was used throughout the interview). The interview proceeded in the following manner:

Researcher: 'We have some water here (in a tumbler), I would like you to put about half a teaspoon of sugar in the water, give it a stir - hold it (the tumbler) in your hand in case you spill it - and tell me what you think is happening in there (tumbler).
(Depending on the response) 'What do you think that word means? What happens to sugar when it ... (pupil's word(s))?'
'Anything else happening?'
This may be followed by further probing depending on the nature of the responses.

The survey tasks

Each step in the procedure, illustrated below, was demonstrated by the researcher as he, and the class, read aloud the description of each activity. In the case of the drawing activity they were asked to imagine what 'snapshots' would look like after, say, one minute, then two minutes. In the last tumbler sugar could not be seen.



The Survey Task

6.4 Aims in the analysis of responses

It was envisaged that by allowing children to observe sugar being stirred with water and not at the same time employing any words that could cue a particular view of the phenomenon, its designation, or mechanism, it might be possible to analyse for the aims listed below.

* Identify the children's words for and/or descriptions of 'dissolving'.

* By taking up the children's words during interviews and probing them, attempt to ascertain what meanings they give to these words (e.g. to 'dissolving', 'melting', 'evaporating' etc.).

* Enquire into possible changes in the use of words and their meanings, through the school years.

* Identify any underlying ideas about matter that are uncovered by the task, in particular, any atomistic ideas that pupils may possess.

6.5 Analysis procedure for interview and survey responses

Analysis was undertaken by scanning interview transcripts and survey responses for: first, the words/phrases used to describe dissolving; second, for the suggested reasons why sugar could not be seen; and third, for the types of diagram offered to illustrate the 'fate' of a dissolving sugar crystal.

Within the three sections, a particular response was compared and contrasted with each successive response. Then similar responses were grouped into categories. Each category was labelled with an identifying code label for both convenience in handling data and computer purposes.

In the first section, the words used to describe the phenomenon of dissolving were, in fact, the basis for category grouping. However, interview probing indicated that the same word might have different connotations when used by different children; also, different words might have a similar connotation. Thus the category system, outlined above, does not take account of these more precise features and should therefore be studied with these limitations in mind. The more precise features of the meanings assigned to particular words are discussed in the analysis of interview responses by year-group. Clearly, such probing was not possible for survey responses. Although it was not requested, a few children offered some explanation of the dissolution process. These explanations were categorised as indicated above.

In the second section, where pupils were required to explain the invisibility of sugar, the basis for the explanatory category was the level of explanation. These levels were: molecular conceptions that incorporated ideas from prior experiences (i.e. molecules fitting/hiding between molecules or molecules too small to be seen); visual perception extended to an abstract conception (i.e. granules reduced to a size that could not be seen); immediate sense perceptions (i.e. the transparency of both granules and water, or the change from solid to liquid); and, descriptive only (i.e. that's what happens when sugar dissolves, melts etc).

In the third section, where pupils were required to draw a diagram, the basis for category grouping was either successively smaller diagrams of the crystal, or broken-up crystals, or a combination of both types of diagram. Essentially, these were the only types of diagram offered.

6.6 Findings from the interview responses

6.6.1 General characteristics of the responses

Pupils responded readily and with remarkable interest to this simple task of dissolving sugar granules in water. Younger pupils tended to describe first the circular motion of the granules, and then how they sink to the bottom of the tumbler. While the granules were still visible, pupils would sometimes describe the solution as 'white'. They often stopped stirring when they spoke and needed to be reminded to continue stirring, sometimes, on more than one occasion. They didn't appear to expect half a teaspoonful of sugar to dissolve in about 50 cm^3 cold water. If they offered a single word to describe the process of dissolving, they were asked what they understood by that word and also describe other occasions when they had used that word. Often they were unable to offer their meaning for words like 'dissolving' or 'melting' but they could give examples of substances and occasions when they thought these words applied. A few pupils offered ideas about how dissolving happens. Again, some did this later in the interview - as though they had been working on the problem during the interview.

6.6.2 Characteristics of responses considered by year-group

Third-year schoolchildren (7/8-year-old)

When asked to describe what happened as they stirred a spoonful of granulated sugar with water, most of these children responded with the plain statement: 'it's dissolving' (or 'it's melting'). Further probing as to what happens to sugar when it dissolves, elicited phrases such as 'it disappears', 'it's gone away', 'it's all gone' and 'can't see them'. The frequency with which immediate visual sense impressions were reported suggests that the vanishing sugar was the most dominant feature of this year-group's experience of 'dissolving'. Still further probing as to where the sugar had gone often evoked the response 'into the water'; thereby indicating that the sugar had, in some (as yet) undisclosed way, been preserved.

Some pupils generated a variety of ideas about the means by which this 'vanishing-act-yet-with-continuance' was accomplished. One child suggested that the sugar was merely disguised:

> 'when they (sugar granules) get wet, they are more camouflaged like the army people' (3.209b)

This response appears to hint at an early conception of transparency - embedded in the phrase 'when the sugar is wet'.

Some children offered 'melting' as an explanation of the phenomenon. They supported this view of dissolving with observations such as:

> 'they (sugar granules) just go all runny' (2.202g)

By such means pupils showed they had a notion of change of state of sugar along with its continued existence. Further probing of their personal experience of 'melting' evoked memories of ice-cubes, snow, wax, chocolate and plastic. Since the accepted conceptions of melting and dissolving often share a common visual feature (i.e. change of state), though they differ in the number of substances participating in change, the lack of differentiation is understandable at this age. (Furthermore, these pupils had the added disadvantage that both sugar and water were colourless). It would appear that these children focussed particularly on the transformation of the sugar without taking the water into consideration.

Other pupils took account of both sugar and water. Generally, they regarded water as the active agent for dissolving:

> 'the water's made the sugar turn to water' (3.211b)

When this kind of response was given, it was usually possible to establish that the pupils did not mean transubstantiation. Such responses were probed by asking whether the 'water' was the same as the water in which they put the sugar - pointing to each container in turn. 'Different, it'll be sweet' or 'kind of a bit cloudy' were their replies.

They did not have a word in their vocabulary to describe 'what looked like water' but was really a 'solution', so they called it 'water'. The 'invented' cloudiness of water highlights this difficulty. On a number of occasions the researcher has noticed that some children's descriptions included 'observations-that-are-beyond-vision'. They seemed to do this when they were unable to convey their meaning in any other way. For instance the 'cloudiness' quoted above may have been used to indicate that something else was present in (transparent/clear) water. It may be regarded as an early attempt to differentiate between a 'solvent' and a 'solution'.

Some third-year pupils explained the 'vanishing sugar' by suggesting that the granules had become so small they could not be seen, for example:

> 'you stirred them so much they went into tiny little bits, you can't see them' (3.207g)

Further responses and their diagrams showed that this was not a construction of Daltonian atomism but simply a subdivision of granules into smaller bits of granules. It was an example of Piagetian atomism[1]:

> 'the atoms of our subjects are nothing other than particles themselves cut down in size and having become entirely invisible' (Piaget,1941/74)

It is interesting that none of these pupils conserved the weight of sugar in a subsequent conservation task. Their 'atomistic conception' did not assist them to conserve weight/mass; it could be that the idea of granules getting smaller had the reverse effect.

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1. Piagetian atoms, are from a science viewpoint, 'continuous bits' of matter i.e. aggregates of Daltonian atoms.

Although the (imaginary) 'bits' of sugar granules were rarely mentioned when third-year pupils were describing what happens when sugar is stirred with water, these 'atoms' were quite common when they were asked to draw what they might 'see' in the 'water' after they had actually stirred sugar and water together. Most of them described what they had drawn as 'little bits' of sugar (see chapter 9).

It would appear that the 'continuous bit' atomism is comparatively easy to handle in the imagination but it may be difficult to 'hold on to' when they observe solid disappear; there may be a cognitive conflict. Because these 'atoms' are 'bits of sugar' they are 'seen' as solid bits and there is evidence from children's responses that pupil's cannot decide the end point of the 'bit-making' process (see chapter 9). In that case some pupils may feel more comfortable with a liquefaction concept. The researcher has encountered a similar difficulty when trying to illustrate the solution process using solid models (such as silver dragees 'dissolving' in 'hundreds and thousands'). The model was not accepted because in the pupil's view, the dragees did not dissolve[1].

Fifth-year schoolchildren (9/10-year-old)

Although this year-group offered similar ideas to those of the lower year-group, interesting differences arose as the pupils attempted to differentiate existing concept-words and adopt new ones.

The word 'melt' for example was used in three ways. Some continued to use it in the same sense as third-year pupils:

> 'it melts like ice and just changes into water, nearly all gone now' (5.305b).

Another used the word 'melt' as an analogy for 'dissolve':

> 'it sort of melts, it isn't melting' (5.311b).

while another used it synonymously with 'dissolving', for when she was asked what happens when sugar melts, she replied:

> 'the sugar's goin' and disappearin' you can't see it in the water most most of them well about all of them have gone there's only tiny little bits left gone into the water and made the water taste' (5.312g).

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1. Their view of dissolving was closer to 'disappearing' than it was to mixing and dispersing.

A 'new' word for dissolve appeared in the responses of this age group, namely 'evaporate' and this caused differentiation problems. Some of the conceptual difficulties arising from an attempt to use this new word are illustrated in the following conversation between the researcher(R) and David(D):

R: I'd like you to put about half a teaspoon of sugar in that water, give it a stir, and er tell me what is happening to the sugar in there.

D: It evaporates

R: That's a big word, hold it (the tumbler) in your left hand, what does evaporate mean?

D: erm disappears into the air

(stirring continued until a clear solution was obtained)

R: So where is the sugar now?

D: It's disappeared

R: Where has it gone to do you think?

D: Still in the cup but you can't see it

R: Just now you told me it had gone into the air - and now you tell me it's in the cup, - which is it in? - or is it in both? what are you trying to tell me?

D: I just 'ad another idea, cos you might be stirring it and stirring it and crushing it up tinier and tinier, like a mint when you suck it and it eventually goes.

R: Well, tell me did you mean it was in the water or in the air which did you mean?

D: In the water and you can't see it

R: Did you at one time believe it went into the air?

D: Yes

R: When did you change your mind? - can you tell me?

D: Just now

R: What made you change your mind do you think?

D: It can't go into the air really

R: Um um that's interesting, why do you think it couldn't go into the air?

D: 'cos it wouldn't go I'd see it

R: So, what makes you think the sugar's still there

D: Don't know, I just think it is

R: Is there any way of finding out do you think?

D: Using a microscope

R: And what would happen if you used a microscope?

D: Look into the water and see if you could see any bits.

It would appear that, originally, David's construction of the word 'evaporate' just fitted David's model of dissolving sugar. Conceptual change took place, it seems, when he realised that, if his model was viable, he would be able to see the sugar going into the air. This he did not observe, he was somewhat embarrassed by his former idea and very soon generated a new one based on a personal experience. He continued to hold this new model throughout the rest of the interview and was able to propose an experiment to verify it. (At his age, he could not be expected to know the limitations of a microscope).

Five out of the eighteen pupils in this year-group gave responses that included the word 'evaporate'. The kinds of association they made with the word 'evaporate' are illustrated in the following interview quotations:

> 'like tea when you put a spoonful, it goes down it evaporates and goes into water' (5.305b)
>
> 'it dissolves it evaporates it floats' (5.318g)

When asked for their ideas of what happens to things when they evaporate:

> 'sometimes when the rain comes down it goes back up' (5.303b)
>
> 'they disappear' (5.306b)
>
> 'they disappear into the air' (5.315b)

It seems the main associations in their construction of 'evaporate' are 'disappearance' and 'upward movement' - not necessarily liquid changing to gas. It appears that they mapped <u>visual effects</u> and <u>motion</u> onto the 'new' word more readily than information about initial and final physical states (or maybe a definition they had been given).

It is also interesting to note that four of the five pupils who related 'evaporating' to 'dissolving' did <u>not</u> conserve the weight of the sugar at a later stage in the interview. This would suggest a 'consistent' scheme. Indeed, when the fifth pupil (a conserver) was reminded that she had previously described dissolving as evaporating immediately said, 'it would be lighter, this cup would be lighter' (5.318g).

Seventh-year schoolchildren (11/12-year-old)

Attention seemed to be focussed on the sugar 'going into' the water, at least judging by the number of times the word 'in' and 'into the water' were used.[1]

The destination of the sugar was water - most agreed on this, but some of the pupils were beginning to generate ideas on how this could happen - the mechanism by which it took place. Note has been taken of the other year-group responses that were descriptive of what could happen to the sugar. In this year-group some were constructing ideas about how the granules 'get smaller' or how sugar was able to 'get into water'. The following interview extract illustrates one idea:

R: For the next few minutes I want you to imagine you are Super-Carl Would you like to draw for me what Super-Carl might see in there (a beaker of water in which Carl has dissolved some sugar)?

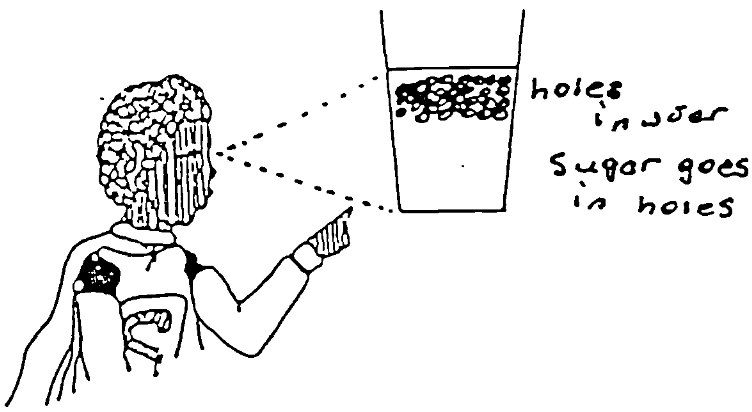
C: (Draws small circles in the water)

R: You are drawing a lot of circles, what are all those?

C: (stops drawing) See Sir, I think that they are inside there (one circle) there could be the sugar - the water's taking in the sugar in little holes.

R: So those (circles) are the holes, are they?

C: um, then the sugar's going into there - into them.



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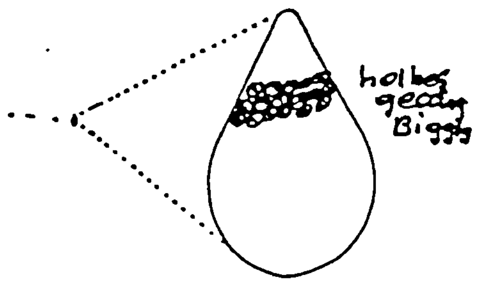
1. Another phrase often used at this age was: 'dissolving into'

Although Carl did not know it, he was re-stating the 'pore theory' of liquids that was seriously held by eminent scientists of the 17th century - see chapter 5.

According to Carl's notion the sugar was accommodated in the 'holes' of the water. This 'hole' idea was also retained in his description of 'drops' of solution.



For others the issue was not how water could accommodate sugar, but how sugar granules, in view of their size, 'get into' water. Granules were imagined to get 'smaller and smaller'. This idea was mentioned by a number of pupils but Daren has a notion as to how it happens:

> 'when you are mixing it round it gets rubbed down by the water and dissolves' (7.403b)

So far as pupils of previous year-groups were concerned the size reduction of sugar granules 'just happened' or was achieved by stirring, in this case water is regarded as the agent that was attributed 'abrasive' qualities.

The use of the word 'melting' continued in this age-group but the pupils meant dissolving rather than fusion. However, some conceptual problems were in evidence when one pupil was asked to think about 'melting', for example:

P: 'It's all dissolved'

R: What do you suppose happens to things when they dissolve?

P: Just melt

R: Like er, like what have you seen melting?

P: No, it evaporates

R: You think it evaporates?

P: Things vary: some things melt, some things evaporate

R: What does this word evaporate mean?

P: It's like water, it changes into steam, if you turn it back into water again it condenses.

R: So you think the sugar's evaporating do you?

P: Umm. (7.411g)

Apparently, 'dissolving' had been differentiated from 'melting' but not from 'evaporating'.

Tenth-year schoolchildren (14/15 year old)

The generation of ideas about how sugar could 'get into' water, that began to emerge in the previous year-group, became far more prevalent in this year-group. The variety of ideas can, in part, be traced to a transition in conceptions of matter from an essentially continuous viewpoint to one based on atoms/molecules regarded as 'building units' of matter. Consequently, the character of the responses ranged from macroscopic conceptions, of the types already discussed, to particulate ideas that included portions of kinetic-molecular theory.

As with previous year-groups some interviewees appeared satisfied with the view that dissolving 'just happens', but others looked for 'causes' and may, for example, have visualised water as an active agent in the process.

At the macroscopic level of thinking water was 'seen' to be:

'soaking it (sugar) up into it (water)' (10.614b)

This idea of solution by penetration and permeation is a very deep-rooted idea in human experience[1]. The words 'soak' and 'absorb' were picked up in written responses at this age also.

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1. The word 'soak' is derived from the old English 'soc' meaning sucking at the breast. (Shorter Oxford English Dictionary,1972)

Another 'basic' experience that has been mentioned in a lower year-group, was found in the response:

> 'it (water) sort of rubbing it, smooths it down like a piece of glass' (10.604b)

when asked how the water managed to smooth it down he said that it was the 'molecules in the water' and 'you stirring it'.

The idea of the 'breaking up' of sugar was the most frequent conception of dissolving in this year group. The action of water or water molecules was described in dynamic terms with verbs like 'knocking', 'pulling' and 'getting-in-on'. This was the first year-group explicitly indicating that water may be considered to have intrinsic energy and that suggest ways of interaction between sugar and water. Some interview extracts below illustrate the dawn of the construction of molecular ideas.

> 'it kind of er breaks up and mixes with the water.... the water molecules could knock against it with it's (water molecules') energy it's (water's) got more than the solid crystals so it kind of pulls bits off I suppose.... it gets more energy when you heat it'. (10.602b)

> 'dissolving... is it where all like all water particles break 'em up so that they're even smaller.... sugar's joined up with the other water particles' (10.603)

> 'it's dissolving, all atoms have come out of the arrangement so that they are just loose they disperse into the water all the atoms of sugar break up break away from each other and disperse in the water'.[1] (10.611)

> 'well it's dissolving, the water's well the sugar's sort of bonded together the water's coming and getting in on the bond it's making it get in on every molecule forming part of it, so it's making it dissolve... sugar's all structured together and the water's coming in and splitting it up' (10.617)

Another development of molecular ideas was apparent in the extension of the conception of 'holes' in water, referred to in the previous year-group discussion. (It also 'fits' with the familiar (language based) conception of sugar 'going into' water). The 'holes' became spaces between molecules:

> 'the sugar goes into the spaces of the water... all the molecules with spaces between which the sugar goes into' (10.615g)

It is sometimes possible to infer that pupils link new ideas to existing knowledge. Tresca for example made an interesting connection between the 'deep-rooted' idea of 'soaking up' and an intermolecular spacing conception of dissolving. A thread of ideas may be traced:

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1. The idea of 'loosening' is contained in the original derivation of the word 'dissolve'.

dissolving - disappearing - soaking up - got holes - gaps between molecules - goes up into gaps.

The following interview extract illustrates this:

T: It's dissolving, the sugar's dissolving in the water, it's disappearing

R: What do you imagine is happening to those sugar granules when they've dissolved?

T: They get soaked up in the water surrounding them

R: So what do you imagine water is like if it soaks up sugar? Any picture in your mind of what

T: It's got holes in it

R: um hum I see, can you stir a little bit more

T: It's got gaps in to let the sugar in it

R: I see, any other ideas, what else is there besides gaps would you say?

T: It's er solid shapes round it, atoms

R: Round the gaps?

T: Yeah but not like a shape, it's not, they're not uniform shape all higgledy piggledy

R: Oh yes

T: If it was solid you wouldn't be able to move it

R: So what do you suppose happens to the sugar then that it erm, what did you say? the sugar,

T: It'll <u>go up into</u> the gaps

R: Into the gaps?

T: In the water

R: What will it? er have you any picyure in your mind what it might be like when it goes into the gaps, what sort of state it's in, do you imagine those granules going into the gaps, is that what you have in mind or do you have some other idea?

T: They're broken up more

The mental picture of 'dissolving' painted so vividly by Tresca, portrays 'broken up' sugar granules <u>'going up into'</u> the spaces between molecules of water. The <u>upward</u> movement of sugar particles is particularly interesting in the context of conservation of weight. The same kind of mental image, anti-gravitational in this context, was present when she was asked why she thought that the tumbler containing dissolved sugar would be lighter. She replied:

> 'it would be forced <u>up into</u> the solution, it won't be like all at the bottom, so ~~it's got~~ all it's weight <u>up in</u> the solution, so it makes it lighter' (10.609g)

Here, sugar is perceived to have 'weight' when it is seen to be en masse at the bottom of the container, but it loses 'weight' when it 'goes up into' the solution.

The initial construction of atomistic conceptions of dissolving appears to be an attribution of all the properties, currently associated with gross matter, to atoms or molecules.

John is an example of a pupil who was at an early stage in constructing atomic explanations but, in addition, was overwhelmed by sense data. At first he attributed the disappearance of matter to the destruction of atoms, then having no confidence in this explanation he suggested the transmutation of atoms. The following interview extract illustrates these points.

J: It's beginning to dissolve

R: When you use the word dissolve, tell me what you feel is happening in there

J: It's disappearing

R: So, dissolving is disappearing

J: You can't see it, it's erm taken up by the water,

R: When you say it's taken up by the water what do you suppose happens

J: I don't know, has it's atoms been destroyed? I don't know

R: It's atoms destroyed um hum

J: I think steam went there

R: you think it's made up of atoms, do you - the sugar's made up of atoms?

J: yes and it's atoms become water atoms

R: it changes from sugar to water does it?

J: erm if you keep stirring, it's nearly all gone now

Unfortunately the interviewer did not probe the reference to steam - it was probably quoted as evidence of energy release. The shimmering effect, due to localised changes in refractive index as the sugar dissolved, could have given the impression of steam. Nevertheless, this pupil's strategy, when adopting a science atomistic perspective, was to map his sense data about matter onto his conception of atoms.

Twelfth-year schoolchildren (16/17 year-old)

The set of responses from this year-group was characterised by a broadening of the spectrum of ideas about dissolving. At one extreme, a pupil predicted that sugar would dissolve on the basis that both sugar and water contained polar molecules, that solvation energy was involved, and that individual molecules of sugar would be 'pulled off with the energy released'. Clearly, in his view, sugar and water are constituted of theoretical entities that can be expected to behave in predictable ways. At the other extreme sugar is 'seen' to be 'swallowing up the water' and 'melting away - but doesn't actually melt as it does with heat'. That is, in her view, the change is 'seen' on the macroscopic scale. Also, she made a spontaneous effort to clarify her meaning of the word 'melting'.

Between these extremes some model of dissolving was frequently offered. The most popular idea was some form of combination between sugar and water (or their molecules) such as 'joining', 'attaching' or 'reacting'. Almost as popular was the idea of 'breaking' or 'splitting' of granules into bits or molecules. A further idea was that of sugar fitting in gaps between water molecules.

6.7 Findings from the survey responses

6.7.1 General characteristics of the survey responses

Survey data about the dissolving process were largely descriptive in character. The first question was designed to provide both an orientation and a context for what was to follow - hence the need to begin by requesting a simple description of what was happening in the tumbler as the sugar was stirred with water. More often than not, pupils wrote a few words, to the effect that the sugar had dissolved, but sometimes other words were used instead of 'dissolve' and, occasionally, a pupil volunteered an idea about imagined microscopic or sub-microscopic changes that had taken place in the solution.

Pupils found the second part of the task more difficult. Instead of providing an explanation the majority of younger pupils regarded the invisibility of the sugar as something that was merely a consequence of dissolving, mixing etc. A minority of younger pupils, and just over half of the older pupils offered some explanation.

As already indicated the diagrams fell mainly into two categories. Frequently, the changes attributed to the sugar granule took place either in the centre of the solution or at the bottom of the tumbler.

6.7.2 Categories of dissolution ideas, their prevalence and possible schemes that underlie these ideas

6.7.2.1 Describing the phenomenon of dissolving

As indicated in the analysis procedure, pupils' descriptions may be considered in two ways: the words they used and the mental models they volunteered. The relevant data is summarised in Tables 6.1 and 6.2 together with Figure 6.1.

The words they used.

The lower year-groups described the phenomenon by a wide range of words and/or phrases. The most popular - apart from 'dissolve' - were: 'disappear', 'gone-into-water', and 'melted-into-water'. The common characteristic of these words is that they describe immediately perceptible features of the phenomenon. Sometimes they added a word 'away' for example, 'gone away' and 'melt away'. The overall trend, with year-groups was to abandon these and other words so that, eventually the accepted word 'dissolve' was used almost exclusively.

Between the lower and higher year-groups the word 'evaporate' was, at first, increasingly popular. However, this word also was eventually abandoned. It would appear that as pupils learned this new word, some of them had difficulty in differentiating it (conceptually) from dissolving, just as many had a similar problem with another change of state, 'melting'. Word differentiation was discussed in the interview data section.

Despite of the fact that the conception of 'dissolving' is frequently introduced, during secondary school, in connection with mixtures, pupils use of the terms like 'mix' and 'mixtures' diminishes with year-group. Perceptually, solutions do not look like mixtures, though they are often made by stirring (or mixing). Younger pupils seemed to pick up the latter idea. In order to maintain the 'mixture - conception', after stirring ceases, it is necessary to imagine kinetic - atomistic model. Few pupils appear to have developed such a model.

TABLE 6.1 PERCENTAGE OF PUPILS USING WORDS SPECIFIED TO DESCRIBE FIRST IMPRESSIONS ON STIRRING OF SUGAR WITH WATER

Words used to describe what happens to sugar when stirrd with water	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. Dissolves	29	26	63	58	93	73	147	96	80	93
b. Disappears/vanishes	20	18	10	9	8	6	-	-	-	-
c. Gone into water	12	11	3	3	1	1	-	-	-	-
d. Gone to bottom	4	4	1	1	-	-	-	-	-	-
e. Melted into water	19	17	7	6	4	3	1	1	-	-
f. Mixed in with water	7	6	7	6	3	2	-	-	-	-
g. Evaporated into water	2	2	4	4	14	11	-	-	-	-
h. Disintegrated in water	6	5	6	6	2	2	-	-	-	-
i. No response	5	5	4	4	2	2	6	4	6	7
j. Unintelligible or uncodeable	8	7	4	4	-	-	-	-	-	-

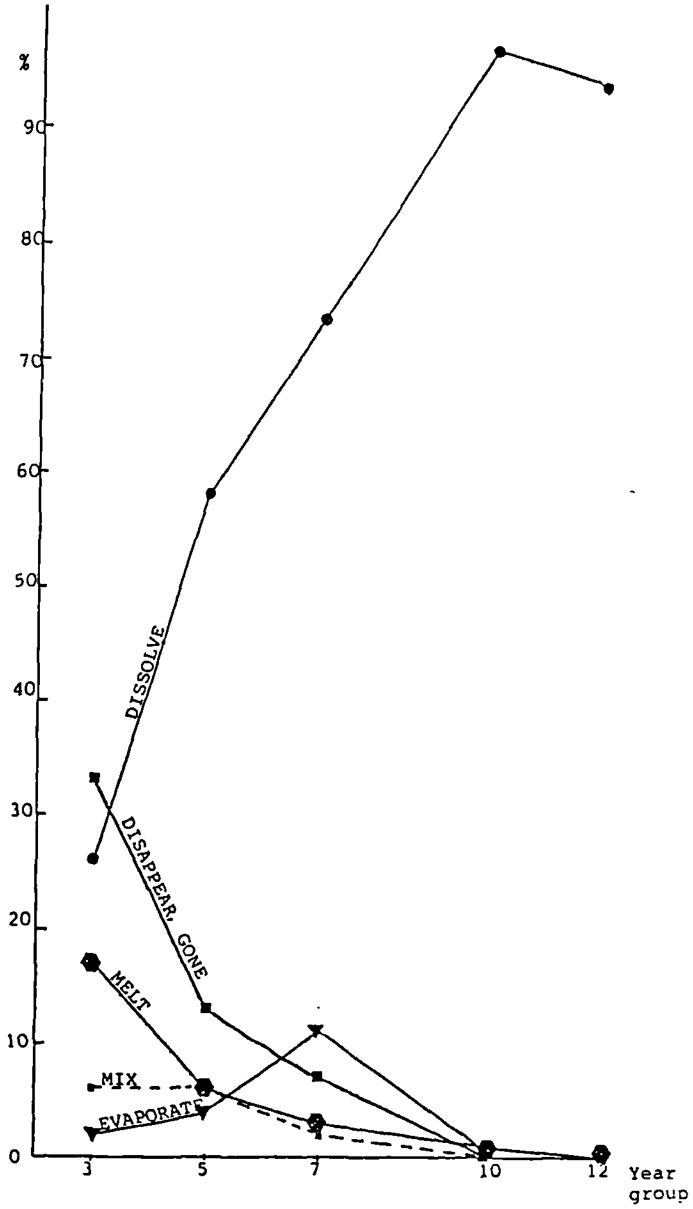


Fig. 6.1 Graph showing pupil's use of specified words to describe 'dissolving'.

<u>The models they volunteered</u>

A small proportion of pupils offered mental pictures or models of the dissolving process that extended beyond sense data or common language descriptions. The relevant data is summarised in Table 6.2.

The most common of these ideas was that the sugar granules had reduced in size, in some way. Older pupils sometimes added that the sugar had spread out.

The sugar has been broken
down into pieces which
have spread through the water

The sugar has been broken down into pieces which have spread through the water (10.015g)

Two processes by which this size reduction took place were postulated. Some suggested the sugar had 'broken up' and others thought that the sugar had undergone a surface erosion sometimes described as being like a sweet left in the mouth.

it is like a
sweet it gos smaller
and smaller

it is like a sweet it goes smaller and smaller (3.054b)

Some older children extended the granule-size-reduction ideas to include the notion that the end product of the dissolving process was molecules.

The granuss dissolved The
molecules split and joined with
the H_2O mdeculos

The granules dissolved. The molecules split and joined with the H2O molecules. (10.120g)

They have broken up into atoms which move between the water molecules.

They have broken up into atoms which move between the water molecules (10.122g)

TABLE 6.2 PERCENTAGE OF PUPILS OFFERING SPECIFIED MODELS OF 'DISSOLVING'

Models of dissolving spontaneously volunteered	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. Sugar granules are broken down/up (to small pieces.)	1	1	1	1	-	-	10	7	5	6
b. Sugar granules are broken down to molecules	-	-	-	-	1	1	4	3	3	4
c. Molecules of sugar and water mix by dissolved sugar	-	-	-	-	-	-	3	2	1	1
d. Sugar granules fit into spaces/gaps in water	-	-	-	-	-	-	3	2	-	-
e. Molecules of sugar fit spaces between molecules of water	-	-	-	-	-	-	4	3	-	-
f. Molecules of sugar and water 'react'	-	-	-	-	-	-	2	1	-	-

They also went on to 'picture' the arrangement of the 'dissolved' molecules as either a mixture or a gap-filling model. In the latter case the sugar was thought to fit into the gaps between the water molecules.

they have dissolved. ~~At~~ The sugar
particles will be smaller (broken up) than the
water particles therefore they
will fit between them and dissolve

they have dissolved. The sugar particles will be smaller (broken up) than the water particles therefore they will fit between them and dissolve. (10.007g)

Almost invariably water was regarded as the 'active' agent in dissolving and sugar as the passive one.

'water makes sugar particles break up and dissolve the sugar particles' (6045g)

A few pupils envisaged a 'reaction' between sugar and water but did not give any details so they may have used the word 'react' rather loosely.

6.7.2.2 Explaining the invisibility of dissolved sugar

As mentioned in the analysis procedure, the basis for categorising these responses was the conceptual or perceptual or purely descriptive level of explanation offered. The relevant data is summarised in Table 6.3. Molecular conceptions of sugar and water, or just sugar, appeared in the higher year-groups. They employed schemes about sugar molecules fitting in gaps between water molecules, or else, sugar molecules being so small that they could not be seen. These form categories a. and b. in the table cited above.

The most popular explanation in all age groups was an extension of sense data beyond that which could be observed. This forms category c. in the table cited. The 'small particles' were regarded as the product of a 'wearing-down' or a 'breaking-down' process. This conceptual scheme leaves the pupils in a quandry since no limits are imposed on the extent of the imagined process in terms of size or time. No such problem arises with the molecular scheme.

The explanations in categories d. and e. were based on sense data and employed a liquefaction scheme in one case and a similarity-of-appearance (i.e. transparency) in the other. Neither scheme had atomistic content.

Pupils who offered responses in category f. took the disappearance of sugar for granted when it dissolved, melted, mixed, etc. and, apparently, did not see the need for an explanation.

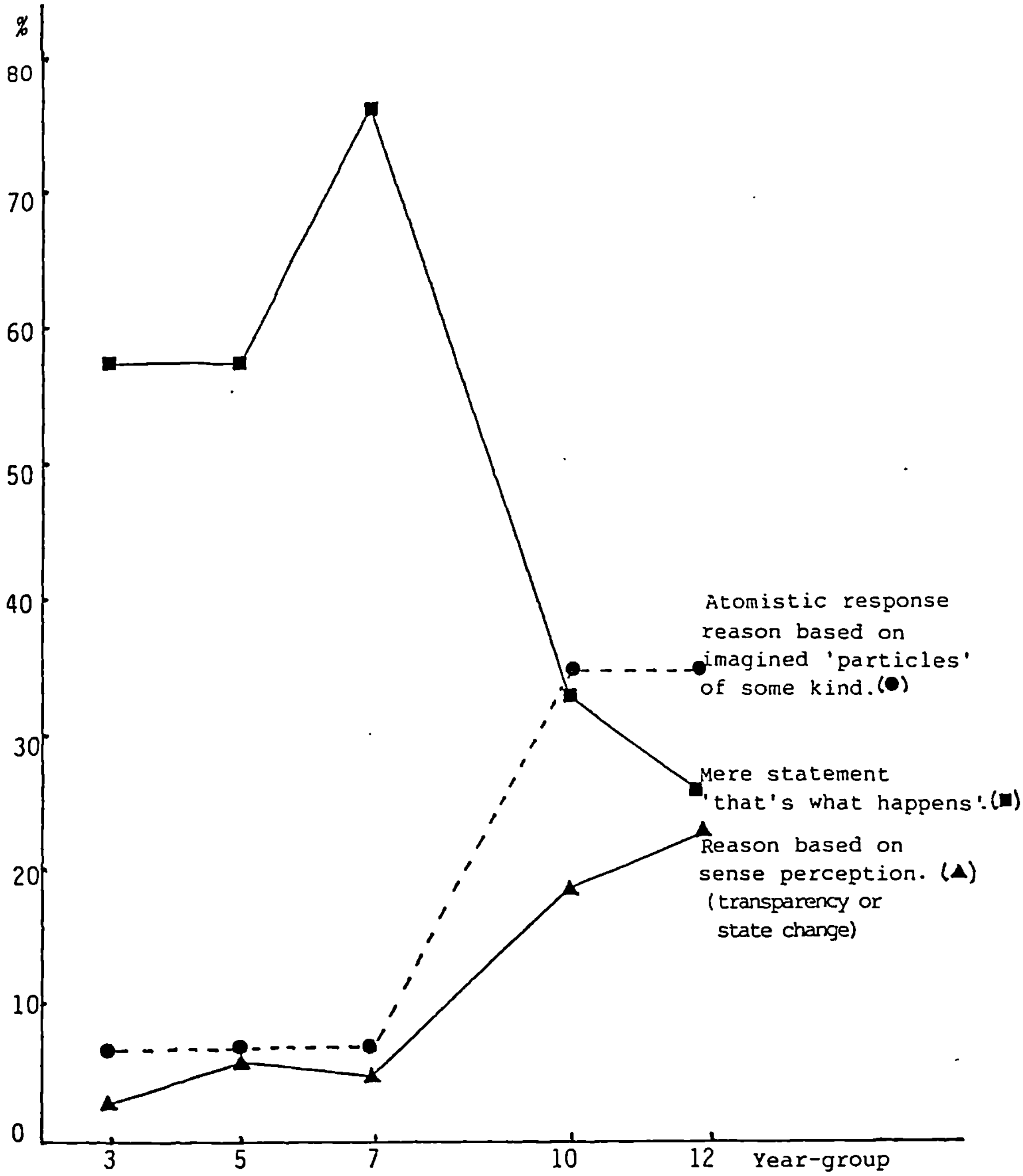


Fig. 6.2 Graph showing percentage of survey pupils offering specified types of explanation for the invisibility of dissolved sugar (based on Table 6.3).

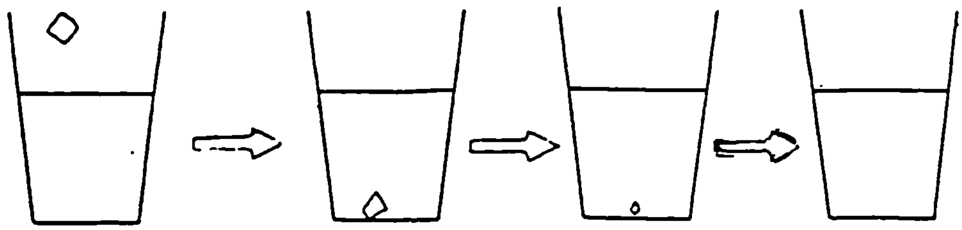
TABLE 6.3 PERCENTAGE OF PUPILS OFFERING SPECIFIED IDEAS TO EXPLAIN INVISIBILITY OF DISSOLVED SUGAR

Ideas about the invisibility of dissolved sugar	Year 3 n=112 no.	Year 3 %	Year 5 n=109 no.	Year 5 %	Year 7 n=127 no.	Year 7 %	Year 10 n=154 no.	Year 10 %	Year 12 n=86 no.	Year 12 %
a. Because sugar molecules fit into/ hide between water molecules	-	-	-	-	-	-	10	7	3	4
b. Because sugar granules are reduced to molecular size	-	-	-	-	1	1	9	6	2	2
c. Because sugar granules are reduced to a size that cannot be seen	8	7	8	7	8	6	34	22	25	29
d. Because sugar granules change from a solid to a liquid	2	2	1	1	4	3	19	12	8	9
e. Because sugar granules and water are transparent	1	1	5	5	3	2	11	7	12	14
f. Because that's what happens when sugar:										
* dissolves	18	16	36	33	50	39	56	36	18	21
* melts	14	12	3	3	7	6	-	-	-	-
* mixes	9	8	7	6	5	4	2	1	3	4
* evaporates	-	-	2	2	11	9	2	1	-	-
* disintegrates	1	1	2	2	3	2	-	-	-	-
* absorbs water	-	-	1	1	-	-	1	1	1	1
* disappears	13	12	8	7	20	16	3	2	-	-
* goes	11	10	5	5	1	1	-	-	-	-
g. unintelligible or uncodeable	14	12	3	3	5	4	1	1	12	13
no response	21	19	28	26	9	7	6	4	2	2

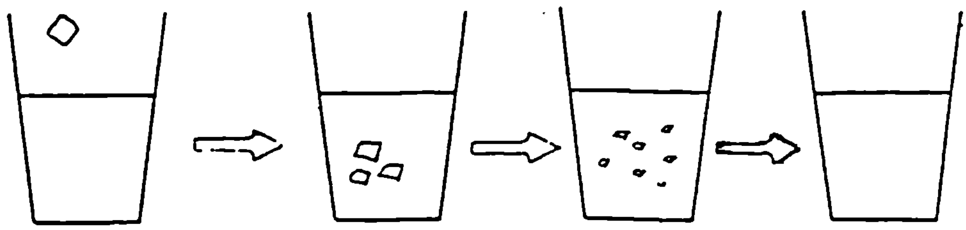
6.7.2.3 Drawing a dissolving sugar granule

Pupil's drawings of a granule up to the time when it could not be seen fell into two main categories. One, a series of diagrams in which the granule was shown to be successively smaller at each time interval. As Table 6.4 shows this was the most prevalent and appears to be based on a 'wearing-down' scheme. Two, a series of diagrams illustrating successive separations of the crystal into smaller bits. It would seem that this is derived from a 'breaking-up' scheme. A few pupils offered a combination of both kinds of diagram. Some examples are shown below.

Surface action:



Successive fracture:



Combination of surface action and fracture:

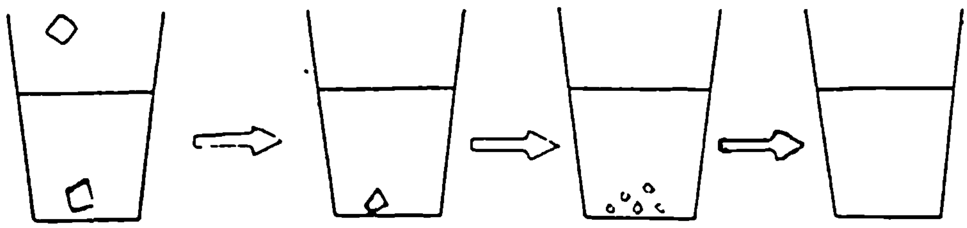


TABLE 6.4 PERCENTAGE OF PUPILS OFFERING SPECIFIED TYPES OF DIAGRAM TO ILLUSTRATE DISSOLVING

Diagram category	Year 3 n=112 no.	Year 3 %	Year 5 n=109 no.	Year 5 %	Year 7 n=127 no.	Year 7 %	Year 10 n=154 no.	Year 10 %	Year 12 n=86 no.	Year 12 %
a. Gradual size reduction - implying a surface action model	45	40	49	45	58	46	104	68	50	58
b. Spontaneous break-up - implying a crystal fracture model	32	29	36	33	46	36	45	29	29	34
c. A combination of surface action and fracture	1	1	1	1	1	1	1	4	3	4
d. No response	6	5	-	-	5	4	1	1	1	1
Unintelligible or uncodeable	21	19	19	17	8	6	3	2	3	3

6.8 Summary of findings from interview and survey tasks

The set of introductory tasks outlined at the beginning of this chapter was designed to elicit how pupils, at various stages in their schooling, describe the phenomenon of 'dissolving'; explain the invisibility of dissolved sugar; and, depict a dissolving granule.

The first general characteristic of pupil's descriptions of dissolving was variety in vocabulary especially the early years. This gradually changed in later years when the conventional word 'dissolve' was usually employed. The 'early' words were often based on immediately perceptible features associated with the phenomenon (e.g. disappearing, gone into water, gone to the bottom, melting, evaporating, disintegrating etc) or with the perceived activity (e.g. mixing). Some words were used in different ways by different pupils For example, some pupils used the word 'melting' to mean 'liquefying' whereas others used it to mean 'disappearing' into the water i.e. synonymously with one meaning of 'dissolving'.

The second general characteristic of pupils' responses was variety in modelling dissolving, which unlike the vocabulary, become more varied through school years. Thus although the designation vocabulary became more uniform the ways of representing 'dissolving' diversified. See Figure 6.3.

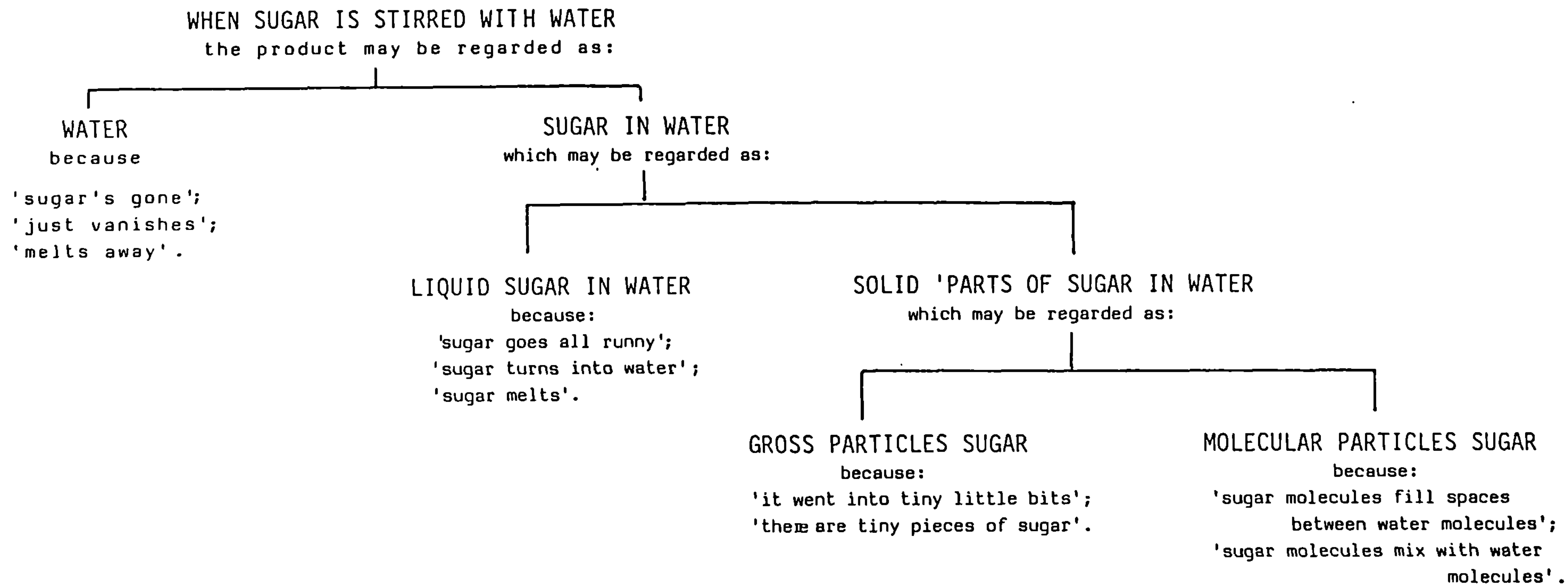


Fig. 6.3 Pupils' alternative constructions of what happens when sugar is stirred with water.

Some early models persisted in a proportion of the surveyed population throughout the school-years; these included ideas of sugar crystals breaking up or breaking down, wearing down, soaking up water, changing state, going into holes in water and such like. In later school-years, pupils began to construct molecular particle models; these ideas included sugar crystals 'breaking down' into molecules that in turn 'hide' or 'fit' between molecules of water. Also molecules of sugar and water were imagined to 'react with', 'attach to', 'join with', and 'associate with' one another.

As indicated in the previous paragraph a third feature that characterised pupils' responses was the growth of atomistic ideas and the change from 'continuous-bit' atomism to 'molecular-particle' atomism.

The <u>place of atomistic thinking</u> in pupils' responses was brought out in some of their attempts to explain the invisibility of dissolved sugar, see Table 6.3. In the early school years, the number of respondents offering 'continuous-bit-atomism' was fairly constant at about one in fifteen, but in later years increased rapidly to about one in five. If, to these, we add those having molecular conceptions of dissolved sugar, the total number having atomistic ideas rises to about one in three, see Figure 6.2. Thus it would appear that a substantial proportion of older children find it possible to use some kind of atomistic model when thinking about matter dissolving.

The other feature that this introductory part of the study reveals is the <u>conceptual changes that various pupils need to undergo</u> if they are to construct qualitative school-science ideas about 'dissolving'. Some of these are listed below.

* from attributing the cause of the dissolving process to <u>one</u> component (e.g. <u>sugar</u> melting or <u>water</u> dissolving)
  to a mutual interaction between both components;

* from regarding the combination of sugar and water as one 'substance' (because no discontinuity is perceptible)
  to regarding it as a (homogeneous) mixture (i.e. a solution);

* from regarding the combination of sugar and water as a continuous blend,
  to regarding it as an intermingling of interacting molecules;

* from regarding the solution as heteromorphic bits of sugar in continuous water,

to regarding it as an intermingling of interacting molecules.

CHAPTER 7

SCHOOLCHILDREN'S UNDERSTANDING OF THE WEIGHT/MASS OF DISSOLVED MATTER

7.1 Introduction

Since the end of the eighteenth century, when chemists began to make use of the balance as an instrument for the study of matter and change, the constancy of the (total) mass of matter throughout a change in physical state or chemical form, has become an established principle. Even the arrival, in 1905, of relativity theory (a theory that regards matter and energy as interconvertible) did not affect the practical application of the 'law of conservation of mass' to changes in physical state or chemical form. This is because the energy changes, and hence the corresponding mass changes, in these transformations, are too small to be detected by a 'chemical balance'.

The construction of certain constancies and permanences, along with any limitations that may apply to them, are important steps also in the psychological development of individuals, and in their knowledge building processes. Not only do established constancies provide a basis for prediction and action, but they may also lead to enquiry into underlying reasons for the constancy. This chapter is concerned with an investigation into the extent to which schoolchildren have constructed the constancy of mass or weight of sugar in spite of its change of state and appearance. It is also concerned with the reasoning that children use to support their constructions. Indications of the extent to which school-science has influenced children's construction (or non-construction) of weight/mass permanence are explored.

The use of the slash in the reference to mass and weight in the previous paragraph indicates that there is often a problem in attempting to separate these ideas in children's responses. Although, from a science viewpoint, the apparatus presented required pupils to compare the gravitational forces on masses of dissolved and undissolved sugar and water, few pupils 'saw' the situation that way. Consequently, it may be helpful to begin by considering the conceptions of mass and weight that children develop during school-years and also explain why the composite term weight/mass was used.

From an early age children probably notice how various objects differ in the way they 'press down' on the hands, shoulder or head. Eventually a 'felt' conception of heaviness, that they later associate with the word 'weight', becomes established. When asked to compare the weights of two objects they usually compare 'effects' that are felt by the hands. If they are not allowed to 'feel' the weight they may make judgements based on qualities that they associate with weight, such as size or hardness i.e. qualities that are accessible through the senses. Further, ideas about comparing the weights of objects develop as they play on a 'see-saw' and use 'scales' at home or school. During this period they may attribute 'feelings' to the scale pans similar to those they feel on their hands. Thus the notion of 'weight' is egocentric in that it is understood from the perspective of personal (sensed) experience.

However, early in secondary education, they are expected to make two conceptual changes in their thinking about weight. First, they are expected to abandon their egocentric view of weight and imagine a gravitational force acting on objects - a force which changes with position around, above or below the earth's surface. And, second to conceive of an amount of constituent 'stuff' in an object (an amount that does not vary with location) called 'mass'. The decentration required to effect the first conceptual change and the absence of a needed conception of 'inner constitution' for the second, may well make both changes a very slow and difficult process for many. As a result, 'weight' may continue to be regarded as 'an object pressing down on a scale pan'. Also 'mass' often becomes associated with the phonetically similar word 'massive' (meaning large in size) instead of the intended association. Thus both words 'mass' and 'weight' tend to become associated with size or volume, and pupils often make estimates of mass and weight from the 'amount' they see. (This strategy could pose a problem when observing a dissolving substance disappear).

In addition to conceptual differentiation difficulties with the words 'mass' and 'weight', pupils do not always find their laboratory experience particularly helpful for clarifying their ideas. They may be asked to weigh a substance and then record the weight in units of mass. Mass is measured by using a balance that compares the weight of an unknown with a reference 'weight'. The reference 'weights' are labelled in units of mass.

In view of the differentiation problems, outlined above, it was decided that in this study 'weight/mass' would be used to report pupils ideas about mass or weight.

7.2 A school-science view of the weight/mass of dissolved sugar

It is usual for pupils in the sixth school-year to perform experiments that involve the weighing of solutes and solutions. For example, a common experiment is to determine the solubility of a solid substance. Solubility may be defined as 'the maximum number of grams of any solid that dissolves in 100 grams of solvent at a given temperature' (Lewis et al,1982). Pupils begin the experiment by preparing a saturated solution of a solute at a particular temperature. A portion of this solution is transferred to an evaporating dish of known mass. When the mass of the dish and saturated solution has been recorded, the mixture is carefully heated so that the water content may evaporate and leave the solute behind. The mass of the dish together with that of the solute is then recorded so that the separate masses of the solute and water content of the solution may be obtained by difference. The solubility may then be calculated by simple proportion.

This procedure provides experimental evidence for the preservation of dissolved solute and uses the principle that the masses of solute and solvent are additive. It might therefore be expected that most pupils in the seventh and later years should be able to predict the conservation of dissolved sugar. Whether or not they do so is partly the subject of this chapter.

In the seventh or eighth school-year they may be taught that matter and, therefore solutes and solvents, are 'built up' from small atomic/molecular particles and that these particles have a very small but finite mass. They may also be taught that, on dissolving, solids separate into atomic/molecular particles which are too small to be seen. Also these particles intermingle with the solvent molecules and, thereby, add their mass to that of the solvent. It might be expected that pupils in the ninth school-year and above could interpret the preservation of mass of dissolved matter in terms of the permanence of the component particles. The extent to which they do so forms part of this study.

7.3 The eliciting tasks

7.3.1 The interview tasks

At this point in the interview, each pupil placed beakers containing equal masses of water, and bags containing equal masses of sugar, on scales and observed 'balance'. Pupils were then asked to remove one beaker and bag of sugar, transfer the sugar to the water and return the bag to the scales. They stirred the mixture until the sugar could not be seen and the interview continued:

Researcher: "Suppose you were to put the beaker back on the scale pan, would you expect the pan to be level like that (researcher illustrates), or 'up' like that or 'down' like that?"
"What makes you think that (the pan will be as you predict)?"
If the pupil, in effect, predicted that the weight would be less (or more) than before, then, at the end of the whole interview s/he was asked to actually replace the beaker on the scale pan and explain what was happening. Usually pupils commented spontaneously. In any case the researcher gave some reassurance that others had a similar opinion.
"Many pupils have told me that the balance pan would be 'up' (or 'down'), what do you think is going on? Why do they think that?"

The nature of probing questions that followed depended on the content of the responses.

7.3.2 The survey task

Each step in the procedure, illustrated on the next page, was demonstrated by the researcher as he, and the class, read aloud the description of each activity.

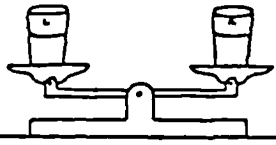
7.4 Aims in the analysis of responses

It was anticipated that the task could elicit answers to the areas of enquiry listed below.

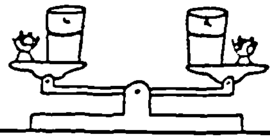
* To what extent did the pupils in each year-group conserve the weight/mass of dissolved sugar?
* In what ways did children justify their predictions of conservation or non-conservation of dissolved sugar?
* What underlying schemes about matter and weight may be inferred from pupils responses?
* What part, if any, does atomism play in children's ideas about the conservation of weight/mass of dissolved sugar?
* What changes in children's ideas about the weight/mass of dissolved sugar are apparent during school-years?

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

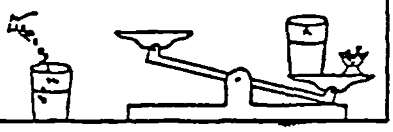
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



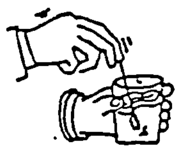
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

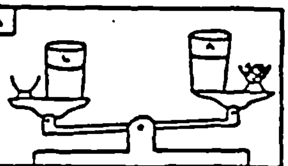


4. Liz stirs the water until she cannot see the sugar granules.

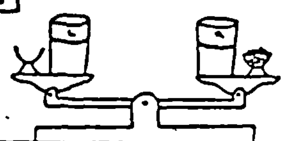


5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:

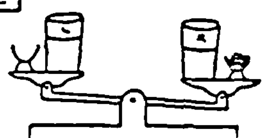
A



B



C



A ☐ B ☐ C ☐

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because..

....

....

....

The Survey Task

7.5 Analysis precedure for interview and survey responses

The analysis was undertaken in two parts. First, the responses (i.e. interview transcripts and survey multiple choice answers) were categorised according to the predicted positions of the balance pans. Each of the three possible positions of these pans indicated a child's view about the weight of dissolved sugar. The three categories are summarised below.

Predicted category	Mass/weight implication
a. Left-hand pan below right-hand pan.	Sugar weight/mass greater after dissolving.
b. Left and right-hand pans at the same level.	Sugar weight/mass unchanged after dissolving.
c. Left-hand pan above right-hand pan.	Sugar weight/mass is less after dissolving.

The responses were tabulated by year-groups so that any trends in the data could be followed.

Second, the reasons that children offered to support any of the above predictions were used in two ways. Reasons offered in the interviews were usually more rich in terms of explanation than those obtained in the survey because probing was only possible in the former case. Consequently, the justifications obtained in the interview were considered most useful for comparing developmental trends in children's understandings. On the other hand, the survey responses provided a broader range of supporting ideas (for pupils' predictions) and they were used to gather information about the prevalence of possible underlying schemes.

7.6 Findings from the interview responses

7.6.1 General characteristics of the responses

Pupils of all ages readily responded to this task. Young pupils especially were fascinated by the motion of the scale pans and did not appear to have any difficulty in understanding what was required of them. Indeed, some had to be restrained from giving an answer before the question had been completed.

Some pupils appeared to regard the sugar as a 'weight' which was either to be added to the water or imagined to disappear, though a few had more subtle ideas about the 'weight'. Others regarded sugar as a soluble substance that was either permanently present or which ceased to exist when it could not be seen. A small number in the highest two year-groups employed the term 'mass' of sugar but this word often appeared to mean the volume of sugar rather than the amount of substance.

As Table 7.1 shows the number of pupils who preserved the weight of the sugar diminished after the third school-year but then increased again. However, the number decreased again in the twelfth year. The number of pupils who failed to compensate for the weight of the sugar on the other scale pan, but nevertheless conserved sugar, diminished to zero after the fifth-year.

TABLE 7.1 NUMBER OF INTERVIEWEES OFFERING SPECIFIED PREDICTIONS ABOUT WEIGHT/MASS OF DISSOLVED SUGAR

Prediction	Year 3 n=18 no.	Year 5 n=18 no.	Year 7 n=18 no.	Year 10 n=18 no.	Year 12 n=18 no.
a. Left-hand pan below right-hand pan (i.e. sugar heavier after dissolving)	2	1	-	-	-
b. Left and right-hand pans at same level (i.e. no change in mass/weight)	11	9	12	14	11
c. Left hand pan above right-hand pan (i.e. sugar lighter after dissolving)	5	8	6	4	7

7.6.2 Patterns of response by year-group

The development of ideas about the mass/weight of dissolved sugar will now be discussed by looking at the responses in ascending year-groups.

Third-year school children (7/8-year-old)

When children were asked to compare the positions of balance pans, before and after dissolving a mass of sugar in a mass of water, they generated ideas that matched all three possible judgements. Out of 18 pupils interviewed, two predicted that the mixture would be heavier, 11 that there would be no change and five that it would be lighter.

The 'sugar is heavier after dissolving' prediction

The judgement that the sugar solution would be heavier than separate sugar and water was made by two pupils who had the ideas that 'sugar made the water heavier' (3.202b) and 'sugar added water'[1] (3.209b). Both pupils correctly attributed more weight/mass to the solution[2], but then failed to compensate for this by taking account of the undissolved sugar on the other balance pan.

Two other pupils (3.211 & 3.216) made the same error at first, which was self-corrected immediately in one case, and, after attention had been drawn to the sugar packet, in the other[3]. These apparently 'restricted-field-of-view-errors' were confined to younger children and may be attributed limited processing of proximal data since the 'chain' of explanation appears to stop half way through. Whatever the reason, the oversight was readily corrected and the pupils indicated that they conserved the weight/mass of sugar.

The 'no change in weight/mass of sugar' prediction

The majority of this cohort, 11 out of 18, judged that after dissolving the sugar, the balance pans would be at the same level, but it appears that they came to this decision by different 'routes'

Most of them, 7 out of 11, offered the idea that sugar was 'still there'. The keyword 'still' suggests that they faced up to an alternative idea that sugar substance had vanished - as it had appeared to do - and then rejected it. In general they seem to have constructed responses from the propositions that 'you put it (sugar) in there' and the 'sugar balanced before'. As a result they predicted a 'sameness' about the initial and 'final' states of the solution. Others reasoned that because the substance was 'still there' then the weight would be the same, for example:

> 'going to be the same 'cos you've <u>still got the sugar</u> from there (packet), but it's in the <u>cup an' it'll make the cup weigh more</u> an' then when you've got the cup on there it'll <u>weigh the</u> same again, you know it <u>must be in there somewhere</u> but it's just that you can't see it <u>... because it was there</u> an' just 'cos you haven't got X-ray eyes you can'<u>t see right</u> down like'. (3.214g)

----

1. Child's designation of a clear solution.
2. Pupil 3.202 also said that: 'heavy sugar's gone down'
3. A procedure adopted in this case only.

The remaining 'conservers', 4 out of 11, appeared to 'see' sugar as an 'object-having-weight' and that 'weight' was a permanent property of an object, for example:

> 'I think it would probably be the same ... 'cos whatever happens to that - it's disintegrated - and it's still got it's normal weight, it's just you can't see it' (3.217b)

The 'sugar weighs less after dissolving' prediction

Five of the children in this third-year cohort were unable to conserve the weight/mass of sugar through it's physical change. Three of them were completely overwhelmed by their immediate sense perceptions. They predicted that the beaker containing dissolved sugar would be lighter because:

> 'because that's got sugar on and that hasn't' (3.203g);
>
> 'all the sugar's sort of gone and that isn't gone' (3.207g);
>
> 'because there's no sugar here' (3.212g).

In each case a conception of weight appears to be linked to visual appearance of sugar substance. They were unable to re-present the weight of a substance they had actually placed in water which they could not physically see. This may be because they were unable to re-present sugar substance once it had dissolved.

At the end of the whole interview they were re-introduced to the balance task and allowed to place the tumbler containing sugar solution back on the balance pan. Typical responses were:

> 'they are both the same 'cos they've got the same amount because they've got sugar in there (packet) and sugar there in water' (3.203g);
>
> 'it's the same, because your eye can't see it but you sort of think it dissolves, but it's actually still floating around' (3.207g);
>
> 'Oh! they're the same weight
> (Why did you think it was lighter?)
> 'cos the sugar isn't there'
> (Where is the sugar now?)
> 'in there' (3.212g).

In each the sameness of weight was interpreted as the continued existence of sugar substance. The response was so rapid that it is interesting to speculate on the function of their perception of the level balance pans. It seems reasonable to assume that their perceptions confirmed one feasible idea that already existed in their minds, but did not corroborate alternative possibilities.

Thus it may be inferred that their perceptions of the balanced scales assisted them to construct the conservation of dissolved matter[1].

The two remaining 'non-conservers' of weight had different ways of viewing matter and weight. The thinking of one of these appeared to be dominated by an image of the ongoing process of the distribution of sugar (i.e. scattering of parts) and the associated size reduction of parts that he did not consider the sum of the parts of a possible reverse process:

> 'cos it's spread out and won't be as heavy ... it goes down to one grain and one grain isn't very heavy. (3.208b)

His model of matter was quite insightful but the 'one way' association of weight with conceived particle size led to non-conservation.
The other non-conserver based her 'weight' response on an imagined <u>volume</u> change:

> 'when you put the sugar in it goes higher and when it's disintegrated it goes back down' (3.210g)

This decrease in volume, apparently occasioned by the dissolving sugar, was described as 'sugar takes in water'. The pupil, it seems, was searching for 'visible' cues to provide evidence for the continued existence of sugar. The 'sponge' model of sugar will be discussed later in connection with the 'volume task'.

<u>Fifth-year school children (9/10-year-old)</u>

Of the eighteen pupils interviewed, one predicted that the mixture of sugar and water would be heavier than the separate substances, nine that there would be no change in weight and eight that it would be lighter. At some stage in the interview six pupils either changed their minds or suggested alternative answers, so that figures given above represent only the response most favoured by the pupils. In general the responses were characterised by less conviction than those of the third year. Their overall uncertainty was reflected in the language they used as well as in changes of mind. Whereas it was fairly common for a third-year child to predict what the weight 'would be' or 'should be', fifth-year pupils tended to use phrases like 'might be', 'maybe' or 'could be'.

----

1. Older pupils who have had experience of the malfunction of laboratory apparatus may not be so readily helped towards conservation ideas. In similar circumstances the researcher has known them to say that the 'balance was fixed'. Thus the statements above pre-suppose a view of the balance. The scepticism of older pupils may also be attributed, in part, to long-and-firmly-held non-conservation ideas.

The data given at the opening of the above paragraph represents a shift from the 'third-year-data', i.e. from conservation to non-conservation judgements, but owing to the degree of uncertainty shown by the fifth-year it is not really advisable to express its extent in quantitative terms. It is also of interest that whereas one third of fifth year vacillated somewhat between judgements, only one ninth of the third years did so. It may be that as a result of more varied experience of what can happen to matter, the fifth-year are more open to alternatives than the third-year.

Pete is an example of a pupil grappling with alternatives: tempted by perceived appearances but also aware that he had put sugar into the tumbler.

I: Suppose that I put this beaker back on there ((Pete interrupts))

p: They'd probably be the same

I: You think the weights would be the same, or do you think this one would be lighter or heavier than that one. ((insisting that other possibilities are considered))

P: Well I think that one (sugar packet and water) will be heavier

I: Um hum why is that?

P: Because that one's just well ((raising voice)) it'll still be in there but erm, no I think they'll still be both the same 'cos all the sugar's in there now. ((still looks puzzled))

I: Is there something making you think, a bit doubtful aren't you?

P: 'cos it's all gone now

I: And how does that affect the weight do you think?

P: You think it's, you know, you don't know where it is, could be over there er sumat, could be, anywhere

I: Um hum

P: Only I think it's in there but you can't see it

<u>The 'sugar is heavier after dissolving' prediction</u>

Only one pupil in this cohort suggested that the weight of the 'sugar-in-water' tumbler would be larger because:

> 'when you put the sugar in it'll sort of <u>push the water up</u> and it'll seem <u>higher</u>, higher up' (3.313g)

The strength of the dynamic mental image of space-taking sugar appears to have, at least temporarily, taken precedence over a whole-view of the balance and the need for compensation. Although this pupil judged the beaker to be heavier, she later conceded that:

> 'it might be the same size but I don't think it's going to be lighter'

The references to 'higher up' (the tumbler) and 'size' could suggest that, in her view, the dimensions of an object are mapped onto her conception of weight. If this is so, she appeares to be conserving what, in science, would be regarded as volume rather than weight.

The 'no change in weight/mass of sugar' prediction

Similar reasons for justifying conservation were offered in the fifth year as in the third year i.e. the sugar substance was still present, the weight of sugar was merely added to the weight of water or the tumbler had the same amount before and after 'dissolving'.

The 'sugar loses weight/mass on dissolving' prediction

Much the same reasons, given for non-conservation, had also been offered in the third year i.e.

(visible) substance had 'gone':

> 'we've got rid of the sugar and we've got the water left' (5.304g)

(invisible) substance was still there but it had lost weight:

> 'cos the sugar's in the water, makes it lighter, because it dissolves right light - lighter than when in the packet' (5.307g)

(invisible) substance was still there but its parts had become smaller:

> 'cos all the sugar'll be tinier and tinier and will hardly weigh anything' (5.315b)

Seventh-year school children (11/12-year-old)

None of the 18 pupils interviewed offered the prediction that the sugar solution would be heavier than the separate substances, 12 predicted that there would be no change in weight and six that the solution would be lighter.

The 'no change in weight/mass of sugar' prediction

The ideas offered to support the conservation of weight were similar to those of previous years. Most of these contained the 'still there' assertion in some form e.g. 'it's still got stuff'. Others 'saw' the two weights being added, or alternatively expressed the view that there was the same 'amount' on each side. One pupil moved from a non-conservation judgement to a conservation one when she suddenly remembered an experiment with salt:

> 'I think it might be lighter ... because it's all dissolved away into the water and there's no traces of it being there ..

> no, I think it's same ... it'll still be there though because it's just dissolved into the water 'cos if you evap er put it in the sun, it'd evaporate, water'd evaporate and you'd get the sugar, 'cos we did that with salt' (7.406g)

This may illustrate the limited influence of a perceptual illusion in the presence of recollected reversibility.

The 'sugar loses weight/mass on dissolving' prediction

Corresponding ideas, about non-conservation, to those presented hitherto were offered again by this year group. The only fresh ideas were modifications of the 'destination' of sugar 'in the water', particularly in the case of those who conserved sugar substance but not sugar weight.

One of these ideas was that the sugar had become 'part of the water'. This had been constructed from some prior experience:

> 'with both together, it's easier to hold two things together, if they were combined and say they were as one and I held them, I think they might be a little bit lighter if they were together.' (7.401g)

The other idea that there are holes in water and that these cavities are the 'destination' of dissolved sugar has already been mentioned in the section on seventh-year ideas about 'dissolving'.

Overall there was a growth in confidence, over that of the fifth year, when the seventh-year children presented their responses. Only two of them really showed a change in their ideas and their language was more positive.

Tenth year schoolchildren (14/15-year-old)

Once again no pupils predicted an increase in weight when sugar was dissolved, 14 predicted that it would remain the same and four that it would weigh less.

The 'no change in weight/mass of sugar' prediction

This was the first cohort in which there was some mention of atoms or molecules as constituents of sugar solution; the 'particles' described by respondents in lower year-groups were 'continuous bits' of matter. That kind of 'Piagetian atomistic' thinking was used to support non-conservation predictions.

In this year-group two pupils spontaneously mentioned molecules or atoms - one of these, Colin, was a confident conserver, the other, Andrea, began by asserting that the weight would remain the same, then changed her mind, proposing the remaining choices in turn, before ending with a conserving response. Her bewilderment, shown in the transcript below, seems to be a kind of mental maze having a network of paths, some of which she has to retrace. Her 'molecular path', as yet, had not been sufficiently constructed to be of use to her and it eventually became an impasse.

A: It (weight) should just about be the same.

R: Um hum.

A: That might.

R: Do you want to tell me why you think it'll be the same?

A: It might be a little lighter.

R: Um hum, well let's take the two ideas, one is, it's the same, the other is it might be a little lighter, what makes you think it might be the same?

A: 'cos it's just the same amount of sugar you put in the water, that there is over there (on the other balance pan)

R: I see, but you also had the idea that it might be a little lighter, can you tell me why?

A: 'cos some's dissolved.

R: Um hum how does that, how do you think that makes it lighter? when it's dissolved, what about dissolving might make it lighter?

A: Don't know.

R: It's just a feeling you have, is it?

A: Yeah, I don't know, it could be heavier.

R: It could be heavier? what's to be said in favour of it being heavier?

A: 'cos it's got bigger when it dissolved.

R: What exactly has got bigger would you say?

A: Sugar's split up, the sugar's split up, little molecules.

R: Um hum, you mean bigger in that sense? bigger in the sense of spreading out? is that what you are telling me?

A: Yeah.

R: And how do you connect that with heaviness or being heavy?

A: Cover a wider area.

R: So if it covers a wider area it could be heavier um hum, would you like to tell me a little more of your ideas of this word: heavier.

A: Weight, if you put some more sugar in it'll go heavier.

R: Um hum.

A: I should think it should stay the same, 'cos it's still the same amount of sugar in it and the same amount of water and it's got identical beaker.

Colin took a more global approach with the statement:

'It'd be the same, you're not gaining anything, you're not gaining any more atoms'.

In his case the atomistic ideas appear to be used as a supplement rather than the main reason.

The remainder of the 14 conservers did not offer their atomic/molecular conceptions in this task, although many had revealed in prior conversation, that they had constructed some ideas of this kind. The ideas they used to justify conservation were largely similar to those of previous year groups, for example:

a. the sugar substance is permanent:

'cos, still, this (sugar) has been added to that (water), the sugar's still in there' (10.618g);

(similar to the young children's reason: the sugar was put in)

b. the sugar weight is 'seen' as permanent:

'it makes the same weight as them two put together' (10.603b);

c. the amount of sugar is preserved:

'cos there's the same amount of sugar still in there and there'd be the same amount of water' (10.617b).

The only 'different' kind of reason was given by those who it appears were convinced of a 'sameness' within the system and could not detect any intervention from the surroundings, for example:

'we haven't taken anything away, we haven't added anything' (10.608b)

There were two additional features that occasionaly appeared in the responses of this year-group. One feature was an overt deliberation about the destination of the sugar, in order to overcome the perceptual illusion for instance,

'it can't escape, it's got to be in there somewhere dissolved, still there somewhere, so I think it should be the same weight.' (10.616b)

The other feature was to 'see' the situation as an 'additive' one in a quantitative way as in response 10.603 above, also:

'It's still that (sugar) and that (packet) and the water together (10.612g)

This tendency to apprehend the situation 'in the present' rather than refering back to what was put in may be a feature of older children's responses. It may lead them to inquire into an 'affinity' idea about the addition for when one pupil was asked to explain the unchanged weight in terms of molecules, he replied:

'the sugar is drawn to water, attaching itself to the other water molecules, the weight's still there in the water so it's the same weight' (10.616b)

This was the first suggestion of a mechanism, in terms of intermolecular attraction, for the dissolving process.

The 'sugar loses weight/mass on dissolving' prediction

The basis upon which weight was not conserved by four pupils was similar to that encountered previously, namely:

a. the power of the perceptual illusion:

> ''cos it doesn't weigh, there isn't the weight of the granules anymore, the granules have gone,, dissolved, so we haven't got that (sugar) in the water. (10.613g);

b. sugar there but weight is lost - the concerted force exerted by undissolved solid is contrasted with the divided force of distributed sugar:

> 'it's all dissolved and well, it's like it's all separated and dissolved so it'll be in the water now a lot lighter ... when it's all together it's all in one place and it's a lot heavier (10.605g);

c. 'suspended' sugar is lighter:

> 'it's got all it's weight up in the solution, so it makes it lighter' (10.609g).

The other pupil was searching for a visual clue to solve the problem, and expected the water to rise appreciably. When asked why she thought the sugar would be lighter, she replied, 'probably because I can't see it, but also because the water isn't higher, not much higher' (10.601).

Towards the end of the interview, each of the pupils who predicted a weight loss, was asked to replace the sugar solution on the balance pan. They were then asked questions such as: why the weight was the same and what difficulties people generally would have in making a prediction. In answer to the first question they all said 'the sugar is still there' or words close to that. They interpreted the 'balanced scales' as evidence of preserved sugar. In answer to the second question they admitted that the problem was not being able to see the sugar, for example:

> 'I find it really hard, I can sort of, I can see a weight like that (bag of sugar) and think, ah well, that's heavier than the bag (of sugar) there, but I can't see inside, I'm not too sure about it'.

when the interviewer alleged that weight could not be seen she replied:

> 'but you can estimate how heavy something's going to be by looking at it'. (10.601g).

The others similarly claimed that the problem lay in the interpretation of what they saw:

> 'it looks less ... it looks like there's less of an amount, that it'll weigh less' (10.609g);

> 'can't see the sugar ... can't see it anywhere else and that (sugar on the other pan) is all compact so they think it might be heavier'. (10.605g).

Unlike the conservers, these pupils were heavily dependent on visual perception. These pupils spanned the ability range: one high, two average and one low.

Twelfth-year schoolchildren (16/17 year old)

Again, no pupils predicted an increase in weight/mass on dissolution. 11 pupils predicted the weight would remain the same and seven that it would weigh less.

The 'no change in weight/mass of sugar' prediction

There were two pupils in this year-group who spontaneously offered atomistic explanations: 'atoms don't loose mass' and 'no molecules are added or taken away'. The remainder appeared to conserve mass by thinking at the macroscopic level. Five suggested that the same amount/content/mass was there but in a different place, three that nothing appeared to be lost (e.g. by 'reaction') and one that sugar 'can't disappear'.

The 'sugar loses weight/mass on dissolving' prediction

Of the seven who predicted weight loss, four appeared to have their thinking dominated by the immediate perception of vanishing sugar, one by the idea of small particles having negligible weight, one by the idea of dispersed particles not having weight, and one could not account for his prediction.

7.6.3 Atomistic ideas in the conservation of weight/mass responses

So far as the weighing task is concerned, the prevalence of atomistic responses is so rare that the year-groups will be considered together. Table 7.2 indicates that not more than two in 18 pupils of any year offer atomistic responses.

In years three, five and seven none of the 'conservers' put forward an atomistic view of matter to justify their judgements. In the tenth-year one pupil apparently 'saw' matter as made up of atoms and offered the view that no more were added when sugar dissolved.

TABLE 7.2 NUMBER OF INTERVIEWEES OFFERING SPECIFIED REASONS, CLASSIFIED AS ATOMISTIC/NON-ATOMISTIC, FOR WEIGHT/MASS PREDICTIONS

Prediction of weight (dissolved)	Justification offered for weight judgement	Yr 3 n=18 no.	Yr 5 n=18 no.	Yr 7 n=18 no.	Yr 10 n=18 no.	Yr 12 n=18 no.
Sugar has more weight after dissolution	Because sugar 'parts' add (extra) weight (Atomistic response-result: 'conservation'	-	-	-	-	-
	Because dissolved sugar is heavier (since wet) (Non-atomistic response result: 'conservation'	2	1	-	-	-
Sugar has same weight after dissolution	Because sugar 'parts' are preserved through change (Atomistic response-result: 'conservation'	-	-	-	1	1
	Because substance, amount or weight is preserved (Non-atomistic response-result: 'conservation'	11	9	12	13	10
Sugar has less weight after dissolution	Because sugar 'parts' have a negligible weight/spread (Atomistic response-result: non-conservation	1	2	2	1	1
	Because sugar substance/ weight/volume disappears (Non atomistic response-result: non-conservation	4	6	4	3	6
TOTALS	Conserving responses	13	10	12	14	11
	Non-conserving responses	5	8	6	4	7
	Atomistic responses	1	2	2	2	2
	Non-atomistic responses	17	16	16	16	16

This is some way from the fundamental concept, taught in school, that 'atoms' (regarded as the building units of matter) survive (low energy) changes despite appearances. The majority manage to conserve mass/weight without overt reference to atomistic ideas.

Atomism of the 'continuous-bit' kind was found among the responses of non-conservers in all year-groups. It would appear that the mental image of dispersed diminishing 'bits' of matter led pupils to predict a loss of weight. This weight loss was generated in a number of ways. Some could not imagine that spread out matter could exert pressure on a balance pan whereas compact matter (e.g. solid sugar on the other pan) did so. Others imagined that the 'bits' became so small that their weight was negligible - they did not 'sum' the weight of the bits. Yet others regarded dispersed matter as 'part of the water' and could not imagine any associated weight. This was rather similar to the idea some had that sugar was 'suspended-in' or 'supported-by' the water.

7.7 Findings from survey responses

7.7.1 General characteristics of survey responses

The task was in two parts: a multiple choice prediction and a written explanation for the particular choice made - see para. 7.3.2.

An interesting feature of the responses was the general construction of the sentences containing the explanation. Most of the pupils mentioned that sugar had undergone a change in appearance and then proceeded either to deny or to support the view that this change had also altered the weight/mass/amount of sugar. Those who refuted the idea that a change in the sugar had any influence on the mass/weight of sugar constructed statements that generally fell into two kinds of pattern. The most common pattern was:

	[an emphatic conjunction]	[a perceived transformation]	[a conceptually dominated outcome]
e.g.	[even though]	[the sugar disappears]	[the weight would be there]

In the other kind of 'conserving' pattern an adverb was used to disassociate a perceived transformation from any speculated link with a reduction in the amount of substance or its weight.

	[a disassociat-ing adverb]	[a perceived transformation]	[a conceptually dominated outcome]
e.g.	[only/just]	[broken into small parts]	[so mass is still the same]

On the other hand, if the change in the sugar was thought to change the sugar mass/weight/substance as well, then the response statements took a different form such as:

	[a perceived transformation]	[a perceptually dominated outcome]
e.g.	[sugar granules disintegrate & go]	[so they don't weigh anything]

<u>7.2.2 Prevalence of types of prediction of mass/weight and possible schemes that underlie these predictions</u>

The survey responses were categorised in a similar manner to the interview responses, i.e. according to a predicted increase, decrease or no change in mass/weight resulting from sugar dissolution. The prevalence of each of these responses within particular year-groups is shown in Table 7.3. As table 7.3 shows the percentage of pupils who preserved weight/mass of dissolved sugar <u>diminished</u> after the third year but then increased through subsequent year-groups. A similar trend had been noticed in the interview responses. The features that characterise the various kinds of responses together with inferred underlying schemes will now be considered.

TABLE 7.3 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED PREDICTIONS ABOUT WEIGHT/MASS OF DISSOLVED SUGAR

Prediction	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
A. Left-hand pan below right-hand pan (i.e. sugar <u>heavier</u> after dissolving)	15	13	9	8	12	9	7	5	2	2
B. Left and right-hand pans at same level (i.e. no change in mass/weight)	58	52	45	41	56	44	101	67	61	71
C. Left-hand pan above right-hand pan (i.e. sugar lighter after dissolving)	39	35	55	51	57	45	46	30	23	27
No response	-	-	-	-	2	2	-	-	-	-

<u>7.7.2.1 The prediction: sugar solution is heavier than its components</u>

As Table 7.3 shows the percentage of pupils who made this prediction decreased with age. Their explanations indicated that they were focussing solely on the sugar, in particular, the sugar getting wet or the sugar adding weight.

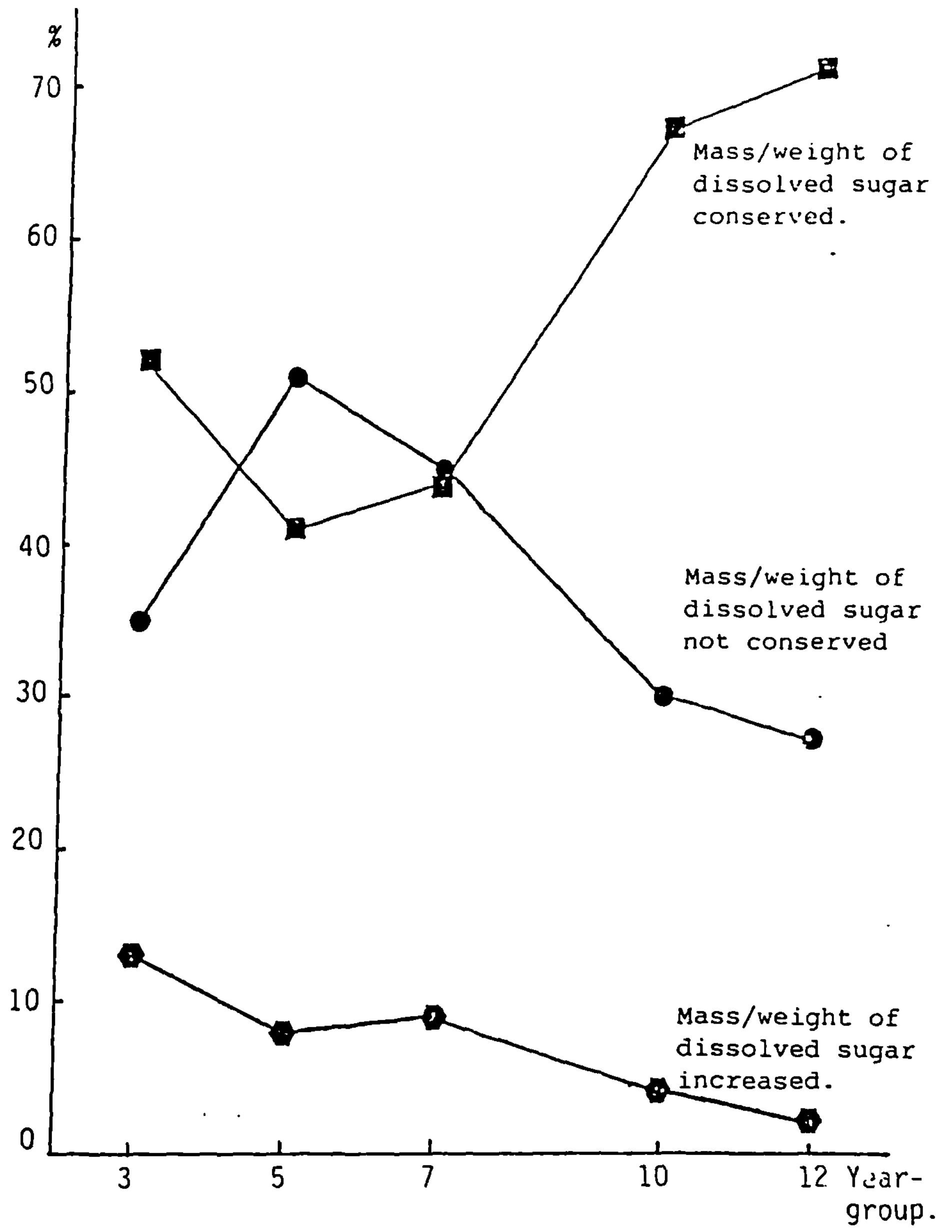


Fig. 7.1 Graph showing percentage survey pupils offering specified predictions about the weighing task.

In the former case their experience of wet things was that they were heavier than dry things; whereas in the latter case it appears that either a compensation scheme was missing or else their focus of attention (i.e. the solution rather than the whole balance) was severely limited. Nevertheless, as the example below shows, they did conserve the weight of sugar.

Example 7.1

> I chose this answer because. when the sugar dissolved it gets heavier as you've added it to the water....

when the sugar dissolved it gets heavier as you've added it to the water (10.131g)

Example 7.2

> Because water makes things heavy cause when I go swimming my things a light when I come out they are heavy

Because water makes things heavy cause when I go swimming my things a light when I come out they are heavy. (5.008g)

Example 7.3

> I chose this answer because. If Liz put her sugar granules in her glass and Rob did not the sugar granules on Liz's will weigh the most because sugar is very fatening and weigh ...

If Liz put her sugar granules in her glass and Rob did not the sugar granules on Liz's will weigh the most because sugar is very fatening and weighs more. (5.042g)

7.7.2.2 The prediction: sugar solution has the same weight/mass as its components

Unlike the previous prediction, the percentage of pupils giving this response increased with age - apart from a small decrease in the fifth school-year.

The explanations that pupils offered showed that the same prediction could be supported in a variety of ways. This was, in all probability, because sugar was 'seen' in different ways by different pupils. Some 'saw' sugar as added <u>weight.</u> In their view, whatever had been added to water (on a balance) would have added 'weight' to the water. Example 7.4 illustrates this idea. These pupils also showed an awareness that sugar had undergone considerable change - variously described, for example 'disappeared' or 'gone to nothing'. Nevertheless, in their view, the weight remained. It may be inferred that these pupils employed the schemes: <u>'added objects add weight'</u> and <u>'weight is a lasting quality'.</u> It was characteristically expressed by one pupil who wrote: 'The weight is the same all the way to the end'.

Example 7.4

I chose this answer because..I..think....that...if...you.add...
..any....weight...and.it..dissolves...it..will..stay...
.the...same...weight....as...before..it..was.........
..dissolved.(7.013g)...

I think if you add any weight and it dissolves it
will stay the same weight as before it was
dissolved. (7.013g)

Example 7.5

I chose this answer because...When....the.....Suger....dispares
.it...is......the......Same.......whight....as.....before
.So.....they....will......be.......the......Same.(7.031g)

When the suger dispares it is the same whight as
before so they will be the same. (7.031g)

Some other pupils appeared to regard the sugar as a <u>solute</u> that was 'still there' after transformation and so, they said, its weight was 'still there'. Thus the preservation of weight was based on the preservation of substance. They seemed to use the scheme: <u>'substance survives transformation, so weight is the same'</u>

Examples 7.6 and 7.7 could illustrate the operation of these schemes.

Example 7.6

> I chose this answer because..The..sugar...has..dissolved...but..it..
> ..is..still..in..the...cup..so..the..cup...is..still..the..same......
> ..weight. (7.051b)

The sugar has dissolved but it is still in the cup so the cup is still the same weight. (7.051b)

Example 7.7

> I chose this answer because..the..sugar...would..still..weigh
> the..same..even..if..you..can..not..see..it
> because...the..sugar...could...not..come
> out...of...the..glass...I..don't....think..(5.105g)

the sugar would still weigh the same even if you can not see it because the sugar could not come out of the glass I don't think. (5.105g)

It appears that some other pupils 'saw' the sugar as 'an amount of material'. These words suggest the advent of the conception of mass (i.e. amount of substance - example 7.8 and 7.9). In that case it is possible they had a scheme that: 'transformation does not alter the (fundamental) constitution of substance'. However, it could be that some of them did not share such a fundamental view and were thinking merely in terms of the volume of material.

Still other pupils 'regarded' dissolved sugar as many small pieces, each one of which contributed to the total weight. They appeared to have the schemes: 'each piece of sugar has weight' and 'the sum of the weights of the pieces is equal to the whole (initial) weight'. (see example 7.10)

Some other pupils, but hardly any below the tenth year, appeared to look for possible effects that were external to the solution under consideration. However, they did not find any evidence that substances had been removed or added. This scheme of looking for matter escaping to the surroundings or matter entering from the surroundings, is likely to be the outcome of laboratory experiences such as gases 'given off'. This supposition would account for the occurrence of the scheme among older children. See examples 11 and 12. One pupil regarded his response as a theoretical one, possibly because he was aware that one cannot always observe the absorption or escape of matter.

Example 7.8

I chose this answer because...the same amount of sugar has been added to Liz's mug as in in Rob's egg cup so they should balance out because they both equal amount of sugar and water. (10.047g)

the same amount of sugar has been added to Liz's mug as in Rob's egg cup so they should balance out because they both equal amounts of sugar and water. (10.047g)

Example 7.9

I chose this answer because...The same amount of material is still there just in a different form. If the same amounts are there, there should be no weight change.

The same amount of material is still there just in a different form. If the same amounts are there, there should be no weight change. (10.137b)

Example 7.10

I chose this answer because...the sugar was disolved in the water and the granules have become smaller (see before) now there combined weight should still be the same as before. (10.150b)

the sugar was disolved in the water and the granules have become smaller (see before) now there combined weight should still be the same as before. (10.150b)

Example 7.11

I chose this answer because..When the sugar was put in the water and dissolved it lost no weight because nothing was actually removed totally from the scales

when the sugar was put in the water and dissolved it lost no weight because nothing was actually removed totally from the scales. (10.051b)

Example 7.12

I chose this answer because in theory nothing has been added or taken away from either side of the Scales

in theory nothing has been added or taken away from either side of the scales. (10.108b)

Only two pupils seemed to employ what might be called a science atomistic scheme, namely, that the permanence of matter through change may be based on the conception of the <u>permanence of atoms</u> through change. See examples 7.13 and 7.14 below. It is fairly common for pupils to write 'elements' and mean 'atoms'. It will also be noticed that the atomistic scheme, in one case, is used merely as a support for a macroscopic scheme.

Example 7.13

I chose this answer because. the Sugar still remains on the Scales. No other Substance is gained and none is lost. Atoms cannot gain or lose weight unless they gain more Substance (10026b)

the sugar still remains on the scales. No other substance is gained and none lost. Atoms cannot gain or lose weight unless they gain more substance. (10.026b)

Example 7.14

I chose this answer because..although..the.sugar..granules..have...
dissolved..and..cannot..be.seen..the..elements...that..made
up...the..sugar..still...exist,.in..the.water..now..though..This
should..keep..the.weight...the.same..as..the..elements.are.still
there.

although the sugar granules have dissolved and cannot be seen the elements that made up the sugar still exist, in the water now though. This should keep the weight the same as the elements are still there. (10.113g)

Thus, in a variety of ways, these pupils conserved the weight/mass of dissolved sugar - as one pupil summarised conservation thinking: 'because we can't see it, it don't mean to say it isn't there'. (7.120g)

The prevalence of each of these conservation schemes is shown in table 7.4 below. The most prevalent ones are those in which either the sugar weight is regarded as a lasting quality or the sugar weight is deemed constant because the sugar substance remains. It is interesting that the trend in the data for the latter follows a similar trend to that of the conservation judgements made in the multiple choice task - see fig. 7.1 and fig. 7.2.

TABLE 7.4 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED REASONS FOR CONSERVING WEIGHT/MASS

Conservation schemes	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. 'weight' is a lasting quality despite change of state	20	18	26	24	29	23	27	18	5	6
b. Invisible substance remains and so its weight remains	17	15	10	9	15	12	37	24	26	30
c. Amount of substance remains the same despite change of state	-	-	1	1	5	4	11	7	20	-
d. Weight of dispersed bits is same as weight of whole	-	-	-	-	-	-	10	7	-	-
e. No loss to, or gain from surroundings	-	-	3	3	3	2	12	8	4	5
f. Invisible molecular particles remain despite change of state	-	-	-	-	1	1	3	2	4	5

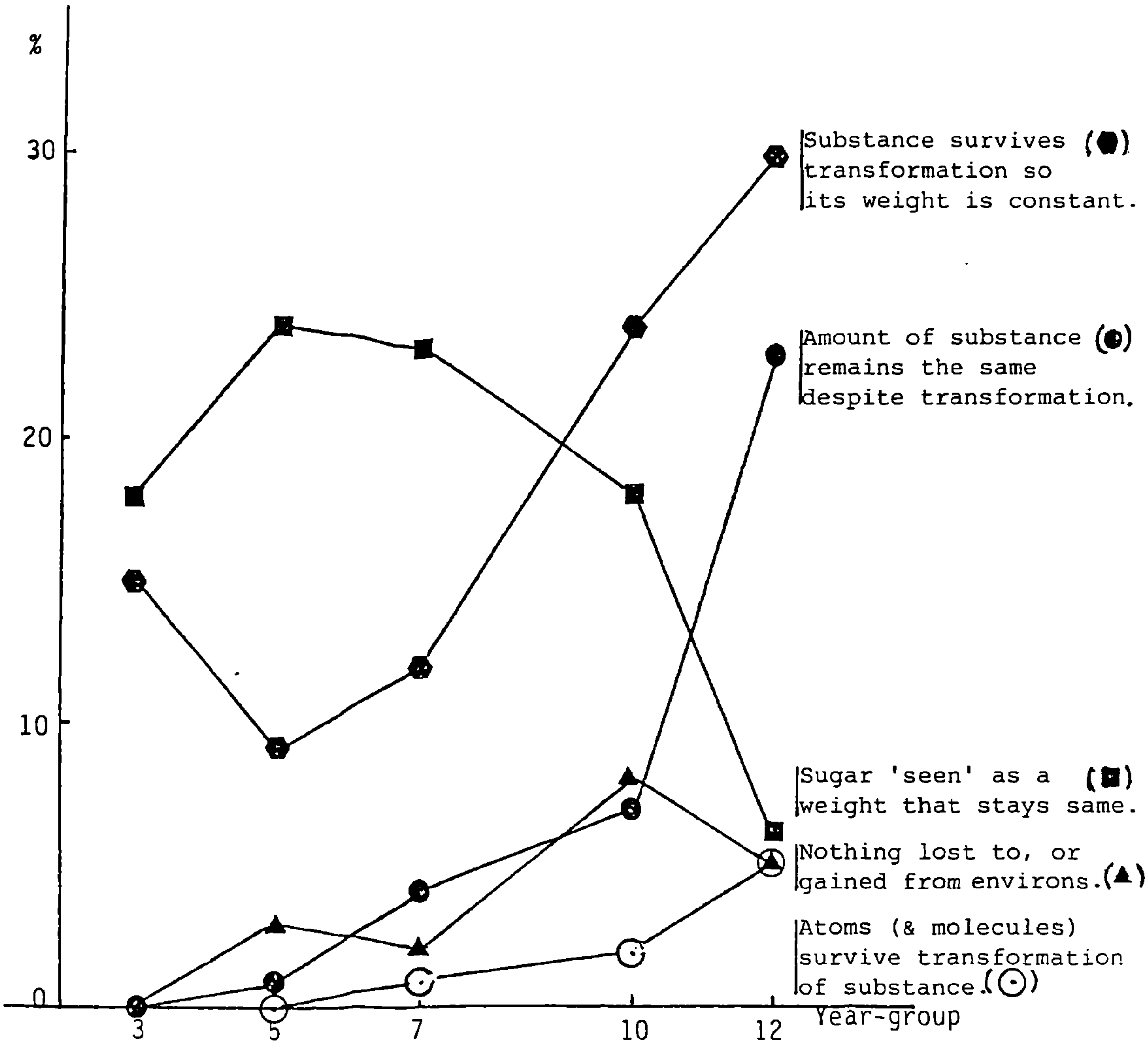


Fig. 7.2 Graph showing percentage of survey pupils offering specified reasons for conserving weight/mass.

This may suggest that a conception of the continuance of substance underlies a major proportion of the predictions even though the respondents were not always able to offer a reason in writing. Another interesting feature of Table 7.4 is the growth in the idea of the amount of (unchanging) substance with year-group. As was found in the interviews, few pupils offered the idea of the permanence of molecular particles or their weight through change.

7.7.2.3 The prediction: sugar solution has less weight/mass than its components

The percentage of pupils giving this kind of response showed a similar trend with year-group to that obtained in the interviews. That is, the percentage of non-conservers increased up to the fifth-year and then diminished.

As in the case of responses reported in the previous section (para. 7.7.2.2) it seemed that non-conservers also 'saw' the sugar in different ways. Again, some regarded bulk sugar as a 'weight' for the purpose of completing the task. The difference, however, was that only visible sugar i.e sugar seen to be (pressing down) on the scale pan was thought to possess the weight property. Accordingly, when the sugar disappeared, so did the weight. Thus pupils described 'dissolving' as the weight being 'taken off' for example:

> 'it Liz stur's her sugar it take's the weight of and Rob has still got is in so it will stay the same so Rob's is hevea (7.029b);
>
> 'Liz has no wate of sugar left so Robs weights more than Lizs. (7.024).

The scheme that appears to be used is that 'weight is associated with an observable solid (pressing) on the scale pan'. According to this view, when the sugar has dissolved it 'looks' as though the weight has been taken off the pan.

It seems that another scheme in use was: 'sugar mixed with water or part of water has no weight'. It could be that pupils were thinking of the sugar being suspended and apparently weightless, for example:

> 'the sugar has dissolved into the water so it is not as heavy as before seeing it is mixed in with the water' (7.012g)

In this case substance is preserved but weight is not preserved.

An alternative approach by some pupils was to focus on the transformation of sugar and to argue loss of weight from apparent loss of substance. This idea that because substance has disappeared, its weight ceases to exist was expressed in a variety of ways. It was reported that sugar had 'melted away', 'turned into nothing', 'evaporated in the water', 'disappeared in water', 'just left a flavour'.

Those who used 'particle' ideas to support non-conservation appeared to use schemes such as: the smaller the particle the less would be its weight; the more spread out the particles the less dense would the solution be. For example,

> '... it won't be as heavy because the sugar granules will have shrunk to smaller than a pin head' (10.041g)

> '... the water would spread the sugar molecules out and many would be so small they would lose weight' (10.005b)

The prevalence of the non-conservation schemes is displayed in Table 7.5 below. The most prevalent are based on ideas either about weight (as such) being lost or about substance vanishing. Both of these reach maximum prevalence in the fifth-year. Few pupils used 'particle' schemes in their responses.

TABLE 7.5 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED REASONS FOR NON-CONSERVATION OF WEIGHT/MASS

Non-conservers schemes	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. 'weight appears to be taken off (disappears) or sugar becomes part of water and weight-less	8	7	23	21	24	19	26	17	12	15
b. 'Substance'appears to vanish (dissolves, melts only water left) so it has no weight	16	14	26	24	28	22	12	8	4	5
c. Particle ideas support weight loss (shrink - less size - less weight, spread out - less dense, fit into spaces)	-	-	-	-	-	-	7	5	6	7

7.8 Summary of findings from interview and survey tasks

At the outset of this chapter, a view of children's developing conception of weight/mass of objects, was outlined. It was based on how children described, by words and gestures, their experience of 'heaviness' and an 'amount of substance'.

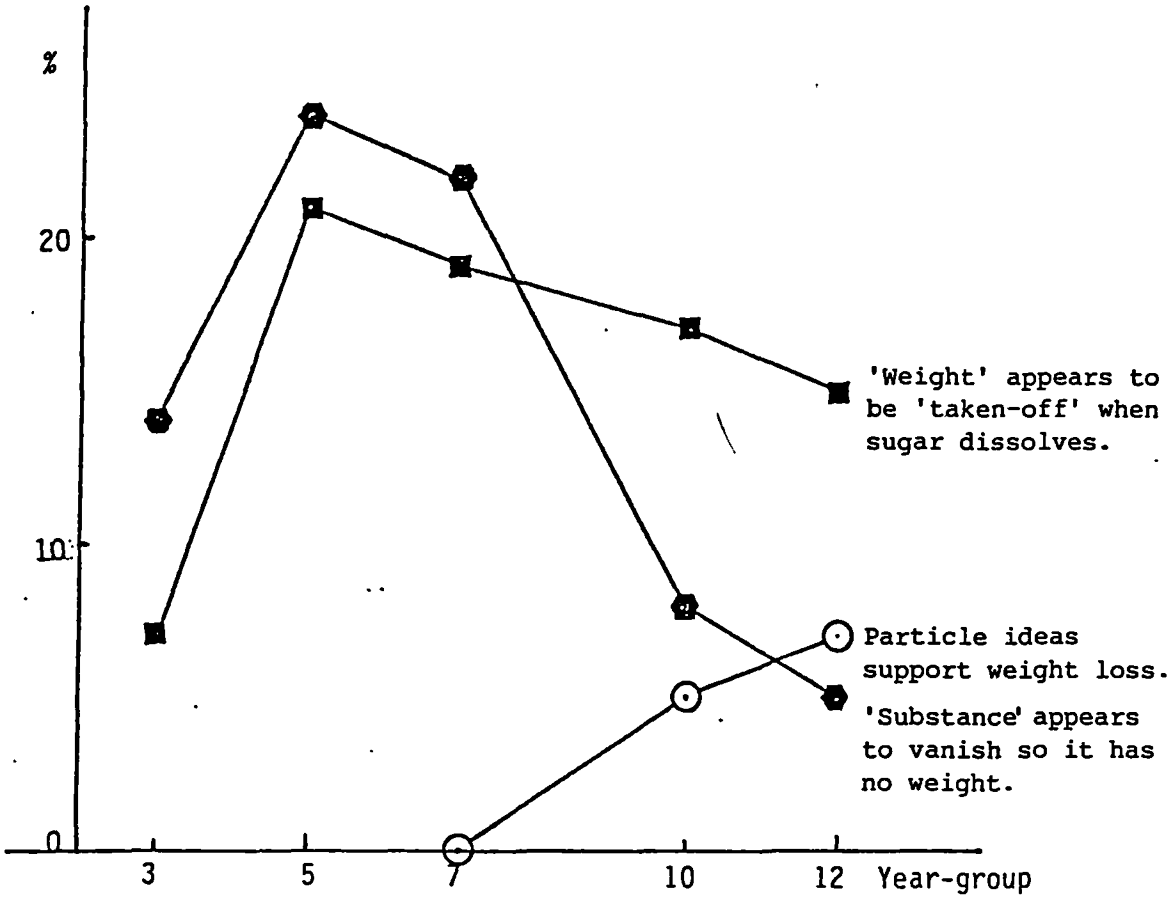


Fig. 7.3 Graph showing percentage of survey pupils offering specified reasons for not conserving weight/mass.

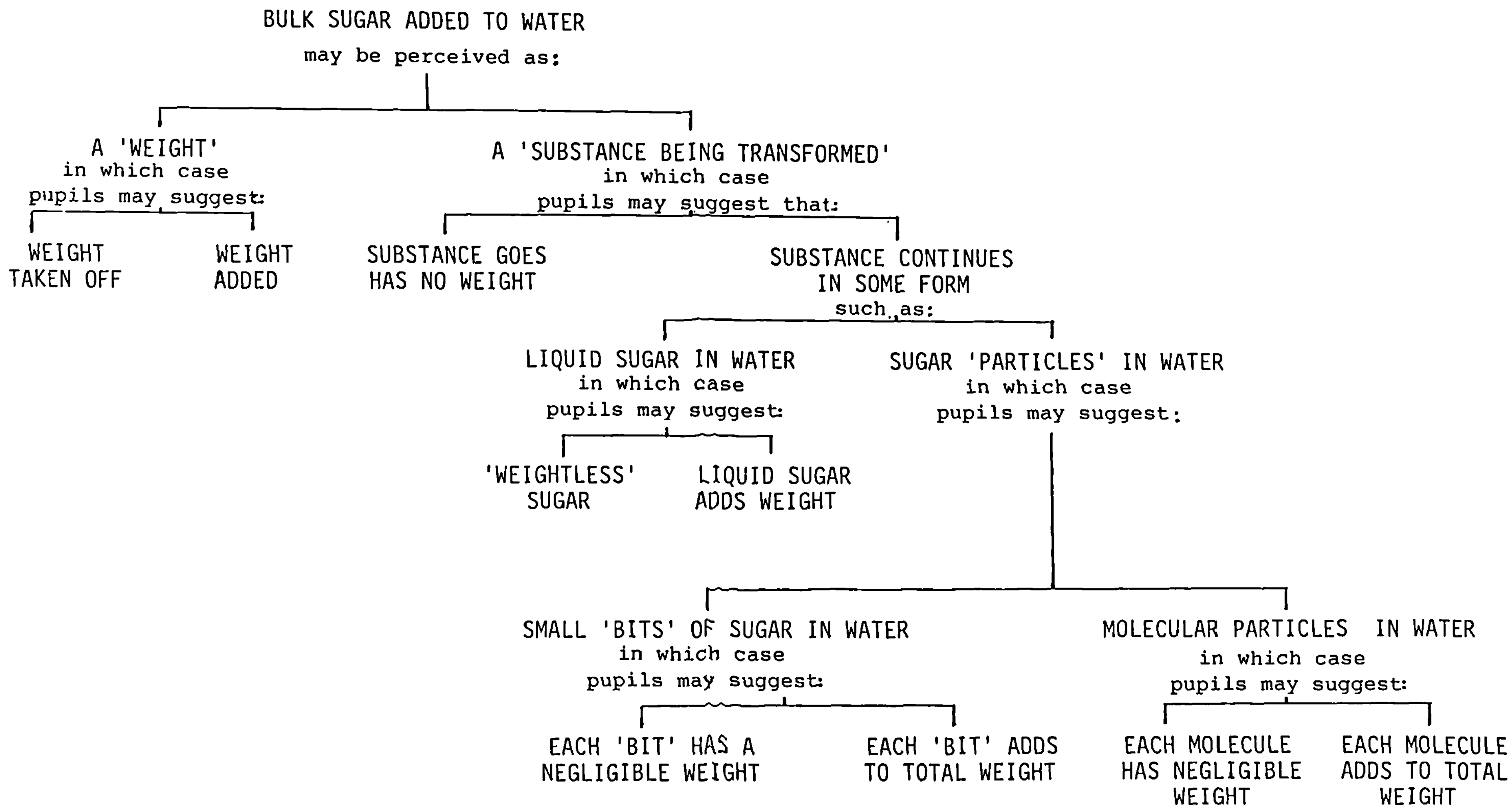


Fig. 7.4 Pupils' alternative constructions of the weight/mass of dissolved sugar.
[Developmental 'moves' (in science direction) would be left to right, and top to bottom of diagram.]

Their conception of weight/mass appears to have been derived from 'feeling' and 'seeing' - how things 'press down' and how 'large' they look. Some older children adopted the science view that an unseen gravitational force produced the feeling of heaviness.

The chapter continued with an attempt to model children's predictions about the weight of dissolved matter - a situation in which they did not have the aid of visual or motor-muscle data. Task responses showed that pupils expected the weight/mass of dissolved sugar to either decrease or to remain the same. A U-shaped pattern emerged in the change of proportion (with age-groups) of pupils who made conserving responses (see fig. 7.1 and 7.3). In the third school-year about 50% conserved weight/mass, this proportion diminished to its lowest point (about 40%) in the fifth-year; thereafter it steadily increased again reaching about 70% in the twelfth year-group.

Pupils justified each of the three kinds of prediction in several ways. This variety seemed to be a consequence of the several <u>initial</u> foci of attention together with the subsequent reasoning. The different foci included: the sugar 'seen' as a <u>weight,</u> the <u>transformation</u> of the sugar and its perceived resulting form; the <u>sameness</u> or otherwise of the initial and final substance; and, the <u>environs</u> of the tumbler. Schemes about matter and weight/mass inferred from pupils' responses are summarised in the remaining paragraphs of this chapter.

It would seem that, in this chapter, the general findings may be summarised under five heads. First, <u>the existence of a range of alternative supporting ideas for a particular prediction.</u> These ideas are reviewed in fig. 7.5 - a diagram that has been assembled for summary purposes. It is not meant to indicate a pathway of any particular pupil's thinking, though parts of it may crudely represent certain thought patterns. The reason for presenting these ideas, predominantly in a dichotomous manner, is that many of the pupils' responses had polar connotations and occasionally pupils switched from one to the other during interview, or else they suggested them as plausible alternatives.

The summary diagram indicates that, initially, pupils may focus attention either on the (bulk) <u>weight</u> of sugar, or on the transformation of the sugar. In the former case, the weight of sugar appears to be 'taken off' as bulk sugar disappears and unless this is countered by a conception of permanence of substance, a weight loss is predicted. If, on the other hand, the conception of permanent sugar takes precedence then sugar is 'seen' as added weight.

However, if initially, the transformation of sugar is the focus of pupils' attention, then either a perception of disappearing solid leads to the prediction that its weight disappears, or a predominant conception of permanence of matter leads to the prediction that sugar continues to exist in some form.

The way in which pupils describe the changed form of sugar is taken to be a representation of their modelling of matter. Pupils' models appear to have a considerable influence on their ideas about the conservation of weight/mass. For instance, if sugar is 'seen' to liquefy (melt) then it may be regarded as 'weightless' (because, they say, it is 'part of the water') or else 'liquid sugar' is thought to add weight. On the other hand, dissolved sugar may be imagined to exist either as small 'bits' of sugar or as 'molecular particles'. Either way, the parts may be considered too small to contribute to the weight of water or else the sum of the weights of the invisible parts may be reckoned equal to that of the whole. In addition to predicting loss of weight from smallness of particles, other reasons were dispersion of particles (spread out matter weighs less) and suspension of particles (buoyancy effects). However, these were comparatively few for, as we shall see in chapter 9, the growth of a conception of homogeniety is slow.

Second, the decreasing ability, in the overall population, after the third-year, to conserve weight/mass. This is followed by an improved ability in later school years. The fact that Tables 7.1 and 7.3 show a minimum number of conservers in the seventh-year suggests that some newly formed schemes are, in some cases, in conflict with existing schemes, and there could be a period of disequilibrium that needs time for adjustment. Maybe, for many third year pupils, there is just one dominant factor in the prediction making process, namely, that the sugar was put into the water. But, pupils in the subsequent year-groups, as a result of more varied experience, (books, the media, school-work, etc), begin to make sense of a plurality of ideas about the microscopic world - the invisible micro-organisms in water is just one example. In some cases, as chapter 9 will show, this information about microscopic species is, in their view, more significant than the presence of sugar. Further, there was a general tendency, as pupil's became older, to think more about what might happen to the sugar during dissolution and to model the imagined 'fate' of sugar. For instance, they were concerned as to whether it was 'liquid sugar', 'suspended solid sugar', 'dispersed sugar', 'settled out sugar' and how each of these 'images' of sugar would influence the 'weight'. Thus it would seem that the intertwining of mental images of matter with views of weight, along with other new (fascinating) information taking precedence over the immediate task content, produces a temporary fall off in the number of conservers.

Third, the place of atomism in the development of conservation of weight/mass ideas. In common with the work of Selley (1979), this study found very little explicit evidence that pupils used or were assisted by atomistic ideas in the context of weight/mass conservation. Indeed, it appears that atomism sometimes assists non-conservation since the 'size-weight' scheme supports the view that small particles and atoms are too small to have any significant weight - see Table 7.2. This finding conflicts with Piaget's hypothesis that atomism assists conservation. However, it was found that pupils (somewhat older than those that Piaget interviewed), who possessed a science idea about atoms being regarded as the building bricks of matter, were indeed conservers of mass. Nevertheless, the majority of conservers used schemes that were non-atomistic in character.

Fourth, the conceptual changes that are required if the pupils are to move, in their thinking, towards school-science ideas. As a result of reflecting on children's alternative ideas about the weight/mass of dissolved sugar (as summarised in fig. 7.3) it is suggested that the following conceptual shifts may be required:

* from a 'change-of-physical-state-changes-weight/mass' view to a 'change-of-physical-state-leaves-weight/mass-unchanged' view;

* from a 'suspended/distributed/dissolved-matter-has-no-weight/mass' view to a 'dispersed-matter-retains-its-weight/mass' view;

* from a 'matter-is-made-up-of-broken-down-parts' view to 'matter-is-made-up-of(durable)-built-up-particles/atoms' view;

* from a 'particles/atoms-have-negligible/no-weight/mass' view to a 'particles/atoms-contribute-to-the-total-mass-of-an-object'.

Given this information teachers may contrive strategies that may or are likely to facilitate these conceptual changes.

Fifth, <u>the development trends towards the school-science view of matter and weight.</u> In part, these may be regarded as conceptual 'moves from the left to right and from top to bottom in fig 7.5. The developmental 'picture' is not linear but branched as a result of diverse combinations of conceptual elements that children make. Some of these combinations have been illustrated in second point made above. Thus there is a deviation from direct developmental growth towards conservation of weight/mass and a school-science view of matter. For example, through the schoolyears, there is an increase in the diversity of representations of dissolved matter and some of these dispersed parts are not attributed weight. Not until children have a gravitational view of weight, are they likely to conserve weight as well as substance.

In addition to a general increase in the diversity of representations of dissolved matter and a slow conceptual change in a view of weight, there appears to be a growth among some children (albeit a small proportion) in a conception of mass as 'an amount of substance' - see Table 7.4. Further, if the task is viewed as a problem to be solved, then it could be said that there is an increase with year-group in the number of strategies used to solve it; for example, to focus on the environs of the container for loss or gain of substance.

CHAPTER 8

SCHOOLCHILDREN'S UNDERSTANDING OF THE SPACE TAKEN-UP BY DISSOLVED MATTER

8.1 Introduction

From a science perspective, one of the most characteristic features of matter is its occupancy of space. Despite change of state or transformation into other forms of matter it continues to 'take up' space. In this chapter we shall explore pupil's ideas about the space 'taken up' by dissolved sugar. (Pupils' ideas were probed after observing that undissolved sugar displaced water). We shall try to ascertain whether pupils continue to assert that sugar occupies space when it has dissolved and, if so, how they construct this idea. Alternatively, if they imagine that 'sugar-space' has vanished, what ideas of matter underlie such a view. Then, again, we shall look at the impact, if any, of atomistic ideas on the idea of conservation of space taken up by dissolved matter.

It should be borne in mind that this is not a precise study of quantitative volume changes that accompany the solution of a solid in water. From a science standpoint the total volume of the components may increase, decrease, or remain the same, after dissolution, depending on the nature of the interaction between particles of substances and accompanying energy changes. (It so happens that when sugar dissolves in water a small decrease in overall volume is observed. Scientists hypothesise that this is a consequence of enhanced intermolecular attraction between water and sugar molecules).

However, the concern of this study is to explore speculations about phenomena that children make and to draw inferences regarding their underlying 'schemes' related to matter. We are not trying to estimate the number who produce the 'accepted' answer to the volume change. Rather, we are using the phenomenon of dissolution to explore the nature and prevalence of ideas about matter that children generate in this context.

The chapter opens with an outline of ideas about volume change on dissolution that are commonly taught in school science. (It will be appreciated that children below the seventh school-year are unlikely to have encountered these ideas). The tasks used to elicit pupils' ideas are then described. The aims of the analysis and the procedures for analysing responses follow. Next, the findings from analysis of interviews and the survey are discussed. Following that, prevalent schemes, inferred from the responses, are summarised.

8.2 A school-science perspective on the space occupied by dissolved matter

Although at an early age children have many experiences of mixing solids and/or liquids of various kinds, it is unlikely that they will have measured changes in volume that result from mixing before the seventh school-year. During or after that year, they may be encouraged to interpret volume changes when substances such as ethanol and water are mixed. (See, for example, Mee, Boyd and Ritchie, 1980, p. 53.) Intuitively, one might expect pupils to predict a total volume equal to the sum of the component volumes. The diminished total volume that actually results from the mutual solution of one liquid in the other is supposed to help pupils to construct a particulate theory of matter. The school-science explanation, at this level, is based on a hypothesis that if both liquids are composed of particles then there is a certain amount of vacant space between them. On mixing, it is supposed that the particles of one liquid partially occupy some of the space between particles of the other. In order to add plausibility to this explanation, pupils are asked to observe the result of mixing equal volumes of peas and barley.

In later school-science the volume changes that result from dissolving substances may be interpreted as a mutual interaction between the respective particles. (See, for example, Hall, Mowl and Bauser, 1973) At this level, forces of attraction between the particles of different molecules are hypothesised. These forces, it is supposed, reduce the distance between particles and hence the overall volume that they occupy.

8.3 The eliciting tasks

The interview task

At this stage in the interview, each pupil had already immersed a single large crystal of sugar [1] in a measured volume of water. The crystal was visible on the bottom of the measure and the water level had risen. Earlier in the interview a similar crystal had been seen to dissolve in water without the aid of stirring. The interview proceeded in the following manner:

---

1. The volume of the sugar crystal was about $0.5cm^3$.

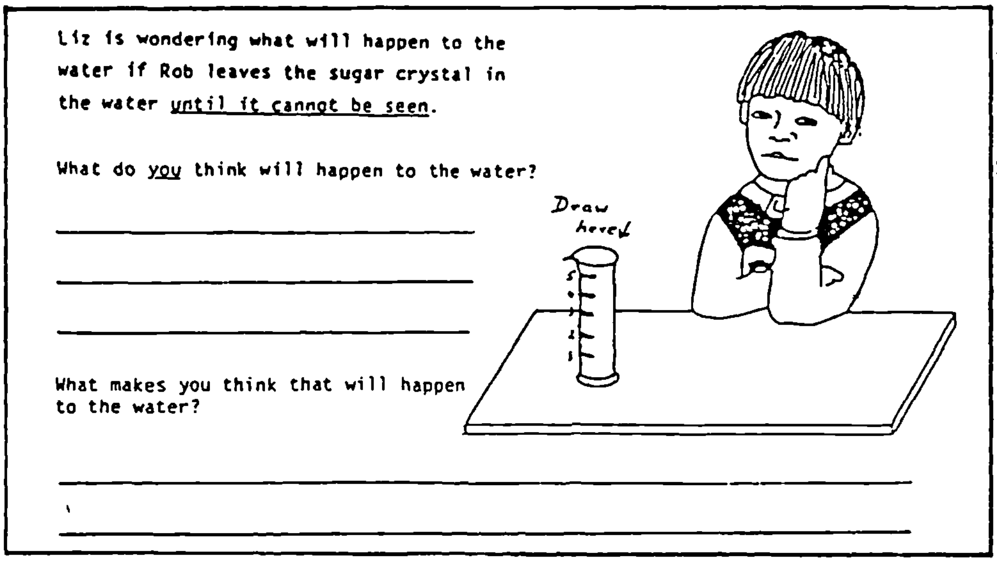
Researcher: 'Suppose you left the crystal in there (pointing to the measure) - just as you left the other crystal a few minutes ago - what do you think would happen to the water in the measure?'

(Depending on the response) 'What makes you think that will happen to the water?.

This would be followed by probing questions related to the nature of the response.

<u>The survey task</u>

Each pupil was given a single crystal of sugar to handle and also shown a measuring cylinder with water in it.


Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water <u>until it cannot be seen</u>.

What do <u>you</u> think will happen to the water?

What makes you think that will happen to the water?

8.4 Aims in the analysis of responses

It was envisaged that the task could elicit answers to the areas of interest listed below.

* To what extent, did pupils in each cohort, regard immersed sugar substance as though it continued to occupy space after dissolving?
* If it was so regarded, did they expect it to occupy space in addition to that of the water, or occupy interstitial space? In either case what kinds of thinking induced the construction of these ideas?
* What underlying schemes about matter and displacement may be inferred from the pupils' responses?

* What part, if any, does atomism play in children's ideas about the conservation of space taken up by dissolved sugar?
* What changes in children's ideas about the space taken up by dissolved sugar, appear to take place during the school-years?

8.5 Analysis procedure for interview and survey responses

The analysis was undertaken in two parts. First the responses (i.e. interview transcripts and survey written answers) were categorised according to the prediction pupils made about the volume of sugar solution after the immersed sugar crystal had dissolved. Each of the five possible outcomes implied a view about the space occupied by the dissolved sugar. The five categories may be summarised as follows:

Prediction category	Spacial implication
a. The liquid level rises.	Sugar takes up more space after dissolution
b. No change in the level of liquid.	Sugar takes up the same space after dissolution as it occupied previously
c. A somewhat diminished fall in level, but still above original level.	Sugar takes up some space after dissolution but not as much as before dissolution or, there is a redistribution of occupied space.
d. A return to the original water level.	Sugar does not occupy any space after dissolution, or else sugar has entered the space occupied by water.
e. The liquid level falls below the original water level.	Some water has entered the space occupied by sugar.

Each prediction response was assigned to one of the above categories. After that, justifications for the responses within each category were compared by year-group so that developmental trends could be followed. The greater depth of probing, that interviews allowed, made it possible to follow the development of atomistic ideas in particular.

In the analysis of the survey data, the second stage was to gather evidence for the prevalence of ideas in a larger population. The survey also captured a wider range of ideas and provided more material for the inference of underlying schemes. An iterative procedure was adopted in which each response, within a category defined on the previous page, was reflected upon in order to interpret each pupil's justification for his/her response. It was found, that in all the categories cited on the previous page (apart from category 'e') the pupils had made assertions about:

* the presence/absence of the volume of dissolved sugar 'seen' in either bulk or particle form;
* the presence/absence of the weight (or force/push) of dissolved sugar;
* the presence/absence of dissolved sugar substance.

Consequently, each of the categories, cited on the previous page, could be subdivided into four sub-categories depending on pupils' assertions about the conservation/non-conservation of:

(i). Bulk volume of dissolved sugar;
(ii). Particle volume of dissolved sugar;
(iii). Weight/force/push of dissolved sugar;
(iv). Dissolved sugar substance.

However, the subcategories, so formed, yielded very small numbers.

8.6 Findings from the interview responses

8.6.1 General characteristics of the responses

In general pupils found this task more difficult than previous tasks and often took a somewhat longer time to think before responding to the interview questions. In all cases however, they gave a prediction about a final volume - sometimes 'changing their mind' as they formulated their ideas. A number prefaced their responses with the phrase, 'as it dissolves the level ...'. This seemed to indicate that they were describing an imagined process as it happened. The four types of prediction together with the prevalence of each are shown in Table 8.1.

As the table shows, there is a considerable increase in the number of preservers of space taken up by dissolved sugar after the seventh school year. Alongside that trend there was an increase in the number predicting a small reduction in overall volume. Among those who preserved the volume of sugar there was a decrease in the number who failed to compensate for the space vacated by dissolved sugar. Examples of responses in relation to their year-groups are discussed in section 8.6.2.

There was a variety of ways in which pupils justified their predictions about volume changes. Some seemed to generate ideas from their immediate perceptions, others from a mental image of dissolved matter, yet others reasoned from the absence of external influence or from assertions about object permanence. In general the responses illustrated a diversity of perceptual elements used by pupils to construct ideas.

TABLE 8.1 NUMBER OF INTERVIEWEES OFFERING SPECIFIED PREDICTIONS ABOUT VOLUME OF DISSOLVED SUGAR

Prediction	Year 3 n=18 no.	Year 5 n=18 no.	Year 7 n=18 no.	Year 10 n=18 no.	Year 12 n=18 no.
a. A rise in the level of the liquid (i.e. sugar takes up more space after dissolution)	6	5	3	1	1
b. No change in the level of the liquid (i.e. sugar takes up some space after dissolution)	1	1	2	10	8
c. A diminished fall in liquid level (i.e. sugar takes up somewhat less space after dissolution)	1	1	-	1	3
d. A return to the original water level (i.e. sugar takes up no extra space after dissolution)	10	11	13	6	6

8.6.2 Patterns of response by year-group

In order to follow the development of pupil's schemes that relate to 'dissolving and displacement' the kinds and prevalence of responses will now be reviewed by the school-year groups.

8.6.2.1 Third-year schoolchildren (7/8-year-old)

Six pupils judged that, as a crystal of sugar dissolved, the level of the water would rise, ten that water would return to its original level, one that the level would stay the same and one that it would diminish by a small amount. The manner in which pupils justified each of these predictions is discussed below.

The 'further increase in volume' prediction

Those who predicted an increase in the level of water preserved the space occupied by the sugar substance but failed to take account of the space vacated by the sugar crystal. It is noteworthy that all of the pupils who, either initially or subsequently, failed to compensate (for undissolved sugar) in the balance task also omitted to compensate for space in this task. The greater number on this occasion may be due to the fact that the vacated space has to be imagined and held alongside other more impactful images. Alternatively, the required schemes may be absent or not appropriately structured.

One powerful image was that of the crystal disintegrating and it's parts decending thereby actively displacing the water upwards. Their imagined descriptions included phrases like:

> 'That (crystal) will go into more little pieces inside and they'll drop down to the bottom and push some more (water) up.' (3.202b)
>
> 'It will rise with the sugar coming off 'cos the sugar will go down and keep pushing the water up.' (3.211b)
>
> It will go in some little bits will go in which will cause it (water) to rise up a bit more.' (3.209b)

These responses could suggest that 'action schemes' underlie their view of displacement. Two schemes appear to be involved: one has to do with the crystal breaking up and the other with the weight of the parts pushing the liquid upwards. The action of the 'pieces' of sugar may also be seen as a replication of a prior and familiar event (i.e. displacement by the large crystal). Kelly (1950) hypothesised that, faced with a new situation, persons tend to use related and familiar experience from the past. He called the process 'construing a replication'.

Others accounted for a predicted volume increase by focussing on the change in state of the sugar. This, they thought would produce more 'liquid', for example:

> 'when it melts it'll go up an' up...cos if it melts it's melted...it'll melt it'll go up to the top.' (3.217b)
>
> 'It's putting more water in an' it'll go up.' (3.218g)

The schemes inferred in these cases have to do with liquefying sugar and the adding of its volume.

Although the space previously occupied by the sugar was overlooked, whether pupils used the 'weight displacement' scheme or the 'liquefied sugar addition' scheme, both groups managed to conserve sugar - in the first as 'pieces-having-weight' and in the second as 'liquid-having-volume'.

The 'no-change-in-volume' prediction

The two pupils who mentioned the possibility that the overall volume would be the same, after dissolving, appeared to base their reason on a conception of sameness and hence permanence of material. One said that sugar ' just dissolves', implying that nothing else happens to it, and the other said, 'because it's still got the sugar' (3.213b)

It would appear that a scheme relating sameness of substance to sameness of 'volume-property' has been generated.

The 'return-to-original-volume' prediction

The last mentioned pupil was, however, also persuaded that the water 'might go down' because, he thought the original crystal was 'big enough to push the water up' but then 'it disappeared'. (It is worth noting in passing, that there appears to be an action scheme about 'size (of object) pushing' here). However the main focus of this paragraph is on the pupil's visualisation of the disappearing crystal - apparently to nothing. This kind of image seems to underlie the responses in the category under discussion. They thought that if the substance vanished, then so also would its perceived properties of size, weight and force, then the water would return to its original 'place', for example:

> 'the water'll be able to go where that (crystal) is, back in it's old place.' (3.201b);
>
> 'it won't be as heavy, and the water will go down' (3.205g);
>
> 'it will go back to...where it was before 'cos the weight's melted away.' (3.214g).

As noted above there is evidence here also for an action scheme about 'weight pushing up'.

'The somewhat diminished volume' prediction

One pupil's thinking appears to have been influenced by the image of the sugar 'going into' the water as though she imagined space within water:

> 'it would go down 'cos then it wouldn't need very much space for it because it would 'ave sort of perhaps gone in, it would still be up a bit' (3.07g)

Part of the origin of this idea could be language (i.e. 'sugar going into water') and partly prior experiences of 'fitting things into available spaces and thereby saving space'. Whatever the schemes used this child appears to have conserved the 'sugar-space' internally.

8.6.2.2 Fifth-year schoolchildren (9/10-year-old)

Small changes in the numbers of pupils predicting the possible changes in volume were observed: five judged that the water level would rise again, 11 that it would return to its original level, one that it would stay the same and one that it would diminish somewhat but not to its original level.

The 'further-increase in volume' prediction

There was no change in the kinds of reasons offered justify the prediction of a rise in 'water' level; similar ideas about fragments of sugar pushing the water upwards, or sugar changing state and adding it's volume to that of water, were obtaind, as in the third year.

The 'return to original volume' prediction

Two 'new' ideas were found among the 11 whose thinking appeared to be limited by appearances. In addition to the third-year ideas that either 'water-refils-vacant-space-left-by-crystal' or 'crystal-loses-weight/force', this cohort offered the notion that 'sugar-fragments-occupy-a-negligible-space'. The atomistic thinking here was that the sugar, having split up into bits, became so small that its size could be neglected. It is clear that these pupils displayed atomistic thinking but lacked reversibility; otherwise they would have considered that the sum of the volume of the very small bits would have been equal to that of the original crystal.

The other 'new' idea that emerged in this year-group was a 'sponge-like' conception of sugar:

> 'sugar might be sucking all the water into the sugar then it (water) will lower' (5.09g)

This scheme in which sugar is regarded as an absorber of water was found in all higher year-groups as well as this one and may have originated through observing tea and coffee penetrating a sugar 'cube'; (although, in this task, they were using a single crystal of sugar).

The 'somewhat diminished volume' prediction

One pupil, in an endeavour to use his perceived model of dissolving and its cause (i.e. weight), predicted a diminished liquid level but higher than that of water alone:

> 'when that thing dissolves, all the bits'll go on the bottom and melt so, and the water'll come down a bit to there but it'll have lost weight1 just don't know what made it loose weight.

When asked to point to where the level would be, he said:

> 'about there (above the original level) ... cos some of the weight'll be still in the water, 'cos the bits that are left keep it up.' (5.317b)

It seems that he was using two schemes which conflicted with one another to some extent and caused some puzzlement. On the one hand the disappearing bits led him to predict a diminished volume but on reflection he realised that this should be the outcome of a loss in weight; for according to his other scheme it was the weight of sugar that had the ability to force the water upwards. Ultimately, he felt that some of the weight must be there and suggested a compromise 'level'. Thus the outcome of one scheme was to compensate, to some extent, for the outcome of the other.

8.6.2.3 Seventh-year schoolchildren (11/12-year-old)

In this year-group, three pupils predicted that the water level would rise as sugar dissolved, 13 that it would return to its original level and two that it would remain at the same level.

The 'further increase in volume' prediction

The continued reduction in the number of pupils judging that the water level would rise indicates a progression in the ability to take account of the original space occupied by the crystal before dissolution. One pupil supposed that the sugar merely added its volume to the water volume and the other two assumed that the displaced water would be supported by the weight/force of the undissolved 'bits' of

---

1. In response to the balance task, he had said the weight would be the same (because 'if the sugar was put in there it would make the water a bit more heavier')

sugar.

The 'no change in volume' prediction

Two pupils judged that water would remain at the same level but only one was able to justify her response. She said it would 'stay the same 'cos it's the same amount of sugar', and when probed as to her meaning of 'amount' she replied 'how much there is the volume of it'. A 'no change in volume' judgement was quite rare in the first three cohorts: out of 54 pupils interviewed only three gave this kind of prediction. This does not mean that only three 'conserve-space-occupied-by-sugar'; some conserve without compensating and others conserve dissolved sugar-space in the intertices of water.

The 'return to original volume' prediction

Among the 13 responses seemingly dominated by immediate sense perception, one idea emerged that had not appeared in younger children's responses but did so, frequently, in those of older children. It was an early attempt to construct 'dissolving' as an intermingling of particles. The following quotation contains the first mention, in the context of this task, of 'water particles':

> 'if it all dissolves it would go back to where it (water) was before ... 'cos it (sugar) is going into the spaces between the water particles.' (7.412b)

No details of the sugar particles were given but his small rectangular diagrams seem to imply that they were minute replicas of the original sugar crystal. The remaining responses, containing the prediction that water would return to its original level, were justified by similar ideas to those of previous year-groups. Some examples are:

* dissolved 'bits' have negligible weight:

  'when they get little they don't weigh hardly anything.' (7.417b)

* dissolved 'bits' have negligible volume:

  'there'll only be little bits about so it's not as big as that (crystal) and it (water)'ll come down so it (water)'s got room to come back.' (7.413b)

* dissolved sugar doesn't weigh anything:

  'you see it's not weighing nothing when it's evaporated ... the crystal's got like evaporate into the water and it won't weigh anything.' (7.415b)

* sugar vanishes:

  'if it's dissolved into the water it won't be there anymore.' (7.409g)

* sugar crystals behave like a 'sponge':

'the stone (crystal) might just have sucked some water down to four (cm3 graduation mark).' (7.407b)

8.6.2.4 Tenth-year schoolchildren (14/15-year-old)

One of the members of this cohort predicted that the water level would rise after immersed sugar dissolved. Ten pupils predicted that the level would stay the same, one that it would fall a little and six that it would fall back to its level when no sugar was present.

The 'further increase in volume' prediction

The sustained decrease in the number of pupils who omitted to take account of the space previously occupied by the sugar crystal could suggest that the required compensation schemes had been established.

The 'no change in volume' prediction

In comparison with the previous year-group, one impressive feature was the marked prevalence of the 'no-change-in-volume' response. This judgement was justified in a number of ways, for example,

* the substance was preserved:

  'when it's dissolved, it will still be there.' (10.616b)

* the weight (perceived cause of displacement) was preserved:

  'it's going to separate out, dissolve, so it, mass of it won't change weight ... well it's the weight that's raised the water.' (10.606g)

* the 'space taken up' was preserved:

  it's just going apart, away ... it's not, it's just going in different directions apart ... it'll still take up space in the water.' (10.614b)

* the 'inner constitution' (number and size of atoms) was preserved:

  'the atoms would just be spread out but you wouldn't have lost or gained any atoms, they don't change in size or anything when they dissolve.' (10.611b)

* absence of external influence:

  'nowt else has been added to it ... so it can't really change.' (10.618g)

Assertions about the permanence of substance, weight and volume had appeared in the previous year group, albeit along with the compensation error at times. The 'new' construction put forward in this year-group was the unchanging number and size of atoms when sugar dissolves i.e. conservation of the 'building units' of matter.

The 'return to the original volume' prediction

Another striking feature of the responses of this cohort, taken as a whole, was the comparatively few pupils (six) who predicted a fall in the level of water to its original value. Two of these seemed to be overwhelmed by an image of a disappearing crystal, for instance,

> 'it (dissolved sugar) isn't actually taking up space 'cos it's flavour in it.' (10.613g)

This pupil also had a conception of 'flavour-without-substance'. The other four indicated, by their responses, they had the 'sugar-particles-filling-spaces' idea of dissolving and, in that sense, they were conservers of space occupied by sugar. This idea had been elicited in year-seven and there was still a certain suggestion that pupils had not constructed the conception of a sugar crystal dissociating into molecules but rather to aggregates of molecules, for instance:

> 'cos it dissolves, all the little bits go in between the molecules of water so it kind of fills up the spaces.' (10.602b)

This may be due to the persistance of the (continuous) 'bit' conception of dissolved sugar.

The 'somewhat diminished volume' prediction

The pupil who predicted a slight fall in the level of water, justified it on the basis that spread out material is likely to take up less space than one piece,

> 'because the sugar's spread out more and diffused, it's not one solid shape.' (10.605g)

It would appear that there may be a scheme of more 'economy of space' when packing little bits rather than bulk material.

8.6.2.5 Twelfth-year schoolchildren (16/17 year-old)

One pupil suggested that the liquid would rise as a result of dissolution of sugar, eight that the liquid would remain at the same level, three that the level would diminish somewhat and six that it would return to the original water level.

The 'further increase in volume' prediction

In contrast to the lack of compensation (for the space taken up by undissolved sugar) that characterised previous responses of this kind, this twelfth-year response did not have a reasoning omission. It was based on a model of sugar 'spread out in a liquid' being 'less tightly packed' than solid sugar.

The 'no change in volume' prediction

Of the eight pupils who suggested that the level remained constant, six had the idea of sameness of materials present, one that the 'dispersed particles added up to the volume of the crystal' and one that the 'molecules were still there'.

The 'return to original volume' prediction

Two pupils thought that the sugar particles would not take up extra space, one that particles would replace air that previously occupied the spaces, one that particles spread out would not take up space, and two that the sugar had dissolved i.e. disappeared.

The 'somewhat diminished volume' prediction

Of the three who made this prediction, two explained that it was due to a certain amount of 'gap filling' between water molecules, and one that 'spread out' sugar takes up less space.

8.6.3 Atomistic ideas in preservation of space responses

A summary of elicited data related to atomism and the conservation of 'dissolved-sugar-space' is shown in Table 8.2. Each judgement category is split according to either an atomistic justification or a non-atomistic one. Now, the development of atomistic ideas and their possible influence on conservation[1] will be discussed.

In the third-year eight out of 18 pupils predict that the water level would rise or stay constant and it is tempting to think that there are eight 'conservers-of-space-occupied-by-dissolved-matter' in this cohort. Because four of these apparent 'conservers-of-volume' express atomistic ideas of the (continuous) 'bit' kind, it is also tempting to speculate that as a result of 'picturing' dissolved sugar as 'bits' of matter, they are helped in some way to conserve space occupied by matter and to overcome appearances. However, it will be recalled that the weight of these 'bits' played a significant role, in their 'displacement-thinking', by providing the driving force for the upward motion of water. Thus, in their view, the rise in water level is due to the weight of the 'bits' and not to the space they occupy.

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1. This means that the sugar is considered to take up space - either 'outside' or 'inside' the original volume of water.

TABLE 8.2 NUMBER OF INTERVIEWEES OFFERING SPECIFIED REASONS, CLASSIFIED AS ATOMISTIC/NON-ATOMISTIC, FOR VOLUME PREDICTIONS

Prediction of space occupied	Justification offered for volume prediction	Yr 3 n=18 no.	Yr 5 n=18 no.	Yr 7 n=18 no.	Yr 10 n=18 no.	Yr 12 n=18 no.
Sugar takes up more space after dissolution	Because sugar 'parts' have weight/force/push/volume (Atomistic response-result: 'conservation')	4	2	2	-	1
	Because dissolved sugar adds volume (Non-atomistic response - result: 'conservation')	2	3	1	1	-
Sugar takes up same space after dissolution	Because sugar 'parts' just spread out (Atomistic response - result: 'conservation')	-	-	-	2	3
	Because there is the same substance/amount/weight (Non-atomistic response-result: 'conservation'	1	1	2	8	5
Sugar takes up somewhat less space after dissolution	Because sugar 'parts' intermingle (Atomistic response - result: conservation)	-	-	-	1	3
	Because less space needed when sugar 'goes in' (Non-atomistic response-result: 'conservation')	1	1	-	-	-
Sugar takes up no extra space after dissolution	Because sugar 'parts' fit spaces between water parts (Atomistic response-result: 'conservation')	-	-	1	4	4
	Because sugar 'parts' have negligible weight/volume (Atomistic responses-result: 'non-conservation)	-	3	3	-	-
	Because sugar loses visibility/weight/volume (Non-atomistic responses result: 'non-conservation)	10	8	9	2	2

TOTALS	Conserving responses	8	7	6	16	16
	Non-conserving responses	10	11	12	2	2
	Atomistic responses	4	5	6	7	11
	Non-atomistic responses	14	13	12	11	7

It transpires, therefore, that the four pupils who use atomistic ideas, in actuality, conserve the weight of sugar and not the space it occupies.

The other four 'conservers-of-space' appear to map a conception of 'occupied-space-that-survives-change' onto their conception of sugar substance. As a result they predict an increase in volume without reference to weight or atomistic ideas.

The remaining ten pupils who do not conserve space occupied by dissolved matter would seem to be so overwhelmed by the image of a disappearing crystal that they are unable to conceive that sugar continues to occupy space. Six of them, who had conserved weight in the weight-task, do not use the 'weight-causes-displacement' framework as others do to conserve space. The other four had not conserved weight in the 'weight-task' so, perhaps, one would expect their thinking to be governed by 'immediate sense perception' anyway.

When pupils imagine that dissolved sugar exists as 'bits' of matter the problem for many of them is the effectiveness of these 'bits' in maintaining an upward 'push' on the displaced water, for they have an underlying idea that the weight or force of the crystal is the cause of the initial displacement.

It has been shown that, in the third-year, the 'bits' seem to retain their ability to 'push' the water up, however, in the fifth-year some appear to hold the view that their 'push' is negligible or ineffective. Thus a supposed loss of weight and consequent fall in liquid level may be explained. For example:

> 'When it (the crystal' goes down it will push the water up but when it's in granules, millions of granules, erm it'll be in the water and so it'll be in the body of the water itself, so it won't, it won't be forcing the water up, it will probably go back down again.' (5.314b)

This changing conception of matter is possibly due to an increasing exposure to ideas about the microscopic world.

As well as having an increased awareness of the small weight of the sugar 'bits', ideas about the space they occupy begins to emerge: pupils use phrases like 'room taken up' and 'little' pieces. Unfortunately, this atomistic conception of matter often destabilises conservation ideas because it seems to induce conceptions of negligible weight and volume. Few appear to have a notion of reversibility that can counter this destabilising tendency.

Little change in atomistic ideas is discerned in the seventh year, but in the tenth year, as Table 8.2 shows, there is a considerable increase in atomistic responses that use a scheme in which particles of sugar are thought to fit in spaces between particles of water or else intermingle with particles of water. This change may be accounted for by the construction of the idea of water particles. Prior to the tenth-year, water seems to be regarded as continuous so that the whole space available is filled by water or water-with-sugar-'bits'. However, the majority of tenth-year pupils offer non-atomistic responses, apparently preferring to reason from an assertion of conservation of substance or amount or weight rather than use a mental picture of constituent molecules. This situation is reversed in the twelth-year when the majority offer atomistic responses. In particular there is an increase in the number who think in terms of 'economy-of-space' due to particle intermingling.

8.7. Findings from the survey responses

8.7.1 General characteristics of the survey responses

The data contained written responses together with a representation of a liquid in a 'medicine' measure. (see p.8.4) Pupils usually portrayed the liquid by shading the outline diagram provided.

A considerable number of younger children did not offer responses to this task despite the fact that all interviewees had responded to it. (Although all pupils had a crystal to inspect, only those interviewed actually handled the 'measure', the others merely observed a 'measure' that was demonstrated by the researcher.) Another characteristic of younger children's responses was the absence of a reference to the volume (or level). This may have been partly due to the open nature of the question, partly the problem just referred to and partly the absence of a displacement scheme. Although the openness of the question may have caused a loss of some data about displacement, it was interesting to discover other spontaneous ideas. Most of these ideas had to do with the perceived appearence or taste of the solution. For example, the appearence was variously described as cloudy, a bit grey, misty, darker, funny, different, white etc. Quite a number thought it would be 'fizzy like soluble aspirin'. The tendency to regard a solution as 'darker' in some way has been noted before. After the seventh year, descriptions of the appearance of the solution were rare and the responses were characterised by 'displacement' ideas. This, it seems was due to exposure to teaching about Archimedes principle - a feature overtly referred to in many responses. To summarise, there was a change in type of response from sense perceptual domination to conceptual ideas about dissolved matter occupying space. It will be shown later that the weight of the sugar sometimes played a part in conceptual development of displacement ideas.

A further feature of the responses was the change in language with year-group as pupils attempted to portray the displacement process. Only two pupils below tenth-year used the word 'volume' so the words 'room', 'space' and 'big', utilized by mainly younger children, were interpreted as conveying the general idea of 'volume taken up by'. Similarly words like 'heavy', 'push', and 'force' were associated with the general idea of 'weight in action'. The word 'mass' did not appear until the tenth-year, though it frequently meant 'volume' as, for example, in the statements:

> 'The mass of the crystal will take up the space where the water was.' 10.034g;
>
> 'The dispersed mass of the sugar granule will take up space (area).' 10.050b.

And, as the last statement shows, 'area' was sometimes used when volume was intended. Also 'water' was used when 'solution' was meant. Young children, of course were unlikely to know the word 'solution', for example:

> 'it (i.e. sugar) disappears and makes more water.' (5.069g)

but some older pupils made statements like:

'the water will be a bigger solution, will measure more', (10.018g)
in which 'water' and 'solution' were interchangeable.

8.7.2 Categories of predicted volume changes, their prevalence and possible 'schemes' that underlie these predictions.

The survey responses were grouped in a similar way to the interview responses, i.e. according to a perceived increase, decrease or no-change in volume. However, two extra categories were required: one to take account of predictions of a volume which was less than that of the original water, and another to accommodate nil or incomprehensible responses. The categories, together with the frequency of each type of response, are shown in Table 8.3.

TABLE 8.3 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED PREDICTIONS ABOUT THE VOLUME OF DISSOLVED SUGAR

Predictions	Year 3 n=112 no.	Year 3 %	Year 5 n=109 no.	Year 5 %	Year 7 n=127 no.	Year 7 %	Year 10 n=154 no.	Year 10 %	Year 12 n=86 no.	Year 12 %
a. A rise in the level of the liquid, (i.e. sugar takes up more space after dissolution)	16	14	16	15	14	11	4	3	1	1
b. No change in the level of the liquid (i.e. sugar takes up same space after dissolu-	14	13	18	17	40	32	48	31	36	42
c. A diminished fall in liquid level (i.e. sugar takes up somewhat less space after dissolution)	1	1	5	5	10	8	22	14	16	19
d. A return to the original water level (i.e. sugar takes up no extra space after dissolution)	47	42	42	39	49	39	69	45	28	33
e. A fall in level below original water level (i.e. sugar absorbs some water)	7	6	10	9	3	2	8	5	2	2
f. No response or incomprehensible response	27	24	18	16	11	9	3	2	3	3

The prevalence of each category, together with examples of pupil's responses are discussed below. In addition some underlying schemes, that may be inferred from the responses, are cited.

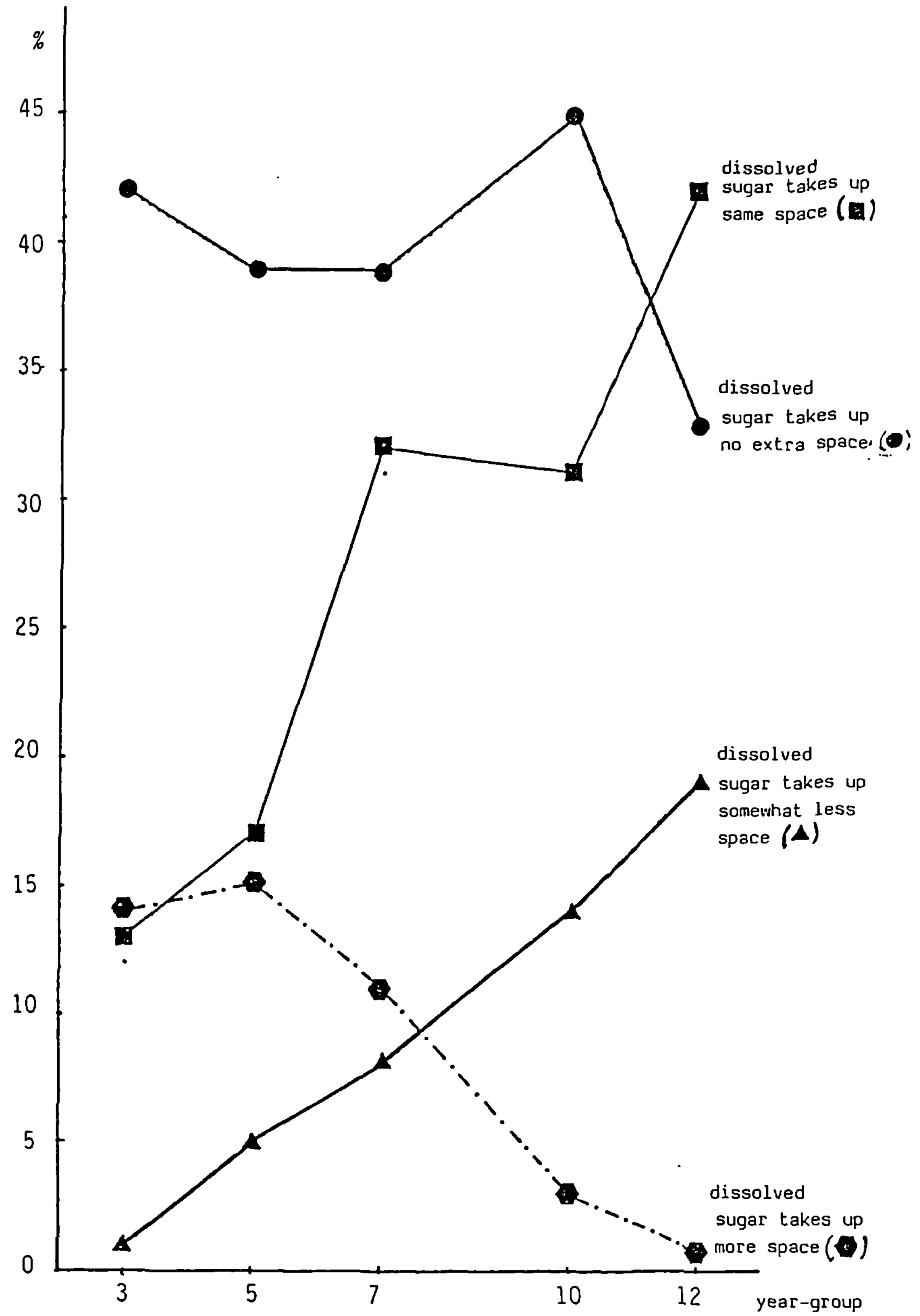


Fig.8.1 Graph showing percentage of survey pupils offering specified predictions about the volume of dissolved sugar.

In general, it would appear that pupils perceive the cause of displacement/non-displacement of water to be due to the presence/absence of either the 'volume of dissolved sugar' or its 'weight (force/push)' or its 'substance'. Also some refer to dissolved sugar as gross matter and others describe it as either pieces of gross matter or as molecular particles.

8.7.2.1 The prediction: immersed sugar takes up more space after dissolution

As Table 8.3 shows, the tendency to predict a rise in the level of liquid as a result of dissolution diminishes with age. The reasons offered by pupils indicate that they were focussing solely on a perceived transformation of sugar and did not take account of the space vacated by the sugar crystal.

The age related prevalence of this type of response suggests that it is related to the developmental process and the construction of a 'displacement' scheme. The schemes that they appeared to have generated were:

a. A 'liquefaction → addition' scheme, i.e. the sugar is transformed into a liquid and this adds to the volume; see Example 1, also:

> 'Because the crystal would melt just like if you put a piece of ice near some water so then it would make more water.' (7.065b)

b. A 'weight (force/push)' action scheme, i.e. the weight of the dissolved sugar pushes the water upwards (just as the crystal had done previously), see Examples 2 and 3, also:

> 'because the weight of the sugar will would push the water up.'
> (because the wiegt of the sugr will wud push the water up.)
> (5.098b)

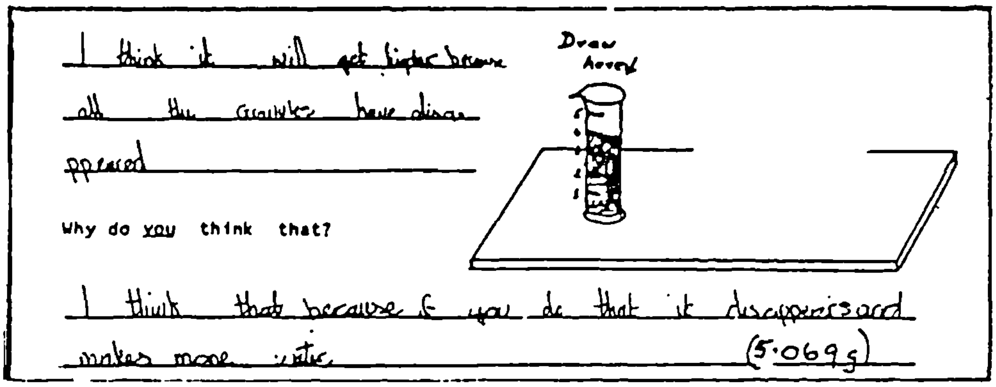
Older pupils may generate a justification by using taught ideas in unexpected ways, for example:

c. A 'change of internal solution structure' scheme, i.e. when solid changes to liquid the distance between the molecules increases → as a result the solution expands:

> 'Because the sugar is being changed from a solid to a liquid and the molecules are further apart in a liquid.' (12.065g)

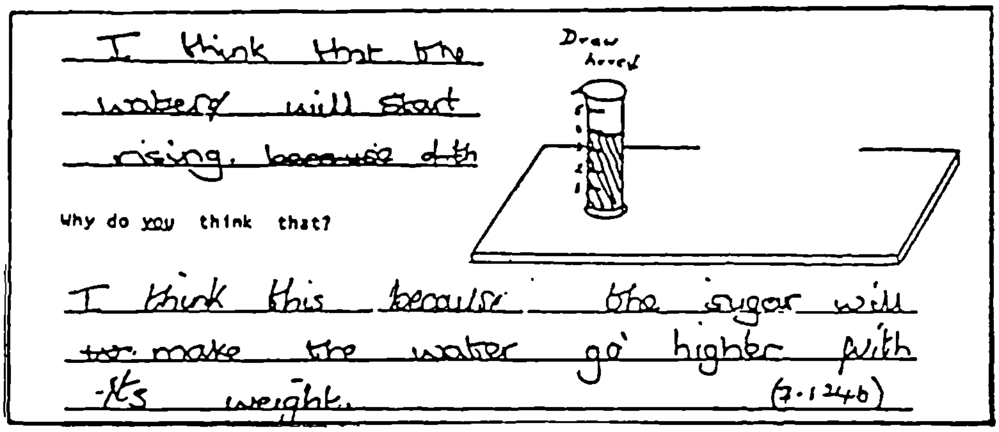
This scheme is a product of focussing on the possible distribution of particles, rather than inter-particle forces or inter-particle 'fitting'.

Example 8.1



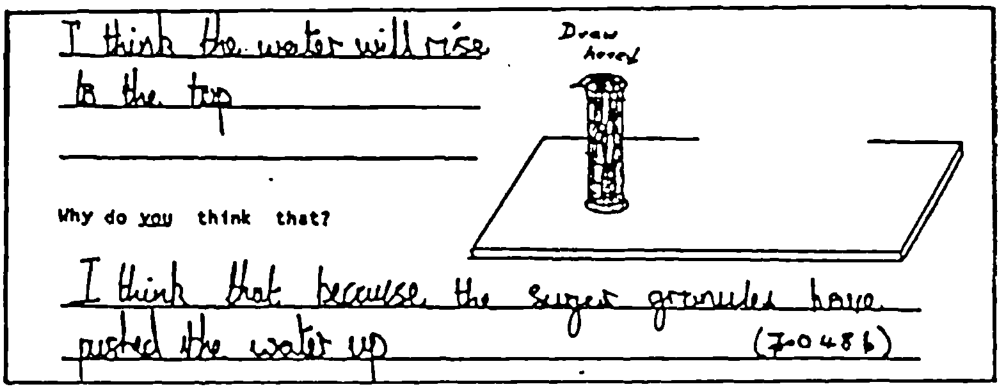
I think that because if you do that it disappears and makes more water. (5.096g)

Example 8.2



I think this because the sugar will make the water go higher with its weight. (7.124b)

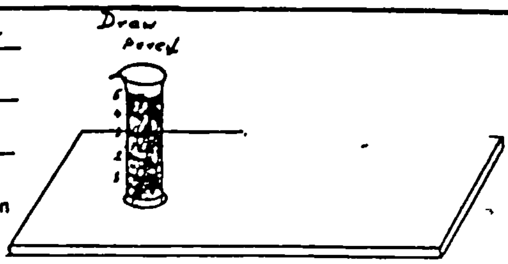
Example 8.3



I think that because the sugar granules have pushed the water up. (7.048b)

Example 8.4

The level of the water
will rise again



What makes you think that will happen to the water?

Because the sugar is being changed from a solid to a liquid and the molecules are further apart in a liquid (12.065g)

Because the sugar is being changed from a solid to a liquid and the molecules are further apart in a liquid. (12.065g)

Examples of pupil's predictions that the liquid level rises (again).

8.7.2.2 <u>The prediction: immersed sugar takes up the same space after dissolution</u>

Unlike the previous kind of response, the prevalence of this one tended to increase with year-group. The trend is probably 'flattened' because of competition with conserving ideas that also underlie the prediction in para 8.7.2.1.

The schemes that underlie this conserving prediction appear to be:

a. <u>A 'whole is equal to the number of its parts' scheme</u>

i.e. when dissolved, the (whole) crystal has broken up into many small parts and:

either, the <u>sum of the weights</u> of these 'parts' has the same 'push' on the water as the whole crystal,

or, the <u>sum of the volumes</u> of these 'parts' is equal to the volume of the whole and hence displace the same volume of water.

For instance:

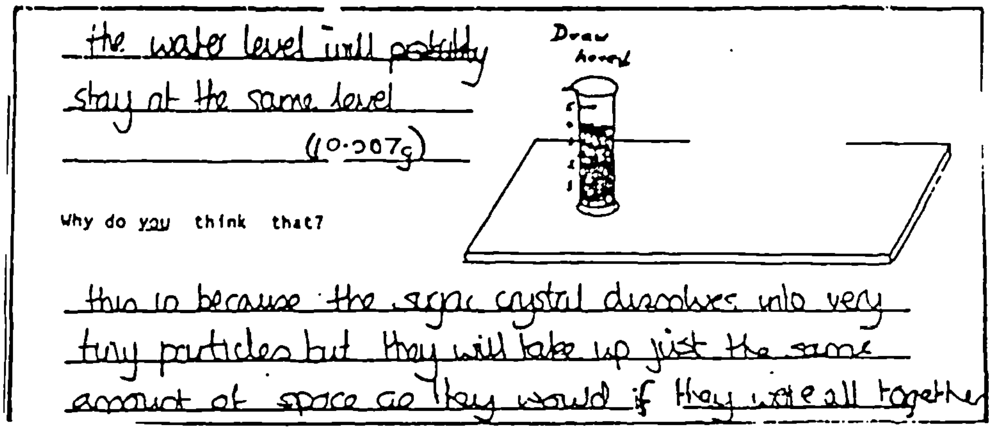
> Because the sugar crystal has dissolved the sugar crystals that are very, very, very small will <u>still have the weight</u> of the solid sugar as they joined together.' (7.010b)

(see also example 8.5).

b. <u>A 'permanent substance' or 'still there' scheme</u>

This may have its origin in the observed re-appearance of crystals from a solution after solvent has evaporated. Also, it could result from the association of taste with the presence of a particular substance. In either case, there is an added implication that dissolved sugar takes up the same space, see example 8.6.

Example 8.5


the water level will probably stay at the same level (10·007g)

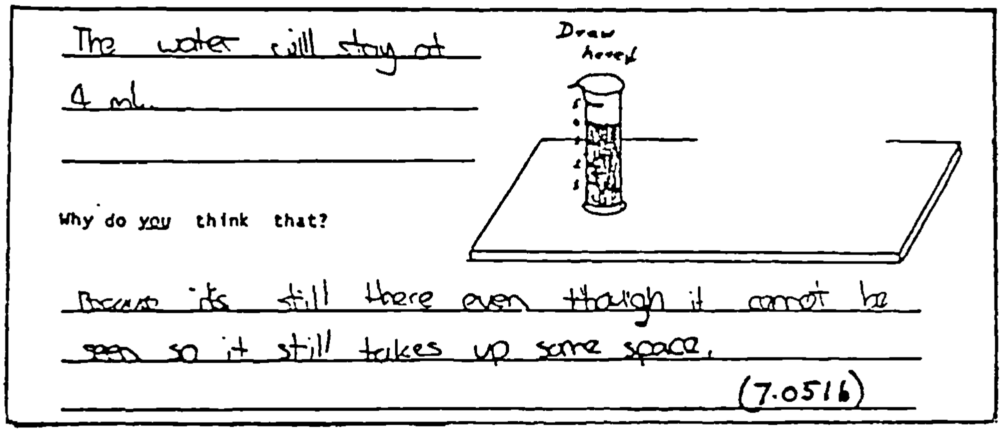
Why do you think that?

this is because the sugar crystal dissolves into very tiny particles but they will take up just the same amount of space as they would if they were all together

Draw here

this is because the sugar crystal dissolves into very tiny particles but they will take up just the same amount of space as they would if they were all together as one. (10.007g)

Example 8.6


The water will stay at 4 ml.

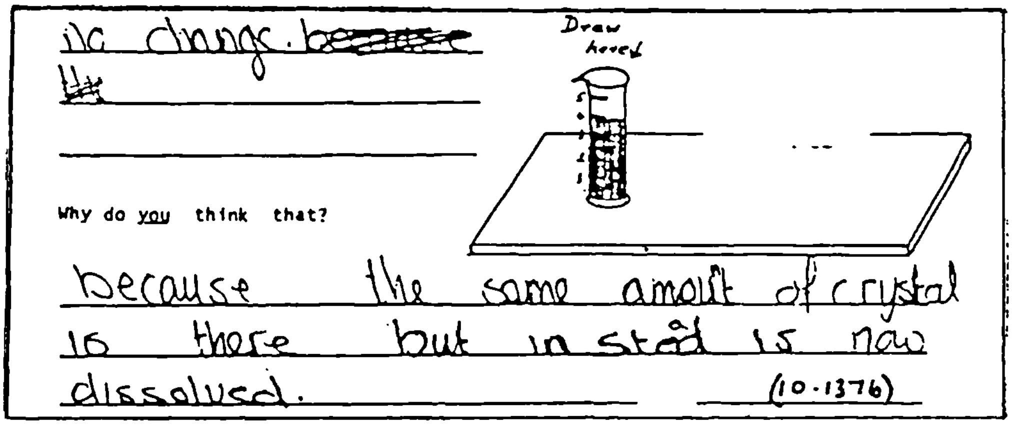
Why do you think that?

Because its still there even though it cannot be seen so it still takes up some space. (7.051b)

Draw here

Because its still there even though it cannot be seen so it still takes up some space. (7.051b)

Example 8.7


no change. ~~because~~ ~~the~~

Why do you think that?

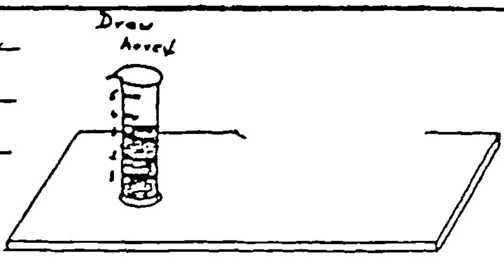
because the same amount of crystal is there but in stead is now dissolved. (10·137b)

Draw here

because the same amount of crystal is there but in stead is now dissolved. (10.137b)

Example 8.8

it should stay at
The Same level



Why do you think that?

Because thoght the lump is gone From Sight The Same amount of atoms take up the Same Space (10.141b)

Because thought the lump is gone from sight the
same amount of atoms take up the same space. (10.141b)

c. A 'sameness' or 'identity' scheme

This is so similar to the previous scheme that one is tempted to fuse them into one. However, this scheme would appear to arise from a view that nothing has happened to change the amount of matter, see example 8.7.

Very few pupils related this identity scheme to the taught idea of atoms as the 'building units' of matter, see example 8.8.

8.7.2.3 Prediction: immersed sugar takes up somewhat less space after dissolution

There was a steady increase, with year-group, in the number of pupils who offered this response. For older pupils it was essentially an economical way of conserving space, whereas for younger pupils it appeared to stem from conflict between an image of disappearing matter and a conception of permanence of matter. Thus the inferred schemes appear to be:

a. A 'fitting in gaps' scheme, i.e. sugar 'parts' fit between water 'parts' so that there is an overall reduction in required space, (see example 8.9 on next page).

b. A 'smaller particles have less push' scheme, i.e. dissolved sugar consists of smaller 'bits' that are less heavy and are less able to 'push' the water upwards, (see examples 8.10 and 8.11).

c. A conflict between two schemes, one is:

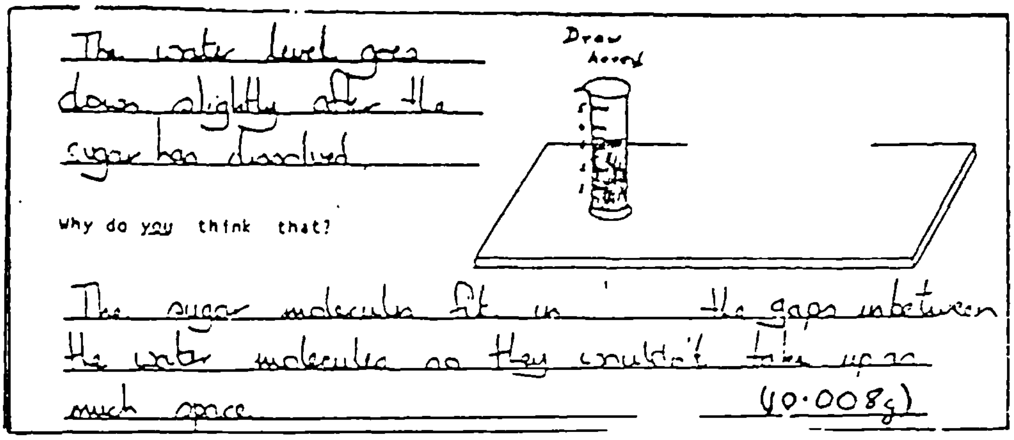
'when sugar disappears, matter disappears',

and the other is:

'sugar is still there'.

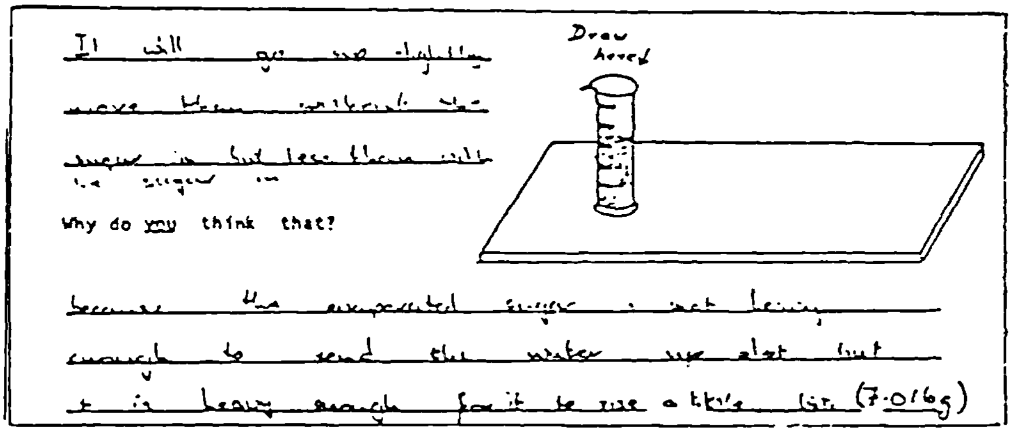
This conflict may be resolved by predicting a compromise liquid level - between no change and return to the original. See for instance example 8.12 and especially the word 'but'.

Example 8.9



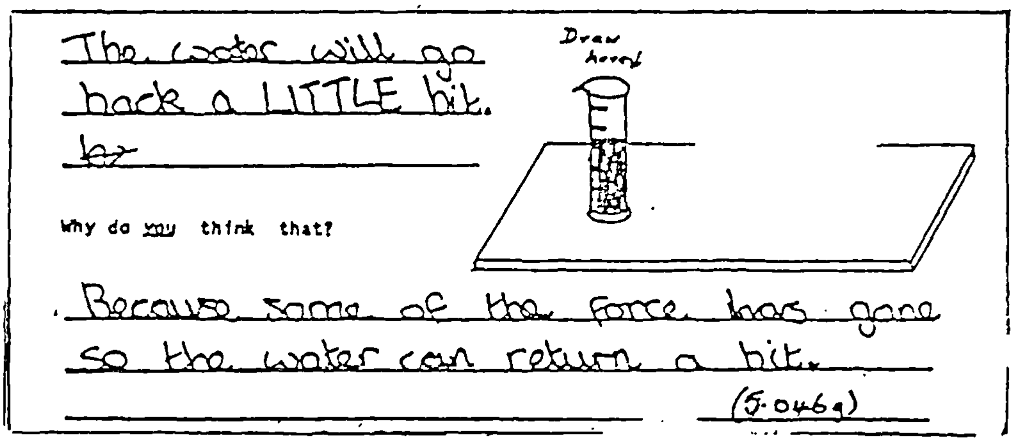
The sugar molecules fit in the gaps in between the water molecules so they wouldn't take up as much space. (10.008g)

Example 8.10



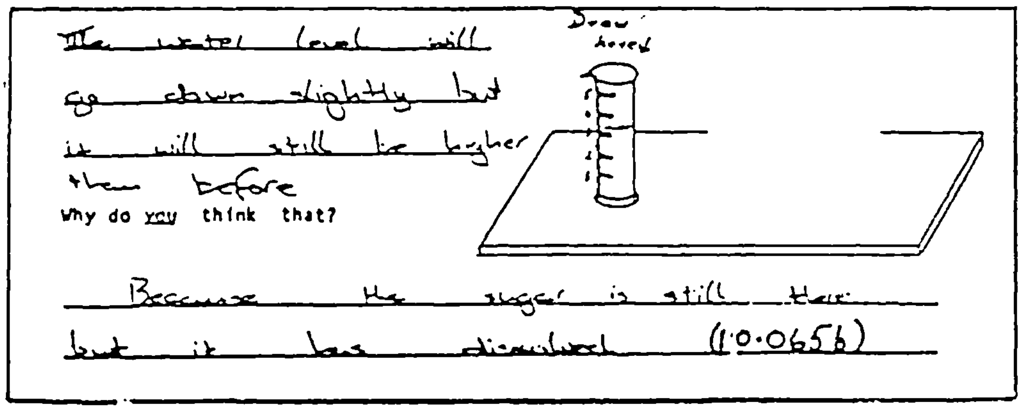
because the evaporated sugar is not heavy enough to send the water up alot but it is heavy enough for it to rise a little bit. (7.016g)

Example 8.11



Because some of the force has gone so the water can return a bit. (5.046g)

Example 8.12



Because the sugar is still there but it has dissolved. (10.065b)

8.7.2.4 Prediction: immersed sugar takes up no extra space after dissolution

In general, this was the most prevalent prediction and it was the closest to a sense perceptual understanding of the situation. Along with the image of a disappearing crystal, there was a perceived loss of volume, weight and substance; sometimes, 'molecules' did not escape loss of volume and weight:

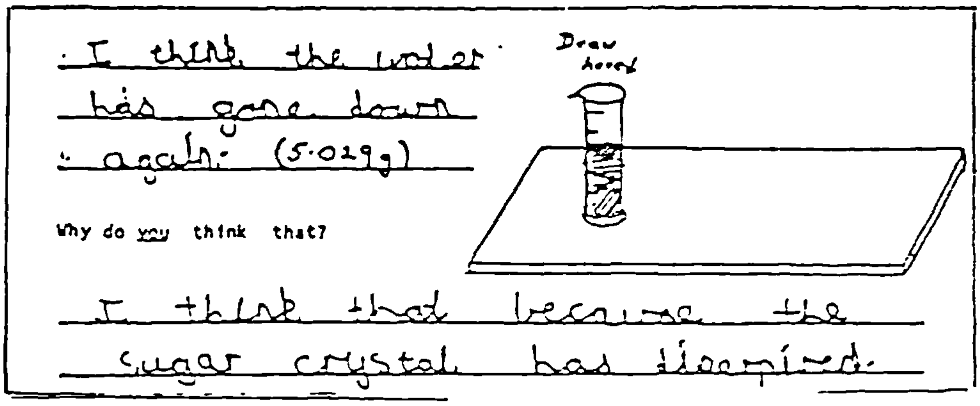
> 'the molecules will not take up any room and will not be heavy' (7.076b)

However, some older pupils did manage to conserve 'sugar space' by using particle ideas. Thus the inferred schemes appear to be:

a. A 'when sugar disappears, substance disappears and/or weight disappears and/or volume disappears' scheme, see examples 8.13, 8.14 and 8.15.

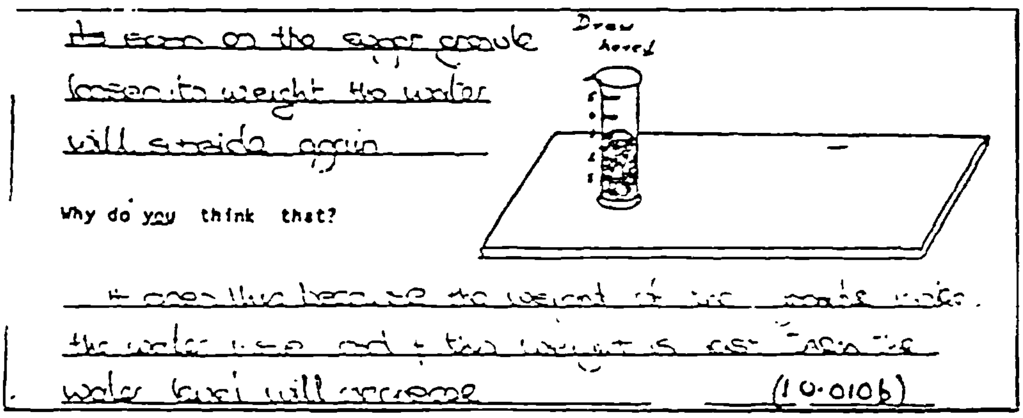
b. <u>A 'sugar particles fit in the spaces between water particles' scheme.</u> As a result there is change in volume of solvent. See example 8.16. This is a more compact 'fitting into' gaps than that referred to in para. 7.23 so that the particles of sugar are regarded as 'hidden'.

Example 8.13



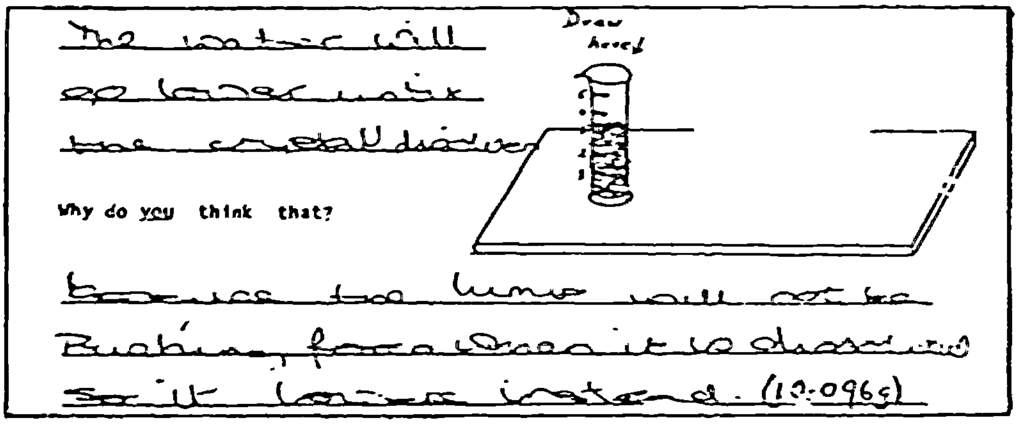
I think that because the sugar crystal has <u>diserpired.</u> (5.029g)

Example 8.14



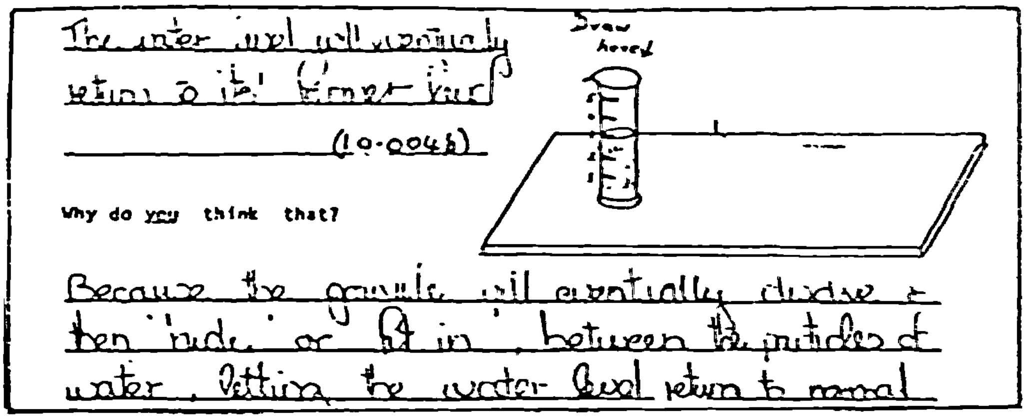
It does this because the weight of the granule makes the water rise and if this weight is lost then the water level will decrease. (10.010b)

Example 8.15



because the lump will not be pushing force when it is dissolved so it lowers instead. (10.096g)

Example 8.16



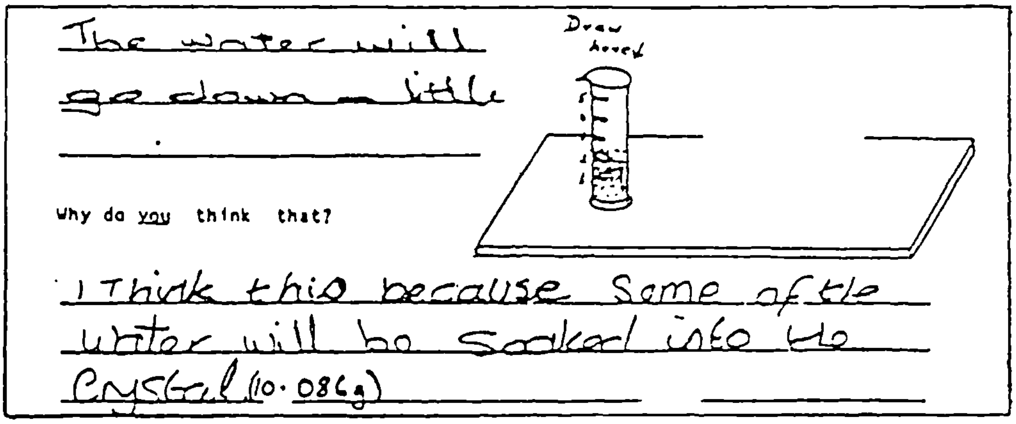
Because the granule will eventually disolve & then 'hide' or 'fit in', between the particles of water, letting the water level return to normal. (10.004b)

8.7.2.5 Prediction: immersed sugar absorbs water, so that the final volume is less than the original volume of water

Comparatively few pupils offered this prediction, even so, it does illustrate how pupils make use of common daily life experiences to interpret physical phenomena. For example, they see many substances in the kitchen that absorb water and apparently make it disappear.

The responses in this category contained words like, 'soak up', 'take up' and 'absorb' suggesting that they regarded sugar as porous material. Perhaps they had associated a sugar crystal with a sugar cube that may have been seen to 'take up' tea or coffee. Thus a scheme that may be inferred is:

A 'solids absorb liquids' scheme, i.e. if sugar absorbs water then the level of solution falls below the original level of water, for example:



I think this because some of the water will be soaked into the crystal. (10.086g)

8.8 Summary of findings from interview and survey tasks

The major purpose of the 'volume' task was to elicit pupils' ideas about the actual space taken up by sugar itself once it had dissolved in water. Early in this chapter it was noted that each possible response implied a view of the nature of matter along with ideas about space conservation, despite a change in physical state. The ability to predict the 'right' answer was not the concern of this study, but was rather to model the schemes, conceptions or theories that appear to be part of pupils' personal knowledge.

It would appear that the findings emerging from this chapter may be summarised as four main outcomes. First, not only did pupils offer a variety of predictions, they also used a number of different schemes when justifying each of those predictions. Most of the alternative ideas, that were elicited, are summarised in Fig. 8.2. Some of the sources of the alternative ideas may be deduced from the this diagram. For example, there were different ways of accounting for the displacement process. Some attributed it to the weight of the crystal's 'parts' - this weight was 'seen' to have an ability to push the water upwards. This was most common among, but not limited to, younger children.

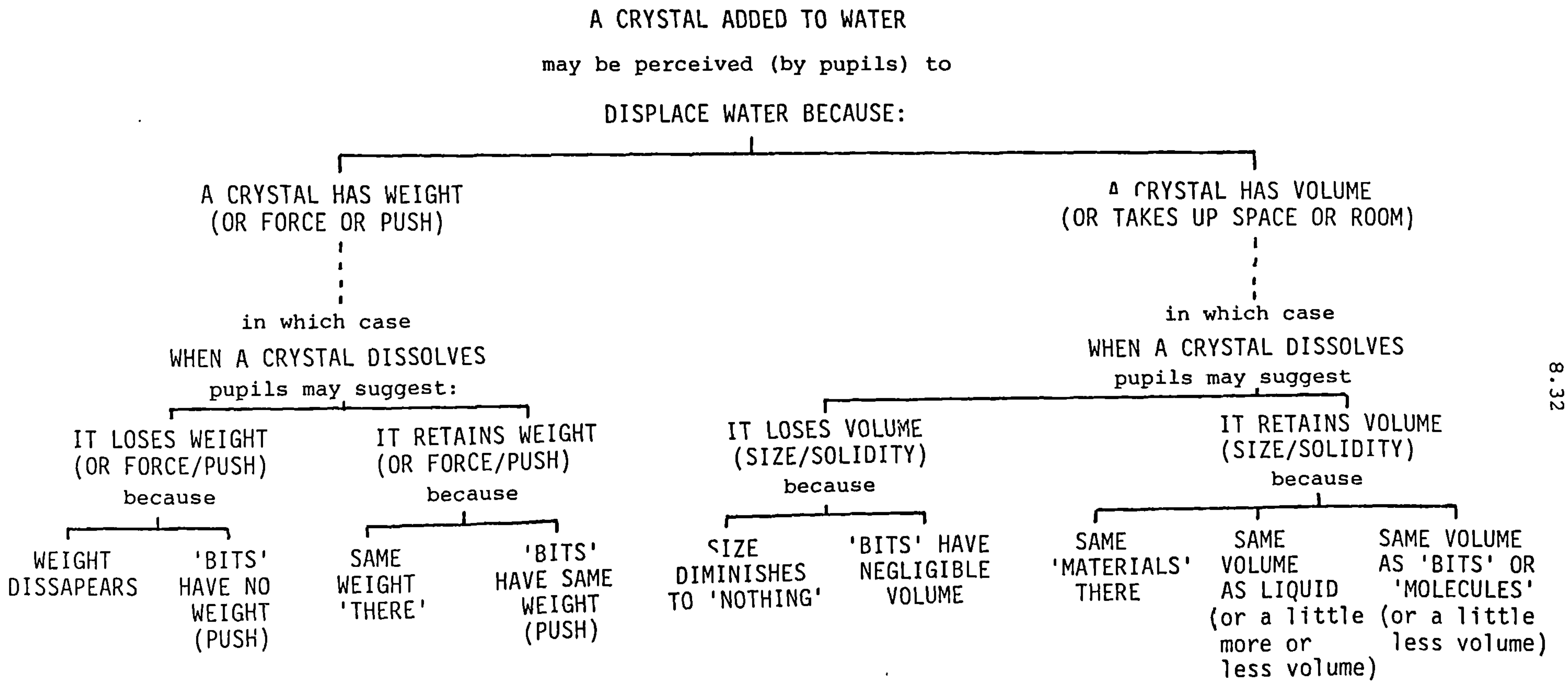


Fig. 8.2 Pupils' alternative constructions of the volume of sugar dissolved in water.
[Developmental 'moves' (in science direction) would be left to right and top to bottom of diagram.]

Another 'action scheme' used to account for displacement was the size or volume of the crystal pushing the water upwards. Another source of the alternative ideas was different ways of modelling dissolved sugar (e.g. as liquids, bits, or molecular particles). Additionally, individual pupils were influenced, to different extents, by their immediate sense perceptions. This, again, gave rise, to alternative responses.

Second, the development of conservation of the space taken-up by dissolved sugar itself appears to be a gradual process. If the reasons offered for volume predictions are examined then the increase in the number of pupils conserving the actual space taken-up by sugar, with year-group, is almost linear. This is represented in fig. 8.3 where it may be noted that after the seventh school year some of this space is conserved within the original volume of water. That is, in the tenth and twelfth-years, particles of sugar are considered (by about 13% of pupils) to occuoy spaces between particles of water, without changing its overall volume. This may be ragarded as attempt to construct a molecular particle theory of solutions, but it does not tale account of the comparatively large size of the sugar molecules. However, some other pupils, about 7%, seemed to appreciate the spacial consevation outcomes in packing 'particles' of different sizes and they predicted a final volume greater that the original water volume but less than the sum of the volumes of water and undissolved sugar.

Comparison with the development of weight/mass of dissolved sugar would suggest that the conception of space taken-up by dissolved matter arises much later. Developmental problems appear to arise from reliance on immediate sense perception, packing ideas and a change in model (continuous bit to molecular particle type). The latter will be considered in the next paragraph.

Third, atomism seemed to play a larger part in the responses to this task than it did in the weight task. It may be thought that this was a consequence of the task sequence so far as the survey data was concerned. However, in the interviews, the drawing task (which possibly could trigger atomistic ideas), was given before the weighing task; and, still the volume task produced many more atomistic responses than the weighing task.

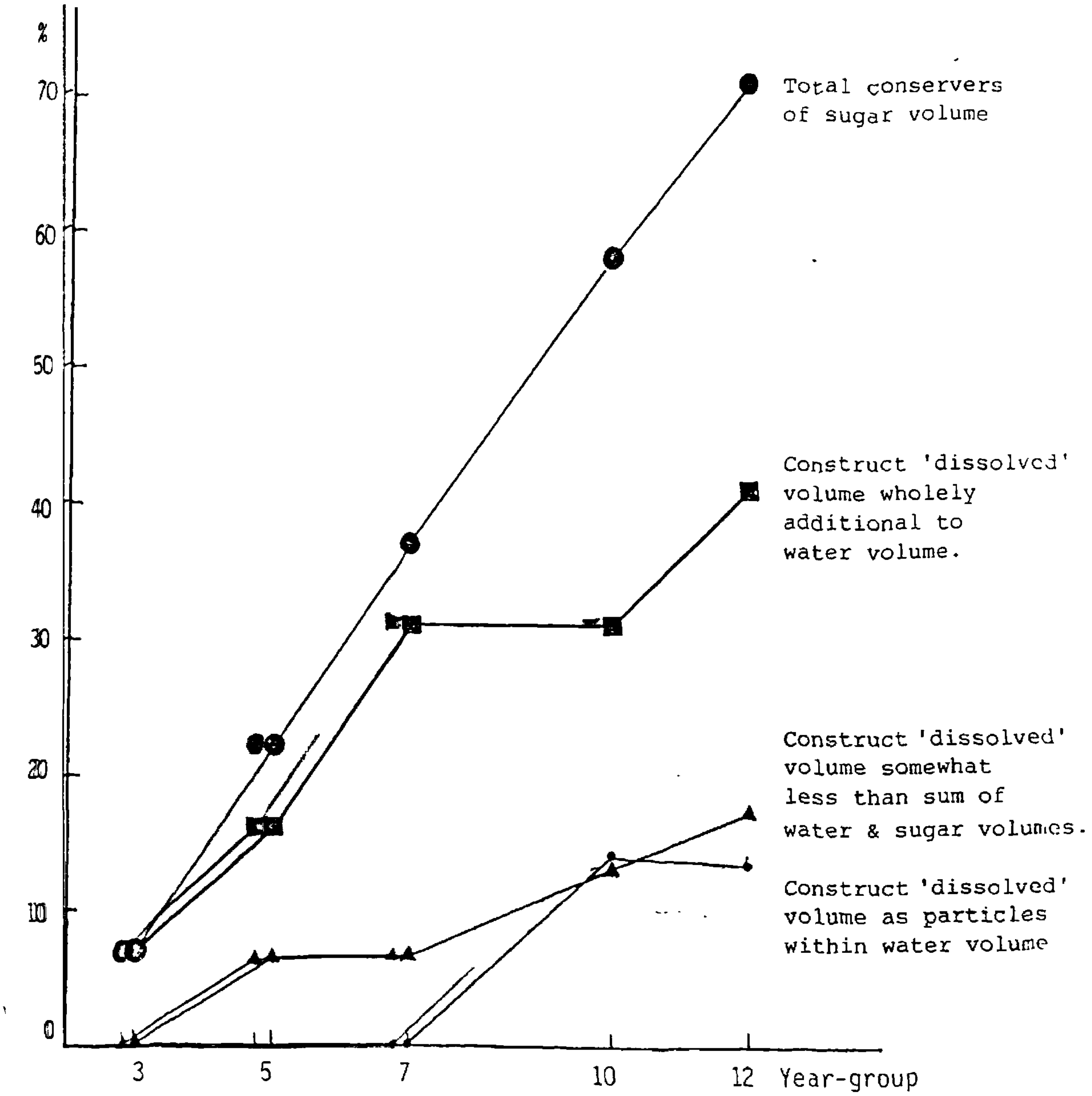


Fig. 8.3 Graph showing percentage of survey pupils conserving space taken-up by dissolved sugar. (Based on <u>reasons</u> offered for predictions.)

(Compare Table 8.2, p. 8.161, with Table 7.2, p. 7.19). Perhaps children find it easier to handle ideas about the 'space-taken-up' by particles than they do about the weight of particles. The findings about atomism from the volume task will now be summarised using Table 8.4.

It appears that the 'continuous bit' atomism found in the early school-years assists pupils to conserve the space taken up by sugar because the 'atoms' are 'seen' as fairly gross particles to which they attribute the charateristics of bulk material, namely, 'weight/force-push' or 'space-taking push'. But, in later years, when the 'atoms' are 'seen' to be exceedingly small, pupils attributed negligible size to them. When this is the case, atomism does not assist conservation. Also pupils appear to view matter as made up of 'parts' which are the result of a <u>breaking down</u> process - indeed this is how they may have probably been introduced to 'atoms' in the first place. ('If I keep on cutting this chalk, ruler, etc in half', says teacher, 'eventually ...' and so on). And, the influence of first acquaintance with a concept is often a powerful one. When, at a later time, they may re-orientate their ideas towards regarding matter as 'built-up' from space filling component atoms, increasing numbers of atomistic responses may be used in support of conservation predictions.

Fourth, the major types of pupil's responses, reviewed in this chapter, <u>illustrate 'where the pupils are' from a conceptual standpoint. Together with the kinds of conceptual change required if pupils are to be assisted towards school-science ideas.</u> Some of these changes are:

* from a 'weight initiated' view of displacement to a 'space occupied' one;

* from a 'negligible weight/size' view of particles to a 'summated weight/size' one;

* from a 'continuous (broken) bit' view of particles to a 'molecular building unit' one.

* from a 'passive' view of a mixture of particles to a 'kinetic and interactive' one.

TABLE 8.4 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED REASONS, CLASSIFIED AS ATOMISTIC/NON-ATOMISTIC, FOR VOLUME PREDICTIONS

Prediction of space occupied	Justification offered for volume prediction	Yr 3 n=112 no.	%	Yr 5 n=109 no.	%	Yr 7 n=127 no.	%	Yr 10 n=154 no.	%	Yr 12 n=86 no.	%
a. Sugar tales up more space after dissolution	Beacuse sugar 'parts' have weight/force/ push/volume	-	-	-	-	-	-	1	1	1	1
	Because dissolved sugar adds volume/weight/ push	5	5	8	7	10	8	3	2	1	1
b. Sugar takes up same space after dissolution	Beacuse sugar 'parts' just spread out	-	-	-	-	2	2	8	5	9	11
	Because there is the same substance/amount/ weight	3	3	9	8	27	21	36	23	24	28
c. Sugar takes up somewhat less space after dissolution	Because sugar 'parts' and water 'parts' intermingle	-	-	-	-	-	-	10	7	7	8
	Because less space needed when sugar 'goes in'	-	-	7	7	8	6	10	6	8	9
d. Sugar takes up no extra space after dissolution	Because sugar 'parts' fit spaces between water parts	-	-	-	-	-	-	21	14	11	13
	Because sugar 'parts' have negligible weight/volume	-	-	-	-	1	1	-	-	-	-
	Because sugar loses visibility/weight/ volume	12	11	22	20	32	25	44	29	19	22
TOTALS	Conserving responses	8	7	24	22	47	37	89	58	61	71
	Non-conserving responses	12	11	22	20	33	26	44	29	19	22
	Atomistic responses	-	-	-	-	3	2	40	26	28	33
	Non-atomistic responses	20	18	46	42	77	61	93	60	52	60

In general there was an increase in the number of pupils (with year-group) who it seems had undergone these conceptual changes, but there were many older pupils who still retained naive conceptions.

CHAPTER 9

SCHOOLCHILDREN'S UNDERSTANDING OF THE INTERNAL COMPOSITION OF A SOLUTION AND A SOLUTE

9.1 Introduction

This chapter explores the kinds of pictures generated when schoolchildren were asked to reflect in a particular way on the inner constitution of a sugar solution and a sugar crystal. All that they could observe was a transparent solution and a transparent crystal, consequently they could have no immediate sense perceptions about the inner constitution of either material. Faced with that situation, were pupils able to offer a pictorial representation of the constitution of matter and, if so, what kind of representation did they manage to generate? These are some of the questions we shall address in this chapter. In addition we shall hypothesise as to how children construct their pictures. We shall also look for indications of consistency in the atomistic/non-atomistic notions they may have about the solid and solution states of matter.

The chapter begins with a description of the solution task in both interview and survey settings. The aims of the data analysis and the analytic procedure follow. Then there is an overview of the information derived from the data together with a discussion of the pupils' responses by year-group. Inferences are then made about possible processes of the picture generation and the children's ideas are summarised. The next section explores children's pictures of the inner constitution of a sugar crystal. A similar approach to that used for the previous task is adopted. In the final section, pupils' atomistic ideas, elicited in each of the 'picture' tasks are compared.

9.2. A school-science perspective on the inner constitution of a solution and a solid solute

A picture of a solution most commonly presented is that of individual molecules of solute dispersed throughout the water molecules. The molecules of solute do not settle out after mixing. Further, the 'mixture' is not static, the water molecules move incessantly along with the solute molecules and experience transient net attractive force from neighbour molecules of both kinds. Once homogeneity is attained, it is maintained by the unceasing molecular mixing.

Thus a diagrammatic representation of the inner constitution of a solution contains a number of conceptual units:

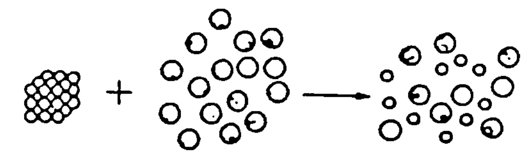
* extraordinary minuteness of component particles;
* similarity of solute particles and similarity of water particles;

* unceasing motion of particles;
* transient bonding of particles;
* overall uniformity of distribution of particles.

None of these is apparent to the naked eye and hence they have to be imagined - in most cases despite contrary appearances. Some examples of diagrams from common texts are shown:

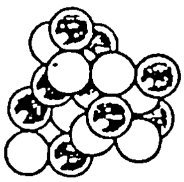
Examples of 'pictures' of solutions from school textbooks

1. 'Science 2000', Book I[1] p.54



2. 'Thinking Chemistry'[2] p.28

Solutions When you look at a solution you can see it is clear. There are no pieces big enough to be seen. The particles of each sort are evenly mixed together.

Fact	*Theory*
A solution is a mixture of matter in one state only.	 Single particles of one sort are surrounded by those of a different sort. Both particles are usually of roughly the same size. There is an even spread of one type of particle through the other. Separating solutions is not as easy as separating suspensions, because the mixing process is much more complete in a solution. It is impossible to trap just one kind of particle from a solution, using a filter funnel.

1. Mee, Boyd and Ritche, 1980.
2. Lewis and Waller, 1982.

In a diagramatic representation of a crystal, the main structural feature is order. A conception of 'orderliness' within crystals is generally introduced by asking children to reflect on the external appearance of a crystal and on the result of cleaving a crystal with a razor blade. Subsequently, teachers may suggest that observed properties of crystals may be explained by supposing that a crystal is made up of very small similar 'building units' arranged in a repetitive pattern. Such patterns are often illustrated with polystyrene balls and/or balls joined by springs. Similar and further ideas may be developed by observing crystals 'grow' to larger ones having a similar shape. Reflection on crystal growth may lead to inferences about intermolecular forces to be made.

To conclude, a school-science portrayal of the constitution of a sugar crystal contains a number of conceptual units:

* prefabricated parts or 'building bricks' called molecules;
* minuteness and multitudinousness of molecules;
* a regularly repeating 'pattern' of molecules;
* limited motion of molecules (vibration about an average position);
* a net attraction between adjacent molecules.

As in the case of solutions, none of these conceptual units is visible, so that each has to be imagined. Some examples from textbooks are shown on the next page.

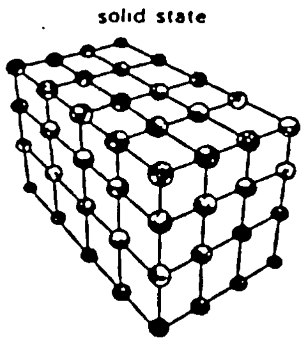
9.3. Schoolchildren's pictorial representations of dissolved sugar

9.3.1 The eliciting tasks

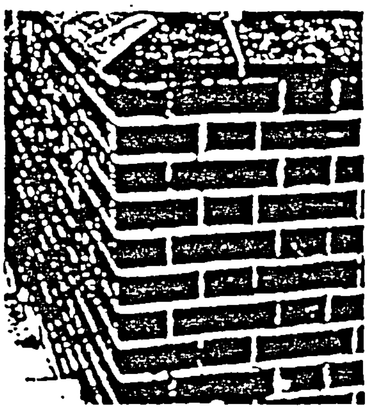
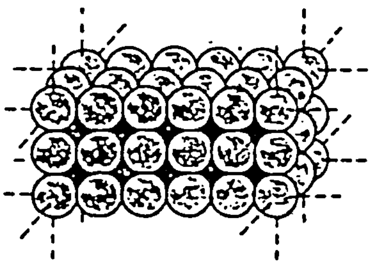
In both the interview and the survey task procedure each pupils's attention was drawn to the tumbler in which sugar had been stirred with water. The contents, like the beaker, were colourless and transparent. Pupils were then asked to pretend that they had Superman's ability to see inside objects. Each pupil was asked what, if anything, might be seen if Super- (name of pupil) looked inside the tumbler. If they had any 'pictures', they were invited to draw them on a prepared diagram. The eliciting diagrams are illustrated on page 9.7. Diagram 2 was revealed after Diagram 1 had been completed, so that Diagram 2 was really used for probing and elaboration of ideas during the interview. (Had <u>both</u> diagrams been seen together, pupils might have taken them as a cue to thinking that a diagram of some constituent <u>must</u> be drawn).

Examples of 'pictures' of the composition of a solid from school textbooks.

1. 'Science 2000' , Book I,[1] p.56.



2. 'Thinking Chemistry'[2], p.24.

Facts	*Theory*
A solid has a definite shape. It is hard. 	The particles are held together in a definite, fixed pattern; they are unable to move past one another. There must be strong forces of attraction between the particles.  An ordered arrangement of particles in three dimensions is called a lattice.

1. Mee. Boyd and Ritche, 1980.
2. Lewis and Waller, 1982.

In the survey, only one diagram was requested for a similar reason. There was also the difficulty of stepwise probing under survey conditions.

Although this was a difficult task, particularly for young children, the procedure allowed for responses to be made in a variety of ways (oral, drawing and writing). Thus the procedure allowed for elicitation via some channel of expression in which pupils were likely to have a measure of proficiency.

Interview elicitation task:

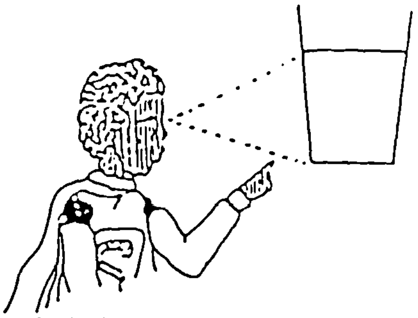
Researcher: 'Now I want you to imagine something rather exciting. I want you to imagine, for a minute, that you are Superman. You are wearing his clothes and you have special eyes that can see inside buildings, boxes and inside this tumbler. Do you think you would see anything inside the tumbler if you had super-eyes or would it be just like that?'
(Depending on the response) 'Would you please try to draw your idea here?'
(Depending on the diagram) 'Would you like to tell me what that means?' (Researcher points to some feature).
(Depending on the response) 'Suppose you looked into one drop - magnified many thousand times - what do you think you might see? Draw your idea here.'

9.3.2 Aims in the analysis of responses

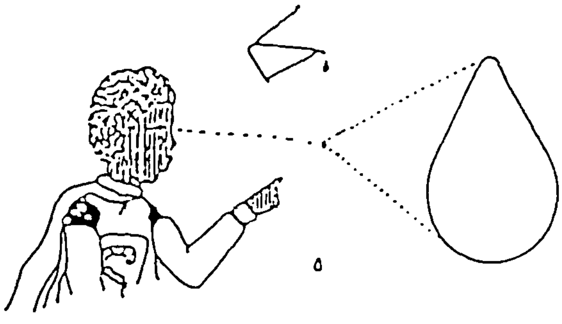
The diagram task was designed to elicit information of the kinds listed below.

* Whether the children (mentally) preserved 'solid' sugar through a change to the solution state. It had been found in pilot trials that children's predictions about the loss of weight and/or volume did not necessarily signify loss of sugar substance, for example a child might regard sugar that is suspended in water as 'weightless', however, the weight task alone does not reveal whether or not he thinks that sugar is still in the water. A diagram could settle the matter either way.

* The kinds of mental pictures of the constitution of matter generated by children. The ability to imagine and manipulate mental pictures of the invisible world of particles and particle processes is a useful aid towards understanding school-science. It was envisaged that this task could elicit features of children's atomistic ideas that are more difficult to access by other approaches. Also it may be possible to make inferences about how they generate such ideas.



Eliciting diagram 1.



Eliciting diagram 2.

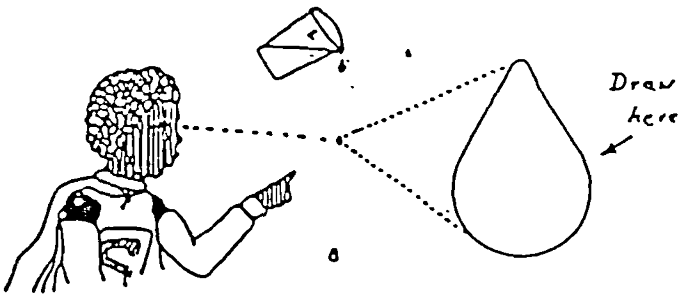
Survey elicitation task

Rob is pretending he is Superman,

~ he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

____

____

The task was an open one in the sense that no suggestion was made as to what constituents might be present[1]. Consequently, spontaneous pictures were expected.

* How children's mental pictures of solutions may change during school-years. At some stage pupils are presented with pictures of solutions; it would be useful to know how they interpret taught pictures and to what extent they retain self-generated ideas.

9.3.3 Analysis procedure for interview and survey responses

Pupil's diagrams and transcripts obtained in the interview were analysed by, in effect, asking three questions:

* in what ways, if any, did pupils depict dissolved sugar and the water or the solution?
* if dissolved sugar was predicted, how was it distributed in the solution? and,
* what names, if any, were used to denote the distributed sugar?

The actual analytic routine was to prepare an analysis table having columns headed: 'identification number', 'diagram', 'particles depicted', 'particle shape', 'type of distribution', 'particle name' and 'other interesting features'. Tables were completed for each pupil in each year-group. After that column entries were enumerated and data were categorised as types of depiction, distribution and denotation as shown in Table 9.1.

The most prevalent combinations of diagrammatic features of interest were also enumerated and the emergent categories are tabulated by year-group in Table 9.2.

The survey data was analysed in a similar manner except that the 'homogeneity' feature was excluded. This was because the majority of pupils appeared to understand that the volume of a drop was so small that its contents could be regarded as homogeneous. The most prevalent combinations of features, i.e. whether continuous or discontinuous, and if discontinuous, whether particles were gross or molecular, were noted and grouped into categories.

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1. An alternative would have been to ask direct questions eg 'Could it (sugar) be broken into smaller pieces?' 'How small?' 'Could it be broken into molecules?', (see, for example, Whitman, 1975).

9.3.4 Findings from interview responses to 'solution' drawing task

9.3.4.1 General characteristics of the data

Pupils' responses to this task usually included a 'picture' together with a descriptive statement. The detail in the 'picture' comprised even shading or dots, squares, circles etc, or some combination of these figures, distributed either uniformly or non-uniformly over the space provided. The majority of pupils represented sugar only – in some atomistic form, and left a background of 'plain' water – presumably because they regarded water as continuous. However, some older children offered a particulate representation of water as well as one of sugar. The statements that accompanied pupils' diagrams usually named the 'parts' of the picture and described their location. Most pupils regarded a 'drop' of the solution as having a similar constitution to that in the beaker.

9.3.4.2 Evidence for preservation of sugar substance

The following numbers of pupils indicated that, in their view, sugar substance was still present after it had dissolved.

	3rd-year n=18	5th-year n=18	7th-year n=18	10th-year n=18	12th-year n=18
Pupils preserving sugar	15	16	18	18	18

As the above data show, the majority of pupils explicitly signified that sugar substance was still present. It should also be noted that one could not be absolutely sure that pupils who were unable to provide a diagram or talk about <u>dissolved sugar</u>, did not conserve sugar because they may have had a semantic problem. So far as many young children were concerned the word 'sugar' meant the 'white/colourless solid' only. Once it dissolved they were unable to designate it as 'sugar'. If sugar was dissolved in water and one asked <u>these</u> children whether any sugar was there, the answer would be 'no'. If one then pointed to the solution and asked whether there was sugar that could not be seen, the question itself was likely to suggest an affirmative response. If one asked whether or not the liquid had a taste it was still not possible to reach a definite conclusion because many children were found to dissociate flavour from substance. It seemed that there was no way of resolving this problem. The most effective approaches appeared to be oblique ones such as asking for drawings and then requesting their meaning.

9.3.4.3 Features of 'solution-pictures' elicited by drawing

Table 9.1 illustrates the different ways in which dissolved sugar was depicted, distributed and denoted by pupils in the various year-groups.

TABLE 9.1 NUMBER OF INTERVIEWEES OFFERING SPECIFIED KINDS OF DEPICTION DISTRIBUTION AND DENOTATION OF SOLUTIONS

Characteristic features of pictures of the constitution of a solution	Year 3 n=18 no.	Year 5 n=18 no.	Year 7 n=18 no.	Year 10 n=18 no.	Year 12 n=18 no.
a. Kinds of depiction of dissolved sugar					
* as dots	8	6	11	5	7
* as irregular shapes	5	5	4	2	-
* as square shapes	2	3	2	4	4
* as circles	-	-	-	6	7
* as liquid	-	-	1	1	-
* none	3	4	-	-	-
b. Kinds of distribution of sugar parts:					
* homogeneous (all over)	4	4	10	13	15
* heterogeneous:	11	10	7	5	3
near the bottom	9	6	5	5	3
near the top	1	1	1	-	-
sides,middle,corners	1	3	1	-	-
* none indicated	3	4	1	1	-
c. Names used to denote sugar parts					
* bits, pieces, grains	10	10	11	6	6
* crystals	2	2	2	2	-
* atoms/molecules	-	-	-	7	10
* liquid	-	-	1	1	-
* sugar	3	1	3	1	2
* un-named	3	5	1	1	-

Although the majority represented dissolved sugar by 'dots', some attempted to draw shapes. The number who drew irregular shapes diminished but those sketching regular shapes increased with year-group. This suggests a growth in the idea of 'internal order' within matter.

The data on distribution suggests a growth in the idea of homogeneity of solutions, though a sizeable proportion appeared to think that the weight of the sugar 'parts' caused them to settle out.

With regard to the naming of the sugar 'parts', there is an overall decrease in the use of 'daily-life' labels and an increase in 'science' labels.

TABLE 9.2 NUMBER OF INTERVIEWEES OFFERING SPECIFIED COMBINATIONS OF DEPICTED PARTICLE KIND WITH DISTRIBUTION TYPE

Combination of type of distribution with kind of particle	Year 3 n=18 no.	Year 5 n=18 no.	Year 7 n=18 no.	Year 10 n=18 no.	Year 12 n=18 no.
a. Homogeneous distribution of 'continuous bits' of sugar	4	4	10	7	6
b. Homogeneous distribution of 'molecular particles' of sugar	-	-	-	6	9
c. 'Settled-out' (to the bottom) 'continuous bits' of sugar	10	6	6	2	2
d. 'Settled-out' (to the bottom) 'molecular particles' of sugar	-	-	-	2	1
e. Other combinations e.g. various particles in middle or rising to the top	4	8	4	1	-

Table 9.2 illustrates the prevalence of combinations of the principle features of the responses i.e. homogeneity/heterogeneity with pieces/molecular particles. It shows the rise and fall in the prevalence of a homogeneous distribution of (continuous) pieces of sugar along with an increase in the idea of the homogeneous distribution of molecules.

9.3.4.4 Patterns of response by year-group

Third-year schoolchildren (7/8-year-old)

Of the 18 pupils interviewed, 15 indicated by their diagrams and/or subsequent talk that they had generated some ideas about the preservation of sugar, in some form, after stirring it with water. The remaining three pupils did not depict sugar in any form - just specks of dirt or air bubbles.

Depiction

The most common way of depicting their idea of 'preserved sugar' was to pepper the diagram with dots, however five pupils drew irregular shapes representing different sized pieces and two drew square shapes. It would appear that the latter generated their response from the shape of the original granules whereas others may have drawn on their experience of broken things.

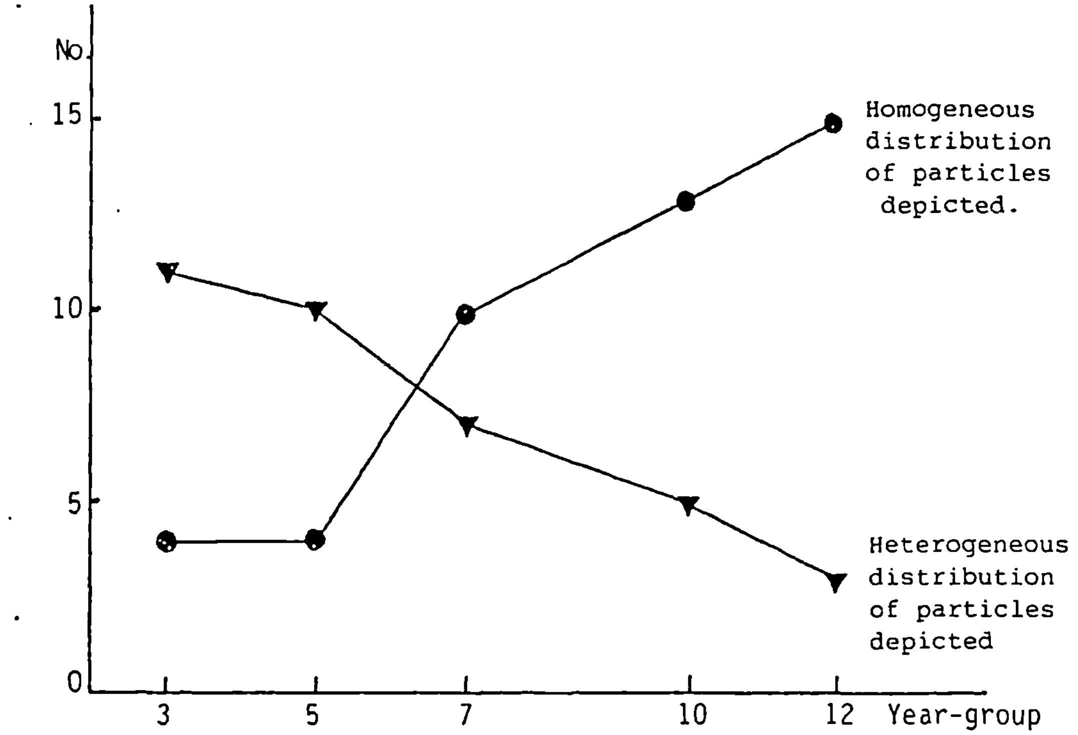


Fig.9.1 Graph showing number of interviewees offering depictions of homogeneous and heterogeneous distributions of particles of some kind.

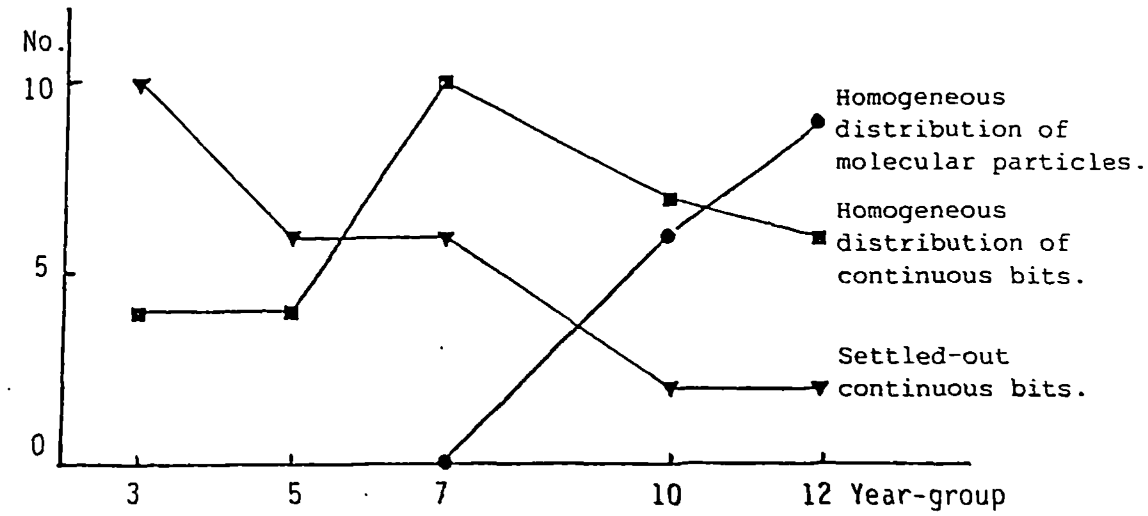


Fig.9.2 Graph showing number of interviewees offering specified combinations of kind of particle with type of distribution.

Distribution

Four pupils depicted a homogeneous distribution of dissolved sugar; in their words the sugar was 'all over'. Nine thought the dissolved sugar would be near the bottom. It was noticeable that many young pupils were impressed by the original sugar 'going down' in the water and, possibly, they thought that the dissolved sugar would replicate that movement. Also they may have been influenced by the 'settling' of the dissolving sugar, between stirring actions. For example, when one pupil was asked what made him think that it (dissolved sugar) was at the bottom, he replied:

> 'well, when we put it in, it all sank to the bottom and when we stirred it round it went to the bottom' (3.202b)

The reasoning behind the prediction of homogeneity is difficult to ascertain, as the interview extract overleaf will show. Homogeneity of solutions is a useful conception to hold and it is of pedagogical interest to know how pupils construct the idea. Apart from the notion which amounts to 'that's what happens', illustrated in this interview, the only other elicited reason was:

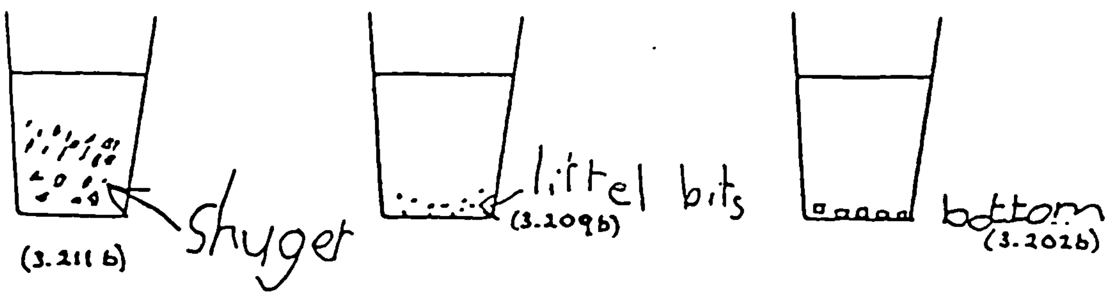
> 'because you are able to see right through' (3.216g)

Some older children also reasoned from the impossibility of the converse idea i.e. if the sugar 'parts' were 'clustered' they would be seen and reduce transparency.

Denotation

The most popular word they used to denote the dissolved fragments of sugar was 'bits'. This was frequently accompanied by the adjective 'little' so it would appear that these pupils were thinking of smaller parts of the same material i.e. they were manifesting 'continuous-bit' atomism.

Thus it transpires that, in this imaginative context many pupils readily generate the kind of atomism which Piaget posited. So far as the majority of pupils were concerned these 'bits' were deemed to behave in a similar fashion to macroscopic granules i.e. they were likely to sink and settle out. Also, some thought that 'bits' have the same shape as the original granule.



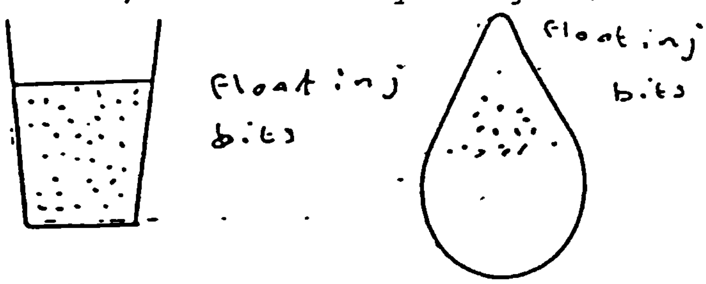
Example of part of an interview with Alan (A), aged 8

(The researcher attempts to explore the ideas that underlie Alan's intuitive notions of 'floating bits'[1] and homogeniety.

R: Imagine you had super-eyes what do you think you would see in there? Would you like to draw?

A: I'd see bits of sugar

R: Draw whatever you think, whatever ideas you've got....



R: What are these?

A: The sugar

R: What gives you the idea they are floating in there?

A: They couldn't be anything else

R: You are showing me that they are all over this, are you?

A: Yes

R: How did you get this idea?

A: If you put half a teaspoon in the water they just go all over

R: When you put the half teaspoon in, they all went to the bottom, how come they are floating now all over the place?

A: They'd be rising up to go to thin air

R: What makes them rise up do you think, to go into thin air?

A: Water

Fifth-year schoolchildren

Of the 18 children in this cohort 16 indicated that they had preserved sugar, in some form, after dissolving but two of these 'conservers'

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1. The conception of floating bits did not influence his ideas about weight conservation. ~~He said~~ the weight would be the same because the sugar is 'just still on it' (5.301b)

were unable to depict preserved sugar. The two remaining pupils did not provide any evidence that they had ideas about preserved sugar except for a single dot representing a granule that had not dissolved.

Depiction

The representations depicted in the pupil's diagrams were similar to those of the third-year, i.e. dots (6), irregular shapes (5), squares (3).

Distribution

Also the proportion of pupils offering homogeneous and heterogeneous distributions of sugar 'parts' was similar to that of the previous year-group. However, there did appear to be a decrease in the number who predicted that dissolved sugar would be 'near-the-bottom' and an increase in the number who predicted locations such as edges (or sides of the beaker) and corners. This was probably because the stirring motion appeared to drive sugar to the sides and that's where it was 'last seen'. 'Corner' suggests a hiding place for the disappearing sugar. (The diagram of the beaker appeared to have four of these 'corners' where sugar could 'hide'.)

Denotation

There was a slight variation in the names of the 'parts' of the dissolved sugar: 'bits' became less popular and was replaced partly by 'grains'. Another small language change was the use of the adjective 'tiny' in addition to, or instead of, 'little'. One pupil described the dissolved parts as 'extremely tiny'. A developing conception of the 'microscopic' world was evident at this age.

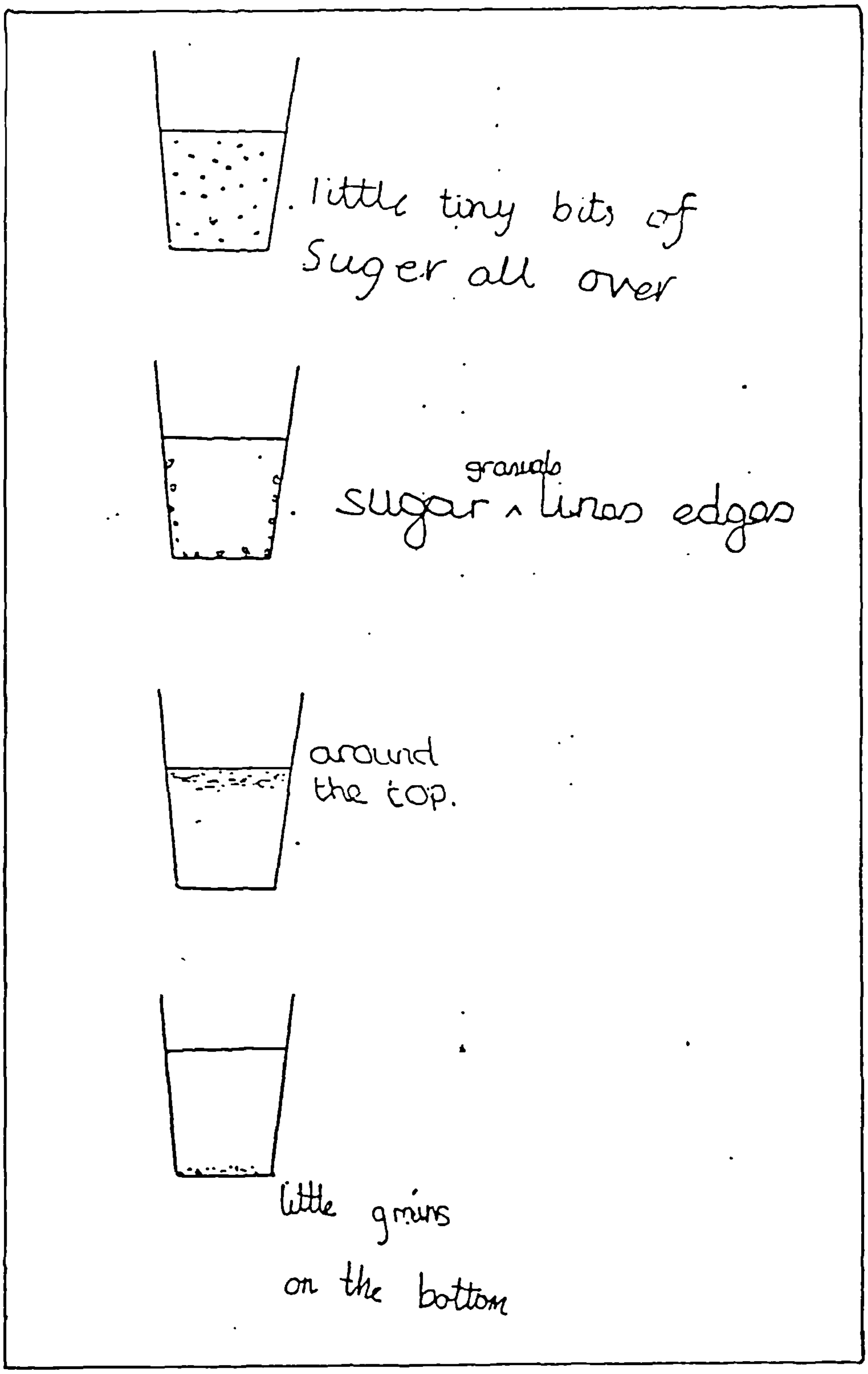
Seventh-year schoolchildren

Depiction

There was an increase in the number of children who generated representations of dissolved sugar and all 18 depicted it in some way, generally as 'dots'.

Distribution

There was also a considerable increase in the number of pupils predicting a homogeneous distribution of dissolved sugar; it rose from four to ten.



The different positions in which dissolved sugar may be found according to fifth-school-year pupils.

Denotation

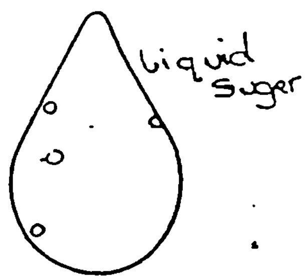
The names assigned to fragmented parts of sugar were similar to those previously discussed. Pupils' ideas about sugar 'parts' remained much the same as for previous years. One different idea however did emerge - that of liquid sugar:

> 'you'd be able to see like sugar, probably, and it would be kind er like bubbles'

when asked what she thought was inside the bubbles, she replied:

> 'bits er kind er like liquid sugar'

The idea of liquid 'particles' was fairly uncommon. More frequently, pupils suggested that the sugar broke up into small solid bits. Clearly, that scheme interfered with her conception of the liquid state.



Tenth-year schoolchildren (14/15-year-old)

As was the case in the previous year-group, all 18 pupils preserved the dissolved sugar; 17 depicted the sugar in some way and, one, who suggested that two liquids (water and liquid sugar) were present, left his diagram plain.

Depiction

In this year-group there was a considerable change in the number of pupils offering alternative kinds of pictures of dissolved sugar. The less informative 'dot' was largely replaced by more specific portrayals of fragmented sugar. The advent of similar sized circles (or spheres) in the drawings hinted that some pupils were beginning to construct the school-science representation of atomistic ideas. When one pupil was asked, in this context, about her 'belief' in the existence of the molecules she had depicted, said:

> 'they (teachers) do it with little balls, they show us. It's it was hard to start with but now we've had it drummed into us so many times that we just take it for granted now that they are like that'. (10.601g)

One third of this year-group also depicted water as circles or spheres and in almost every case sugar molecules were portrayed smaller than water molecules. This idea, it would seem, followed from a scheme that 'sugar molecules fill the spaces between water molecules'.

Four pupils represented the particles as similar sized 'squares' or cubes, one of these labelled them 'molecules' and another wasn't quite sure whether to label them 'molecules' or 'crystals'. Probably the 'square-molecule' was constructed to replicate it's original crystal. It may also illustrate the mapping of the relatively new word 'molecule' onto a prior idea about 'bits-of-continuous-sugar'. It also illustrates one of the difficulties when teaching a conception of molecules via the successive splitting of macroscopic materials. There is a tendency for pupils to impute to 'molecules' of sugar all the characteristics they perceive are possessed by sugar granules/crystals.

Distribution

In this year-group there was a further increase in the number of depicted homogeneous distributions of sugar 'parts', though almost one-third of the pupils retained the idea that after a while there would be more dissolved sugar near the bottom of the beaker. Homogeneity of solutions appears to be a difficult conception to develop so it is of interest to enquire how pupils in this year-group justify it. Previous year-groups were hard-pressed to explain it. None of the pupil's gave the accepted science explanation that molecules, as a consequence of their intrinsic energy, move ceaselessly around the solution.

Pupils seemed to justify their assertion of homogeneity in two main ways:

a. by positing methods by which sugar particles could <u>be held in position</u>:

   * <u>joining</u> to water [1] (10.601,603,610)

---

1. 'it's joined up with the water particles' (10.603b)

* trapped by water[1]
(10.602)
* supported by water[2] (10.66)

b. by reasoning from the appearance of the solution, for example:

'when the sugar was together you could see it, now it has broken up you can't see it, it looks like water' (10.613g)

It is noteworthy that there is an element of reversibility also in this kind of justification.

All these pictures present a 'static' representation of a solution once the homogeneous system has been set up. Although some of these pupils suggested that 'diffusion' was responsible for 'setting up' the homogeneity, it seems that thereafter particle motion ceased (so far as they were concerned).

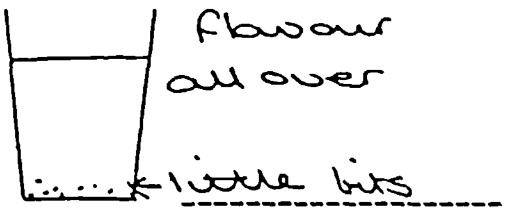
Denotation

The most noticeable change in the nomenclature of sugar 'parts' was the diminishing use of 'daily-life' names and the increasing use of 'science' names. However, as was discussed above this change in name did not necessarily carry with it a science connotation. One pupil found it difficult to decide between 'molecules' and 'crystals' when he labelled his diagram, however, he finally decided to use the word 'crystal'. One of the difficulties with the 'continuous bit' conception is that the pupils have no way of knowing at what stage, if any, the breaking down process ends.

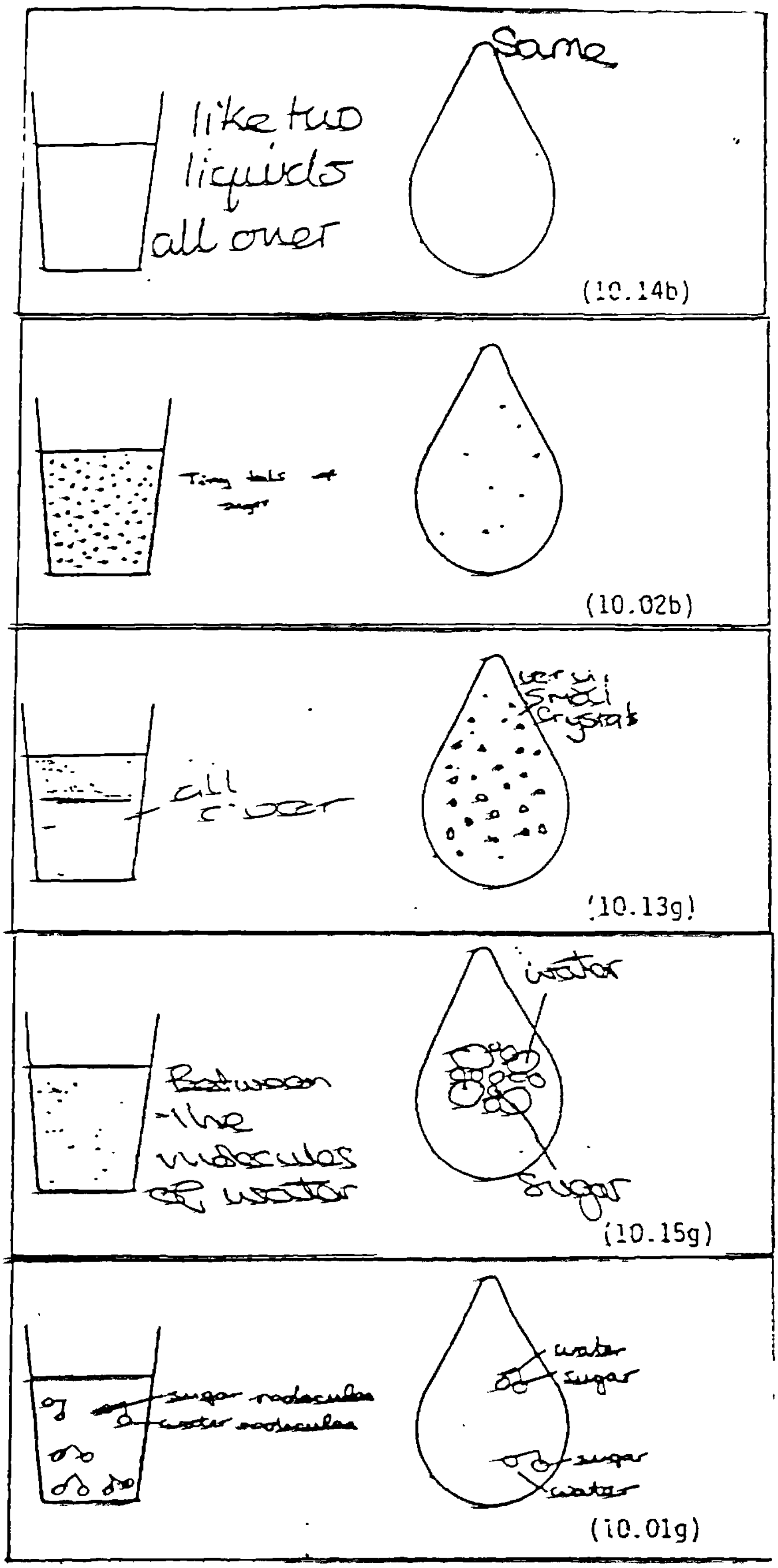
Another response was one in which the pupil dissociated the 'bits' of sugar from the flavour of the sugar:

'if it dissolved, if they were in bits, they'd be in the bottom, but the flavour like it's all over' (10.612g)

There may be two schemes operating here: a 'Free Fall' or 'gravitational' one about imagined bits and a 'taste' one based on experience.



1. 'they get trapped between all the water molecules' (10.602b)
2. 'might get held up by the water molecules they are big enough to do that' (10.606)



Examples of the range of representations of sugar solution offered by tenth-school-year pupils.

Twelfth-year (16/17-year-old pupils)

Each of the 18 pupils in this cohort indicated by their drawings and oral responses that they conserved sugar through the dissolution process.

Depiction

They depicted dissolved sugar in similar ways to the previous year-group and offered about the same number of space-filling sketches of molecules. There were fewer attempts to depict water molecules however, though the oral responses indicated that pupils had ideas about them.

Distribution

With regard to conceptions of homogeneity held by this cohort, there was a further increase in the number representing a homogeneous distribution and in the kinds of explanations for it. Some were aware of attractive forces between molecules and constructed homogeneity from this idea, for example:

> 'because they (sugar molecules) are attracted to the water (molecules) in the same way as they (sugar molecules) are attracted together in the crystal' (12.710b)

A dynamic explanation, however, was offered by another pupil who suggested that:

> 'the molecules will be rushing around colliding - it's the energy' (12.705b)

Denotation

There was a further decrease in the variety of labels for the 'parts' of sugar depicted. More pupils used the word 'molecule' though two of these suggested that they split up into sugar 'ions'. Presumably they were mapping onto sugar, some ideas about salt. Some of those who used the word 'molecule' still retained the intuitive connotation of 'continuous bits', for example, they said that water molecules were like small drops of water and sugar molecules were shaped like sugar crystals:

> 'using my particular theory, if that's a particle of water ... erm that jug of water's built up of little drops then that one has some sugar joined onto it' (12.706b)

9.3.5 Findings from survey responses

9.3.5.1 General characteristics of the data

The data comprised children's sketches, depicting their mental pictures of the composition of a drop of solution, together with descriptive statements about the sketches. Descriptions of the sketches were frequently missing from the responses of the younger pupils - possibly because they found verbalisation of meaning difficult. (Some possible reasons for this have been discussed in section 9.3.4.2 of this chapter.) Consequently, a large number of uncodeable responses were made by younger children.

Since there were no diagrams of the contents of a tumbler of liquid in the survey responses, homogeneity of particles was not an issue for investigation in this case. The main concerns of the analysis were to gain information regarding children's ideas about the preservation of substance and to enquire into how they represent dissolved sugar.

9.3.5.2 Evidence for the preservation of 'substance'

It is difficult to be precise about the percentage of pupils who preserved sugar through the dissolving process because of the problem of uncodeable responses referred to above. By the tenth school-year, however, almost all the pupils managed to preserve sugar, see Table 9.3.

9.3.5.3 Features of the 'solution' pictures elicited by the survey drawing task

By their drawings and descriptions pupils indicated the kinds of atomistic or non-atomistic ideas they had generated; from these response categories were established. The categories are as follows:

a. Depictions of a continuous liquid, i.e. the absence of atomistic ideas about the solution. This category was subdivided into responses which indicated that sugar had been preserved and those that did not do so.

b. Depictions of parts (gross particles) of (continuous) solid or of solution. Again this category was subdivided into representations of sugar (or solution) particles only, and representations of both sugar and water particles.

TABLE 9.3 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED KINDS OF DEPICTION OF SUGAR SOLUTION

Type of depiction offered	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. Depiction of 'water'/ solution as a continuous liquid	20	18	25	23	29	23	15	9	5	7
*sugar not preserved	8	7	12	11	9	7	2	1	1	1
* Sugar preserved	12	11	13	12	20	16	13	8	5	6
b. Depiction of sugar parts as 'continuous-bits'	65	58	75	69	84	66	91	59	30	34
* Sugar parts (or liquid parts)	65	58	70	64	83	65	86	56	28	32
* Sugar parts and water parts	-	-	5	5	1	1	5	3	2	2
c. Depiction of sugar parts as 'molecular particles	-	-	-	-	2	2	47	31	47	51
* Sugar molecules only	-	-	-	-	-	-	21	14	17	20
* Sugar molecules & water molecules	-	-	-	-	2	2	26	17	27	31
d. Other responses	27	24	9	8	12	9	1	1	6	7
* No response	3	3	5	5	3	2	-	-	-	-
* Insufficient data for coding or not codeable within categories	24	21	4	3	9	7	1	1	6	7

c. Depictions of <u>molecular particles</u> of sugar in the solution. Also, this category was subdivided into representations of sugar molecules only, and representations of both sugar molecules and water molecules.

The population of each of these categories together with uncodeable responses is shown in Table 9.3. As the table shows, the majority of

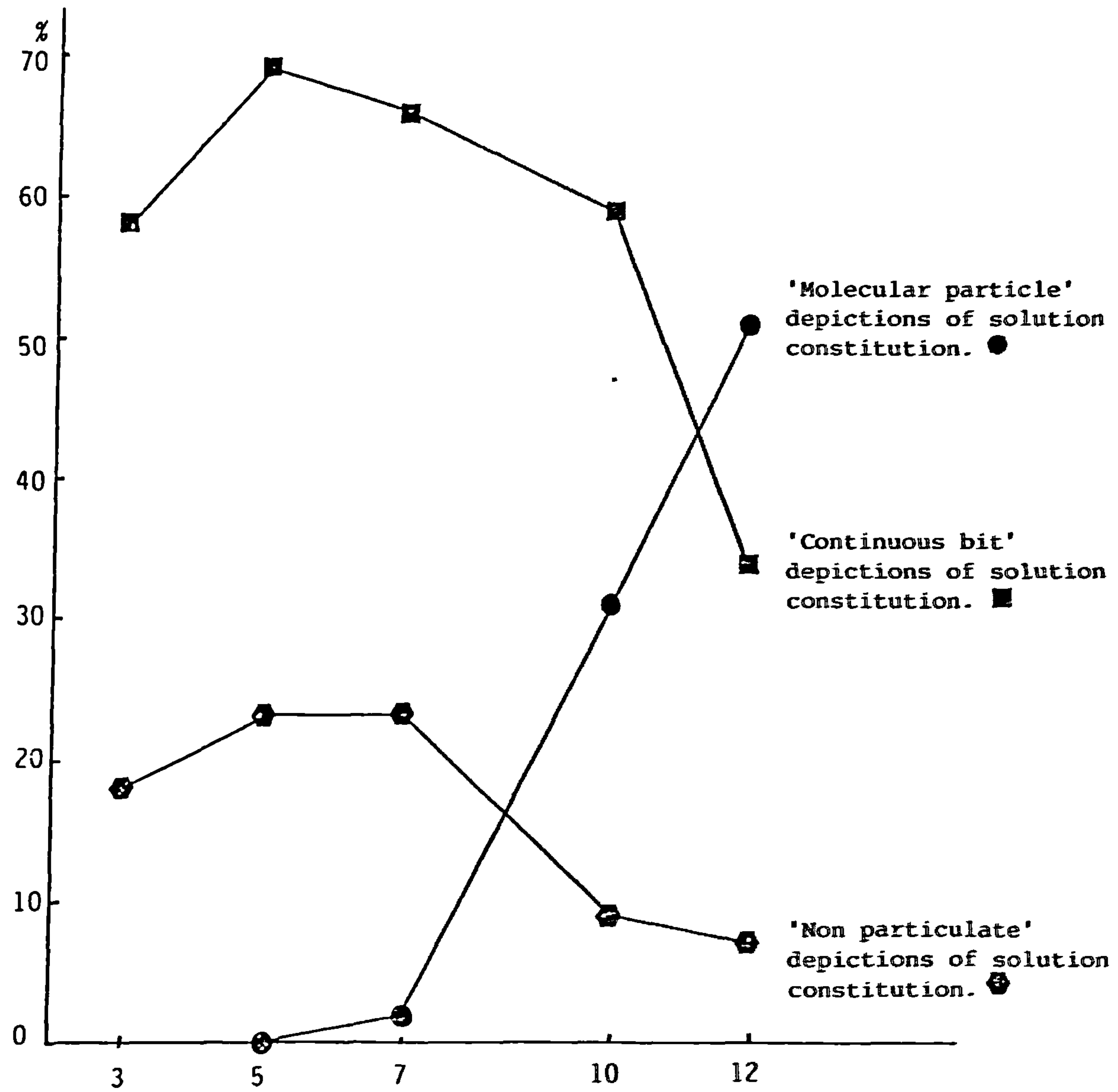
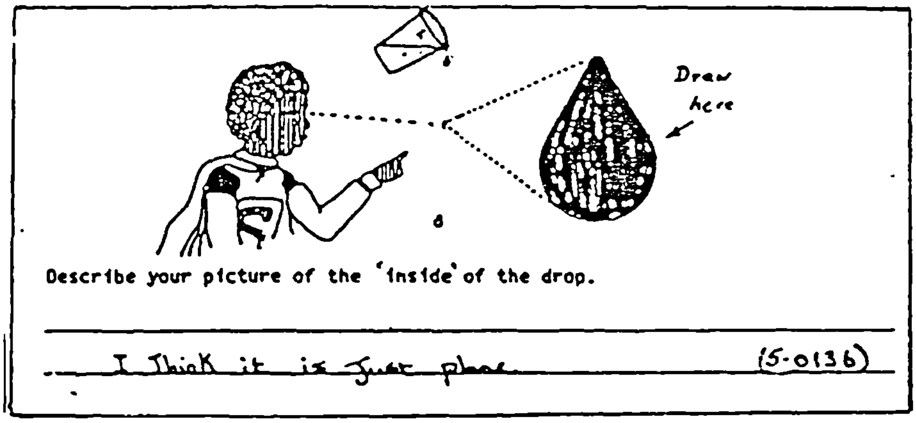


Fig. 9.3 Graph showing percentage of survey pupils offering specified kinds of depiction of a sugar solution.
(Graphs based on Table 9.3)

pupils depict sugar solution as (gross) particles of (solid) sugar dispersed in (continuous) water. The next most prevalent depiction, at least up to the tenth-year, is a continuous idea of a solution. However in the tenth-year, the molecular particle idea appears to take precedence over the continuous idea. Each of these conceptions will be now reviewed.

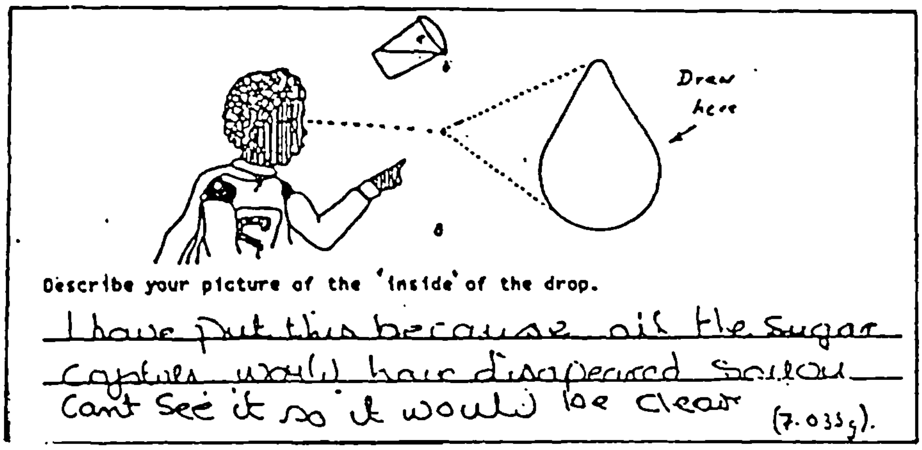
<u>a. The 'continuous' conception of a solution</u>

If pupils described the drop as plain, clear, etc, and they did not depict particles of sugar, water, or solution then they were categorised as having a continuous conception of a solution, for example:



I think it is <u>just plain</u> (5.013b)

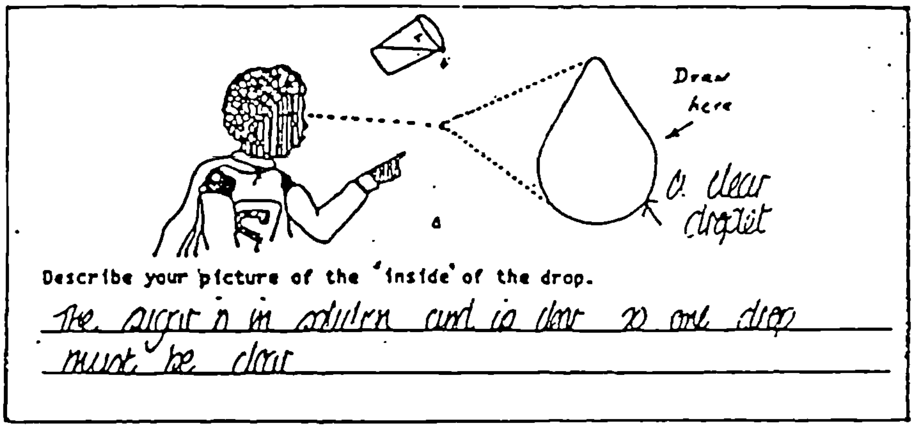
Sometimes they made the reasoning that underlay their conception explicit, for instance:



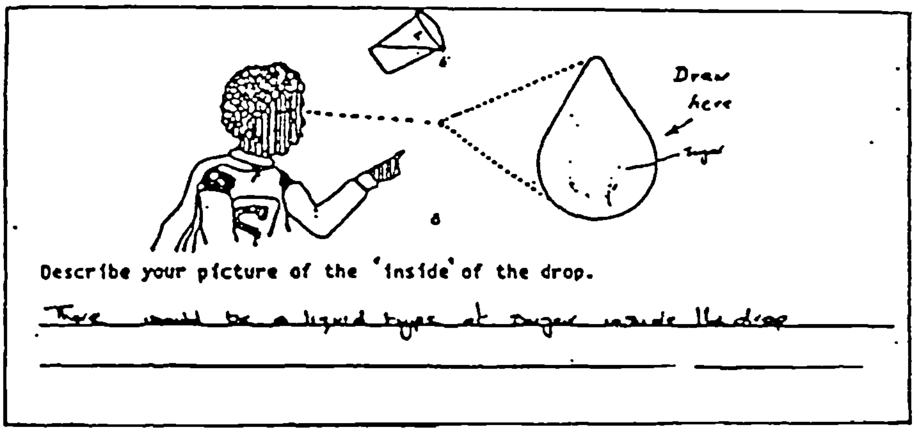
I have put this because all the sugar crystals
would have <u>disapeared</u> so you can't see it so
<u>it would be clear.</u> (7.033g)

The reasoning employed by pupils in this category suggests that their mental constructions were governed by sense perception.

It is noteworthy that this 'plain' representation did not necessarily carry with it the idea that sugar had been destroyed. It was held that the sugar was preserved but in an invisible form, possibly liquefied, for instance:

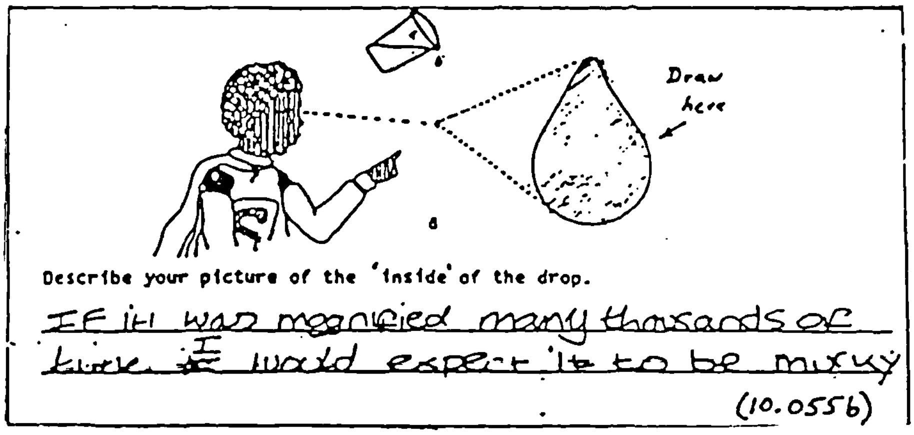


The sugar is in solution and <u>is clear so one drop must be clear.</u>



There would be a <u>liquid type of sugar</u> inside the drop

Some considered that the presence of dissolved sugar would 'darken' the solution in some way. They shaded their diagrams and described the contents of the drop as 'misty' (10.077b), 'murky' (10.055b), 'blurry' (6052b), and even 'black' (3.004b), for instance:

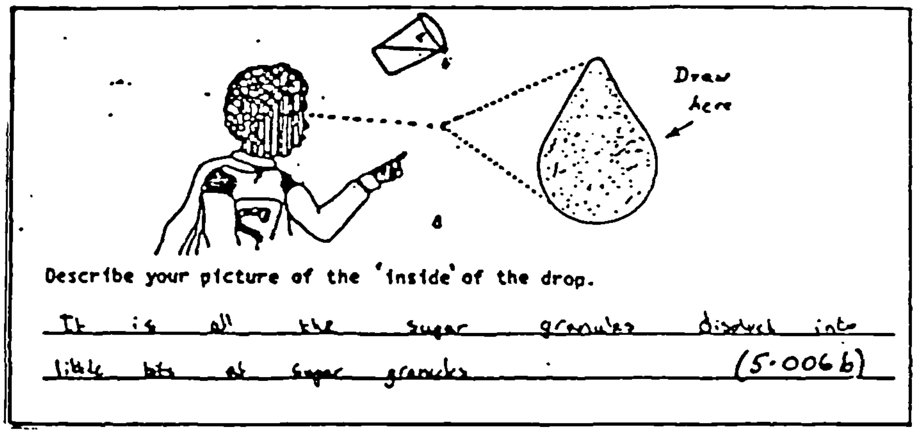


If it was magnified many thousands of time I would expect it to be murky. (10.055b)

b. The dispersed 'piece' and/or 'drop' picture

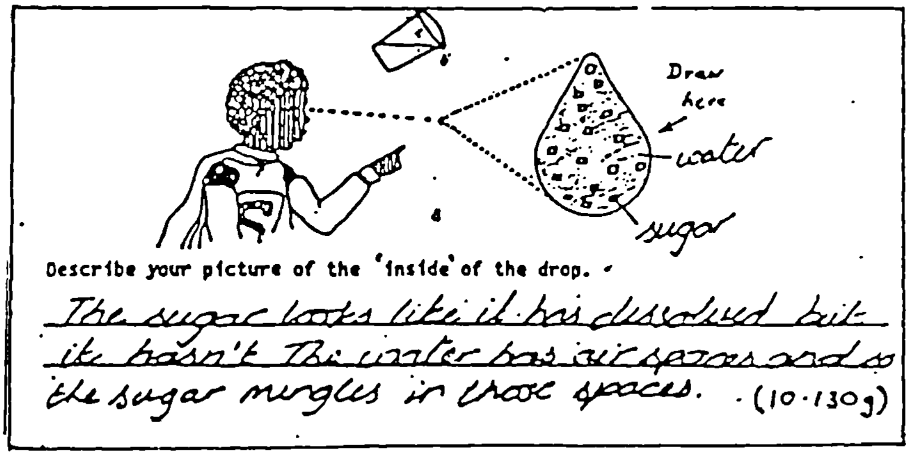
Responses were placed in this category if pupils indicated that their diagrams contained 'continuous-bits' of sugar or both sugar and water.

Continuous bits of sugar were depicted as dots, squares, circles or irregular shapes and labelled sugar. The rest of the diagram was sometimes plain - possibly representing continuous water, for example:



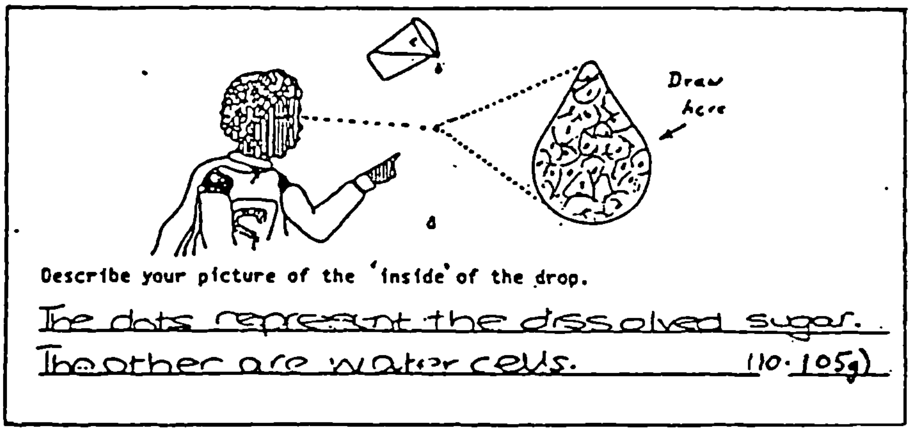
It is all the sugar granules disolved into little bits as sugar granules. (5.006b)

Some pupils had ideas about exactly where the sugar was located in the solution - it seems they were trying to construct ideas as to how the sugar 'got into' in the water. Some imagined that sugar bits were accommodated in air pockets that were thought to be distributed around the water.



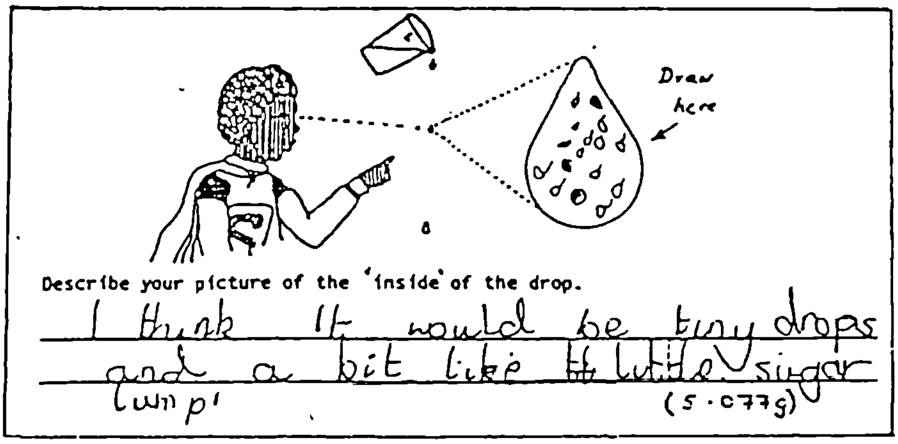
The sugar looks like it has dissolved but it hasn't
The water has air spaces and so the sugar mingles
in those spaces. (10.130g)

Others had the view that the sugar was located in water 'cells' - a picture resembling 'tadpoles'.

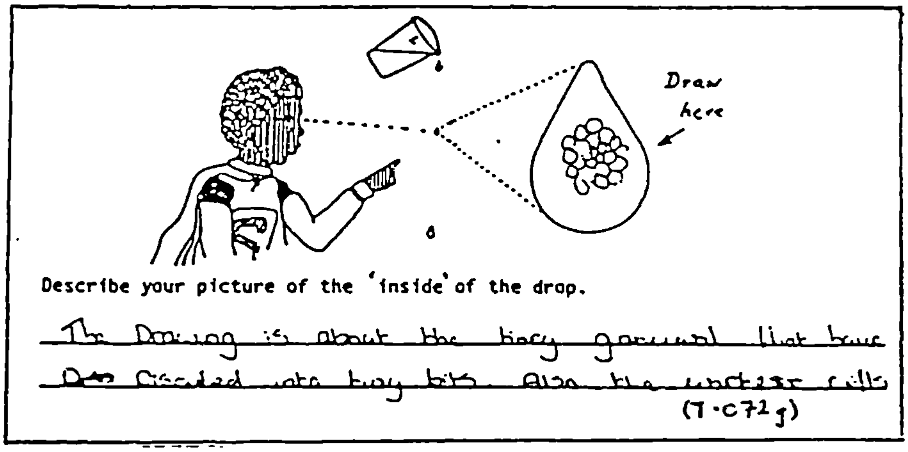


The dots represent the dissolved sugar. The
other are water cells. (10.105g)

This diagram really belongs to the second subcategory of 'continuous-bit' responses in which pupils portrayed both constituents as gross particles. Generally these 'particles' were depicted as separate entities (i.e. bits of sugar and drops of water intermingled) rather than sugar embedded in water. Two examples follow.



I think it would be tiny drops and a bit like
little sugar lump. (5.077g)

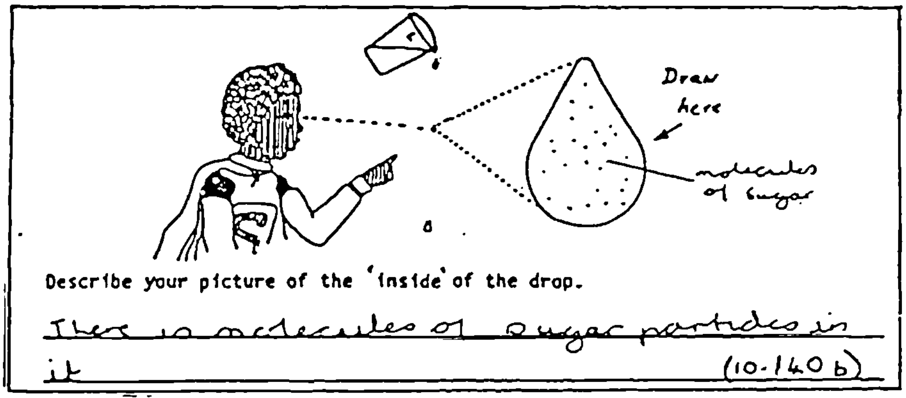


The drawng is about the tiney granual that have
disovled into tiny bits. Also the warter cells
(7.072g)

c. The dispersed 'molecular particle' picture

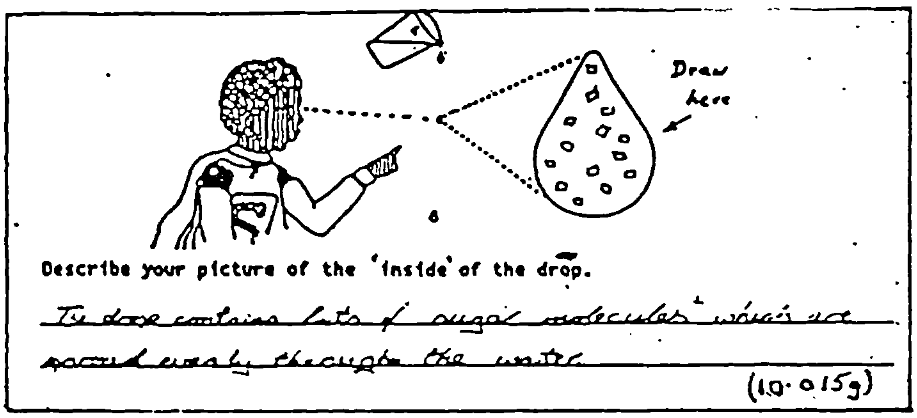
Pictures of solutions included in this category depicted, either sugar molecules on a plain background, or sugar and water molecules intermingled with one another.

An example of the first kind of picture is shown below:



There is molecules of sugar particles in it (10.140b)

Some pupils depicted sugar molecules as having a similar shape to the original crystal. This suggested that they imagined a molecule as a small piece of sugar. If that was so, then applied a new name (molecule) to a former conception. An example of such a picture is shown below. Also, it would appear that water was regarded as 'continuous'.

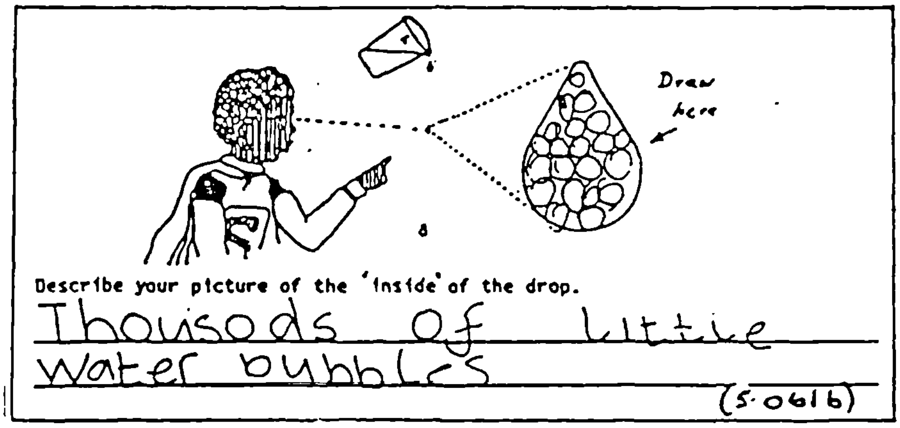


The drop contains lots of sugar molecules which are spread evenly through the water. (10.015g)

The other type of representation that featured one kind of particle was a picture which conveyed the idea that a large drop is made up of smaller drops. It was quite common for pupils to denote a 'solution' as 'water', for instance one pupil stated that:

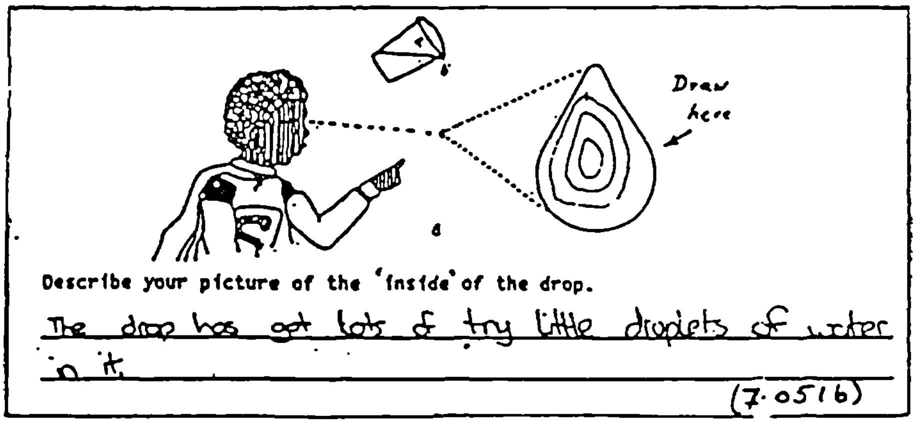
'The water is made up of sugar and water' (5.036b)

Thus they frequently labelled diagrams 'water' when they really were referring to sugar 'solution'. Diagrams in this category were characterised by small circles packed together in the outline drop provided, for example:



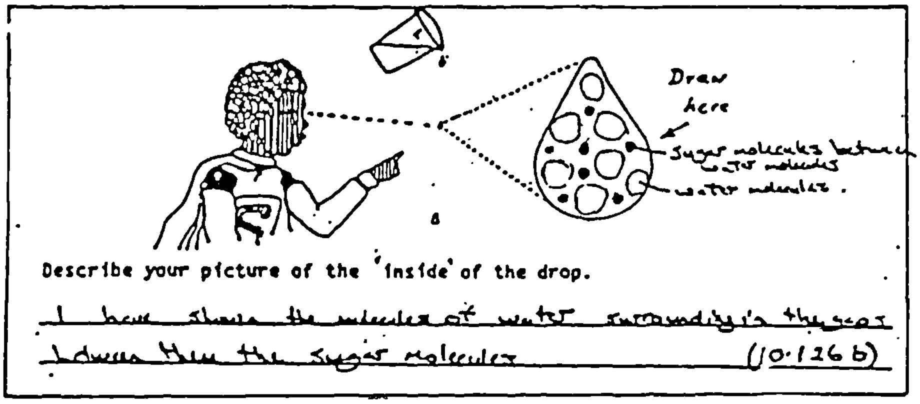
Thousods of little water bubbles. (5.061b)

Sometimes each drop was depicted as embedded in a larger drop like a Russian doll, for example:



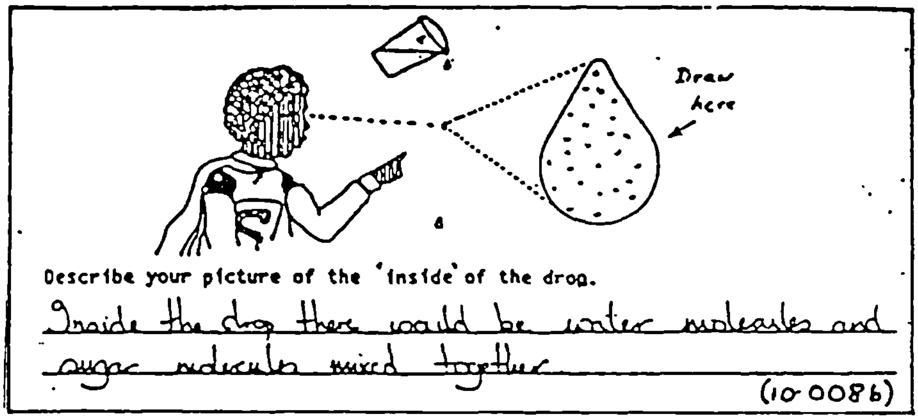
The drop has got lots of tiny little droplets of water in it. (7.051b)

The other responses within this category contained pictures that featured both sugar molecules and water molecules. The depiction of molecules as circles necessarily left 'gaps' between them. And, these gaps, formed an important part of explanatory statements; they certainly had a strong influence on the pupils conceptions of relative molecular sizes and the dissolving process, for example:



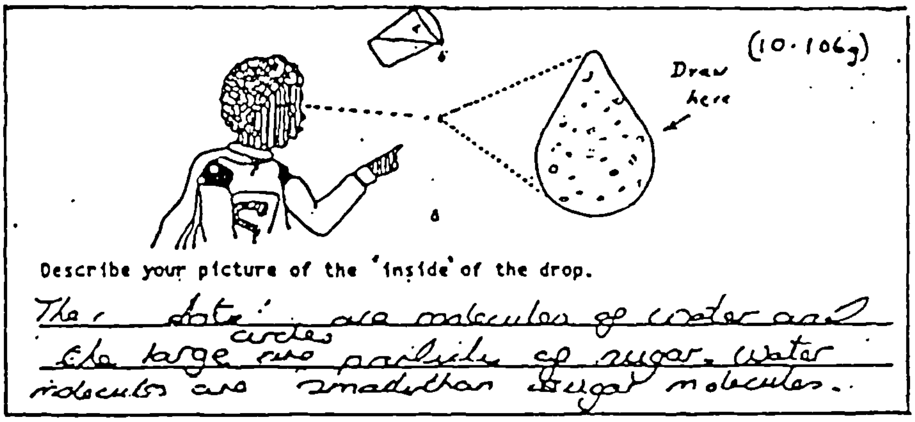
I have shown the molecules of water surrounding in the gaps I draw there the sugar molecules. (10.126b)

From the pupils' standpoint, the water molecules were 'there first', the sugar molecules had to be 'fitted in'. The outcome of this kind of model was that half of the responses contained the idea that water molecules were larger than sugar molecules. On the other hand some drew a more spaced diagram in which the water and sugar particles were roughly similar in size. Their model was less constrained by space and portrayed a 'spaced' mixture of particles, for example:



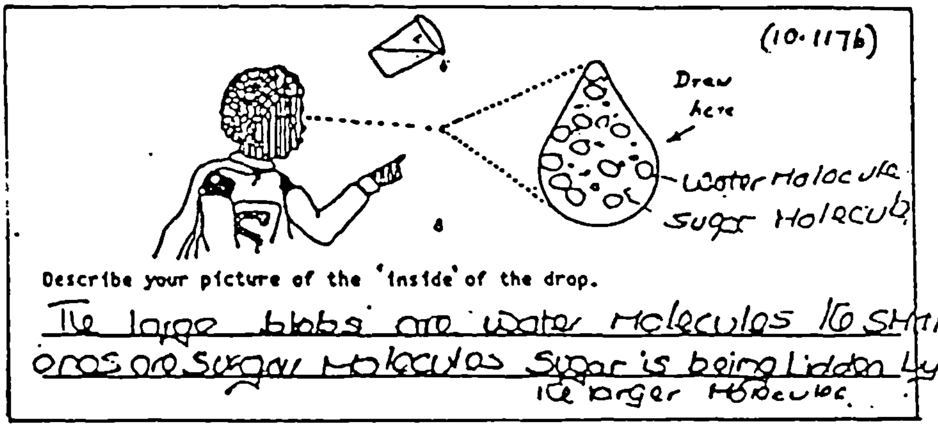
Inside the drop there would be water molecules and sugar molecules mixed together. (10.008b)

There were some, however, who expected that a sugar molecule would be considerably larger than a water molecule, for instance:



The dots are molecules of water and the large circles are particles of sugar. Water molecules are smaller than sugar molecules. (10.106b)

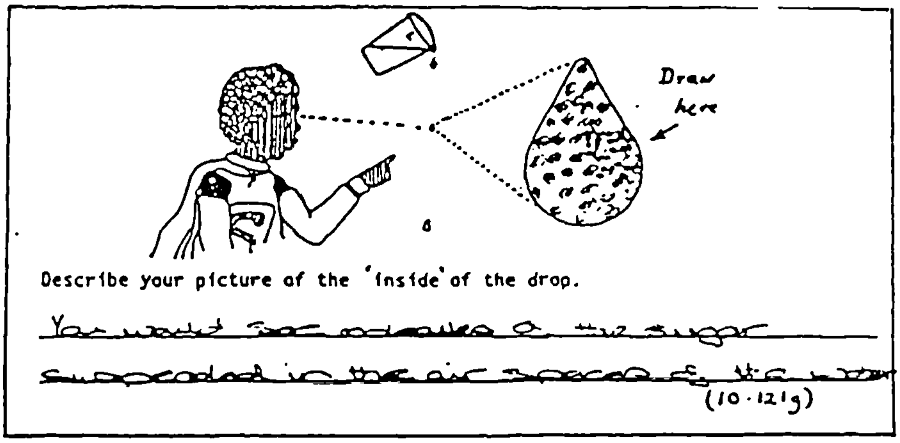
So far as some children were concerned, the notion of gaps between water molecules aroused primitive ideas about 'hiding places' for sugar molecules, for example:



The large blobs are water molecules the small ones are sugar molecules sugar is being hidden by the larger molecules. (10.117b)

There may be some significance in the fact that more boys than girls offered a 'gap fitting model' of a solution. Girls tended to present more open diagrams with less space restriction between particles.

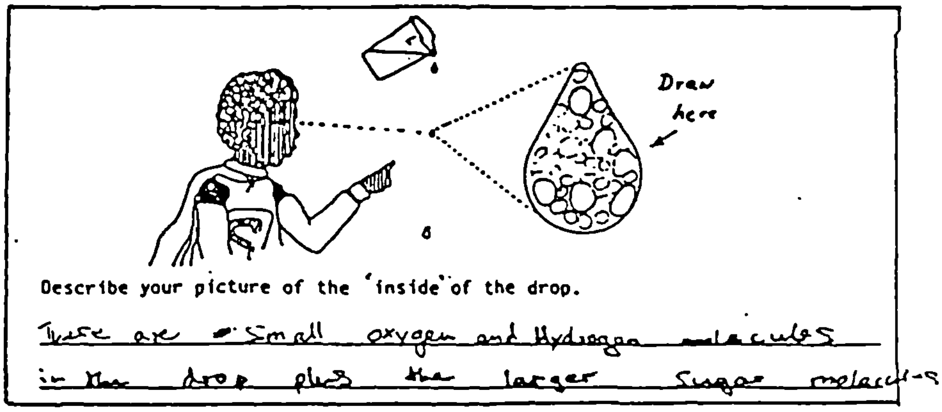
The space, alluded to above, was sometimes thought to contain air, for example:



You would see molecules of the sugar suspended in the air spaces of the water. (10.121g)

Many pupils appeared to be aware of the presence of dissolved air in water. It would seem that, in their view, air filled the spaces between the particles of water.

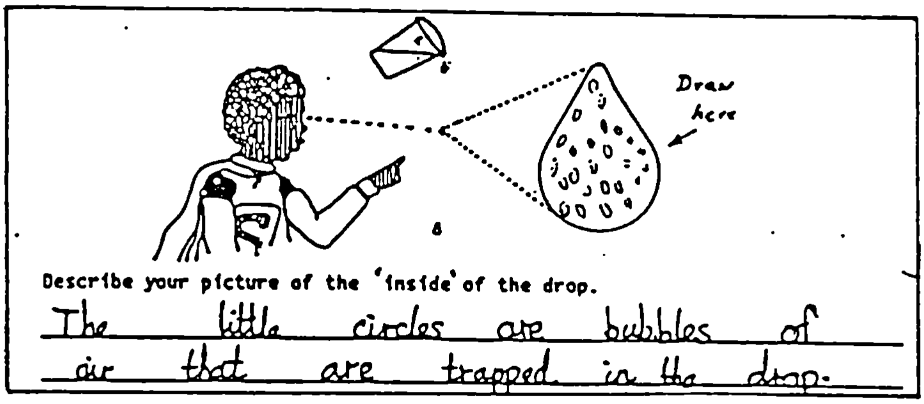
Some pupils represented water as made up of separate molecules of hydrogen and oxygen, i.e. they represented a compound as a mixture.



There are small oxygen and Hydrogen molecules in the drop plus the larger sugar molecules. (10.153b)

d. Pictures that depicted species other than sugar and water

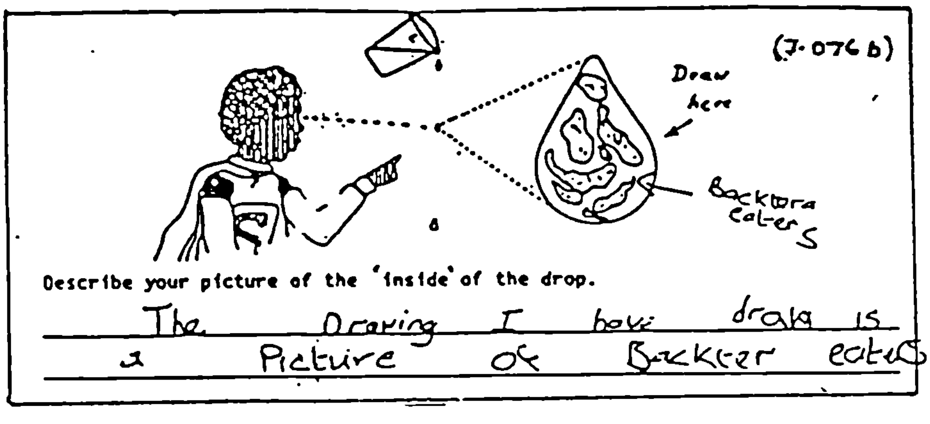
The portrayal of air in water has already been mentioned alongside the portrayal of sugar and water. However, in some cases air was the only component that could be imagined present in the sugar solution, for example:



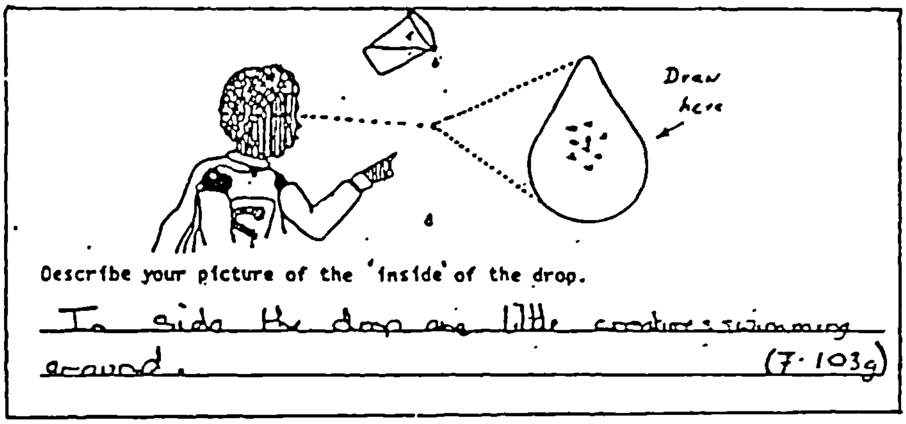
The little circles are bubbles of air that are trapped in the drop. ((7.019g)

It would seem that the existence of 'air-in-water' is well established in the young mind. This is probably due to their experience with pond life, fish tanks, goldfish and so on.

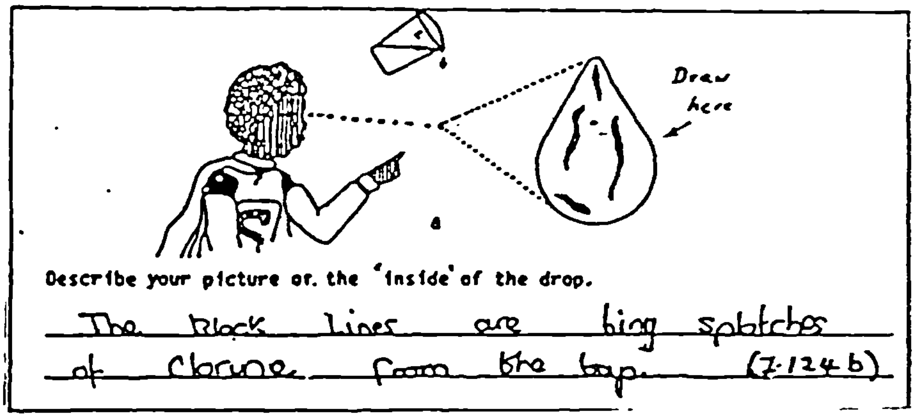
The 'open' character of the eliciting task invited ideas about a wide range of living creatures and materials that might be present in sugar solution. Some of these are illustrated on the next page. The greatest variety of these was found among schoolchildren in the seventh year. They portrayed: 'bacter eaters' (bacteria), germs, bugs, little creatures, dust, glass, impurities, chlorine and fluoride.



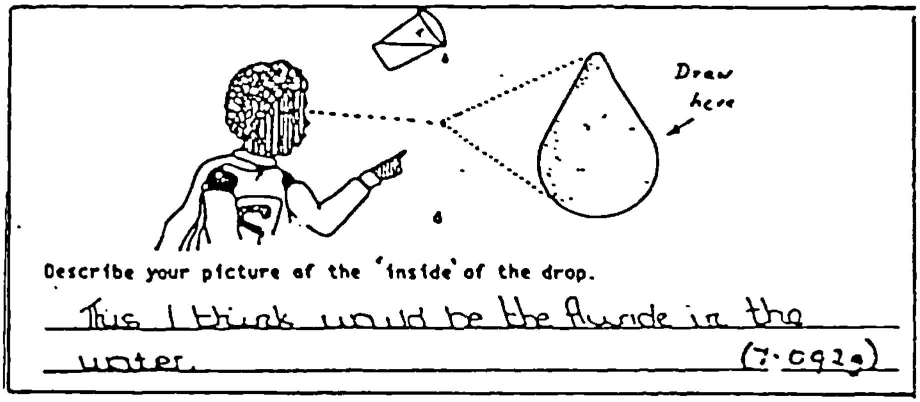
The drawing I have dran is a picture of Backter eaters. (7.076b)



Inside the drop are little creatures swimming around. (7.103g)



The Black lines are bing splotches of clorine from the tap. (7.124b)



This I think would be the fluride in the water. (7.092g)

9.3.6 Hypothesised processes for the generation of pupils' pictures of dissolved sugar

The statements children made when describing their diagrams suggests that the following processes may be used to generate their ideas:

* Replicating the most recently related visible event. Young children especially are impressed by the added sugar 'going down to the bottom' of the tumbler and by stirred sugar 'going down' also. Many appear to imagine that invisible sugar behaves in the same way.
* Older children appear to find this idea inadequate for they argue that if the 'invisible' sugar is concentrated at the bottom if the container returns to its 'visible' form. The alternative is to assume that it is dispersed within the solution. Thus, some pupils appear to reason that a replication of the visible event is inadequate. Further the alternative may be supported by their experience of uniformity of taste or colour throughout a solution.
* Some pupils appear to draw on experience that operated in what they regard as analogous situations since they use expressions like 'sugar joining water', 'water trapping sugar' and 'water supporting sugar'.
* Replication of visual appearence of gross 'particles' also seems to play a part in the depiction of pieces of sugar as either 'broken bits' or 'minute cubes'.

A summary of possible mental constructions generated by the pupils is shown in Fig. 9.4.

9.3.7 Summary of findings regarding children's pictures of dissolved sugar

The chapter has provided a description and categorisation of drawings that result from children's thinking about the inner constitution of sugar solution. It would appear that these findings may be summarised under three headings: the range and possible origin of the several types of response; the development of the various models of matter with year-group; and, the conceptual changes that are required if children's ideas are to be moved towards school-science ideas. Each of these will be reviewed in turn.

First, the task elicited a range of responses that reflected alternative ideas about 'hidden' composition of a solution. These alternative conceptions are summarised in fig 9.4. Prior to meeting with atomistic ideas in the science curriculum, it appears that about 20% of the surveyed pupils had a 'continuous' view of a solution. That is, their image of its constitution mirrored their perception of a 'clear' solution.

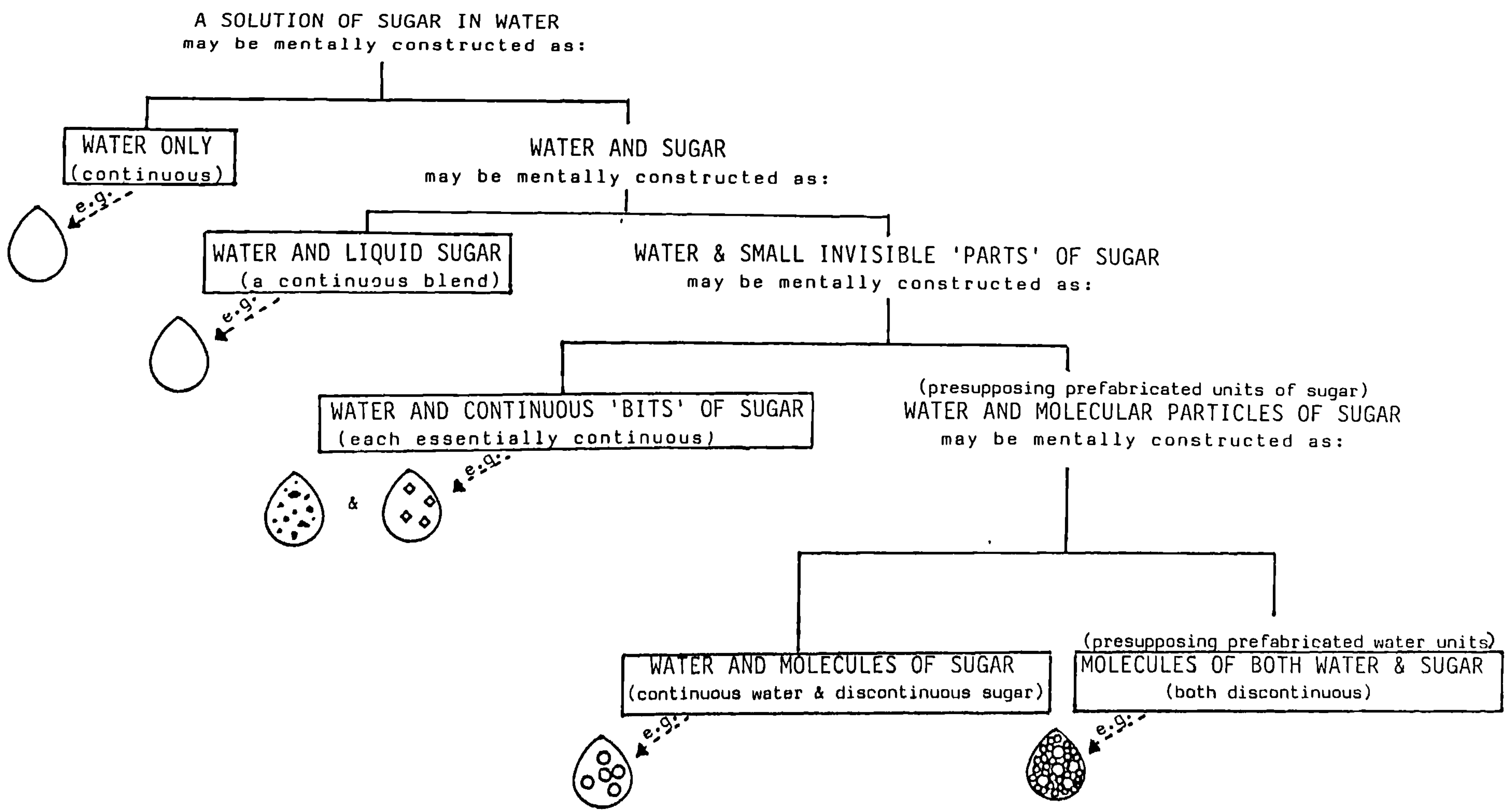


Fig. 9.4 Pupils' alternative constructions of the inner constitution of a sugar solution.
[Developmental 'moves' (in science direction) would be left to right, and top to bottom of diagram.]

Some of them appeared to view a solution as continuous 'water' but a larger proportion 'saw' it as a continuous blend of water and sugar. In contrast, about 60% had the pre-instructional idea that a solution was constituted of 'parts' that have, in this study, been designated 'continuous bits' of sugar (and/or drops of 'water'). Both of these representations of matter diminished as pupils encountered atomistic ideas in curriculum so that 'molecular particle' ideas eventually became more prevalent, see Figure 9.3.

Second, the development of atomistic ideas about solutions over time may be summarised according to the manner of depiction, the type of distribution, and the kind of label given to them. In general there was a growth of the idea of uniformity of constituent parts - a process that began before formal instruction. Although the majority of lower-year pupils depicted the 'parts' as dots or irregular shaped figures, some drew similar 'squares' or 'cubes'. The latter depiction continued to some extent in the tenth and twelfth school-years though 'similar circles' were then the most prevalent depiction of particles see Figure 9.3. Thus there appears to be an intermediate stage in the development of uniformity of particles, namely, that the appearance of 'parts' resembles the appearance of the 'whole' crystal. Also, there was a growth in the conception of the homogeniety or uniformity in the dispersion of particles in a solution. The majority of pupils in the lower years appear to regard solutions as non-uniform and generally they depicted solute particles near the bottom of the container. A small proportion maintain this idea throughout the school years but, overall, there is an increase in a homogeneous type of representation through the school years. Another development is a change in the label (for the constituent parts) from a life/world one to a science one, though, as has been mentioned previously, there is not necessarily a change in conception associated with the change in designation. Further, the representation of a solid as made up of 'parts' would appear to precede that of a liquid. Fewer pupils represented water-as-particulate than sugar-as-particulate. Possibly there is conflict between the experienced smoothness of water and the 'graininess' of the molecular idea of water. Of the higher year-groups, only about half of those who presented sugar as molecules did so for water.

Third, the major conceptual changes that may be required in order to shift pupils towards the school science ideas may be summarised as follows:

* from a 'continuous picture' of solutions to a 'particle picture' of solutions;

* from a 'heterogeneously dispersed' view of solute particles 'homogeneously dispersed' view;

* from a 'continuous piece picture' of solute in a continuous solvent to a 'molecular particle picture' of both solute and solvent;

* from 'heteromorphic representations' of solutes to 'similar sized homomorphic representations'

* from a view that 'sugar molecules are small enough to fit the space between three or four molecules of water' to a view of 'mutual attraction between (large) sugar molecules and water molecules'.

* from a 'state' to a 'dynamic' view of particles in a solution.

9.4 Schoolchildrens' pictorial representations of the inner constitution of a sugar crystal

9.4.1 The eliciting task

Pupils were introduced to this task in a similar manner to that used in the previous task.
Attention was focussed on a single transparent sugar crystal[1] (about $0.5cm^3$ in volume) and pupils were given the opportunity to check that 'they could see through it' by placing it over printed words.

Then, they were asked to imagine what might be seen inside the crystal if they had 'super-eyes'. After being invited to draw their mental pictures or 'mind's-eye-pictures' in a space provided on paper, they were asked to explain the features of their pictures.

Each pupil who did the survey task was also given a single crystal of sugar to handle and reflect upon. A space for drawing was provided and they were asked to write down what their pictures meant.

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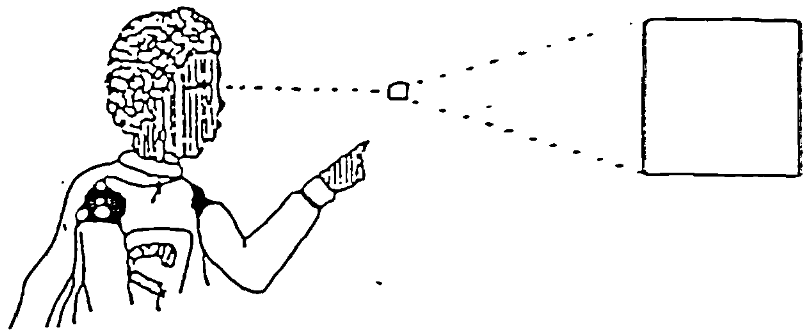
1. They had been given an opportunity to become familiar with a similar crystal at the outset of the interview. At that time they were asked to describe its external appearance.

Interview elicitation task

Researcher: 'I would like you to look at one of these sugar crystals again, let's put it on this page (of writing).
Do you notice anything? (Pupil says he can see letters)
'Yes we can see through the crystal, can you see anything inside the crystal?' (Pupil says he can't see anything inside it)
Do you think you would see anything inside if you had super-eyes, or do you think it would be just like this? (Researcher points to crystal)
(Depending on the response) Would you like to draw your idea here?'
(Depending on the diagram) 'Would you like to tell me what this means?' (Researcher points to some feature of the sketch).



9.4.2 Aims in the analysis of the responses

It was anticipated that the portrayal of the composition of a sugar crystal could elicit some of the information/questions listed below.

* What kinds of pictures, if any, of the inner constitution of a colourless crystalline solid are generated by children?

* What models of matter underlie the various kinds of diagrams and description that children may offer? The 'invisible components' of solid matter (along with their attributed behaviour) form a substantial part of explanatory content of school-science. Consequently, it could be helpful to have some notion of pupil's prior knowledge of this subject especially their understanding of solids before they are dissolved.

* Not only is the range of ideas of interest, but also the changes in prevalence of these ideas that appears to occur during school life. Such data could be used to infer the kinds of conceptual changes that occur and possibly some of the factors which may influence such changes.

* Since the previous task and this one require the pupils to imagine matter in two different states what relationship, if any, exists between the kinds of atomistic ideas proposed in each case? It

would be interesting to know what perceived modifications in matter are thought to underlie the overt change of state.

9.4.3 Analysis procedure for interview and survey responses

Pupils diagrams were scanned for features that could inform the researcher about children's notions of the inner constitution of sugar crystals. Thus, it was necessary to record whether each 'picture' was fragmented or plain; if fragmented, whether the 'parts' were similar or dissimilar and, in either case, whether they were arranged in an ordered or random manner.

Further, it was necessary to examine the transcripts, diagram 'labels' and written responses for a description of the components, if any, in order to interpret their intended meaning. In particular, did the pupil appear to convey an underlying continuous model a discontinuous model or some intermediate model of matter? Where possible an attempt was made to look at the features associated with the pupils' terminology.

In order to assist the analytic process, a table was drawn up having columns headed: 'identification number of pupil', 'diagram', 'fragmented/plain', 'pattern/random', 'fragmented shape', 'model of matter/designation of particle', 'other features'. A table was completed for each pupil in a particular year-group.

Patterns of prevalent features were observed during the analysis process and they were interpreted as five ways of depicting a sugar crystal. These are explained in section 9.4.4.2 and systematised in Table 9.4 and Table 9.5.

9.4.4 Findings from interview and survey responses

9.4.4.1 General characteristics of the data

Responses to this task usually contained a sketch together with a descriptive statement; both of these varied in the extent of detail offered. Pupils' sketches were either plain or evenly shaded or else showed dots, squares, circles and other geometrical figures arranged in a variety of ways. The descriptions of sketches included some of the following features:

* a name of the particle depicted (if any) e.g. bits, grains, cubes, crystals, molecules;
* an estimate of their number e.g. lots and lots, many, thousands,

millions;

* an idea of their size e.g. tiny, little, small, minute, microscopic;

and less frequently:

* a means of cohesion between particles e.g. stuck together, joined, bound, fit together, packed tight, attracted;
* an analogy e.g. like the face of a cliff;
* an explanation of how they dissolve e.g. they are stuck together and come apart in water;
* an idea about the arrangement of particles e.g. neat, fixed or regular pattern, rigid structure, lattice structure;
* an explanation of the crystal shape e.g. the structure of the molecules gives the shape.

9.4.4.2 Types of 'crystal' pictures elicited

Pupils depicted a sugar crystal in five principle ways:

a. a plain or evenly shaded drawing that was inferred to represent a 'continuum' or the absence of particles;

b. a random distribution of diverse irregular shapes (or merely dots) that represented non-uniform bits of continuous sugar;

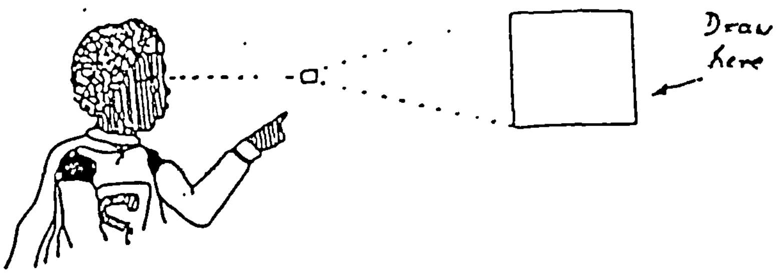
c. a regularly repeating pattern of similar units (e.g. squares) that represented uniform bits of continuous sugar;

d. a random distribution of similar units (e.g. circles) that represented atoms/molecules;

e. a regularly repeating pattern of similar units (e.g. circles) that represented atoms/molecules.

Pictures of type 'd' and 'e' above were essentially isomorphic with school-science depictions of crystals except that a conception of orderliness was missing from the mental image of pupils who portrayed type 'd'. Type 'b' and 'c' pictures exemplified mental images of pieces of continuous matter with type 'c' indicating an added conception of orderliness to the notion of irregular 'pieces of matter'. Ideas of type 'b', 'c' and 'd' could be used as a bridge between the continuous model 'a' and the 'science' model 'e' provided that pupils also come to understand that 'parts' pre-exist.

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

____

____

____

The survey task

TABLE 9.4 NUMBER OF INTERVIEWEES OFFERING SPECIFIED KINDS OF DEPICTION OF A SUGAR CRYSTAL

Type of representation of the inner constitution of a single crystal	Year 3 n=18 no.	Year 5 n=18 no.	Year 7 n=18 no.	Year 10 n=18 no.	Year 12 n=18 no.
a. A plain or evenly shaded drawing-<u>continuous, non-particulate</u> crystal	8	8	8	6	2
b. A random distribution of assorted irregular units-crystal composed of <u>non-uniform bits of continuous sugar</u>	9	8	8	-	-
c. A pattern of similar units-uniform <u>pieces of continuous sugar</u>	-	1	1	1	1
d. A random distribution of similar units-<u>random molecules of sugar</u>	-	-	-	3	3
e. a regularly repeating pattern of similar units-a <u>regular array of molecules</u>	-	-	-	8	11
f. No response	1	1	1	-	1

TABLE 9.5 PERCENTAGE OF SURVEY PUPILS OFFERING SPECIFIED KINDS OF DEPICTION OF A SUGAR CRYSTAL

Type of representation	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. A plain or evenly shaded drawing - continuous, non-particulate	22	20	22	20	30	16	25	16	7	8
b. A random distribution of assorted irregular units - non-uniform bits of continuous sugar	38	34	63	58	85	67	60	39	20	23
c. A pattern of similar units (e.g. squares) - uniform pieces of continuous sugar	1	1	-	-	4	3	17	11	10	12
d. A random distribution of similar units e.g. circles - random molecules of sugar	-	-	-	-	4	3	15	10	14	16
e. A regularly repeating patern of similar units e.g. circles - regular array molecules of sugar	-	-	-	-	-	-	35	23	27	31
f. No response, or incomprehensible, or insufficient-to-code response	51	46	24	23	14	11	2	1	8	9

9.4.4.3 Patterns of interview response by year-group

Third-year schoolchildren (7/8-year-old)

Of the 18 pupils interviewed, nine imagined that the sugar crystal was composed of small 'bits' of (continuous) sugar, eight imagined it would be 'clear', like the crystal itself, and one said that she 'didn't know'.

Those who imagined that the sugar was constituted of small parts described the parts as 'little bits' or 'granules that make the crystal' (3.208b). One pupil described the crystal as being 'built':

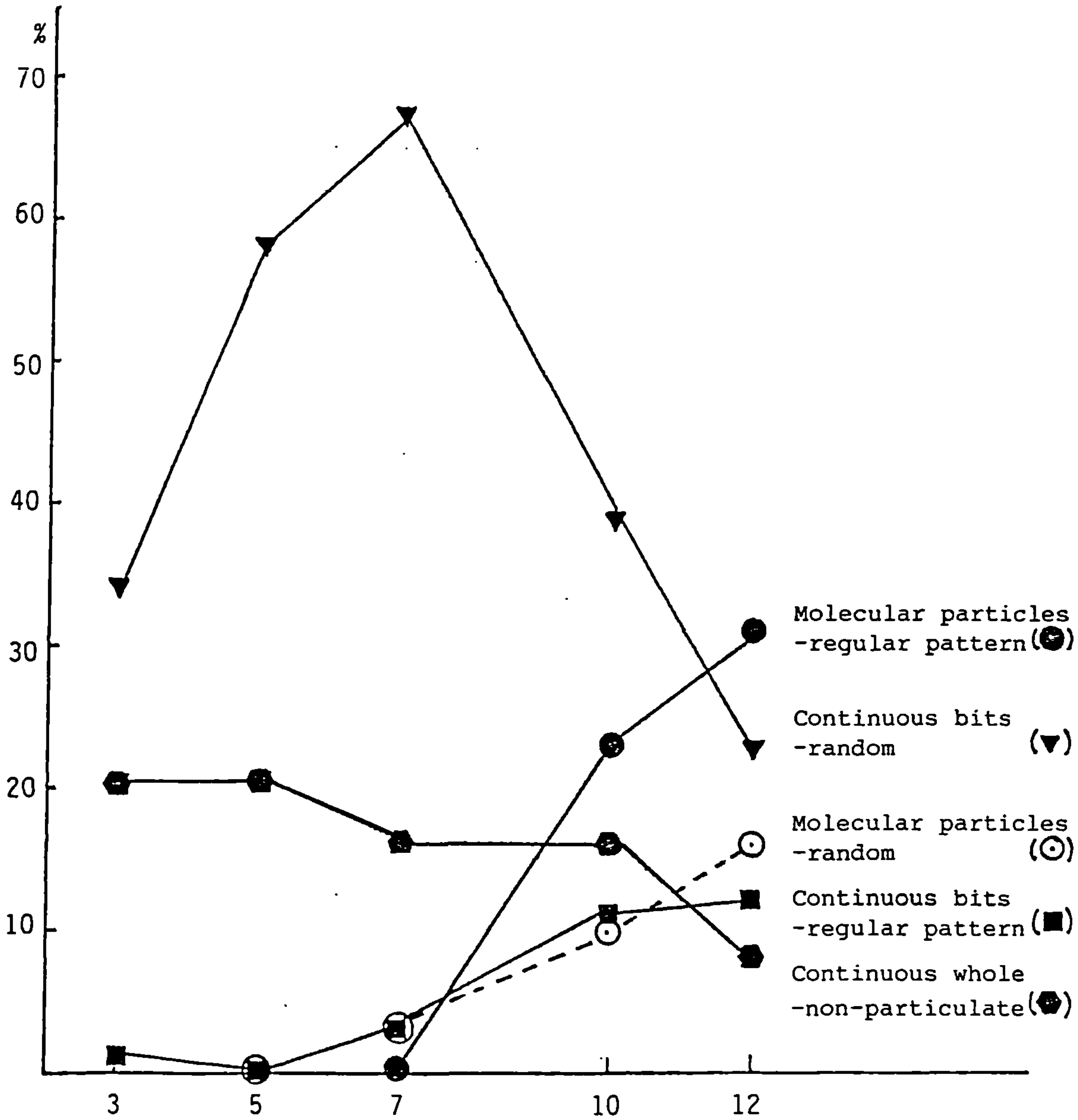


Fig. 9.5 Percentage of pupils offering specified types of 'pictures' of the inner constitution of a sugar crystal. (Graphs based on Table 9.5)

'it'd just be built of them (granules), it's built of that, that's what it's built of, just lots of ones of those (granules), they're built up and they all stick together.'

Pupils rarely mentioned how the bits held together so the researcher took the opportunity to ask this pupil and he replied:

'they must have some way of sticking together so when they, but they, but when water's at them they melt.'[1] (3.217b)

It seems he was trying to link his ideas of atomism in the solid sugar with an idea of atomism in solution (he had drawn similar 'bits' in both cases) thereby generating a model of the dissolving process.

Another relation between atomism in the solid state and atomism in solution, that occasionally emerged, was an image of particles in the solid being smaller than those in solution. Whereas there were 'little bits' of sugar in the solution there were 'more littler bits' in the solid. This was somewhat reminiscent of a 'stepwise-build-up' conception of matter held in the seventeenth century.[2]

Two pupils visualised 'little bits of water', as well as sugar, in sugar crystals. It is possible they had generated this idea from an experience with sugar that, in their view, had influenced their salivary glands. Another pupil suggested that bits of glass might be present in addition to bits of sugar but he soon withdrew this idea because 'you'd cut yourself' (3.201b).

The usual response from the eight pupils having 'non-atomistic' ideas was that, when viewed with super-eyes, the crystal would be 'just plain' or 'nothing would be seen' i.e. the internal constitution would resemble the external appearance. One variation of this was to draw a black spot in the middle of the crystal diagram and then label the spot:

'the taste of it.' (3.204g)

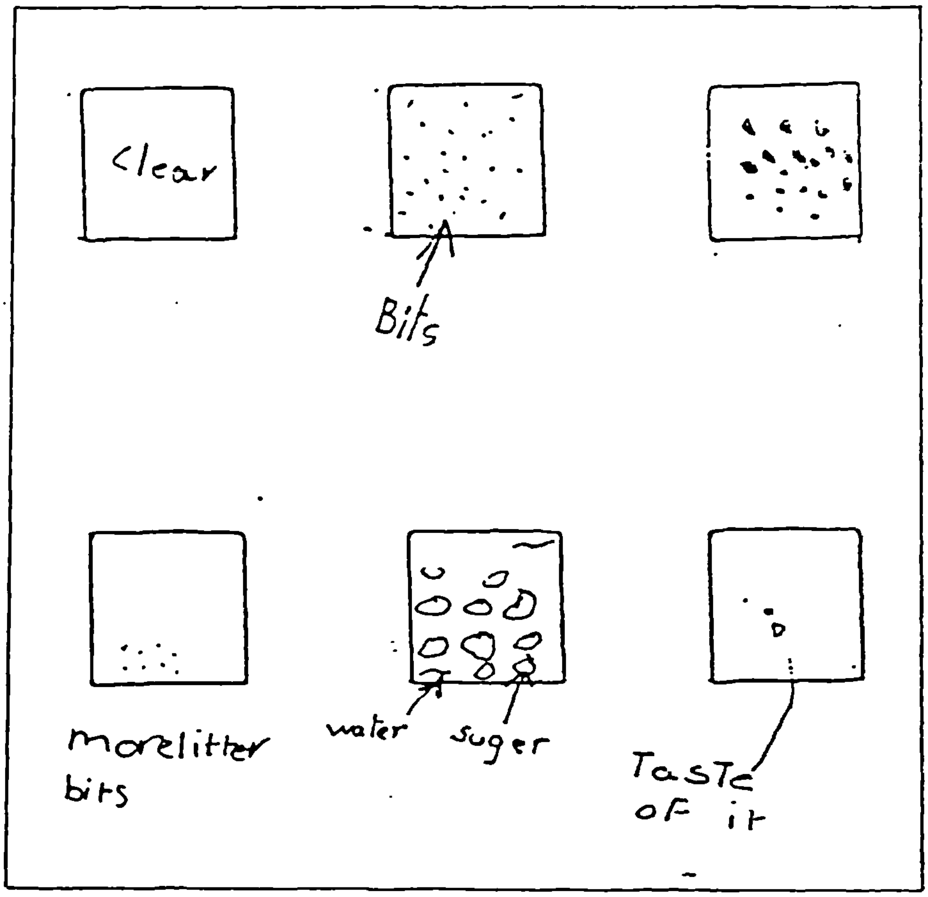
This materialization of taste and its concentration in the centre of a crystal is an interesting conception. Generally, in children's responses, taste seemed to be more permanent than substance, but it is

----

1. 'Melt' carried the connotation 'to separate into little bits'. This pupil had just explained the meaning of the entities in his diagram of the inside of a solution: 'sugar, little bits of it'.

2. Newton did not think '... that matter was simply composed of primitive particles. He suggested that primitive particles cohered to form bigger particles, that these bigger particles in turn cohered to form still bigger particles'. (Goehring, 1976)

rarely depicted. This child was probably endeavouring to express his understanding of taste through a prior experience with unspecified confectionary.



Different types of representation of the inner composition of sugar crystals according to third-school-year pupils

Fifth-year schoolchildren (9/10-year-old)

Nine of the 18 pupils interviewed put forward the idea that the single crystal was composed of 'bits' of sugar and eight pupils offered the opinion that it would be 'plain'. The remaining pupil offered the idea that it contained bits of seaweed - possibly he was confusing it with sugar cane. Occasionally, pupils suggested that sugar was made up of particles of its 'original vegetable source'.

One of the nine 'atomists' drew pictures of grains in linear fashion and commented that 'little grains altogether make one big one' and that they would be 'all over, all inside' (5.316g). Ostensibly, she had begun to construct an orderly arrangement of composite parts. The remaining atomistic responses contained a random distribution of particles.

Another example of a developing conceptual network of ideas about matter, in the fifth year, was a spontaneous estimate, by two pupils, of the number of 'bits' of sugar:

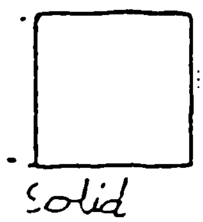
> 'millions of grains.' (5.313g)
>
> 'it's made of millions of tiny granules, er maybe all of them packed together to make it hard, to make it a solid.' (5.314b).

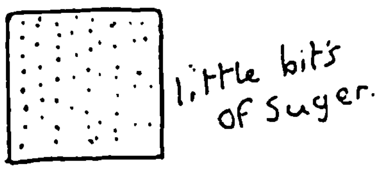
The last quotation contains a tentative, unasked for, extension of his atomistic 'theory of matter' to explain hardness and solidity.

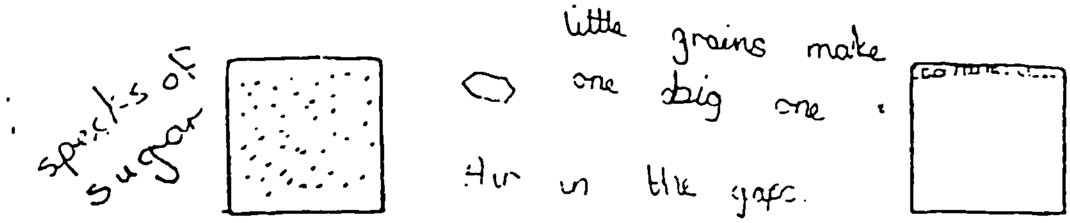
The fact that children of this age can comprehend large numbers, very small sizes, packing, orderliness and closeness may indicate that they could discuss the possibility of certain 'objects' being made up of similar 'building bricks'. (Perhaps this could be done in a low-key exploratory manner with a supportive environment and a supply of modelling material for illustrating and testing ideas).

Nevertheless, about half of the pupils appear to have a 'wholely continuous' conception of matter and it would be useful to know what experience they have of number, size, packing, etc and whether such experience has any influence on their thinking about matter.

Some examples of types of responses by this year-group are shown below:







Types of representation by fifth-year pupils (continued).

Seventh-year schoolchildren (11/12-year-old)

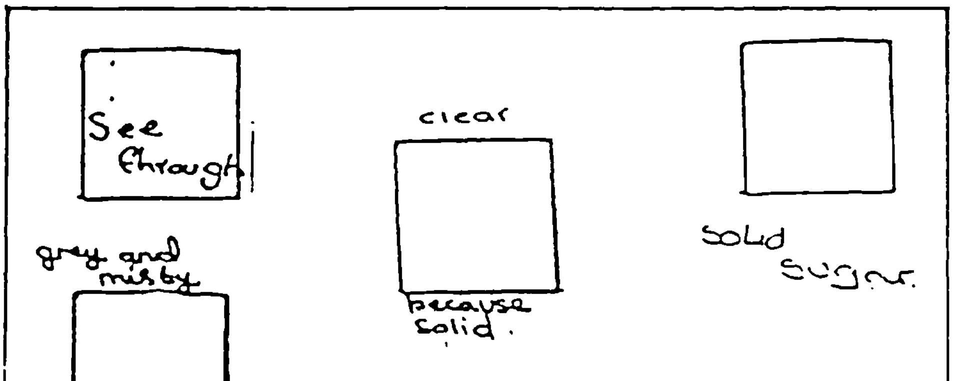
The numbers of responses in the various categories were similar to the previous year i.e. nine suggested that the single crystal was composed of bits of sugar, eight that it was plain, and one 'no response'.

Also the responses offered by this year-group were similar in kind to the previous year, so little further comment is required.

The only 'fresh' point of interest was a justification for a continuous view of crystalline matter. Two pupils linked solidity to continuity, for instance:

'Clear because solid. It's right thick, it's solid.' (7.613b)

A notion of solidity is more likely to lend support to a continuous view rather than a discontinuous one if, as in this case, the child is unable to construct an idea of powerful inter-particle attractive forces.



Examples of various types of 'continuous' representations by seventh-year pupils.

Tenth-year schoolchildren (14/15-year-old)

There was a considerable difference, from previous year-groups, in the number of responses in the various categories. Of the 18 pupils interviewed, eight offered a depiction close to the school science conception, three offered something similar but the component units were randomly distributed. One pupil suggested that the sugar was composed of 'bits of sugar' and these were regularly arranged. Six pupils offered a 'wholely continuous' notion of a sugar crystal.

The eight pupils who depicted a 'pattern of molecules' often used the word 'pattern' and all but one depicted a regularly repeating pattern. Two of them mentioned that the atoms would be bonded or attracted to one another, for example:

> 'these are more tightly packed because the attractive forces are a lot stronger, so it holds them in their position' (10.616b)

In general, however, there was little mention of what might 'hold parts together'. Perhaps it reflected a general lack of construction of the reverse process i.e. the building up of matter from whatever unit parts are conceived and how those parts might be held together.

The pupil who suggested that a sugar crystal was composed of pieces of sugar described them as:

> 'all different little bits in rows, all packed on top of each other, all square shaped.' (10.602b)

Although these were 'bits' of continuous sugar this pupil had imagined an orderly arrangement of similar parts.

Those who had the 'wholely continuous' view of sugar were influenced by the external appearance for example:

> 'I just think it would be clear actually you know ... it's not like it's got little bits all over, it'd just be clear.' (10.605g)

This pupil explicitly rejects atomistic ideas on the basis of appearance. Similarly another pupil who had said the crystal would be 'just clear' was asked, again, whether it would be the same with super-eyes replied:

> 'yes, just be able to see more clearly.' (10.612g)

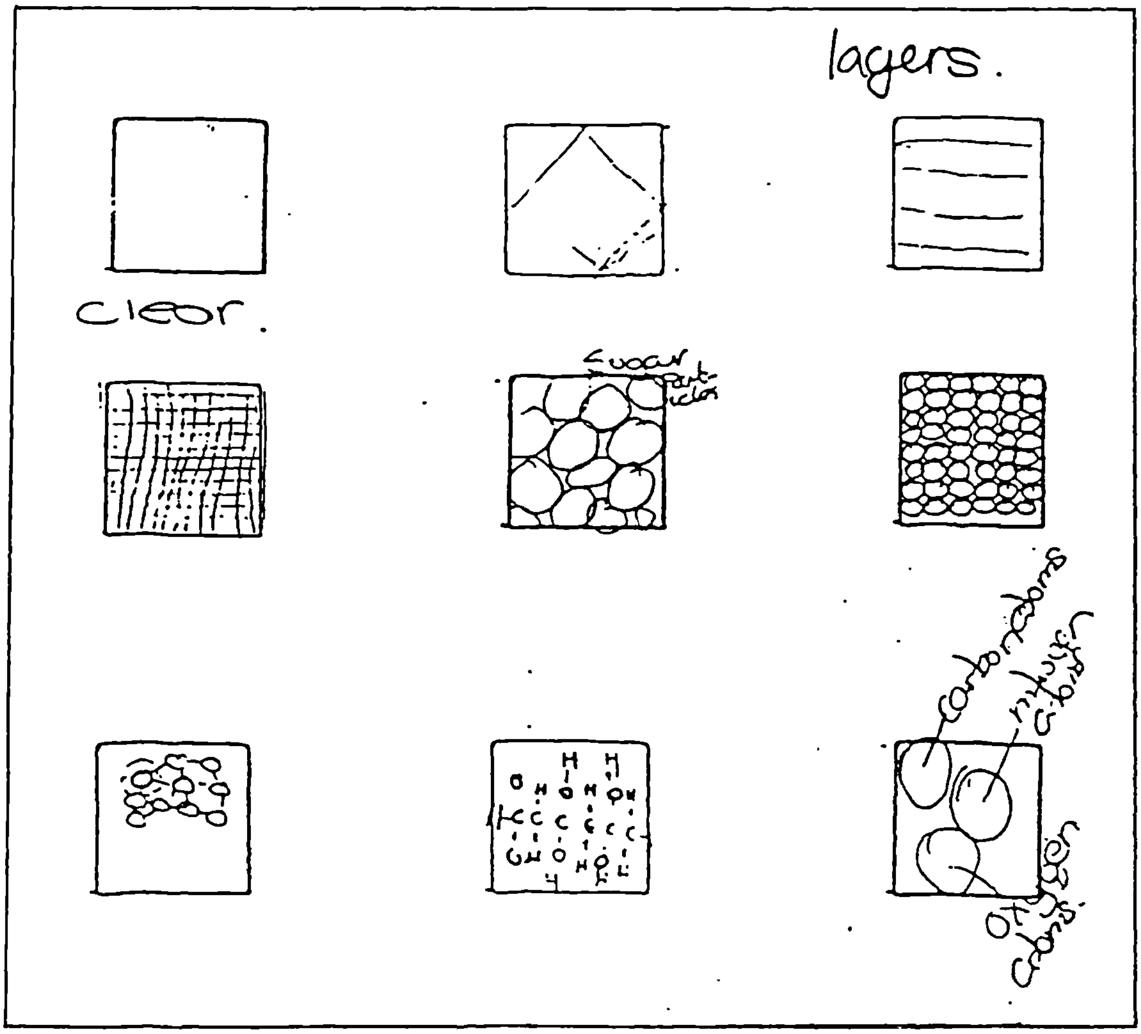
The layers of crystals that are sometimes observed to form when crystallisation takes place could have guided the thinking one pupil:

> 'It (the internal composition of sugar) looks like it is with layers across it it looks like it grew out of ~~loads of little ones (crystals),~~ no, not loads of little ones, but just the way it's formed ... once did an experiment, a piece of cotton with

a crystal on it and we took it out and it all dried up and it made a big blue crystal and that was in type of layers, that's what made me think of that, it was a similar texture to that but a different colour.' (10.614g)

This is an illuminating response because the experiment alluded to is frequently used in science lessons to illustrate particle ideas. However, in this case the pupil continues to generate ideas from appearances.

Some examples of other responses are shown below.



9.4.4.4 Prevalence of response categories in the survey task

The survey responses were categorised in a similar manner to the interview responses (see para. 9.4.4.2). The analysis is shown in Table 9.5. The prevalence and features that characterised each response category are outlined below.

a. A plain or evenly-shaded depiction

It was inferred that this represented a non-particle or continuous conception of the inner constitution of a crystal. About one in five of pupils up to the tenth-year appeared to view the crystal as a single unit. The descriptions they used, such as clear, plain, see-through etc, seemed to indicate that their judgements were based on the scheme that the internal composition of a crystal was similar to the external form. They seemed to find 'solidity' and 'transparency' particularly impressive features, for example:

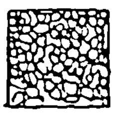
> 'I don't think this would look any different as it is a solid granule and the inside wouldn't look any different.' (12.036g)

> 'As sugar is transparent in a large granule I think it (the inside) would be transparent.' (10.055b)

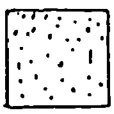
From their point of view, a transparent or solid material was unlikely to be made up of parts. Some young children suggested that one might see other kinds of material in the sugar crystal such as 'frozen water', 'ice', 'glass', or 'diamonds'. These have a similar appearance to sugar. Thus, as in the quotations above, the thinking is circumscribed by sense perceptions. A few pupils went a little beyond appearance and used some prior experience with glass. They proposed that some small 'air bubbles' or 'flaws' or 'cracks' might be present as they had observed in glass. Some proposed that this was a way in which the water could get in and push the crystal apart.

b. A random distribution of diverse irregular shapes

It was inferred that irregular shapes represented bits of continuous sugar (- an intuitive atomistic conception). This depiction of heteromorphic bits was the most prevalent one, especially in the lower school year-groups, where it was offered by about two in every three respondents. This depiction appears to have been based on the scheme that a large 'chunk' of matter is made up of smaller pieces of the same material. Also the pieces were described as 'solid'.

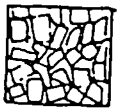


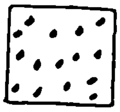
> 'I have drawn lots of microscopic sugar grains all stuck together.' (7.073b)



> 'My pictures shows that one granule of sugar could also be made of tiny solid pieces of sugar which would make a crunch if you stood on them.' (7.025b)

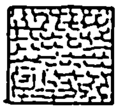
Most of the responses in this category included the conceptual units of minuteness and multitudinousness of parts and a few mentioned some bonding between them (or sticking together). A conception of orderliness of arrangement of parts was not present. The absence of any connection between the shape or arrangement of parts and the regularly shaped whole crystal, that lay before them, is probably due to their notion that the crystal shape had been externally contrived - a notion that had emerged during interviews. (Most young children suggested the crystals had been 'moulded' or 'machine made'.)

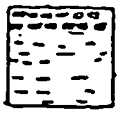

'Rob can see the sugar crystals in the granule'. (7.026b)

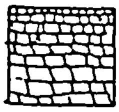

'the tiny particles of solid sugar that form together to make the granule of sugar'. (7.003g)

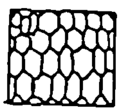
c. A pattern of similar shaped units

It was inferred that this represented uniform pieces of continuous sugar. The depiction of essentially homomorphic bits arranged in an orderly manner was found among one-in-twenty pupils by year-seven and among one-in-ten by year-ten. Although held by a comparatively small, but increasing, number of pupils it implies the development of a conception of 'order' among constituent particles. It would appear to indicate the presence of a scheme that the regularity of the whole crystal gives evidence of the shape and arrangement of its parts. This picture may owe its origin to early experience with 'building-block-toys'. It is noteworthy that about twice as many boys as girls offered this type of picture.


'In the sugar granule I think they would be tiny little sugar cubes (solid ones)'. (7.024g)

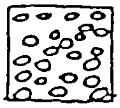

'Thousands of tiny granules which make up one sugar granule' (10.053b)


'He would see little cubes of sugar bonded together'. (10.058b)

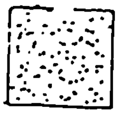

'The granule would have tiny crystals all joined to each other which filled the granule'. (10.042b)

d. A random distribution of similar units - said to represent molecular particles

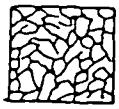
It was inferred that the pupils were attempting to represent taught model of a crystal as formed from the so called 'building-bricks' of matter. Pupils who offered the responses generally appeared to have constructed the idea of similar molecular parts and that close packing of those parts led to the formation of the solid crystal. This represented a considerable conceptual change from the naive idea that a crystal is made of 'tiny solid pieces of sugar'.



'The pieces inside are small round molecules which cannot be seen with the naked eye'. (10.138g)



"Inside the granule is lots of tiny molecules which make up one crystal'. (10.040g)

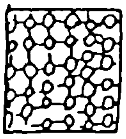


"The sugar granules are made up of atoms also they are attracted to each other but are packed very tightly so that they are unable to move this forms a solid'. (10.038g)

Nevertheless, the re-structuring of their ideas did not include the component of orderliness of arrangement of molecular particles. This omission was probably due to the retention of the corresponding component of the naive conception of the solid state. It could be that these pupils had not been assisted to make a connection between the regular shape of the whole and the similarity of the hypothesised parts. Because molecules are commonly represented by circles or spheres it is difficult for pupils to construct geometrical shapes (of crystals) from packed spheres (representing molecules). It may be that lack of experience with appropriate macro-models may account for some of the random depictions offered.

e. A regularly repeating pattern of similar units that represented molecular particles

Depictions of regular patterns of 'molecular particles', essentially similar to a school-science model, were offered by just over one-in -five of tenth-year and one-in-three of twelfth-year pupils, for example:

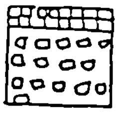


'Inside the granule molecules of sugar would be bonded together in a crystal formation it would have a certain pattern'. (10.008g)

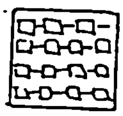
No responses of this kind were found in lower year-groups as the molecular model had not been part of their syllabus.

Pupils in this category, like those in the previous one, had constructed two components of the molecular model, namely, similarity and close-packing of the 'building-molecules'. In addition, they had almost certainly changed (or incorporated) their conception of particle arrangement. In the early years a random arrangement of 'particles' is held by almost all pupils, whereas pupils in this category attribute a regular pattern to the particles. Such a reconstruction of a model of matter appears to be a piecemeal process as witnessed, not only by these two categories 'd' and 'e', but also variations of component conceptions within them. For instance, although all in category 'e' agree on the molecular pattern, some 'molecules' are crystal-shaped but some are not, some 'molecules' are static but others are not, and some 'molecules' interact but others do not. Some examples of these variations are discussed below.

Those pupils who presented the idea that sugar molecules were crystal shaped possibily thought of molecules as the product of successive division of 'parent' crystals rather than in terms of pre-existing particles, for example:



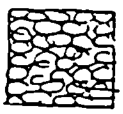
'The structure of the atoms inside the granule making up the sugar.' (10.101b)



'Lots of molecules all linked together, making a regular shape i.e. the sugar granular.' (12.028g)

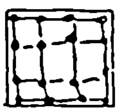
Their model building could be regarded as transitional between thinking in terms of 'bits' of matter and individual molecules.

About half of the pupils in this category (e) explicitly indicated that they had some conception of attractive forces between molecules whereas the rest did not mention any form of bonding or else seemed to think that compact packing was an adequate reason, for example:



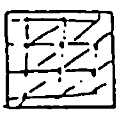
'In a solid the molecules are packed tight and very close together.' (10.139g)

On the other hand the bonding was so real to some that they thought the bonds could be seen:



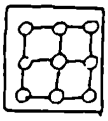
'The inside of the sugar granule would show the bonding of the atoms inside the sugar granule to keep it in a solid state.' (10.124b)

The idea of a strong attraction appeared to interfere with a conception of particle motion (vibration), in some cases, for example:

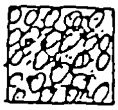


'In the sugar which is a solid, the atoms are stationary, held in a lattice-work by strong attractive forces. The joining lines in the diagram represent the forces, the dots the atoms.' (10.120g)

nevertheless about one in four of this category, 'e', were able to accommodate the idea of vibrating molecules:


'There would be again lots of tiny particles ... arranged in a pattern equal distances apart and they would move ... about fixed points.' (10.017g)

or stated with less precision, but more poetically:


'The molecules are side by side vibrating to and fro'. (10.103b) .

Altogether it would appear that the facility with which the various conceptual units of the molecular model were assimilated or accommodated were in the ascending order:
pattern packing - pre-existing units - interaction - intrinsic energy. This is based on comparatively small overall numbers and does not necessarily apply to individuals.

9.4.5 Hypothesised processes for the generation of pupils' pictures of sugar crystals

Pupils' statements about their diagrams sometimes appeared to disclose the basis on which they constructed them. Inferences were made about their statements in order to develop the speculations listed below.

* Pupils who offered a continuous view of a crystal appear to have been powerfully influenced by its immediate sense perception in particular: transparency and solidity. Neither of these perceived properties, in themselves, appeared to support a particulate constitution.

* If perceived 'transparency' and 'solidity' supported a continuous view, one may wonder why so many should mentally conceive a crystal as made up of small parts (before introduction to particle theory). One reason appears to be an awareness that a crystal may be cracked or cut. This kind of thinking appeared to lead some to think in terms of 'layers' of unspecified parts. Also, some pupils used the general experience of 'wholes' being composed of 'parts'.

* Others, no doubt influenced by the recent experience of dissolving, appeared to be concerned that the dissolving process had to be accounted for in some way. Their thinking seemed to be that the sugar had to 'come apart' in some way. It was suggested that the sugar was 'made up of parts that were stuck together'.

* The experience of seeing aggregates of crystals (for example, in evaporating dishes) seemed to suggest to a few pupils that crystals were composed of smaller crystal parts.

To summarise, it would appear that the two main processes underlie children's thinking about the composition of a sugar crystal are:

* making judgements based on sense perceptions; or
* making speculations that account for current knowledge and experiences.

These processes may suggest a procedure for encouraging pupils to shift their thinking away from immediate sense perception alone, i.e. they may be asked to submit ideas that account for a wider range of experiences (than they have already considered). It is clear that some children were trying to construct conceptions that were consistent with their current knowledge and experiences.

9.4.6 Summary of findings regarding children's pictures of the inner constitution of a solute.

In the second half of this chapter we have described and interpreted children's depictions of undissolved sugar. These will now be summarised.

In the first place, the findings appear to show that pupils hold a range of models, of the inner constitution of undissolved matter, from a 'wholely continuous' view to a 'molecular particle' one. Within the particulate groups, ideas range from the irregularity of parts to uniformity of parts and from randomness of arrangement to regularity of the same. A summary of the main kinds of models offered by the pupils is summarised in Figure 9.6. Many of the children's responses contained dichotomous alternatives. Because of this, the reader may compare the characteristic features of the several types of response. The nature of the thinking that underlies the various types of response has already been discussed in section 9.4.5.

Secondly, there are trends in the prevalence of particular models with school-year, and these were summarised in Table 9.5. A shift towards uniformity of particles and regularity of arrangement is noticeable after the seventh-year. Nevertheless, a substantial proportion of pupils appear to maintain a 'continuous bit' model of undissolved matter. (See also Figure 9.5 which is based on Table 9.5).

Thirdly, it would appear from this section that a number of conceptual changes are required if pupils having alternate ideas are to move towards the accepted school-science ideas.

These changes are summarised below:

* from a continuous view of undissolved matter to a discontinuous one;
* from a 'continuous-piece' to a 'molecular particle' view;
* from a 'dissimilar particle' to a 'similar' view;
* from a 'random distribution' to a 'regularly repeating pattern of particles' view;
* from a 'non-bonded particle' to a 'bonded' view;
* from a 'static' to a 'dynamic vibrating' particle view.

9.5 Comparison of atomistic and non-atomistic ideas about dissolved and undissolved sugar.

To conclude this chapter we shall compare pupils' atomistic thinking about the solid and solution states of sugar. In order to do this we shall look first at the prevalence of responses in which pupils maintain that the same kind of inner constitution obtains in both states, (i.e. both states are continuous, or sugar exists as 'pieces' or 'molecules' in both states). Then we shall consider those cases in which sugar is thought to change its kind of aggregation on dissolving. The relevant data is summarised in Tables 9.6 and 9.7.

The most prevalent idea up to the tenth-year is that sugar exists as 'pieces' of (continuous) sugar in both states. That is dissolving is 'seen' as a loosening process in which parts that were previously together become separated in the water. This concurs with the lexical origin of the word dissolve, i.e. dis + solvere, meaning 'to loosen apart' (The Shorter Oxford English Dictionary, Volume I, p.578). After the tenth year the most prevalent category is the one where molecules are 'seen' to be the component units in both states. The continuous idea is the least popular and it diminishes with age, however, this observation applies to the sugar only. (As mentioned earlier continuous ideas about water are more prevalent and possibly more tenacious).

With regard to the responses in which the constitution of sugar is said to alter when it dissolves, the interview data suggests that the most prevalent idea is that continuous sugar becomes 'pieces' of sugar on dissolving.

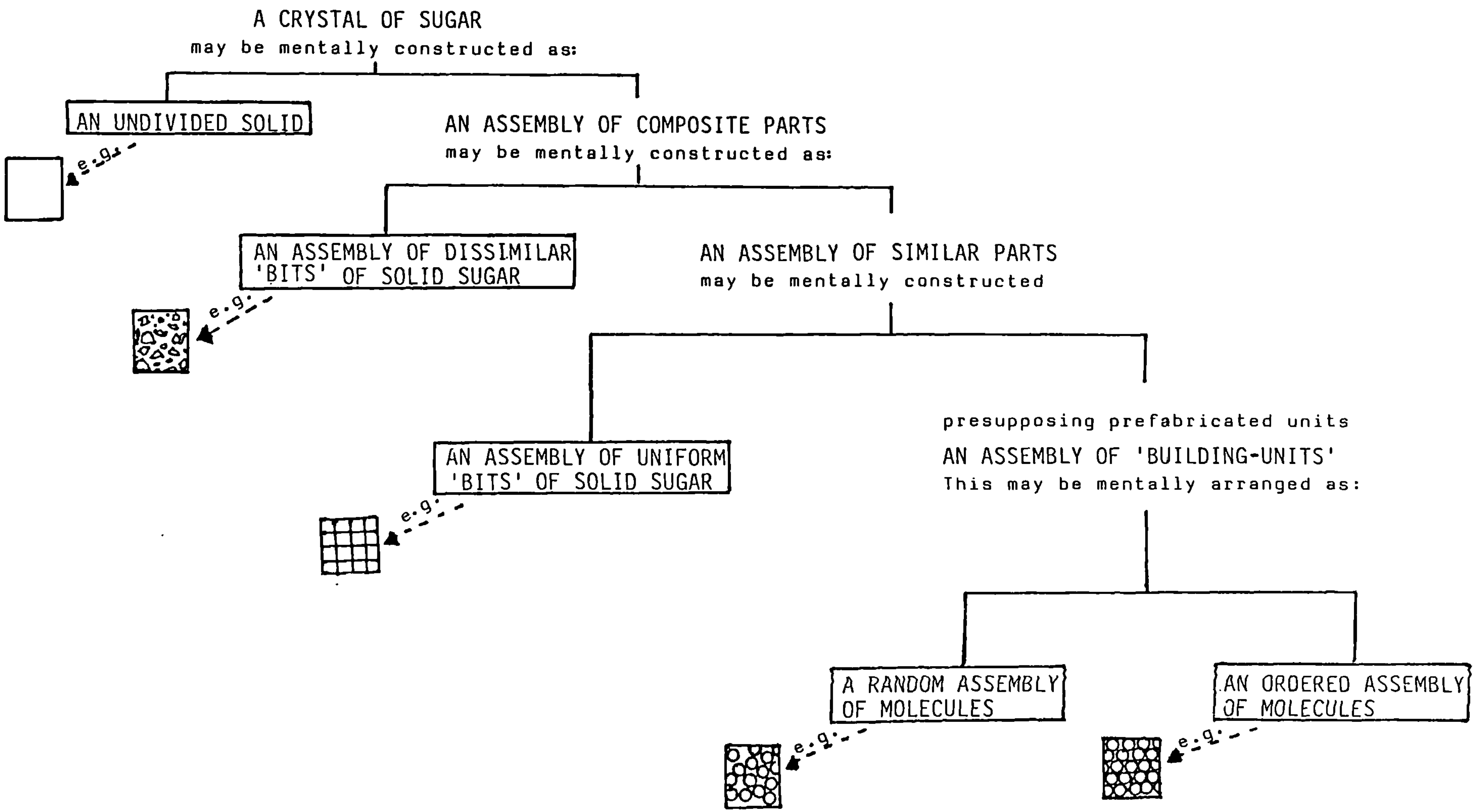


Fig. 9.6 Pupils' alternative constructions of the inner constitution of a sugar crystal.

Pupils giving this idea would appear to be governed by sense perceptions of a crystal but these are subsequently overcome by the idea that sugar must have 'broken up' in some way on mixing with water. The survey data implies that there are a small proportion of pupils who are of the opposite opinion. They start with a particulate view of solid sugar but then appear to be overcome by the perception of continuous sugar solution.

The survey data also suggests that smaller proportions hold that there are different states of aggregation of molecules in the two states. This occurs in later school-years and is probably due to residual conceptions of gross-particles from earlier years. Some hold that 'pieces' of solid sugar become 'molecules' in water, (i.e. they become smaller units) whereas others hold the opposite idea.

Although this comparison of atomistic ideas about the two states gives an awareness of some ideas held by children, quantitative estimation is difficult because of the number of nil responses - particularly among younger children.

TABLE 9.6 NUMBER OF INTERVIEWEES OFFERING SIMILAR OR DIFFERENT ATOMISTIC/NON-ATOMISTIC DEPICTIONS OF SOLID AND SOLUTION STATES

Atomistic conceptions of both undissolved and dissolved sugar	Year 3 n=18 no.	Year 5 n=18 no.	Year 7 n=18 no.	Year 10 n=18 no.	Year 12 n=18 no.
1. SAMENESS OF CONSTITUTION IN SOLID AND SOLUTION					
a. continuous in both	1	3	-	-	-
b. 'pieces' in both	9	8	8	1	1
c. 'molecules' in both	-	-	-	8	11
b. DIFFERENCE OF CONSTITUTION IN A SOLID AND SOLUTION					
a. continuous (solid) to 'pieces' (solution)	7	5	8	6	2
b. 'pieces' (solid) to continuous (solution)	-	-	-	-	-
c. 'pieces' (solid) to 'molecules' (soultion)	-	-	-	-	-
d. 'molecules' (solid) to 'pieces' (solution)	-	-	-	3	3
3. NO RESPONSE IN ONE OR BOTH STATES	1	2	2	-	1

TABLE 9.7 PERCENTAGE OF SURVEY PUPILS OFFERING SIMILAR OR DIFFERENT ATOMISTIC/NON-ATOMISTIC DEPICTIONS OF SOLID AND SOLUTION STATES

Atomistic conceptions of both undissolved and dissolved sugar	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
1. SAMENESS OF CONSTITUTION IN BOTH SOLID AND SOLUTION										
a. continuous in both	8	7	5	5	6	5	7	5	3	3
b. 'pieces' in both	29	26	46	43	56	44	61	40	18	21
c. 'molecules' in both	-	-	-	-	-	-	39	25	38	44
b. DIFFERENCE OF CONSTITUTION IN SOLID AND SOLUTION										
a. continuous (solid) to 'pieces' (solution)	8	7	16	15	18	13	17	11	1	1
b. 'pieces' (solid) to continuous (solution)	5	5	11	10	20	16	7	5	2	2
c. 'pieces' (solid) to 'molecules' (solution)	-	-	-	-	1	1	6	4	9	10
d. 'molecules' (solid) to 'pieces' (solution)	-	-	-	-	1	1	11	7	4	5
3. NO RESPONSE IN ONE OR BOTH STATES	62	55	31	29	25	19	6	4	11	11

CHAPTER 10

SUMMARY OF MAJOR FINDINGS

10.1 Introduction

Whereas in the previous four chapters detailed findings have been presented, this chapter is an attempt to summarise the main issues including those that arise from the literature survey and the theoretical stance taken.

After the introduction the chapter is divided into two parts that address the issues of conservation and atomism respectively. The first part is focussed on findings related to the conservation of substance, weight/mass and volume, the development of these constructs, and any relationships between them. Also included are some findings on what, if any, may be the relation of gender to the development of conservation ideas - another issue that arises in the literature. The second part of the chapter is a survey of the findings related to the possible development of atomism in children's thinking.

10.2 Summary of conservation findings

In the case of the classical conservation tasks used by the Piagetian school (involving liquids or plasticine) the idea of invariance may be built up by the use of the schemes such as qualitative identity, reversibility or covariation of properties. This cannot be so for the dissolving process, for in the latter case the object is no longer visible after its transformation. As a result, the tangibility of dissolved sugar has to be constructed in the mind and therefore the three schemes mentioned above are not applicable in terms of manipulations of a physical substance (though they may be applicable in terms of operations on a mental model). Before discussing 'conservation findings' in each of the three separate areas (substance, weight and volume), we shall take a brief overview of the conservation data for all three areas.

10.2.1 Overview of conservation data

The general trends in the proportions of conservers within their various year groups are shown in Table 10.1 and Figure 10.1. For the most part, the percentage of pupils who conserve either substance or the space-taken-up-by-it increases with year group. On the other hand the percentage of those who conserve weight shows U-shaped development (Strauss and Stavy, 1982) that is almost the reverse of the inverted

U-shaped development of continuous 'bits', see Figure 9.3. It should be borne in mind that, although many children will not have differentiated the concepts of weight and volume these findings are based on children's operational experience of 'weight' and 'volume' through the use of a balance and a measuring cylinder respectively.

The other overall feature of these data is the relative proportion of conservers of substance, weight and volume in any particular year group. There were more conservers of substance than of weight and in turn there were more conservers of weight than of volume.

TABLE 10.1 PERCENTAGES OF SURVEY PUPILS CONSERVING SUBSTANCE, WEIGHT/MASS AND VOLUME OF DISSOLVED SUGAR

Property (mentally) preserved	3rd-year n=112		5th-year n=109		7th-year n=127		10th-year n=154		12th-year n=86	
	no	%	no	%	no	%	no	%	no	%
a. Substance preserved (in diagram of solution task)	77	69	88	81	106	84	151	98	79	92
b. Weight/mass preserved (in balanced task)	73	65	54	50	68	54	108	70	63	73
c. Volume (overall) preserved (in displacement task)	31	28	39	37	64	50	74	48	53	62

10.2.2 Construction of the conservation of dissolved sugar substance

Object (sugar) permanence in this case has to do with the construction of some form of transparent sugar within a colourless environment. Piaget's work on object permanence suggests that this construct is the outcome of the child's co-ordination of experiential data from more than one source e.g. visual and tactual (von Glasersfeld,1974,p.8, Flavell,1963,p.109). Generally, the most commonly accepted evidence for tangibility is found in visual experience but when sugar dissolves it vanishes. Apart from a small change in the level of water, the only sensations available are sweetness and stickiness. None of the children in this study mentioned stickiness. Although sweetness was occasionally acknowledged, it was not always associated with substance - flavour was sometimes regarded as something separate from substance.

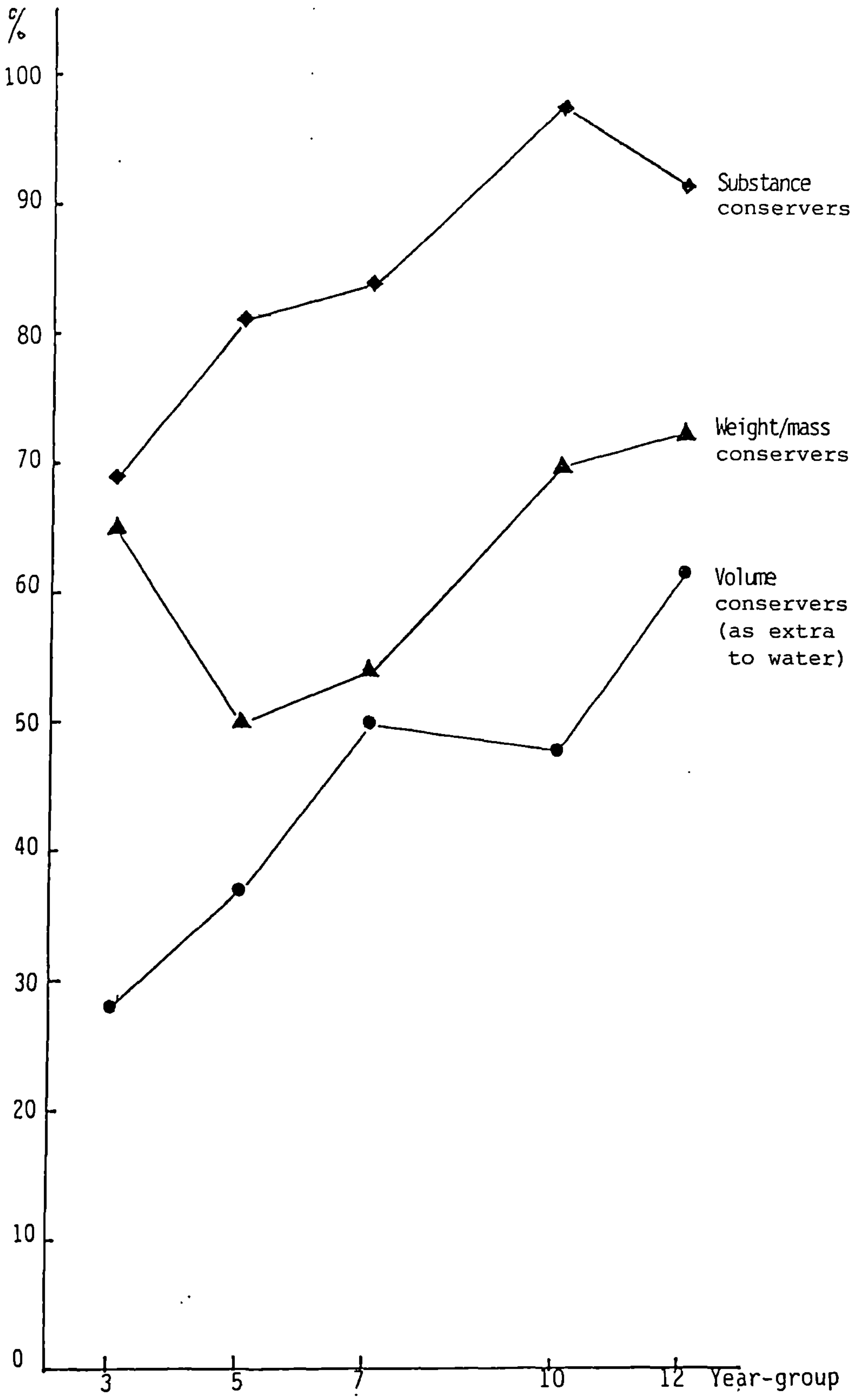


Fig. 10.1 Graph showing percentages of survey pupils conserving dissolved substance, its weight and the 'extra volume' it takes up.

With young children in particular, one could not always discern whether they were talking about sweetness-without-matter or sweet-matter.

In the researcher's view the most reliable guide to the possession of a conception of sugar-in-solution, was probably the drawing of (space occupying pictures of) 'bits' or 'molecules' of sugar in water.

Most of the pupils in the lower age groups and even some older ones depicted dissolved sugar near the bottom of the solution. This may be compared with a step in the early development of object permanence. Just as an infant carries on staring at the place where the object was last seen, so young children draw 'dissolved sugar' at the <u>bottom</u> of the container (where the last few granules disappeared). Intrigued by this response, the researcher surveyed much older children to check on the persistence, over school-years, of this view. He found that 30 out of 50 of the 14/15-year-olds held the idea that a solution of sugar would be sweeter near the bottom than the top, even after vigorous stirring with an electric mixer!

<u>The trend in the proportion of conservers of substance across successive year-groups</u>

Data, from the diagram task, illustrating the percentage of conservers of substance, are shown in Table 10.1. It was collected from Table 9.3 by combining the related categories. The table shows an overall increase in the proportion of conservers up to the tenth-school-year followed by a slight decrease. It will be noticed that the majority of pupils conserve substance (i.e. regard dissolved sugar as tangible matter) by the tenth-year. The proportion of conservers of substance exceeds that of the conservers of either weight or space-taken-up by dissolved sugar.

Pupils had different ways of picturing the dissolved sugar. Their 'pictures' ranged from a continuous blend of sugar and water, through to a suspension of drops of liquid sugar or particles of solid sugar, and finally, to 'molecules' of sugar. Figure 9.4 summarised the various representations of dissolved sugar. Figure 9.3 illustrated the prevalence of the main representations and how the construction of the school-science representation eventually overtakes the continuous 'bit' conception. The prevalence of the 'continuous bit' representation of sugar in Figure 9.3 has the shape of an inverted U. This could be interpreted as an initial growth in the intuitive/self-generated atomism followed by an increasing tendency to construct 'school-science-atomism'.

The trend in the proportion of conservers of substance across year-groups was investigated by applying the chi-square test. The data obtained is shown in Table 10.2.

TABLE 10.2 CHI-SQUARE VALUES FOR SUCCESSIVE YEAR-GROUPS OF CONSERVERS AND NON-CONSERVERS SUGAR SUBSTANCE

Successive year-groups	Chi-square	D.F.	Significance level
3rd year and 5th-year	0.11	1	0.743
5th year and 7th-year	0.64	1	0.425
7th year and 10th-year	5.52	1	0.018*
10th year and 12th-year	0.00	1	1.000
Over all year-groups	17.98	4	0.012*

* = $p < 0.05$

This 'overall' chi-square value is significant at the 1.2% level thus supporting the overall trend in the conservation of substance with year-group. The data in Table 10.2 suggests a significant difference between the proportions of seventh-year *and tenth-year pupils who* conserve or do not conserve, whereas there is no significant difference below or above this age group. This may be interpreted by suggesting that between these two year-groups the pupils' overall 'pictures' of matter[1] undergo considerable change - at this stage they are learning to construct molecular ideas at school. Also by the tenth-school year they have more experience with balances and, as a result, may have obtained some empirical evidence for conservation.

10.2.3 Construction of the conservation of weight/mass of dissolved sugar

Pupils who conserved weight either reasoned that the sugar was 'added weight' (i.e. they disregarded the transformation of the sugar), or they reasoned that because sugar substance had survived transformation its weight also was 'still there'. We may therefore question how it was that some pupils conserved sugar substance without conserving its weight, for it will be recalled that Table 10.1 showed substantially less weight-conservers than substance-conservers.

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1. See Figure 9.3.

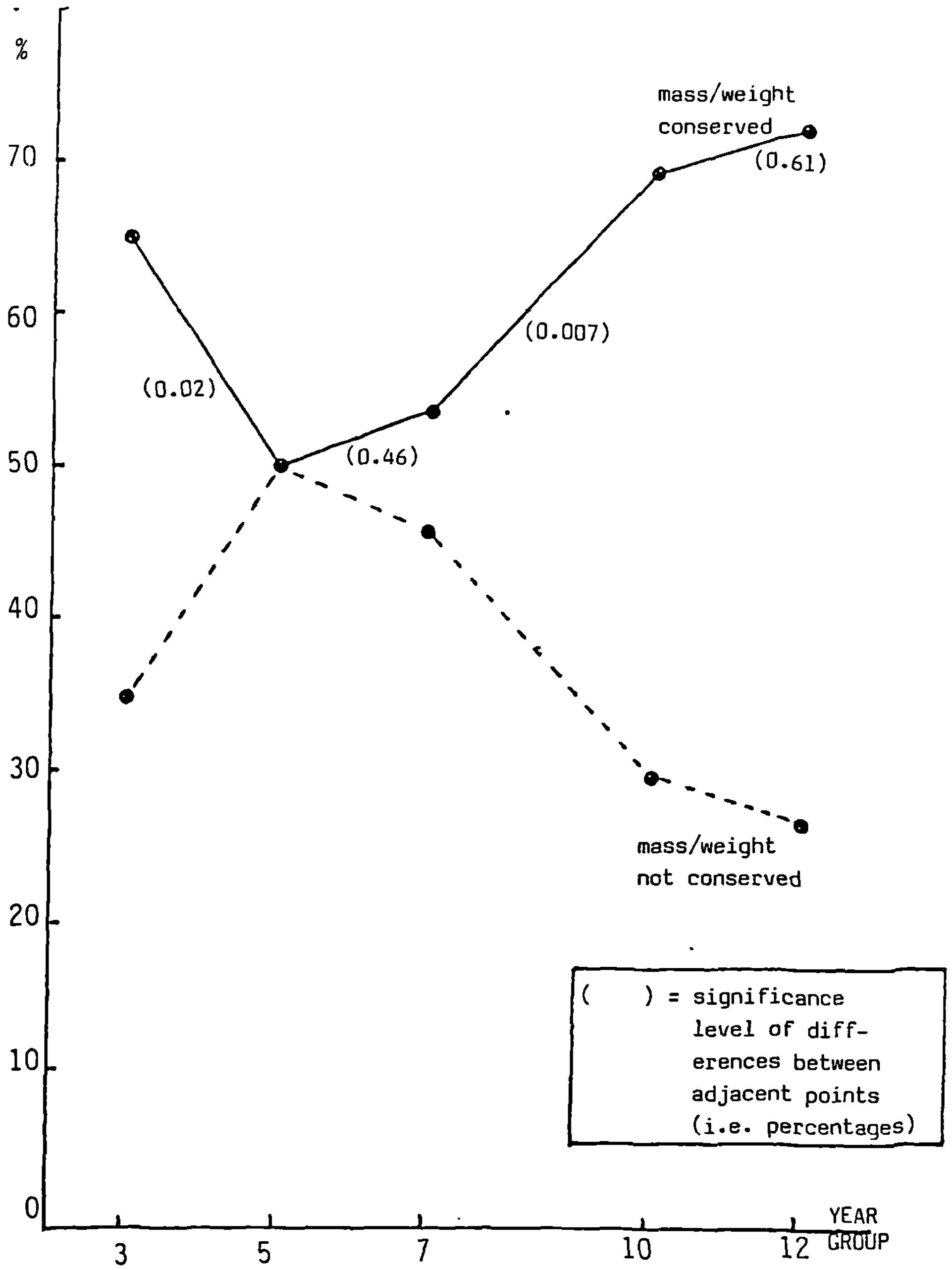

Fig.10.2 Graph showing percentage of survey pupils conserving or not conserving weight/mass; significant differences between year-groups included.

In Chapter 7, it was observed that pupils offered several reasons for predicting that dissolved sugar lost weight. One reason was associated with the change of physical state from solid to liquid; some pupils associated 'solidity' with greater heaviness than 'liquidity'. (Older pupils went on to explain that this was the result of increased intermolecular spacing in liquids - thus indirectly associating weight with a notion of 'density'). A second reason for weight loss was an imagined picture of sugar particles and their perceived distribution (i.e. a solid was thought to be sub-divided into smaller units and/or spread out). That being so, dissolved sugar was not regarded as being as effective as the solid form in 'pressing down' on a scale pan but rather was 'seen' to have its weight 'taken off', possibly due to buoyancy, in the water. A third reason arose from images of 'suspended', 'hidden' or 'evaporated' particles of sugar. These were not imagined to possess weight. In later years, however, weight was seen as an external gravitational force acting on all the components of the beaker. Thus, there were various reasons why it appeared to pupils that although 'substance' was conserved, 'weight/mass' was either partially conserved or not conserved.

To summarise, the factors that appear to interfere with the development of the conservation of weight are the different ways that individual pupils model matter (i.e. solutes and solvents in this context) and the different ways in which they understand weight 'action'.

The trend in the proportion of conservers of weight across successive year groups

The trend, reflected by the shape of the graph in Figure 10.2, is of particular interest because the proportion of weight-conservers appears to follow U-shaped development. In order to test the significance of an apparent association between the 'proportion of weight conservers' and the 'year-group', the null hypothesis was stated, 'that these two classifications are independent'. A 2x2 contingency table was set up for each pair of successive year-groups. Chi-square was calculated as shown in the Appendix 4.1.

A summary of the calculated values of chi-square and the corresponding significance levels are shown in Table 10.3.

TABLE 10.3 CHI-SQUARE VALUES FOR SUCCESSIVE YEAR-GROUPS OF WEIGHT/MASS CONSERVERS AND NON-CONSERVERS

Successive year-groups	Chi-square	D.F.	Significance level
3rd-year and 5th-year	5.50	1	0.020*
5th-year and 7th-year	0.35	1	0.460
7th-year and 10th-year	7.33	1	0.007*
10th-year and 12th-year	0.26	1	0.610
All year-groups	19.71	4	0.006*

* = $p < 0.05$

For one degree of freedom, a value of chi-square equal to or greater than 3.841 would be expected to occur by chance only five in one hundred times if the null hypothesis were true. In Table 10.3 the first and third pairs of year-groups, chi-square is greater than 3.841, so the null hypothesis may be rejected at the 5% level. In other words the proportion of third-year pupils who conserve is significantly different from the proportion of fifth-year pupils who conserve. A similar statement may be made about the seventh and tenth year-groups. On the other hand, there is no significant difference between the proportions of fifth-year and seventh-year pupils who conserve, and the same applies to the tenth and twelfth-year pupils.

Table 10.3 also shows that the value of chi-square (19.71) for a 5x2 contingency table containing all year groups is greater than the statistical table value (9.488 for D.F. = 4). This suggests the possibility of an overall association between the proportion of conservers and the school-year group.

The difference between the third and fifth school-year-groups may be inferred to be the outcome of the advent of the 'modelling-of-matter' factor referred to above. Below the fifth year-group there is little sign of modelling. At that stage pupils appeared to take the view that the sugar was put in and consequently was 'there'. However, from the fifth year onwards more imagination was evident in relation to the 'images' the pupils had of dissolved sugar. As we have shown the various models of 'substance' and 'dissolving' that they imagine seems to interfere with the quantification of weight/mass.

The difference between the seventh and tenth year-groups may be due to a change in the kind of model of substance (from 'continuous bit' to 'molecular particle') and, also, to a change in their view of weight (from internal 'pressing-down' to external 'gravitational attraction') among a proportion of the population surveyed.

10.2.4 Construction of the conservation of the space-taken-up by dissolved sugar

In this section we discuss how pupils appeared to construct the idea that dissolved sugar is a tangible substance which continues to take up space in water. As shown in Table 10.1, fewer pupils in all year-groups held this conception, than that of the conservation of substance and weight already considered. It would appear, therefore, that conservation of volume is the last of the three conceptions to develop.

It may be recalled that the eliciting task invited pupils to use the idea of a displacement-volume in an operational way. Pupils who conserved space taken-up by dissolved sugar regarded it either, as a weight that pushed the water upwards or, as an object that, in occupying space, pushed the water upwards. That is, they attributed to dissolved sugar the same ability (weight-push or bulk-push) as they had done to the crystalline sugar. It may be inferred that pupils were making use of 'action-schemes' previously constructed. Indeed, some seemed so predisposed to employ such 'schemes' that they predicted water would rise a second time (once when sugar is first added, then again when it dissolves) - not taking account of space vacated by the dissolved crystal. Conservers of dissolved volume who used the weight 'action-scheme' should probably be designated as 'pseudo-conservers' of volume since they did not use a conception of 'space-required'; their thinking was dominated by the 'weight-action'. Such 'weight-action-schemes' appeared to be most prevalent in the seventh school-year.

When pupils used the 'continuous bit' scheme about sugar, some regarded the volume of the 'bits' as additional to that of water. Others thought that the 'bits' fitted between 'bits' of water - in that case no overall change in volume was predicted but the space occupied by the 'bits' was conserved. (Relevant data is summarised in Table 8.4).

The idea that water is made up of molecules and interstitial spaces appeared to link in with pupils' prior schemes about the 'fate' of dissolved sugar. In their view, sugar had to fit into those spaces. Thus, they predicted no change in overall volume. This seemed to provide an answer to what had hitherto been a puzzle for them, namely a destination for disappearing sugar. The trend in higher year-groups was a growing realisation that sugar molecules would not 'fit in' as they were much too large - they just spread out among water molecules. This led to more predictions that the final volume would be greater than that of water alone.

The trend in the proportion of conservers of 'space taken up' across successive year groups

The data for this enquiry were shown in Table 10.1. As in the previous two sections a chi-square test for difference between the proportions of conservers in successive year groups was applied and the results are shown in Table 10.4.

TABLE 10.4 CHI-SQUARE VALUES FOR SUCCESSIVE YEAR-GROUPS OF VOLUME CONSERVERS AND NON-CONSERVERS

Successive year-groups	Chi-square	D.F.	Significance *level*
3rd year and 5th-year	0.51	1	0.477
5th-year and 7th-year	2.62	1	0.106
7th-year and 10th-year	0.77	1	0.381
10th-year and 12th-year	4.19	1	0.041*
Over all year groups	15.73	4	0.003*

* = $p < 0.05$

The 'overall' chi-square value is significant at the 0.3% level. This supports the possibility of an overall association of conservation of volume with year-group.

Data shown in Table 10.4 would suggest that, at the 5% level, there is no significant difference between the proportions of pupils in the specified successive year-groups that conserve overall volume. However, between the tenth and twelfth years, the proportions would appear to differ significantly. This difference may be partially attributed to a change in the model of the way sugar is 'seen' to be conserved. In the tenth-year-group there was a tendency to fit sugar molecules between water molecules with the result that no overall change in volume was predicted[1]. However, although this model continued among twelfth-year pupils more of them were aware that sugar particles were larger than water ones and therefore contributed to the overall volume. It is probable that pupils relate to this idea because it is analogous to their experience of packing objects. The other factors contributing to the 'significant difference' are less reliance on visual data and increased 'macroscopic conservation' in the twelfth-year (see Table 8.4).

A tenet of the science conception of 'conservation-of-space-occupied' by dissolved matter is not only that the molecules survive the transformation, but that they must be imagined to have electrical characteristics. That being so, molecules are assumed to enconter intermolecular forces, the strength of which, determines the final volume. Few pupils offered explanations in these terms. Instead, they used explanations based on simple addition of the component volumes or those based on intermolecular packing.

To summarise, it would appear that the quantification of volume, for any particular pupil, is partly a consequence of their model of dissolved substance and partly the result of their 'action schemes' about displacement. Children's early construction of displacement by dissolved substance differs from the adult idea of one substance taking the 'place' of another. Indeed children regarded the dissolved substance as though it was actively <u>making</u> a place for itself.

10.2.5 Comments on Piaget's integrated developmental sequence: conservation of substance, weight and volume

It may be recalled from the literature review (chapter 3) that Piaget suggested a developmental conservation sequence in the acquisition of conservations: first substance, then weight, and, finally, volume. Each invariant was considered to be integrated with preceding ones. As Chapters 7 and 8 have shown, some children do indeed justify conservation of weight by employing a 'permanence of substance' scheme and also conserve volume by employing a 'permanence of weight' scheme. Although about half of the conservers interviewed (in their third and

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1. This explanation has the same outcome as a sense-perceptually dominated one that pays attention solely to the vanishing crystal. Thus, in their view, this 'new' molecular theory would appear to be quite acceptable. Once their 'equilibrium' is disturbed by the relative molecular size factor, an 'accommodation' step can lead to an explanation that is consistent with known empirical data.

fifth school-years) offered justifications that support Piaget's sequence, the other half justified conservation of volume by stating that substance was conserved (that is, it needed 'room' or 'space'). Moreover, the 'permanent weight' justification for displacement almost disappeared with advancing school-years. It could be that Piaget's sequence would be wholely followed by an age group younger than that investigated in this study. It could also be that, with advancing years, the development of a 'substance displacement' scheme makes the 'weight-push' scheme redundant with the result that the sequence is not followed through.

To summarise the relevant findings, in the first place it may be suggested that conservation of substance can, but not necessarily, underlie the conservation of both weight and of volume. It would seem that permanence of substance does not always lead to these further conservations because other schemes may interfere - schemes about the inner constitution of matter, about 'weight', the 'weight of perceived constituents', about 'volume', and 'the volume of perceived constituents'. Second, the conservation of weight sometimes, but not always, leads to the conservation of volume. Lack of conservation may arise because, the perceived image of a dissolving (disappearing) bulk volume dominates thinking. Third, some older pupils inverted the weight-volume sequence by predicting conservation of weight from an expected conservation of bulk volume. In sum then, Piaget's hypothesised conservation sequence may be supported by some younger children's responses but not by all of them; also, the sequence may be abridged or changed by the co-ordination of an increasing array of perceptual and conceptual schemes through advancing school-years.

10.2.6 Gender differences and conservation task responses

It may be recalled that in the literature survey (Chapter 3), Beard noticed a gender difference in ability to conserve dissolved salt.

As Tables 10.5, 10.6, and 10.7 show, the main gender difference appears in pupils' responses to the weight/mass task in both the tenth and twelfth year-groups. In these two year-groups there is a significant gender difference at the 5% level. In addition there is a difference in the overall conservation trend through the year-groups shown in Figure 10.3. The trend for both sexes is U-shaped, but the

'U' for girls shows a broader base than the boys. This indicates a somewhat slower tendency to loose bulk conservation of weight/mass in the early years, followed by a slower recovery of ability to reconstruct conservation based on 'bits' in later years. Nielsen and Thomsen (1983) found a significant gender difference in Danish pupils' performance on a weight task related to the dissolving of sugar in water. In their study fewer girls in the eighth, ninth and later school-years (in the latter case when studying advanced mathematics and physics) conserve dissolved sugar.

Little significant gender difference is shown in the proportion of conservers of either sugar substance (apart from the fifth school-year) or of the space occupied by dissolved sugar. However, it is noticeable in the latter case that, apart from the fifth-year, fewer girls conserved the volume of dissolved sugar (see Figure 10.4). It may be recalled from chapter three, that Beard (1962) noticed a similar gender difference in a volume-of-dissolved-salt task.

TABLE 10.5 CHI-SQUARE VALUES FOR WEIGHT/MASS CONSERVATION BY GENDER

Year group	Percentage of boys	Percentage of girls	Chi-square	D.F.	Significance level
3	66	65	0.00	1	0.00
5	46	53	0.23	1	0.63
7	58	50	0.42	1	0.52
10	79	60	5.57	1	0.02*
12	84	63	3.80	1	0.05*

* = p < 0.05

TABLE 10.6 CHI-SQUARE VALUES FOR SUBSTANCE CONSERVATION BY GENDER

Year group	Percentage of boys	Percentage of girls	Chi-square	D.F.	Significance level
3	94	87	0.58	1	0.45
5	78	98	7.67	1	0.01*
7	91	94	0.05	1	0.81
10	99	99	0.00	1	1.00
12	100	98	0.00	1	1.00

* = p < 0.05

TABLE 10.7 CHI-SQUARE VALUES FOR VOLUME CONSERVATION BY GENDER

Year group	Percentage of boys	Percentage of girls	Chi-square	D.F.	Significance level
3	45	25	2.74	1	0.10
5	38	49	0.77	1	0.37
7	62	46	2.37	1	0.12
10	53	45	0.54	1	0.46
12	67	61	0.60	1	0.76

Although the underlying reasons for gender difference needs more thorough research, the overall nature of the justification responses suggests that:

* more girls than boys asserted that weight was lost (i.e. not 'seen' to be pressing down on the scales).
* more girls than boys stated that sugar was not 'there' after dissolution.

The comparative proportions by gender are illustrated in Table 10.8.

TABLE 10.8 GENDER DIFFERENCES IN REASONS OFFERED FOR NOT CONSERVING WEIGHT/MASS

Year group		3	5	7	10	12
Percentage pupils who justify by asserting loss of weight.	Boys	5	20	19	14	7
	Girls	10	23	19	21	21
Percentage pupils who justify by suggesting sugar is not 'there'	Boys	14	29	21	1	2
	Girls	15	19	23	15	7

Note. These represent the greatest differences. For the whole range of reasons offered see Appendix 4.2

We may conclude that, overall, girls need more learning experiences that are likely to assist them escape from what Gold(1987) has called 'perceptual seduction'[1]. Pupils may be assisted to understand that they have interpreted the disappearance of the sugar as the dominant feature (i.e. the seduction was self-induced) and that they can employ a 'search-scheme' ('it was put in, where could it be?'). Then check-out properties such as weight, volume, etc.

10.3 Summary of findings on the generation of atomism

As the literature survey showed, children's ability to generate atomistic ideas about matter has been a contentious issue since Piaget (1941) hypothesised a 'gradual and spontaneous elaboration of atomism' (p.viii) in childhood. We shall now compare the responses to four tasks in each of which pupils had an opportunity to express atomistic ideas.

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1. A graphic description, but not a constructivist one. Gold (1987,p.33) chose this terminology because "it does seem to convey... something that is 'done to her' by the environment". It would appear that Gold himself has been seduced by a common-sense view of a direct interaction between the child and the (external) environment. He continues 'The error reflects the environment's 'intrusion' on the child, its disturbance of the child, through its presentation of a perceptual cue that is misleading'.

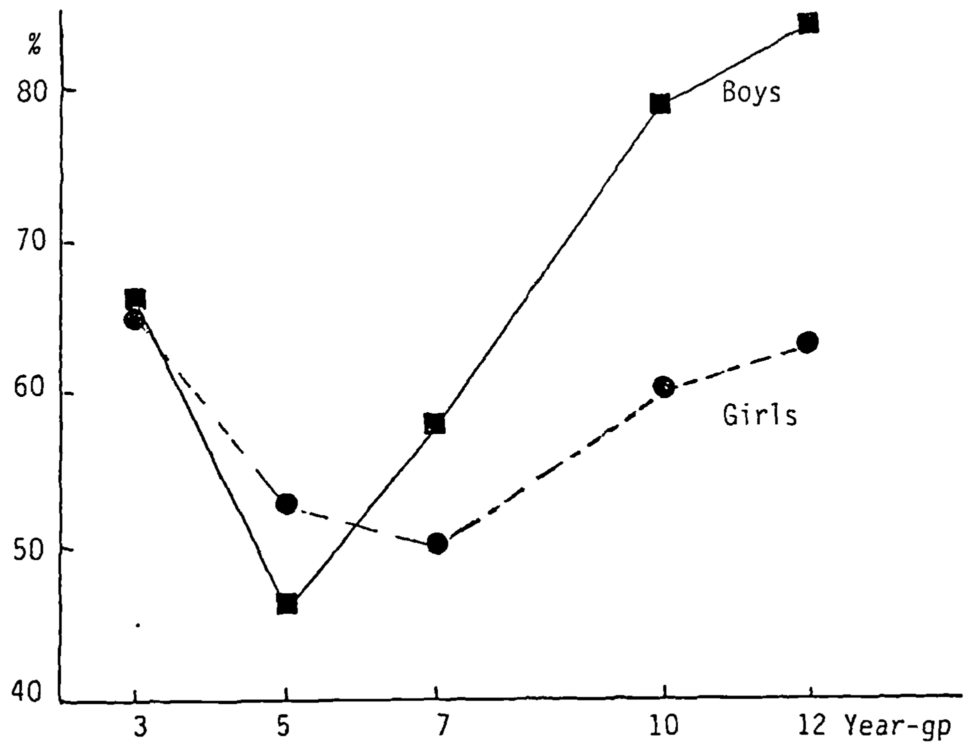

Fig. 10.3 Graph showing gender differences in <u>weight/mass</u> conservation task.

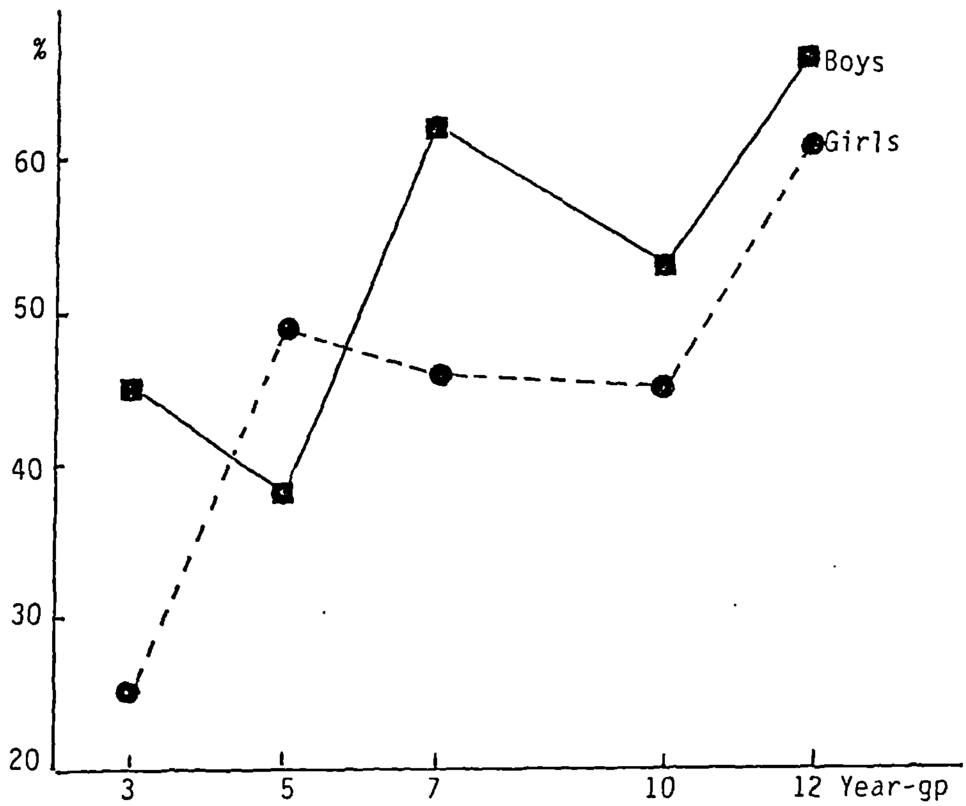

Fig. 10.4 Graph showing gender differences in <u>volume</u> conservation task.

10.3.1 Overview of atomistic ideas in four contexts

The evidence from this study, outlined in Chapters 6-9, suggests that a proportion of children do indeed generate a kind of atomism that the researcher has designated 'continuous-bit' atomism before they are taught formal atomic theory. It was noticed that the proportion of children who expressed this idea depended very much on the situational (i.e. task) context in which they offered their ideas.

'Continuous bit' atomism appears to be mentally modelled from 'broken-down' parts of the original material; usually the parts are regarded as heteromorphic. Occasionally, however, the parts are regarded as small replicas of the whole.

In this study, children's atomistic ideas were explored in four situational contexts related to dissolution. The context in which pupils showed the least tendency to express atomistic ideas was that of weighing dissolved material. The relative proportions of pupils making their atomistic ideas explicit in each of the four contexts is shown in Table 10.9. Not until the seventh school-year did any child overtly link the permanence of weight/mass with a perceived atomistic constitution. After this the proportion increased to 12% by the twelfth year. Since the scientists' construction of the permanence of matter is closely related to the atomistic construct, this evidence about children's ideas has important implications for teaching.

A somewhat larger proportion (about three times as many) used atomistic ideas to explain volume changes on dissolution. Again these were found in the seventh to twelfth years only, reaching a maximum of 33% in the twelfth year. Thus, it would seem that pupils more readily construct a relationship between atomistic parts and space-taken-up than they do between atomistic parts and weight.

TABLE 10.9 PERCENTAGE OF SURVEY PUPILS SPONTANEOUSLY OFFERING ATOMISTIC IDEAS IN THE VARIOUS EXPLANATION TASKS

Contexts in which atomistic ideas were made explicit	Year 3 n=112 no.	%	Year 5 n=109 no.	%	Year 7 n=127 no.	%	Year 10 n=154 no.	%	Year 12 n=86 no.	%
a. Explaining why dissolved sugar could not be seen. (See Table 6.3, categories: a.,b. & c.)	8	7	8	7	9	7	53	34	30	35
b. Explaining prediction about weight/mass of dissolved sugar (See Table 7.4, cat: f. and Table 7.5, cat: c.)	-	-	-	-	1	1	10	7	10	12
c. Explaining prediction about space taken up by dissolved sugar (See Table 8.4, - first part of each cat: a. b.,c., & d.)	-	-	-	-	3	2	40	26	28	33
d. Depicting the inner construction of sugar solution. (See Table 9.3 cats: b. & c.)	65	58	75	69	86	68	138	89	74	86

Section 'a' of Table 10.9 indicates that some pupils in all year-groups constructed ideas about particles when asked to speculate the invisibility of dissolved sugar. They had a view that either the sugar had 'broken-down' to small particles or that sugar crystals had 'worn down'. In both cases the resulting 'particles' were regarded as too small for the eye to see. The proportion of children who suggested this idea increased markedly in the tenth year, by a factor of five.

In contrast to the relatively small proportions of pupils who generated atomistic ideas in the contexts already mentioned, a much greater proportion (of each year-group) offered atomistic ideas when asked to imagine the constitution of dissolved sugar. They revealed a range of atomistic ideas that has been summarised in chapter nine, see, for example, Figure 9.3.

The considerable variation, with task, in the number of pupils that expressed the idea that matter was composed of constituent parts could suggest that the context influences the use of atomistic schemes. Clearly, pupils do not lack the imagination to construct atomistic parts but they do appear to have difficulty in relating those imagined parts to substance properties. The possibility of assisting children to make such constructions constitutes a challenge for the teacher.

With this in mind, some of the associated conceptual problems are presented in the next section.

10.3.2 Summary of the problems associated with the generation of atomistic ideas about solutions

Perceptual bondage

Between 15% and 20% of children below the tenth school-year did not offer atomistic ideas and may be presumed to hold a continuous view of matter. In their words they regarded solutions as 'plain' or 'clear'. Such responses suggest that they were bound by their perceptions of the appearance of a solution.

Size/weight correlation

The few pupils who had constructed the idea that small invisible particles of sugar were present in a solution tended to regard these 'bits' as 'too small to possess weight' or else they thought that the 'bits' had lost weight in some other way. The problem seems to be that the child has no way of telling how far the dissolution into smaller and smaller particles proceeds. As pupils learn more about micro-organisms they develop a greater appreciation of minuteness; they also correlate this minuteness with extremely small weight and volume. Consequently, it would appear to them that minute particles have no weight or volume worth consideration. Even though they may be persuaded that each small part is a little portion of the whole and so possesses a little portion of the weight, they do not appear to be convinced that these dispersed 'weights' have any 'pressing down' effect. So although Piaget suggests that conservation of weight may be constructed by a reversible operation, the child's scheme that relates the weight of minute particles to pressure may still interfere.

'Homogeneity' versus gravity and visual perceptions

The slow development of the concept of homogeneity of solutions may,to some extent, be due to the tenacity of a particulate suspension/settling out model of sugar in water. The view that sugar is 'heavier' than water seems to be maintained when sugar is dissolved in water. Consequently, it is widely held that there is a greater concentration of sugar near the bottom of a solution than there is at the top. Furthermore, since there is no observable mixing or movement in a solution, a static model is fostered. Even the pupils who are convinced that a solution is homogeneous do not invent a kinetic model. They construct static models based on ideas about water either supporting, trapping, or hiding sugar molecules.

Atomistic pictures or images of solvents, solutes and solutions

Pupils construct a range of images about the spacing of particles and the relative sizes of sugar and water molecules in a solution. This is partly due to textbook presentations of models of solutions that differ considerably in the amount of space given to particles and their environment. Furthermore, some pupils have the idea that sugar particles must exactly fit into spaces between water molecules. This again is part of the static picture that pupils have of solutions.

In sum the construction of science atomism appears to be beset with many hindrances such as: domination by immediate sense perceptions, difficulties in relating properties of parts to those of the whole, the retention of early representations, non-reversible thinking, static modelling of particles, and disproportionate images of particles and spaces.

10.3.3 Comments on Piaget's hypothesised spontaneous development of atomism

In the literature survey, it was mentioned that Piaget hypothesised a 'gradual and spontaneous development of atomism' and, furthermore, that he regarded atomism as the 'instrument of conservation'. The discussion in the previous sections (10.3.1 and 10.3.2) of this chapter would support the spontaneous development of atomism (by a major proportion of the population) in the context of imagining the constitution of solution or of a solid solute. The proportion of 'spontaneous atomists' decreases considerably in the 'volume' and especially the 'weight' context, possibly because the subtlties of these properties (weight and volume) are rather difficult to attribute to their models of 'atoms'. Furthermore, it is important to emphasise that the atomism which develops spontaneously is a 'continuous-bit' atomism in which the parts are seen as broken down from the whole and as having similar properties to the substance itself. The distinction between this view and that of 'scientific' atomism is very important from the point of view of science instruction.

It would appear to remain an open question as to whether atomism is an instrument of conservation or not, particularly in the early school years. Part of the reason for this uncertainty is that children are unable to verbalise all they think about this matter. Pupils may have underlying atomistic thoughts about dissolving matter that are not expressed. There was very little spontaneous verbalisation of atomistic ideas in the weight task and it does seem that the majority have other ways of conserving bulk weight/mass. Indeed, as has been shown in Chapter 7, atomistic ideas alone can lead to non-conservation outcomes. If all that is involved in conservation thinking is reversible reasoning about the part-whole relationship between 'bulk' and 'bits', then atomism could well be designated the 'instrument of conservation'. However, as this study has shown, pupils have several models of matter, and of matter dissolving, that may interact with more than one view of weight. Moreover, children have different ways of 'seeing' water (e.g. as continuous, as porous, as particulate and so forth) - a point that Piaget does not appear to consider. Consequently, pupils' cognitive processes would appear to be more complex and wide ranging than Piaget's atomistic hypothesis would suggest.

CHAPTER 11

IMPLICATIONS

11.1 Introduction

Previous chapters have delineated children's understandings of 'dissolving' and offered some insight into ways in which they 'see' matter, construct conservation and generate atomistic ideas. Differences, in these aspects of cognition, between children in the age range 7-17 years have been examined. The purpose of this chapter is to review the implications of these findings for classroom practice and the science curriculum. Some comments on the psychology of cognition are also made and implications for further research are suggested.

11.2 Implications for teaching

The many-faceted responses to the eliciting tasks, indicate pupils' considerable interest and involvement in the types of tasks presented. Furthermore, as Chapters 5-9 have shown, pupils' construction of knowledge has some similarities with the development of these ideas in science itself.

Implications for classroom practice arise from one aspect of a teacher's role, namely, assisting pupils to move their thinking from 'where-they-are' towards school science ideas. This study has attempted to document 'where-they-are' as a necessary precursor to devising 'next-step' teaching and learning strategies. Some suggestions for such 'next-step' strategies are outlined here.

First, pupil's awareness that knowledge about solutions has to be constructed, may be initiated by having them pay close attention to a dissolving crystal. This can help them appreciate that it is not possible, except in imagination, to get inside a liquid and see what 'really' happens. Subsequently, as they become aware of different ways that other pupils interpret the change in state of dissolved matter, they may appreciate that these differences are not to be found in the phenomenon itself but in the minds of the 'observers'.

Then they may be asked to reflect upon how their individual ideas/descriptions emerged. By focusing on their own words such as 'sugar melting', 'sugar breaking up', 'water soaking into sugar' and the like, they may hypothesise that knowledge is built from their previous knowledge and experiences.

Second, a classroom ethos supportive of such knowledge construction may be worth consideration. The re-construction of ideas, in particular, makes high demands on the 'person': distrust of the appearance of things, decentration from one's own perspectives, a shift from the concrete to the abstract and so on. Such potentially threatening situations, need the support of an accepting, encouraging and gently challenging attitude on the part of the teacher and other pupils. Class members may need to be assisted to understand that in knowledge construction just as in toy model building initial inappropriate connections are frequently made. Some initial inapposite links between new perceptions and prior ideas, that eager children express, can easily arouse teacher scorn and classroom ridicule. For instance, a child may incur the derision of a teacher or pupils if he suggests that dissolved sugar is weightless, although he has some 'logical' reason for thinking that way. Such effects may be minimised by anticipatory strategies on the part of the teacher who can encourage pupils by referring to 'common-sense' constructions made by famous scientists mentioned in Chapter 5.

Third, given a supportive classroom climate, teacher-devised tasks may be provided with at least two aims in view. One is to inform both teacher and pupils about the knowledge that class-members have already constructed. (This is necessary because human beings are not always aware of the knowledge they have generated about some object, event or process). For instance, in the context of solutions, pupils may not be aware of their notions of homogeneity or heterogeneity of distribution of solute until they are given an eliciting task. They could, for example, be asked to make predictions about the relative 'saltiness' of samples taken from different regions of a salt solution. The findings of this study would suggest that a range of notions, about the distribution[1] of dissolved salt, may be disclosed.

The other aim is to enlarge pupils' experience so that they may call into question existing ideas and, possibly, produce inferences that direct them towards science ideas. To continue the example of conceptions about the distribution of a solute, the task of measuring the 'saltiness' or concentration of salt, in samples from different

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1. The slow development of a conception of homogeneity of solution was illustrated in section 9.3.4.4 - passim.

regions of a solution could be undertaken. (This task may be elaborated by having different groups devise different methods). Finally, the significance of the results may be discussed.

Fourth, group discussion may be used to provide opportunities to focus on the degree of consistency between current knowledge and experience (or experiment). This gives pupils direct experience of 'scientific' theory making. As philosophers of science have pointed out, scientific theories survive or perish partly on the matter of consistency with ostensive data. Likewise, pupils may explore the 'explanatory power' of their theories. In the area of solution science there are many potential opportunities to raise the question of consistency between perceptions and conceptions or between one conception and another and so 'do what scientists do'. For example, pupils could discuss whether a perceived diminished volume, after dissolution, is consistent with the idea of permanence of dissolved matter. Also, they could discuss whether there is a contradiction between a perceived homogeneity of sweetness of 'Cola' and the idea of a gravitational force on the dissolved sugar present. Again, they could discuss whether the perception of bulk matter being subdivided into smaller and smaller particles applies to the weight of the dissolved particles, and whether this idea is reversible. Such discussions may assist pupils to construct knowledge socially as well as individually.

The general character and outcomes of implementing this style of teaching have been well summarised by Steffe and Cobb (1984):

> In those cases where adult teaching is in harmony with the child's methods, the generative power of the child is extremely exciting and unchartered. Ultimately, the methods the child generates undergo developmental change toward methods that are compatible with the social group in which the child operates. Knowledge of these methods and their developmental progress can provide powerful guidelines to the educator whose aim it is to foster that development. (p.26)

11.3 Proposals for science curriculum design

Implications for the curriculum arise from a view that in moving children's thinking from 'where-they-are' to 'where-school-science-is', a sequential series of experiences may be devised that is consistent with researched 'natural' conceptual development. Such experiences could also include adequate conditions for establishing new knowledge.

The summaries at the end chapters 6,7,8 and 9 indicate that children's knowledge of solutions is frequently quite different from and, indeed, sometimes contradicts that which is set down in the school science curriculum. However, the latter does not usually take account of a possibility that children 'see' the world differently and possess their own ideas, many of which persist for a considerable time. Instead, the science curriculum generally comprises objectives that present the world as 'seen' by physicists, or by chemists, or by biologists. This implies that children are expected just to accept this 'science' package, in spite of its long history of development via the changing constructs of scientists. If, in addition, the curriculum is taught by someone who exclusively 'sees' the world as a physicist, chemist or biologist, and who focusses solely on the 'objectives' (i.e. scientists' constructs) then pupils are unlikely to bridge the lacuna that research into children's understanding has revealed.

Implementation of a constructivist curriculum may take account, not only of the world as seen by scientists, but also the world as seen by pupils. A constructivist curriculum reflects the view that knowledge, packaged by scientists, may contain 'elements' and 'structures' that, initially, have no counterpart in children's thinking. That being so, considerable mental construction and hence time is required to construct these 'elements' and the relationships between them.

In view of these considerations, a curriculum which encourages the personal construction of knowledge about matter and 'dissolving' in particular might have the following general characteristics:

* shows an awareness of children's constructions of solution phenomena (reported in research) and identifies their salient characteristics;
* provides curriculum materials that, in the first place, elicit children's ways of 'seeing' various aspects of matter and dissolving and, in the second place, enable children to see the inadequacy of existing ideas in accounting for their perceived experiences;
* selects, as subjects for study, substances, phenomena and processes that are relevant to daily-life experience of children;

* aims both to promote small shifts in theory change and give pupils the opportunity to review the implications of each shift;
* encourages social interaction (pupil-pupil and teacher-pupil) that develops linguistic skills and laboratory manipulative techniques.

Each of these proposals will now be considered in turn. First, taking account of children's prior constructions can be useful because it gives teachers an opportunity to 'see' solution phenomena from the child's viewpoint. Also, it enables them to reflect the width of the lacuna between a child's ideas and science ideas, and, subsequently, to consider ways of reducing it. For example, some pupils regard the weight of a heap of undissolved sugar as 'pressing-down' on a balance pan. But, when it has dissolved, they may imagine sugar to be widely distributed particles, with the result that, from their viewpoint, the original pressure is removed. In their words 'the weight is taken off'. Such ideas suggest that the children in question hold a different view of weight from the science view. A considerable act of decentration is required on their part to change their 'weight-is-a-heap-pressing-down' view. Such eventualities, together with strategies, time and effort required to facilitate conceptual change, are rarely mentioned in science curricula.

Second, it follows from our discussion of the first implication, that curriculum materials which are effective in eliciting children's conceptions of solutions, may be useful. As has been shown in the previous section this is how children may become aware, not only of their own ideas, but also, of those of others. Thus, idea sharing can assist in 'decentration development' as pupils attempt to understand the points of view taken by other children.

Additional curriculum materials are required to extend the range of pupils' experience. These may be used to trial their ideas in new contexts, appraise their applicability and, as necessary, understand the need to re-construct their ideas. In solution science this entails the investigation of a wider range of solvents and solutes together with a study of further properties of solutions. That is, curriculum materials would aim to encourage the development of more coherent and widely applicable conceptions and theories i.e. in the way that scientists attempt to proceed.

Third, the relevance of curriculum topics and materials to daily life experience is of some consequence because knowledge construction in science need not be regarded as restricted to school and laboratory. Familiar materials may be a motivating factor for encouraging inquiry, but their use is also important in avoiding a divorce between pupils' prior ideas (embedded in daily life experiences) and their 'school science ideas'. Children's investigations of solutions may be focussed on familiar materials and processes found in the kitchen, garage and garden-shed.

Fourth, a constructivist curriculum may aim to promote small manageable steps in conceptual change. Current practice, on the other hand, often tends to impose 'revolutionary' steps too rapidly. For example, there is a tendency to impose molecular ideas about solutions without any prior attempt to assist children to move towards this idea in small steps. A consequence of precipitating such a sudden and broad discontinuity between their ideas and science ones may be an immediate disbelief because their perceptions may still support a continuous view of both liquids and crystalline solids. As Hebb (1975) wrote:

> The world science deals with, what by common agreement we regard as the real world, is nevertheless not directly known in some of its most important aspects. The "real world" is a construct, <u>and some of the *peculiarities of scientific thought* become more intelligable when this fact is recognised.</u> (p.9).

For example, one sixteen-year-old, on seeing a ball and stick model of salt said, "if that is salt, I'll eat my hat". It appears that he had been encouraged to regard models as a 'replica' of reality rather than one way of seeing it. It would seem that if this pupil had been acquainted with the approach to science conceptions encapsulated in the inderlined phrase (in the quotation) above, and his path towards science theory had been gradual, then a better understanding would have ensued.

As an example of gradual 'natural' development of ideas consider the findings from children's drawings of the internal composition of a solution or of a crystalline solid. A large proportion of younger children invent a picture of small dispersed 'bits' having irregular or unknown shapes. This may be regarded as a first small step towards atomic theory for, with increasing year-group, the following trends in 'pictures of dissolved sugar' were noted:

irregularly shaped dissimilar bits/drops	-->	regularly shaped similar bits/drops	-->	regularly shaped similar particles

It is suggested that pupils would construct an atomistic constitution of matter more readily if the 'natural' trend of their imaginative pictures is followed. Such drawings can betray underlying ideas and act as a springboard for curriculum design. It is further suggested that, before formal teaching, pupils' atomistic pictures appear to be the result of a breaking down process. That being assumed, they may be asked to discuss, as a possibility, a notion of the 'reverse process' i.e. building up matter, particularly after they have observed empirical evidence for 'recrystallisation'[1]. Then, it may be appropriate to consider the nature of the 'parts', how they might be held together, the nature of the spaces between the parts and so on.

Furthermore, it may be important that pupils be given time to re-visit their thinking about substance properties (weight, volume, density etc) in the light of each step of theory change. When, for example, the change from 'a-continuous-whole' to 'continuous-bits' has been constructed it may be helpful to review their ideas about the weight and volume of those 'bits', both as units and as an assembled whole. Such an approach adds up to a 'spiral' or 'overlay' curriculum in which properties of matter are revisited in the following series of conceptual steps:

continuous matter -----> continuous 'bits' -----> molecular particles ------> polar molecular particles

It should not be implied that these 'steps' are sharply defined or that each pupil 'passes through' all of them. However, it may be profitable to discuss the merits and demerits of these alternative models.

Figure 11.1 illustrates in outline a suggested approach to a segment of a curriculum related to aspects of dissolution. It is based around a number of pupil activities: describing and interpreting experiences (verbally or by drawings) then subsequently revisiting those experiences and reinterpreting them in terms of further models of matter having greater explanatory power. Pupils may enter the

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1. The researcher has noticed that tenth-year pupils frequently ask whether the same recrystallised substance may be recrystallised again. Thus it would seem important for them to have this experience and thereby be assisted to construct permanence of substance along with atomistic modelling.

curriculum with various models so a necessary procedure is to elicit their 'model' by requesting a drawing of the inner constitution of a solution and then have them 'work out' the implications this has for a solute's weight, volume, or whatever other properties are considered worth investigating. (As has been pointed out the major difficulty for pupils is not imagining a model but relating their imagined model to bulk properties of substances.)

Fifth, the development of both an adequate language to differentiate science conceptions and acceptable techniques for performing science tasks, may be approached, by teachers and pupils, as a constructive activity also. Some teaching starts with a pre-packed assembly of words (i.e. a definition) and it often happens that some of the constituent words, intended to be explanatory, are meaningless to pupils or, alternatively, are interpreted inappropriately by them. Constructivist learning may evoke a desire to differentiate closely related ideas and hence a need for 'words' to communicate, as precisely as possible, their intended meanings. In contrast, it has been the custom to begin the study of solutions with definitions of solvent, solute, saturated solution, concentration, etc. without enquiring into what perceptions pupils have either about these concepts or about the meaning of key-words that constitute their definitions. It was noticeable that only a few pupils used these 'science' words in either their conversations with the researcher or in their writing.

Classroom discussions about physical phenomena and related explanatory theories, constitute one way of developing an adequate language to express science ideas. The language of science developed in the scientific community as its members attempted to re-organise their conceptions and theories in ways that led to mutual consensus (at least for a period) (Kuhn, 1962,p.158).

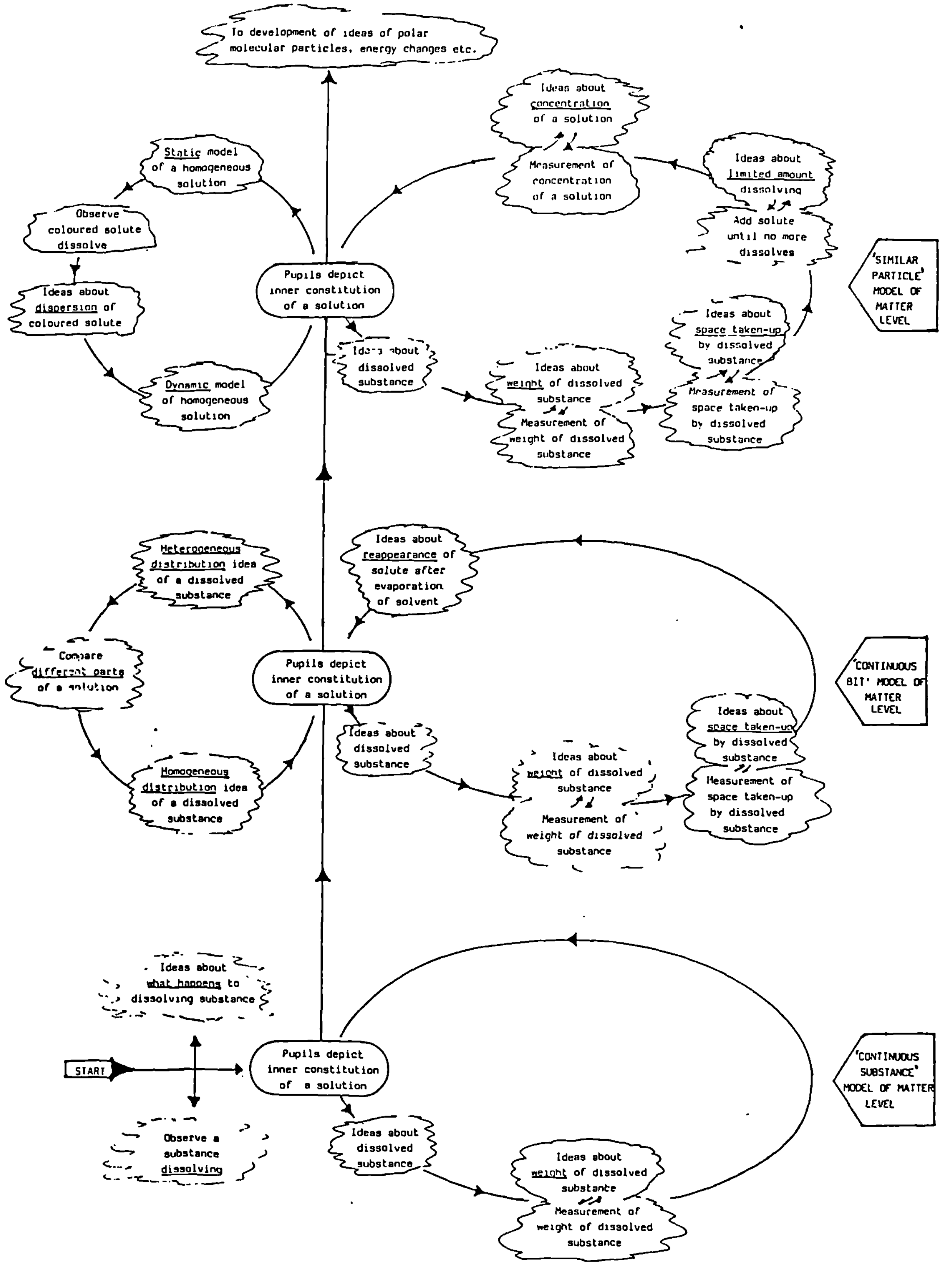


Fig. 11.1 Outline of 'overlay' curriculum that attempts to take account of changes in pupils' models of matter.

With regard to developing techniques for manipulating and investigating materials, in a constructivist way, these can be pupil-generated rather than teacher-given. Through discussion and experiment, the need for particular techniques may be made apparent - and hence more likely to be adopted by pupils. Inevitably, such approaches put time constraints on the curriculum, but the quality of experimental work and its interpretability may be improved.

11.4 Significance for a psychology of cognition

In so far as this inquiry endeavours to model ways in which children 'see' the world, its findings may have implications for cognitive psychology. For, as Kessen (1966) has advocated:

> the concern of a psychology of cognition is the relation between reality and man's representation of reality; the concern of a psychology of cognitive development is the way in which the child comes to know the world (p.55).

In previous chapters, ways in which children, over the greater part of their school life, 'come to know' that segment of the world regarded as the 'nature of matter' were characterised - using the dissolution process as a means to that end.

It has already been suggested that in the process of exploring, explaining and predicting their experiences of the world, children construct, elaborate and change their conceptual schemes. (This view of knowledge acquisition, taken in this study, has been outlined in Chapter 2 where, also, the relation between reality and man's representation of it was discussed.) As an outcome of the study findings, some tentative conjectures are now offered about possible 'raw material and processes' involved in children's knowledge construction. Also, some conjectures about the origin of diversity of different pupil's responses and perceived changes in their conceptual knowledge are proposed.

Conjectures about knowledge construction processes

It was apparent from the task-interviews that even the youngest pupils had assembled their own ideas about matter and its behaviour. Pupils' ideas about 'dissolving' could, frequently, be related to their physical actions and experiences in other contexts. It would appear that thought patterns developed through recurrent experiences, such as breaking things up (or down), wearing things down, hiding objects, trapping objects, dropping articles and the like, may have formed a basis for the conceptual schemes that pupils apply to various aspects of dissolving.

In addition it has been noted that pupils' responses contained personal conceptions of properties such as solidity, hardness, smoothness etc., as though they had been built up through their actions upon common substances. Such individual 'physical' conceptions, were used in many of the task explanations. Thus, in a number of ways this study supports Piaget's view that physical actions may provide the basis for the process of knowledge acquisition.

A further possible mode of pupils' knowledge construction was shown when they imagined the continuation of an observed process beyond the limits of visual perception. For instance, this appeared to happen when sugar crystals were perceived to become 'smaller and smaller'; they speculated that this process would continue beyond the threshold of visual resolution. It would appear that this was their way of explaining a change in physical state without positing a simultaneous loss of permanence (of substance). In some ways, such thinking resembles a science conception of permanence through change; that is, crystals are considered to be composed of (permanent) invisible particles which disperse in water. Such thought patterns show how human beings may construct permanence when limited sensory data is available: they may invent abstract entities and then attribute to them properties considered consistent with experience.

Conjectures about response diversity

Another aspect of the knowledge construction process may be represented as an interaction of sense perceptions of 'dissolving' with existing conceptual schemes. This model is illustrated diagrammatically in Figure 11.2. The left-hand column illustrates hypothesised interactions between a cluster of interrelated conceptual schemes and sense perceptions. (It should be understood that this is merely an outline model - for instance it does not indicate how existing conceptions may influence what is perceived.) The remaining columns show examples of 'items' from the clusters of schemes. These examples were inferred from an interview, with Adr, that is reproduced in Appendix 3.2.1(Adr).

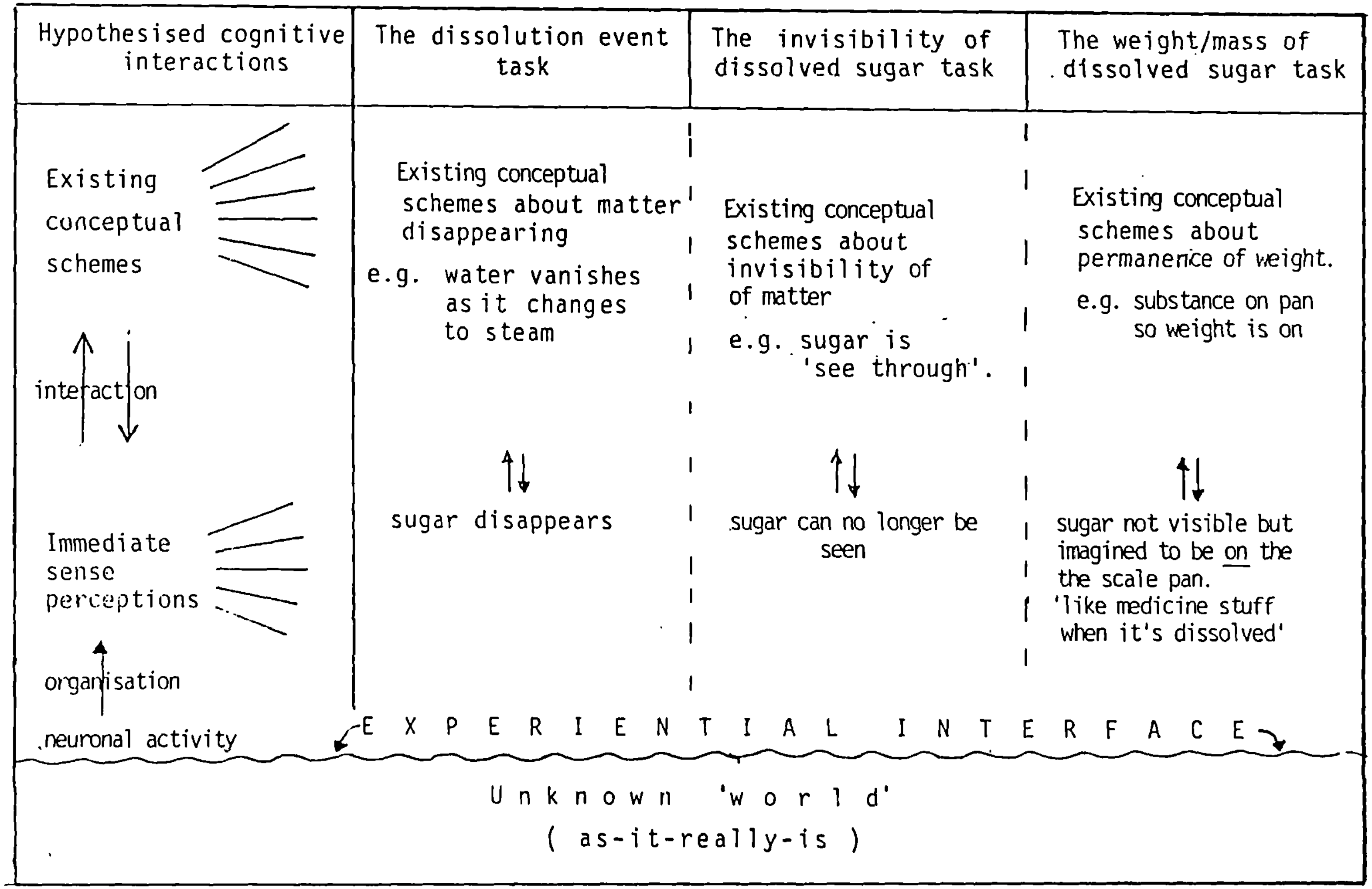


Fig. 11.2 Hypothesised cognitive interactions underlying one pupil's interview responses.
[For interview transcript, see Appendix 3.2.1 (Adr)]

An inspection of Adr's responses or those of other interviewees indicates that pupils' ideas may not, at a particular time, be moving towards the accepted science view, indeed they tend to branch out in other directions that are determined by the particular schemes which pupil's 'call up'. How pupils select particular schemes is an open question, but the choice does not appear to be haphazard. Rather, it seems to be governed by numerous factors such as: the task context, which particular sense perception appears most dominant, some recent experience, their 'view' of the researcher and the questions asked. Further, the relative salience of each of these factors is likely to vary from one pupil to another.

As an illustration, the possible outcomes of the interaction between perception and conception, for two different pupils, are shown in the top half of Figure 11.3. These schemes relate to sugar substance without reference to its dissolved form. The lower-half of Figure 11.3 illustrates how different pupil's models of the 'form' of dissolved sugar could have resulted in different predictions of weight and hence in either conservation or non-conservation of weight. This could explain cases where substance was conserved, but weight/mass was not always conserved. Similar effects may also explain developmental periods, during which a rapidly increasing number of schemes makes scheme selection particularly perplexing. So far as ideas about weight/mass are concerned one of these periods appears to arise between the fifth and seventh school years, when several 'new' notions are encountered at school.

The possibility of several perceptual and conceptual schemes interacting in a variety of combinations may thus account for the diversity of children's responses to the dissolving tasks (illustrated in Figures 6.3, 7.4, 8.2, 9.4, and 9.6). Alternative responses from individual children may arise for a similar reason. Sometimes a pupil would offer both (what they called) a 'common sense' response and then follow it with (what they called) a 'chemical' response. It would appear that, in this case (and others) where alternatives were offered, a variety of perceptual and conceptual schemes were interacting.

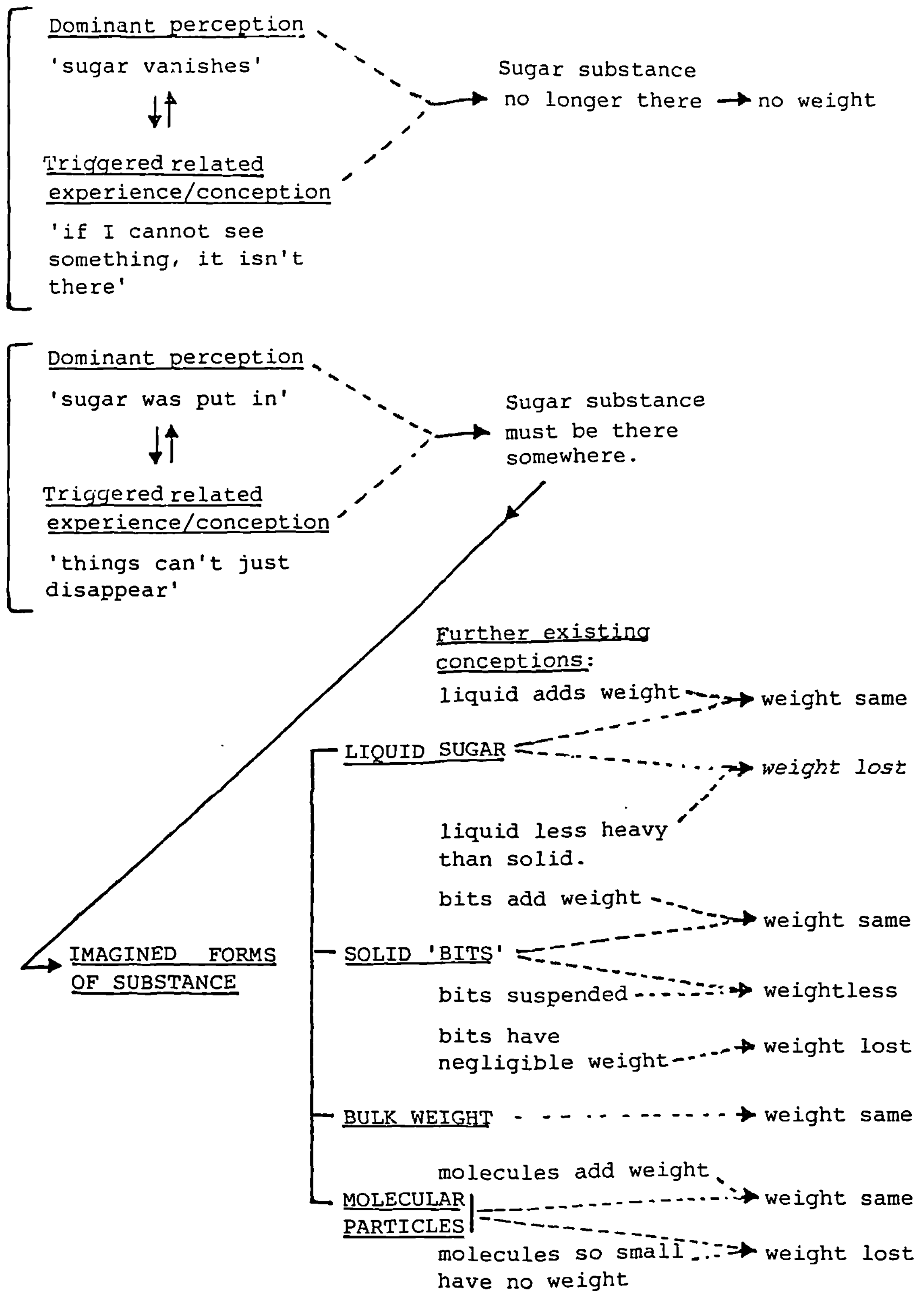


Fig. 11.3 Some hypothesised interactions underlying predictions about weight/mass of dissolved substance.

Conjectures about conceptual change

Evidence that conceptual change about matter takes place, during the school years, may be gathered from the year-group data illustrated in Figures 6.2, 7.1-4, 8.1-3, 9.1-3. Such cross-sectional data do not allow one to monitor and interpret 'within-person' changes. A limited attempt to follow a conceptual change about the weight of dissolved sugar was made with those pupils who predicted a loss of weight. When pupils predicted a loss of weight on dissolving they were shown the results of the weighing task at the end of the interview. Some recognised a discrepancy between their prediction and observation, then changed their minds - asserting that 'the sugar is still there'. Others did not change their minds about the predicted weight loss suggesting instead that 'the balance had been fixed'. This may illustrate certain limitations of conceptual conflict in promoting conceptual change.

11.5 Suggestions for further research

There are a number of issues arising from this study that may be considered worth further investigation. One issue, that frequently emerged, was the slow development of kinetic ideas about solution particles. This was manifest, for example, in the slow development of homogeneity and in naive explanations offered for it. Further research is needed into how pupils may overcome conceptual difficulties about kinetic ideas of matter. These may arise from related energy considerations as well as from sense perceptual ones.

The gender difference (shown in Figure 10.4) in responses to the weight/mass task, that appears to commence at the onset of adolescence, is another issue that may warrant further study. In view of the importance of the construction of the invariance of mass in the building of science knowledge, it would appear that a proportion of girls are at a considerable disadvantage in this respect. Further research may suggest ways of assisting them to conserve mass. Also, it may contribute to the current debate about the merits of psychosocial and biological explanations for gender differences (Halpern,1986).

Finally, it is suggested that action research should be undertaken into the effects on learning and teaching that emerge from the implementation of approaches, proposed in this chapter, for classroom practice and curricula. Driver (1986) has pointed out that educators have yet to take seriously the implications of constructivist epistemology. At this period of time, when interest in constructivism is increasing, it may be considered important to study both teacher and pupil operations and interactions when both are engaged in a constructivist approach to teaching and learning.

BIBLIOGRAPHY AND REFERENCES

ADEY, P. (1976). Two Tasks for the Assessment of Levels of Cognitive Development in Carribean Junior Secondary School. Carribean Journal of Education, 3, 112-138.

ANDERSON, R.D., (1965). Children's Ability to Formulate Mental Models to Explain Natural Phenomena. Journal of Research in Science Teaching, 3, 326-332.

ARRHENIUS, S. (1916). Theories of Solutions. Yale University Press, New Haven.

AUSUBEL, D.P. (1963). The Psychology of Meaningful Verbal Learning. Grune and Stratton, New York.

AUSUBEL, D.P. (1968). Educational Psychology: A Cognitive View. Holt, Reinhart and Winston, New York.

BACHELARD, G. (1933). Les Intuitions Atomistiques. Boivin, Paris.

BEARD, R.M. (1962). The Order of Concept Development Studies in Two Fields, Section II: Conceptions of Conservation of Quantity Among Primary School Children. Educational Review, 13, 228-237.

BENT, H.A. (1971). Uses of the Past. In G.B. Kaufmann, (Ed.). Teaching the History of Chemistry: A Symposium. Akademai Kiado: Budapest.

BOYLE, R. (1661/1930). Sceptical Chemist. Everyman Library, Dent, London.

BRONFENBRENNER, U. (1977). Toward an Experimental Ecology of Human Development. American Psychologist, July 1977, 513-531.

COHEN, I.B. (1980). The Newtonian Revolution. Cambridge University Press, Cambridge.

COHEN, L., and MANION, L. (1980). Research Methods in Education. Croom Helm, London.

COSGROVE, M., and OSBORNE, R. (1981). Physical Change (Working Paper 26), Learning in Science Project, University of Waikato, Hamilton, New Zealand.

DOLBY, R.G.A. (1976). Debates on the Theory of Solution: A Study of dissent in Physical Chemistry in the English Speaking World in the Late Nineteenth and Early Twentieth Centuries. In R. McCormmach, (Ed.), Historical Studies in the Physical Sciences, 7, 279-406. Princeton University Press, Princeton.

DOW, W.M., AULD, J., and WILSON, D. (1978). Pupil's Concepts of Gases, Liquids and Solids. Dundee College of Education.

DRIVER, R. (1981). Pupils' Alternative Frameworks in Science. European Journal of Science Education, 3, 93-101.

DRIVER, R. (1982a). Children's Learning in Science. Educational Analysis, 4(2), 69-79.

DRIVER, R. (1982b). Piaget and Science Education: A Stage of Decision. In S. Modgil and C. Modgil, (Eds.), Jean Piaget: Consensus and Controversy, 351-63. Holt, Reinhart and Winston, New York.

DRIVER, R. (1986). Reconstructing the Science Curriculum: The Approach of the Children's Learning in Science Project. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, April 1986.

DRIVER, R., and EASLEY, J. (1978). Pupils and Paradigms: A Review of Literature Related to Concept Development in Adolescent Science Students. Studies in Science Education, 5, 61-84.

DRIVER, R., and ERIKSON, G. (1983). Theories-in-Action: Some Theoretical and Empirical Issues in the Study of the Students' Conceptual Frameworks in Science. Studies in Science Education, 10, 37-60.

DRIVER, R., GUESNE, E., and TIBERCHIEN, A. (1985). Children's Ideas in Science. Open University Press, Milton Keynes.

DRIVER, R., and OLDHAM, V. (1986). A Constructivist Approach to Curriculum Development in Science, Studies in Science Education, 13, 105-122.

DRIVER, R., and RUSSELL, T. (1982). An investigation of the ideas of heat, temperature and change of state of children aged between 8 and 14 years. Unpublished paper. University of Leeds.

EINSTEIN, A., and INFELD, L. (1961). The Evolution of Physics (Second Edition). Cambridge University Press, Cambridge.

FLAVELL, J.H. (1963). The Developmental Psychology of Jean Piaget. Van Nostrand Reinhold Company, New York.

FRIEDMAN, E. (1982). Investigating Childrens' Ideas About Some Chemistry Concepts. Unpublished M.Ed. Studies Project. Monash University, Victoria, Australia.

GILBERT, J.K. (1982). A Constructivist Approach to Chemical Education. Paper presented at the Annual Congress of the Royal Society of Chemistry, University of Aston, April 1982.

GILBERT, J.K. (1983). Alternative Conceptions: Which Way Now? Paper presented at the American Association of Physics Teachers, New York.

GILBERT, J.K. (1985). Some Barriers to Personal Constructivist Education. Paper presented at the 6th International Personal Construct Psychology Congress, Cambridge, August 1985.

GILBERT, J.K., and WATTS, D.M. (1983). Concepts, Misconceptions and Alternative Conceptions: Changing Perspectives in Science Education. Studies in Science Education, 10, 61-98.

GOEHRING, E.D. (1976). Isaac Newton's Theory of Matter. Journal of Chemical Education, 53(7), 423.

GOETZ, J., and LeCOMPTE, M. (1984). Ethnography and Qualitative Design in Educational Research, Academic Press, London.

GOLD, R. (1987). The Description of Cognitive Development: Three Piagetian Themes. Clarendon Press, Oxford.

GOODMAN, M. (1978). Ways of World-Making. Hackett Publishing, Indianapolis.

GRUTZMANN, F. (1980). Die Vorstellung von "Teilchen versus Kontinum" und "Erhaltung" bei Schulern des 7.bis9. Jahrgangs zu Versuchen mit Verdunaten, Kondensieren, Losen und Kristallisieren. Wissenschaftliche Hausarbeit zur Frlangung des Diploma in Erziehungswissenschaft. Kiel.

GUBA, E. (1981). Criteria for Assessing the Trustworthiness of Naturalistic Enquiries. Educational Communication and Technology Journal, 29, 75-91.

GUBA, E.G., and LINCOLN, Y.S. (1982). Epistemological and Methodological Bases of Naturalistic Enquiry. Educational Communication and Technology Journal, 30, 233-252.

HEBB, D.O. (1958). Alice in Wonderland or Psychology Among the Biological Sciences. In H.F. Harlow and C.N. Woolsey (Eds.). Biological and Biochemical Bases of Behaviour. University of Wisconsin Press. Madison.

HEBB, D.O. (1975). Science and the World of Imagination. Canadian Psychological Review, 16, 4-11.

HALL, W., MOWL, B., and BAUSOR, J. (1973). Patterns 2: Interactions and Building Blocks, Schools Council Publication, Longman and Penguin Books, London.

HALPERN, D.F. (1986). Sex Differences in Cognitive Abilities. Lawrence Erlbaum Associates, London.

HAMPSON, B.L., and EVANS, K.C. (1980). Science from the Beginning. Oliver and Boyd, Edinburgh.

HEMPEL, C.G. (1966). Philosophy of Natural Science. Prentice Hall, Englewood Cliffs, New Jersey.

HUME, D. (1963). An Enquiry Concerning Human Understanding (1748). Washington Square Press, New York.

INAGAKI, K., and HATANO, G. (1977). Amplification of Cognitive Motivation and its Effects on Epistemic Observation. American Educational Research Journal, 14(4), 485-491.

IONA, M. (1975). The meaning of weight. The Physics Teacher, 13, 263-274.

JONES, H. (1981). Pierre Gassendi's Institutio Logica (1658). Van Gorcum, Assen.

KELLY, G.A. (1955). A Theory of Personality: The Psychology of Personal Constructs. W.W. Norton and Company, New York.

KELLY, G.A. (1970). A Brief Introduction to Personal Construct Theory. In D. Bannister (Ed.), Perspectives in Personal Construct Theory (pp. 1-30). Academic Press, London.

KESSEN, W. (1966). Questions for a Theory of Child Development. Monographs for the Society for Reasarch in Child Development, 31, 55-70.

KING, A.L. (1963). More on Weight and Weightlessness. The Physics Teacher, 1, 122.

KITCHENER, R.F. (1986). Piaget's Theory of Knowledge: Genetic Epistemology and Scientific Reason. Yale University Press, New Haven.

KUHN, T. (1970). The Structure of Scientific Revolutions, (Second edition). University of Chicago Press.

LAKATOS, I. (1978). The Methodology of Scientific Research Programmes. In J. Worrell and G. Currie, (Eds.), Philosophical Papers (Vol 1.). Cambridge University Press, Cambridge.

LAYTON, D. (1965). The Original Observations of Brownian Motion. Journal of Chemical Education, 42, 367-8.

LAYTON, D. (1973). Science for the People. George, Allen and Unwin, London.

LeCOMPTE, M., and GOETZ, J. (1982). Problems of Reliability and Validity in Educational Research, Review of Educational Research, 51, 31-60.

LEWIS, M., and WALLER, G. (1982). Thinking Chemistry. Oxford University Press, Oxford.

LONGDEN, K.A. (1984). Understanding of dissolving shown by 11-12 year-old children. Unpublished M.Sc. thesis. University of Oxford.

MANICAS, P.T., and SECORD, P.F. (1983). Implications for Psychology of the New Philosophy of Science. American Psychologist, April 1983, 399-413.

MEE, A.J., BOYD, P., and RITCHIE, D. (1980). Science 2000. Heinemann Educational Books Ltd., London.

MILES, M., and HUBERMAN, A. (1984a). Drawing Valid Meaning from Qualitative Data: Toward a shared craft. Educational Researcher, 13, 20-30.

MILES, M., and HUBERMAN, A. (1984b). Qualitative Data Analysis. Sage Publications, Beverly Hills.

MISCHEL, T. (1971). Cognitive Development and Epistemology. Academic Press, New York.

NEWTON, I. (1952). Opticks or a Treatise of the Reflections, Refractions, Inflections and Colours of Light. Dover Publications Inc., New York.

NIELSON, H., & THOMSEN, P.V. (1983). Gymnanie, Fysik, Rapport nr.1 Hverdagsforestillinger om Fysik. Det Fysike Institut, Aahus Universitet.

NOVAK, J.D. (1976). Understanding the Learning Process and the Effectiveness of Teaching Methods in the Classroom, Laboratory, and Field. Science Education, 60, 493-512.

NOVAK, J.D. (1982). Psychological and Epistemological Alternatives to Piagetian Development Psychology with support from Empirical Studies in Science Education. In S. Modgil and C. Modgil, (Eds.) Jean Piaget: Consensus and Controversy. Holt, Reinhart and Winston, New York.

NOVAK, J.D. (1984). Learning Science and the Science of Learning. A paper presented at the AERA meeting, New Orleans, April 1984.

NOVAK, J.D., and GOWIN, D.B. (1984). Learning how to Learn. Cambridge University Press, Cambridge.

NUSSBAUM, J., and NOVICK, S. (1982). Alternative Frameworks, Conceptual Conflict and Accommodation: Toward a Principled Teaching Strategy. Instructional Science, 11, 183-200.

OSBORNE, R.J., and WITTROCK, M.C. (1983). Learning Science: A Generative Process. Science Education, 67(4), 489-508.

PARTINGTON, J.R. (1951). A Short History of Chemistry. Macmillan and Co., London.

PERRIN, M.J. (1910). Brownian Movement and Molecular Reality. Taylor & Francis, London.

PFUNDT, H. (1981). The Atom - The Final Link in the Division Process or the First Building Block? Pre-Instructional Conceptions about the Structure of Substance. Chimica Didactica, 7, 75-95.

PIAGET, J. (1926/73). The Child's Conception of the World (trans. J. & A. Tomlinson). Granada, London.

PIAGET, J. (1936/63). The Origins of Intelligence in Children (trans. M. Cook). W.W. Norton, New York.

PIAGET, J. (1964). Cognitive development in children: Piaget. Journal of Research in Science Teaching, 2, 176-186.

PIAGET, J. (1967/71). Biology and Knowledge: An Essay on the Relations between Organic Regulations and Cognitive Processes (trans. B. Walsh). University of Chicago Press, Chicago.

PIAGET, J. (1968). Quantification, Conservation and Nativism. Science, 162, 976-979.

PIAGET, J. (1970/72). The Principles of Genetic Epistemology (trans. W. Mays) Routledge and Kegan Paul, London.

PIAGET, J. (1971). Genetic Epistemology. Columbia University Press, New York.

PIAGET, J. (1975/77). The Development of Thought: Equilibration of Cognitive Structures (trans. A. Rosin). Viking, New York.

PIAGET, J., and INHELDER, B. (1941/74). The Child's Construction of Quantities (trans. A. Pomerans). Routledge and Kegan Paul, London.

PLANCK, M. (1950). Scientific Autobiography and other Papers (trans. F. Gaynor). Williams and Norgate, London.

POPE, M., and GILBERT, J.K. (1983). Constructive Science Education. Paper presented at the Personal Construct Psychology Conference, Boston, 1983.

POPPER, K. (1968). Conjectures and Refutations (Second Edition). Harper, New York.

POPPER, K.R. (1982). Quantum Theory and the Schism in Physics. Rowan and Littlefield, London.

PUTNAM, H. (1981). Reason, Truth and History. Cambridge University Press, Cambridge.

RESNICK, L.B. (1981). Instructional Psychology. Annual Review of Psychology, 32, 659-704.

RESNICK, L.B. (1983). Mathematics and Science Learning: A New Conception. Science, 220 : 477-478.

RORTY, R. (1979). Philosophy and the mirror of nature. Princeton University Press, Princeton.

ROSS, D. (1952). The Works of Aristotle Translated into English, Volume XII. Clarendon Press, Oxford.

ROTH, G. (1980). Cognition as a Self-organising System. In F. Benseler, P.M. Hejl and W.K. Koch (Eds.), Autopoiesis, Communication and Society. Campus, New York.

RUMELHART, D.E. (1980). Schemata: The Building Blocks of Cognition. In R.J. Spiro, B.C. Bruce, and W.F. Brewer (Eds.), Theoretical issues in reading comprehension. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

SCHRODINGER, E. (1958). Mind and Matter. Cambridge University Press, Cambridge.

SEARS, F.W. (1963). Weight and weightlessness. The Physics Teacher, 1, 20-23.

SELLEY, N.J. (1979). Scientific Models and Theories: Case Studies of the Practice of School Science Teachers. Unpublished Ph.D thesis, Kings College, London.

SHAYER, M., and WHARREY, D. (1974). Piaget in the Classroom, Part I: Testing a whole class at the same time. School Science Review, 55 (192), 452-458.

SMITH, J.K. (1983). Quantitative Versus Qualitative Research: an Attempt to Clarify the Issue. Educational Researcher, 12, 6-13.

SMITH, J.K. (1984). The Problem of Criteria for Judging Interpretative Inquiry. Educational Evaluation and Policy Analysis, 6, 379-391.

SMITH, J.K., and HESHUSIUS, L. (1986). Closing Down the Conversation: The End of the Quantitative-qualitative Debate Among Educational Inquirers. Educational Researcher, 15, 4-12.

SMOCK, C., and von GLASERSFELD, E. (1974). Epistemology and Education. Mathemagenic Activities Programme, University of Georgia.

SOLMSEN, F. (1952). Aristotle's System of the Physical World. Cornell University Press, New York.

STEFFE, L.P., and COB, P. (1984). Multiplicative and Divisional Schemes. Educational Studies in Mathematics, 15, 11-29.

STRAUSS, S., and STAVY, R. (1982). U-shaped Behavioural Growth. Academic Press, New York.

STRIKE, K.A., and POSNER, G.J. (1985). A Conceptual Change View of Learning and Understanding. In L.H.T. West and A.L. Pines (Eds.), Cognitive Structure and Conceptual Change. Academic Press, New York.

TOULMIN, S. (1972). Human Understanding Vol 1. The Collective Use and Evolution of Concepts. Princeton University Press, Princeton.

VICO, G. (1710/1858). De Antiquissima Italorum Sapienta. Stamperia de Classici Latini, Naples.

von GLASERSFELD, E. (1974). Piaget and the Radical Constructivist Epistemology. In C.D. Smock and E. von Glasersfeld (Eds.), Epistemology and Education. Mathemagenic Activities Programme, University of Georgia.

von GLASERSFELD, E. (1979). Radical Constructivism and Piaget's Concept of Knowledge. In F.B. Murray (Ed.), Impact of Piagetian theory. University Park Press, Baltimore.

von GLASERSFELD, E. (1980). The Concept of Equilibration in a Constructivist Theory of Knowledge. In F. Benseler, P.M. Hejl and W.K. Koch (Eds.), Autopoiesis, Communication and Society. Campus, New York.

von GLASERSFELD, E. (1983). On the Concept of Interpretation. Poetics, 12, 207-218.

von GLASERSFELD, E. (1984). An Introduction to Radical Constructivism. In P. Watzlawick (Ed.), The Invented Reality. W.W. Norton, New York.

von GLASERSFELD, E. (1985). Reconstructing the Concept of Knowledge. Archives de Psychologie, 53, 91-101.

WATTS, M. (1984). Alternative Frameworks: An Alternative to Piaget. Paper presented at the British Educational Research Association, August 1984.

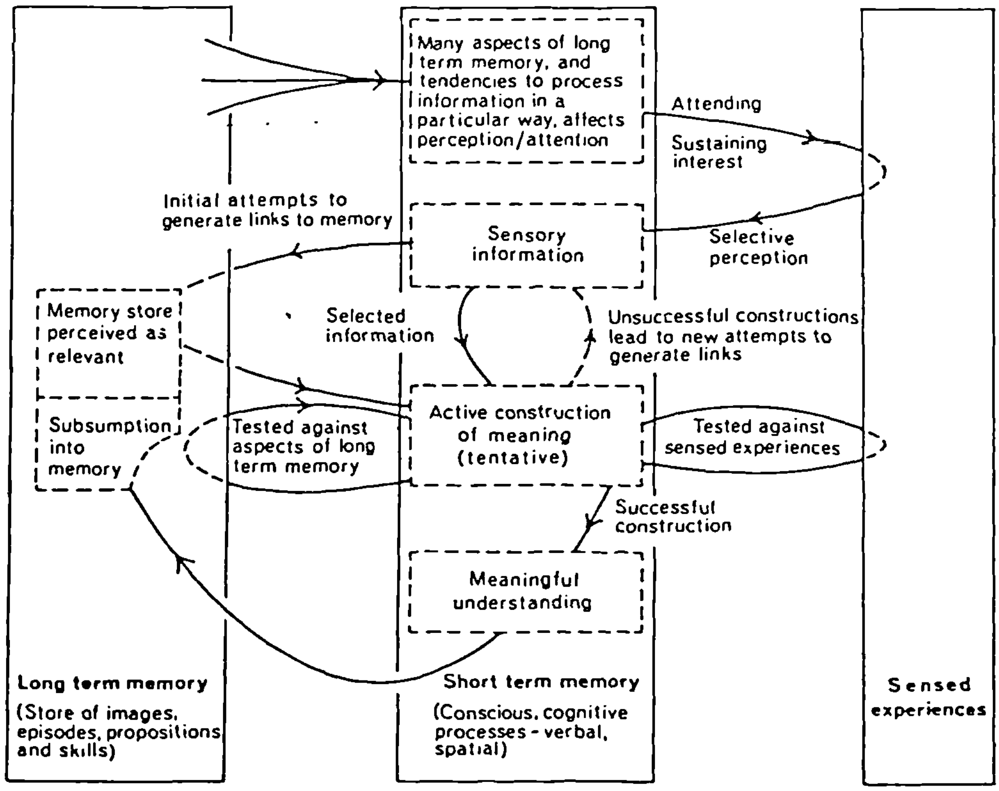
WHITMAN, J.C. (1975). An Approach to the Evaluation of Selected Spontaneous and Scientific Concepts and Misconceptions of Second Grade Children. M.Sc. Thesis, Cornell University.

WITTROCK, M.C. (1974). Learning as a Generative Process. Educational Psychologist, 11, 87-95.

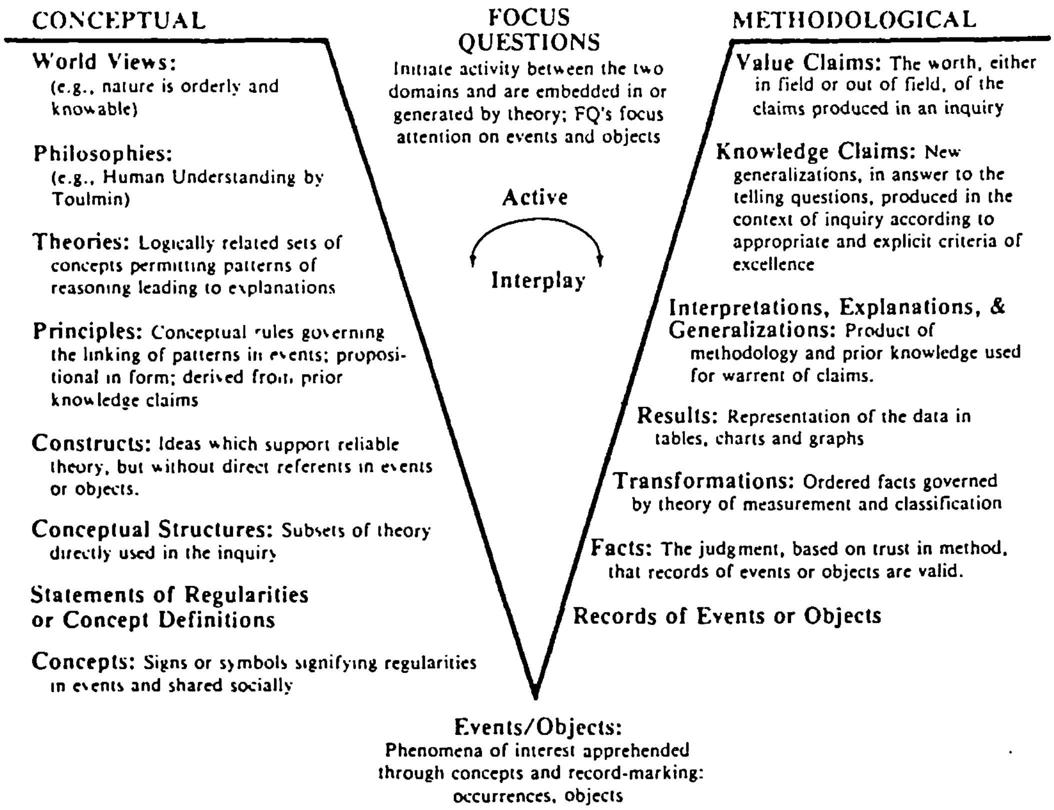
APPENDICES

Contents

APPENDIX 1.1 SCHEMATIC REPRESENTATION OF THE GENERATIVE LEARNING MODEL (Osborne & Wittrock,1983,p.493)



APPENDIX 1.2 GOWIN'S EPISTEMOLOGICAL VEE
(Novak & Gowin,1984,p.56)



APPENDIX 2 A SUMMARY OF RESEARCH RELATED TO CHILDREN'S UNDERSTANDING OF DISSOLUTION

DATE	RESEARCHERS	AGE RANGE	SAMPLE SIZE	METHODOLOGY	FOCUS OF RESEARCH
1941	Piaget and Inhelder (Switzerland)	4-12	100	Clinical	Conservation & atomism
1962	Beard (England)	5-10	140	Interview	Conservation of volume
1965	Anderson (U.S.A.)	9-12	180	Interview	Formulation of atomistic models
1974	Shayer & Wharrey (U.K.)	11-12	35	Class tasks	Cognitive development
1976	Adey (Jamaica)	11-15	527	Class tasks	Cognitive development
1977	Selley (England)	11-15	91	Class tasks/ discussion	Conservation & atomism
1977	Inagaki & Hatano (Japan)	9-10	203	Multiple choice test.	Cognitive motivation
1978	Dow, Auld & Wilson (Scotland)	11-16	not known	Class tasks	Particle concepts
1980	Pfundt & Grutzman	11-15	61	Interview	Particle ideas about solutions
1981	Cosgrove & Osborne (New Zealand)	8-17	43	Interview	Dissolving (events)
1982	Driver & Russell (Leeds/Penang)	8-14	324	Interview/ writing tasks	Dissolving and conservation of mass.
1982	Friedman (Australia)	13-18	34	Interviews	Dissolving (instances)
198[illegible]	Longden (England)	11-12	20	Interviews	Dissolving recognition.
			81	Sentences	Dissolving.

APPENDIX 3.1 INTERVIEW SCHEDULE

Phase 1. Gaining interest and attention

Putting at ease - sharing purpose and interests

Hello (Name of pupil)
Comment on some shared event, situation, circumstance, etc.
Come and sit here (Name of pupil)
I expect you are wondering why you've been asked to come and talk to me,
Well, I'm interested in the ideas young people have about things: what things are made of, what makes them the way they are.
My job is a bit like a collecting hobby.
Do you collect anything?
Further questions about hobbies and 'hobby' talk

Focussing on substances to be used [(I) = Interviewer and (P) = Pupil]
There's a bit of mystery about the things I collect: I can't see them, they're hidden up here somewhere (pointing to P's head), so that's why I'd like us to talk about a few things, for instance,
here are some things. ((I) tips out some large sugar crystals)
Let's have a look at these..Have you seen anything like these before one up...feel it...What do you find interesting?...Would you like to describe it?... Any idea what makes it ____ (e.g. hard)? Is it like anything?...What makes you think that?...

Preparing for later questions

Let's put some water in this dish ((P) puts water in dish)
Now, let's put the ________ in the water and leave it awhile.
((P) puts large sugar crystal in dish)

Phase 2 Focus on 'dissolving'

Here's some granulated sugar, take a spoonful and tip it into this glass of water. How about stirring that and giving a commentary on what is happening...pretend you're a radio commentator...right you're on the air...((I) takes up pupil's words.)
When you say it is ______ (e.g. melting, dissolving, evaporating, disintegrating..) what do you think is happening to these sugar granules? ((I) shows granules)
Why do you think we can't see the sugar?..... Where do you think it has gone?...
Suppose we took some snapshots of the sugar granule....
Would you like to draw it as you think it could be in the water?.... until you can't see it anymore.
(If (P) believes the sugar is still there):
Here is a diagram of a glass of water with sugar in it...you can't see the sugar but suppose you were Superman (Superwoman) and you could see the sugar... Where would you expect it to be? Would you draw that for me? What makes you think it is like that?

Suppose you could see inside a drop from the beaker, what do you think superboy (supergirl) would see... just draw that in there.

Phase 3. Focus on weighing

Conversation to encourage thinking about weight in an operational way
Here are two things (e.g. a Whispa bar and an Aero bar).
which do you think is the heavier? (May use 'heaviest' if better understood)
((P) lifts the two bars)
Why do you say that one is the heaviest?
How can we be sure that the Whispa is heavier? ((I) takes scales out of box)
(P) becomes familiar with the operation of the scales
((P) puts the Whispa on one side and the Aero on the other)
Put these two glasses of water on the balance. ((I) has put unequal weights of water in two plastic beakers.)
Which is the heavier?
(P) about to compare the weight of sugar in water with the weight of sugar and water
((I) transfers (with a teat pipette) water from one beaker to other until the weights are equal.)
What can you say about the glasses now? (If pupil says volume, ask: What do the scales measure?)

Take the glasses off the balance and compare the weights of these bags of sugar. Adjust weights until they are equal.
What can you say about the weights of these packets of sugar?
Suppose we put both sugar and water on each side, what will you notice?
Take the glass off that side and tip the sugar into it...stir it...What is happening?...
If you put that beaker back on the scales again, would it be higher, lower or the same height as the other side?
What makes you say that?
(How does ______ sugar in water make it weigh less (or more))
(In the latter case do not show actual effect until later Phase 5)

Phase 4. Focus on volume measure

I expect you have had medicine at some time and you will know it is important to take a certain amount. How did you measure the medicine? Here is a measure that measures that amount. one.two.three.four.five millilitres. ((I) produces a small measuring cylinder and pours in water)
What do you think it is measuring?
.... and what does ______ mean?
Suppose you put this crystal of sugar in there (pointing to measure) what do you think would happen to the water?
Why do you think that?
Would you put the sugar crystal in the measure then and we'll see what happens ... so that has happened?
Now, suppose we leave it there, like we left the other crystal in the dish, what do you think will happen to the level of the water?
What makes you think that?

Phase 5. For non-conservers only

Let's go back to the scales again...we'll put the sugar bag and water back on one side and the empty bag with the sugar in water on the other
What do you notice?
Now there are many children who tell me, as you did that ______.
Why do you think the weight stays the same?... What do you think is happening?

Phase 6. Review

Thank you for your most interesting ideas.... was there anything we talked about you had not thought about before?
What was the most interesting thing we talked about?
Was there anything that suprised you?

APPENDIX 3.2 EXAMPLES OF INTERVIEW TRANSCRIPTS

Pupil I.D. No.	Gender M/F	Age	School year-group	Curriculum followed	Ability	Date
Adr 2201 (3.201)	M	8.6	3	Primary Science	Low	09.05.85
Cla 3304 (5.304)	F	10.2	5	Leeds Middle School	High	09.11.84
Mar 4405 (7.405)	M	11.10	7	Leeds Middle School	Average	16.10.84
Fle 6605 (10.605)	F	15.3	10	C.S.E/ 'O' Level Biology	Average	28.02.85

Interview with Adr.

I.D. No.:	2201 (3.201)	School-year	3
Gender:	M	Ability:	low
Age:	8.7	Curriculum:	Primary Science

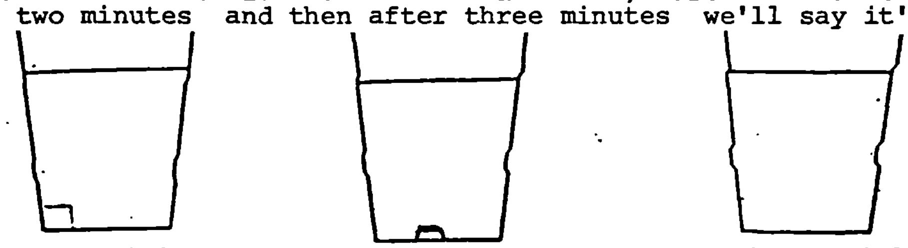
PHASE 1: GAINING INTEREST AND ATTENTION

1. I. So you're a keen collector. Right, come and sit here Adr
2. A. Collect a lot of stuff.
3. I. Do you? And where do you keep it all? Is there room in the house?
4. A. Yes. Only just.
5. I. Does your Mum complain?
6. A. No. I get more stuff every time.
7. I. Do you? That's great. Now you see I've been collecting a few things. Here are some things that I've collected I'd be interested in your ideas about.
8. A. Are they little ice cubes?
9. I. No. They remind you of ice do they? That's a bit broken that one I think. I'd like you to feel it and tell me anything you find interesting about it.
10. A. It's a funny shape.
11. I. It's a funny shape. I see. What's funny about the shape would you say?
12. A. Well it's different.
13. I. Different from what?
14. A. Ice cubes.
15. I. How do you think it got that shape?
16. A. By ....
17. I. Oh, I see, a sort of mould. You make that do you - in school or at home?
18. A. It's shiny.
19. I. Shiny, isn't it.
20. A. Feels slidy.
21. I. Some things like that are hard and other things like this are soft. What do you reckon makes some things soft like this and other things a lot harder would you say? 22. A. ....well this sort of stuff's made to be soft and these are made to be hard.
23. I. Right, well, do you want to say any more about this? You've said it's a funny shape. What shape is it would you say?
24. A. Shape of a diamond.
25. I. Shape of a diamond. You've said it's hard.
26. A. It's an oblong shape.
27. I. Anything else you notice about it?
28. A. No. You can see through it as well.
29. I. Right, well will you put it into that water there and we'll see what happens to it.
30. A. It'll melt.
31. I. Well I'll let you into a little secret actually. These, in fact, are pieces of sugar. Now this is sugar here but these are bigger ones. If you look at this sugar here under a microscope. I don't know whether you can see. There may not be enough light at the moment. Can you see anything?
32. A. Mm
33. I. Well each one of those looks like this, you see. These are big ones. Now when you were rubbing it - what did you say about it? Runny? Well you know why now. I don't want you to tell anybody else it's sugar. That's a secret between you and me. Right. This is sugar as you normally see it.
34. A. It could be sugar or salt.
35. I. Yes, well that's sugar. It looks a bit like salt doesn't it?

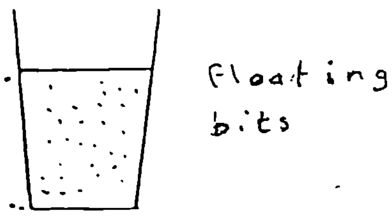
PHASE 2: 'DISSOLVING'

1. I. I'll tell you what - will you put about half a teaspoonful of that in there.
2. A. Half?
3. I. About half a teaspoonful. That's okay. That's fine. Put it in yes. Hold this with your left hand and stir with your right. Stir it, yes. Tell me what you think is happening in there. Pretend you're on Radio Leeds, describing what's happening. What would you say is happening now?
4. A. It's dissolving.

5. I. Dissolving is it? That's a big word for a little boy. What do you think happens to things when they dissolve? Your idea of what happens to it.
6. A. Disappears.
7. I. Mm, disappears. Anything else?
8. A. .... floats up to the top and you can't see it.
9. I. Keep stirring. I think there's still some there isn't there. You say it disappears. Where do you think it's gone to?
10. A. Water usually just goes into steam and just floats about so that must do too.
11. I. You say what? I didn't quite catch that. I'm not very good at hearing. Can you say it a bit louder?
12. A. Just sort of steam sort of stuff and then it just floats out just water so sugar must do the same. 13. I. You think the sugar will do the same?
14. A. Mm.
15. I. Where will it float about?
16. A. (Up here.)
17. I. And you think it's because water does the same thing is it?
18. A. Mm.
19. I. So you think some of this water is floating about at the moment do you?
20. A. Mm
21. I. And whereabouts, for example, would it be floating?
22. A. All over the place.
23. I. All over the place. I see. That's interesting. Can you see it from there?
24. A. Yes.
25. I. Why do you think we can't see it in there....? Why is it not possible to see it any more do you think?
26. A. Because it's see-through and it's disappeared. It's dissolved.
27. I. I see. Right, well we'll leave it there for a minute. I want you to imagine that this is one of the little pieces of sugar you put in. I've drawn it big. Suppose we photograph this in the water, when it's gone into the water we photograph it. What do you think it would look like? In there, after a minute, after two minutes and then after three minutes we'll say it's gone.

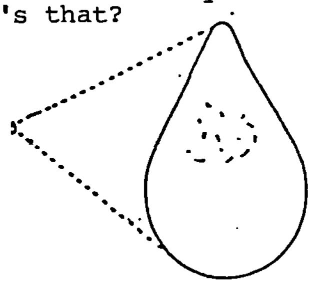


I see. Well it's gone there so you can't draw anything if it's gone can you. Now it's all gone. I see. Thankyou. Where's the rest of it would you say? You've made it small haven't you? You've made it smaller than it was.
28. A. (I don't know)
29. I. Now I want you to imagine something very exciting. I want you to imagine for a minute that Superman gave you his clothes and his eyes and you could actually see in there. Now Superman can see inside buildings and cars and inside houses and so on. Now imagine you had super eyes, what do you think you would see in there.
30. A. I'd see all the bits of sugar.

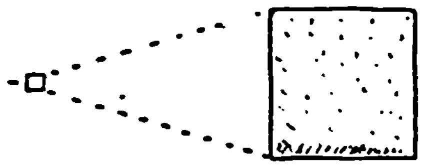


31. I. Draw whatever you think. Whatever ideas you've got. What gives you the idea - what are these by the way? Floating bits?
32. A. The sugar.
33. I. Just put floating bits would you? Do you know how to spell floating do you? Floating bits. Now what gives you the idea they're floating? Where did you get that idea from?
34. A. They couldn't be anything else?
35. I. Couldn't be anything else. Where did you get the idea from that they're all over? You're showing me here that they're all over these bits of sugar. Now how did you get that idea that they're all over?

36. A. They won't be just there...
37. I. Now when you put the teaspoon in originally they went to the botom - remember? How come that they're floating now, all over the place?
38. A. Because they're rising up to go to thin air?
39. I. What makes them rise up and go into thin air?
40. A. Water.
41. I. Now suppose that you took - you had a look at one .... you're looking into one drop magnified with your super eyes, Super Adrian's looking into here, into one drop. What would you see inside do you think? Just in one drop. What's that?



42. A. Sugar
43. I. It's bits again. Righto. Put bits. You needn't bother with floating. Just put bits. Why are they in the middle would you say? What's given you the idea they're in the middle?
44. A. ....They wouldn't be down at the bottom though, they'ed be up at the top.
45. I. What's given you that idea? Can you tell me?
46. A. I just thought that if the water's flying down you'ed be able to see the sugar in the middle but not at the bottom or the top or at each side.
47. I. I see. And if you could see inside - one of those or one of these because they're both the same really. Now we can just see straight through them at the moment.
48. A. Yes. Squares and all sorts of shapes.
49. I. With ordinary eyes you can just see straight through them. They're like diamonds. What I want you to imagine, I want you to imagine that you had super eyes what do you think is inside one of these, if anything?
50. A. Little bits of sugar



51. I. You think it's made of little bits of sugar? Well you draw those bits then? And is there anything between those bits Adr?
52. A. Bits of glass.
53. I. You think there are bits of glass between them?
54. A. Don't know, you would cut yourself.
55. I. So is there anything between those little bits?
56. A. ....some are stuck together.
57. I. I see, they're stick together. Little bits stuck together. Is that what you mean?
58. A. There's a few bits in here stuck together.
59. I. A few bits. They're not all stuck together.
60. A. No, but all the stuff at the bottom is stuck together.
61. I. Why at the bottom more than anywhere else would you say?
62. A. Because they'd float down...they'd all be at the bottom when you tip it up that way..
63. I. Do these have a bottom?
64. A. When you go like that they'd all go to the bottom and then some would stay there.
65. I. You think they move inside do you?
66. A. Mm.
67. I. That's very interesting. What makes you think they move inside when you turn round?
68. A. Because you can see some bits in them.
69. I. Well those are not bits. I think that's just an air bubble. Those sort of come in when they've been made or else it's something stuck on the outside.
70. A. These are quite big.
71. I. Really they're....
72. A. Can see little bits down there.

PHASE 3: WEIGHING DISSOLVED SUGAR

1. I. Right Adr, suppose you,ve got two stones or bricks or two anything and you want to decide which is the heaviest, how would you go about it?
2. A. Weigh them.
3. I. You're weighing them in your hands at the moment aren't you?
4. A. Yes.
5. I. How does that help you?
6. A. If that was the heaviest it would put your hand down so far.
7. I. It would put your hand down would it? It's a bit hard to decide though without using something like this. What are these?
8. A. Scales.
9. I. Use some scales so that's just...There we are. If I put something heavy on, this side goes down. Right. Something heavy on that side, that side goes down. So put one on each side and we'll see.
10. A. I said that was heavier.
11. I. That one's heavier. Well when that one's heavier this goes lower down that side you see. So which sode is nearest the table?
12. A. This one.
13. I. That one. That's the heaviest stone isn't it? Let's weigh some water shall we? Which is the heaviest of those two?
14. A. I'd say that one.
15. I. That one...Well we'll take some out of that one then and we'll put it in this one. Take some out of here and put it in there...Now when it's balanced that mark is opposite there you see. It's about there now isn't it. Right, so what can you say about those two beakers?
16. A. Both the same; they've got the same water in.
17. I. And the same what? What do scales measure?
18. A. The weight's the same.
19. I. Measure the weight don't they? Weight's the same. Okay, we'll take those two off. What I'd like you to do now is to weigh for me a couple of packets of sugar. There we are, put those on. One on there; one on there. What can you tell me about those two packets of sugar?
20. A. Well, one's on the red one and one's on the yellow one and they've got the same amount of sugar in them when you look at it (at the top)..
21. I. Yes. Don't worry too much about what it looks like. Now what do the scales tell us? What are the scales for? They tell us..?
22. A. Which is heavier and which is lighter.
23. I. So what can you say about them?
24. A. Those two are both the same.
25. I. The same weight. Agree - the same weight? If I put these two back on, what would you expect?
26. A. Still the same.
27. I. Still the same. Right, put them on and see. There we are, still the same weight. Now will you take that beaker off there Adr please and put it down that side and put it over here.....Open this packet now like that and pour that in there carefully. That's right, tip it in like that. Thank you. Give it a stir. Tell me what you think is happening in there. Don't press on too hard, just gently. Now what's happening in there?
28. A. It's dissolving and you can see all the bits.
29. I. Mm. Let's have a look. We can't see it any more.
30. A. It's like that medicine, that sort of powder stuff you drink when it's dissolved.
31. I. I see. You have that when you're poorly do you? Now if I put that on that side, back again, would you expect both sides to be the same weight or would you expect this side to be heavier than that side?
32. A. I think it'll be the same, because it's just still on it.
33. I. You think it'll be the same because that's still on it do you?

PHASE 4: VOLUME OF DISSOLVED SUGAR

1. I. Now, talking about being poorly, I expect you've been given some medicine at some time or other have you?
2. A. Yes, a few times.
3. I. I see. Well if you're given medicine they give you a spoon which says on it...What does that say?
4. A. Five.

5. I. millilitre dose. Okay. And this is a better measure really. It's marked off one, two, three, four, five millilitres and we'll put some imaginary medicine in here..
6. A. Where's that stick thing?
7. I. Use it to take some out. There we are. We've now got a 3 mil dose. Now I want you to tell me what'll happen to the medicine or what'll happen to the water....if I put some sugar in, because sugar helps the medicine to go down doesn't it? If we put this in there, what do you think will happen to the water in there? When we put the lump of sugar in there what do you think will happen to the water in there?
8. A. Will it go higher with the weight?
9. I. What do you mean with the weight?
10. A. If I drop one of these pebbles into the water the water would go higher.
11. I. Why does it go higher do you think?
12. A. If I put my hand in there the water would go higher as well.
13. I. And why is that do you think?
14. A. It goes higher because that thing you're putting in makes the water get out of the way of what you're putting in and it goes at the side of it and goes up and up an up.
15. I. I see. Put in it and see what happens. It was on three now it's towards three and a half. Okay. Now suppose we...what's happened to that. Now suppose we left this one in here what's going to happen to that one do you think?
16. A. Same as that one done.
17. I. Yes. And if that happens what do you think will happen to the water in there?
18. A. It'll go back down again.
19. I. Down to where do you think?
20. A. Three.
21. I. And what's making you think that Adr that it'll go back down to three?
22. A. Because the water'll be able to go where that is, back to it's own place and it'll go back down.

PHASE 5: (not required)

PHASE 6: REVIEW

1. I. I see. Very interesting. Well it's been very interesting talking to you Adr. Thank you very much for telling me your ideas on these things. Was there anything you found more interesting than anything else in these? Which did you find most interesting?
2. A. Looking at the sugar.

Interview with Cla.

I.D. No.:	3304 (5.304)	School-year:	5
Gender:	F	Ability:	high
Age:	10.2	Curriculum:	Leeds middle school

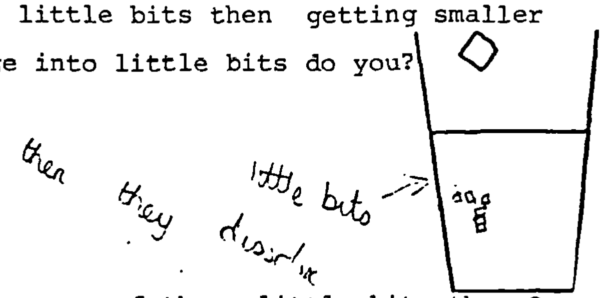
PHASE 1: GAINING INTEREST AND ATTENTION

1. I. Let's have a look at some things -here are a few things - have you ever seen anything like that before?
2. P. um - no.
3. I. you've never seen anything like that before - I see - well would you like to pick one up - have a good look at it - feel it - handle it - urm perhaps it will remind you of something that you might have seen.
4. P. it's like a little but it's like a little ice but it doesn't feel as cold as ice-this.
5. I. I see - um hum er - anything else that's interesting about it.
6. P. it sparkles.
7. I. it sparkles a bit yes - what about it's shape? is it's shape interesting? is it hard or soft?
8. P. it's soft but the edges are quite sharp.
9. I. they are sharp um: I see - well I tell you what - would you put it in that dish of water and we'll see what happens to it - these are actually pieces of sugar that you can get in the Supermarket but you are more used to seeing sugar like this aren't you?
10. P. yes.

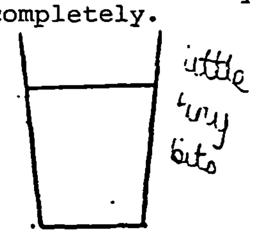
Phase 2: 'Dissolving'

1. I. It says on the packet 'Granulated sugar 1kg' - you've seen that have you?
2. P. yes.
3. I. fine - so let's take some water and perhaps you'd like to put half a spoonful in the water would you? - and er stir it around and tell me what you think is happening in there as you stir it perhaps you would like to be a radio commentator.
4. P. it's - it's not spreading about most of it's all staying together.
5. I. I see keep stirring it - are you left-handed - well hold it with your right hand then.
6. P. when you stir it around you can hardly see the bits of sugar.
7. I. anything else happening Claire?
8. P. it seems to be getting smaller and dissolving in the water.
9. I. um hum what do you think happens to things when they dissolve in water? (7.0) where are they going to do you think?
10. P. is it in the water and when if you felt this water would you feel a little bit of sugar in?
11. I. um hum - well feel it then. what does it feel like?
12. P. it just feels like normal water - it's as if there's a little hole in it and it disappears down the hole.
13. I. there's a hole in where do you think? in the water?
14. P. um
15. I. or do you think it is like having something with holes in and it disappears? where have you come across this idea of having holes in things? things disappearing through holes? where have you seen that happen before?
16. P. when there's um (2.0) like the balck hole and such like
17. I. um hum - I see - you read about that in your comics?
18. P. um - it's as if you are pouring it into something - into a hole.
19. I. that's very interesting let's think about your idea then - here are these little sugar granules - can you see them with the magnifying glass - suppose they are magnified so that we have got something we can draw - they are a bit small to draw - what do you imagine is happening to one of those when it gets into the water? would you like to show me?
20. P. well when it came in the water it was disappearing it (*) disappearing into the water but when you felt it was as if you were pouring it into a hole like.

21. I. I see so what do you suppose happens to this in there? it goes into a hole does it?
22. P. erm (7.0)
23. I. or is it just like going into a hole? it doesn't really go into a hole you don't think?
24. P. no.
25. I. but it's like that it reminds you of that?
26. P. yes.
27. I. I see um hum -
28. P. does it stick to the glass or the bottom if it come in
29. I. um hum whatever you think happens to it - suppose you had a camera and you took some snapshots of it every few minutes what do you think you would see?
30. P. see it starting off lots of little bits then getting smaller little bits.
31. I. so you think this would change into little bits do you?



32. P. um
33. I. um hum would you like to draw some of those little bits there? I see that's interesting - just put a little label at the side 'a few bits' or whatever you would like to describe it do you want to say anything else about them?
34. P. and then the little bits dissolve into the water.
35. I. just put 'little bits dissolve' there and when they dissolve what happens to them did you say?
36. P. it's like it goes into the water but it' like the water that kind of melts it.
37. I. what else have you come across - melting? have you seen anything else melt?
38. P. erm (9.0) if you put some different kinds of things that erm I can't think what kind of things - it dissolves them kind of thing - like a disprin or tab.
39. I. a tablet.
40. P. it dissolves with little white bits in
41. I. suppose you were Superwoman and you can see inside objects what do you think Superwoman would see in there?
42. P. very little - little tiny bits because it might not dissolve - dissolve completely - it might just have very little bits that we can't see
43. I. little tiny bits - would you like to write that there - you said that was because it might not dissolve completely.



44. P. completely.
45. I. when you say it might not dissolve completely you're saying it might not - what?
46. P. it might not disappear.
47. I. it might not disappear altogether - um hum - very interesting might not dissolve completely which means it might not disappear altogether you think that.
48. P. there'll still be tiny bits you can't see but maybe Superwoman can.

PHASE 3: WEIGHING DISSOLVED SUGAR

1. I. Now Claire we'll think about something else - suppose we have two objects - any two objects - like that - how would you decide which of those two is the heaviest? It might be interesting to know which had the most chocolate - if you had 15p to spend.
2. P. well it might say on the packet or if it doesn't say on the packet you might be able to weigh it.

3. I. you could weigh it or sometimes people just lift them - would you like to lift those and tell me what they are doing to your hands? (4.0) why do people lift things like that when they are trying to find out which is the heaviest?
4. P. because whichever goes down the most is the heaviest.
5. I. well - let's see which is the heaviest of those two - it's difficult using your hands so let's weigh with some scales - I'll adjust it now there we are - if something is heavy ((puts on a weight)) this side goes down - put something on that side - that goes down - if they are both the same weight.
6. P. it goes there.
7. I. it goes in the middle - so would you put one on each side then - so which is the heaviest of those two - which has gone down the most?
8. P. that
9. I. so the Whispa is heavier than the Areo - mow instead of weighing Whispa's and Aero's let's weigh some water - just weigh those beakers of water - so which is the heaviest of those two?
10. P. that one.
11. I. now we'll take some water out of that one and we'll put it in this one
now what can you say about the weights of those two beakers of water?
12. P. they are both the same.
13. I. well take them off please - and would you like to weigh those packets of sugar please.
what can you say about those two packets of sugar.
14. P. they both weigh the same.
15. I. suppose we put the water back on - what would you notice do you think?
16. P. they'ed still weigh the same.
17. I. well put them on and check - just stop it swinging. Ok well will you take that beaker off there and the sugar off perhaps you could open the packet of sugar at the top - what you do is pull those apart - now tip it into the water - that's it - tip it all in - shake it out - give it a stir - hold it with your right hand. Perhaps you'd tell me what's happening in the water there as you stir would you.
18. P. well it's all - it's all dissolving into the middle - it's all going into the middle and then it's very slowly dissolving into the water - the water is becomes a bit - a bit darker that the usual.
19. I. keep stirring.
20. P. well it might be the cup - it's a little thing and then it goes down on one side.
21. I. keep stirring that's fine just keep stirring what can you see now?
22. P. it's more or less gone.
23. I. give me the spoon then - now if I put the beaker back on there do you think it's going to be lighter than that side or do you think it's going to be the same as that side or do you think it's going to be heavier than that side? what do you think?
24. P. it;s going to be lighter.
25. I. lighter ah ha.
26. P. 'cos it dissolving into the water.
27. I. can you tell me why your mind is telling you that - why you think that dissolving makes it lighter?
28. P. because when we were weighing before this - the water and the sugar - we've kind of got rid of the sugar and we've got the water left.
29. I. um hum so we've got rid of the sugar that we could see but you were telling me slao that if we were Super then we'd still be able to see the sugar in there --you thought - you were telling me.
30. P. I don't think we'd be able to see all the sugar there.
31. I. you think some of the sugar
32. P. would have dissolved
33. I. when you say dissolved do you mean that it's gone somewhere?
34. P. it's gone into the water really

PHASE 4: VOLUME OF DISSOLVED SUGAR

1. I. We'll think about another measure people use - I expect you've seen one of those have you
2. P. yes

3. I. it says on it 5ml dose - well this measures 5mls, 1,2,3,4,5 it does it in equal ections you see - this can be used like a spoon to measure doses - let's suppose we take a 3ml dose - have you heard the song about a spoonful of sugar?
4. P. no
5. I. well I expect you'll here it one day - suppose we take a piece of sugar - there's our 3ml dose - suppose we were to put a piece of sugar in there - can you tell me what you would see if you put the sugar in the water
6. P. it would start dissolving and maybe the water would come up a bit
7. I. what is going to make the water come up do you think when you put that in?
8. P. well when a heavy object goes to the bottom of a thing the water rises
9. I. I see
10. P. but when it dissolves it'll go back down again a little bit

PHASE 5: WEIGHT REVISITED

1. I. if you have a look at this again - you rememver we had two beakers with water and sugar there and here we put the sugar into the water - when we put them back on the scales like that what do you notice?
2. P. they both weigh the same
3. I. but lots of children I talk to say this side weighs less - now why do you think they tell me that?
4. P. because they can't see the sugar anymore it's like throwing it away
5. I. I see and if you throw it away then you think that what?
6. P. its not there anymore and it's just water
7. I. I see

Interview with Mar.

I.D. No.:	4405 (7.405)	School-year:	7
Gender:	M	Ability:	average
Age:	11.10	Curriculum:	Leeds Middle Science

PHASE 1: GAINING INTEREST AND ATTENTION

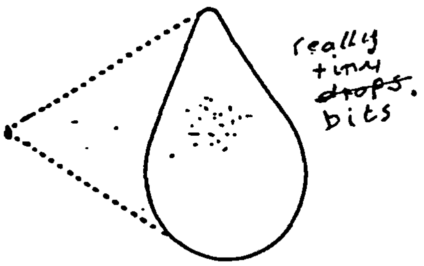
1. I. perhaps you'd be interested in some of these things I've got here ((large sugar crystals)) - just have a look at those and tell me -er feel them handle them - tell me what you might call them (5.0) - if you saw some of those on the street and you said 'pick those up' what would you say? 'pick so and so'up
2. P. are they crystals?
3. I. hum hum - you'd call them crystals - is there anything you find interesting about them --just have a good look at it - tell me anything that's
4. P. it's a funny shape - its square - it's square almost every part of it is square
5. I. anything else fascinate you?
6. P. you can see through it - just - a square
7. I. how do you think it got to be like this?
8. P. was it been cuttin' - has it been cut
9. I. you think it might have been cut?
10. P. yeah
11. I. do they remind you of anything - these?
12. P. er you find them in stones - in different stones 'cos you see - if you pick a stone up - and see sparkling bits and you pick a stone up you find little bits of these
13. I. oh I see
14. P. would you put that one - there's some water in a dish there - put it in the water and we'll come back to it in a bit and see what happens to it

PHASE 2: 'DISSOLVING'

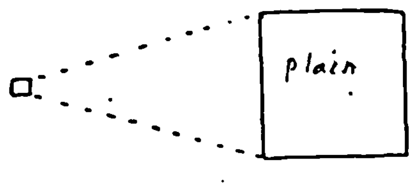
1. I. you have just handled crystals of sugar - what I'd like you to do - just put about half a teaspoonful of sugar into this water and erm - that's fine - just pop that in - give it a stir and pretend you're a commentator giving a commentary on what's happening - well just keep stirring and tell me what's happening in there
2. P. the water's going a funny colour - urm the dark - is type of darkish is a type of greyey white colour - and the sugar - the sugar crystals aren't - aren't floatin' in the top - they're goin' straight to the bottom
3. I. ((place a white card underneath)) here have a nice clean surface - there you are
4. P. thank you and they're just goin' straight to the bottom
5. I. keep stirring
6. P. and gradually they'll all start dissolvin'
7. I. will they?
8. P. they're not staying all - they're not staying pure as I stir them they're dissolvin'
9. I. when you say they're dissolving - what do you think is happening to them?
10. P. (7.0) I don't know really they's just dissolvin' gettin' as I stirred them - gettin' water into them and the spoon's breaking them up then they're all dissolvin' 11. I. you think they're getting water in them do you?
12. P. I think they've all gone now - they've all dissolved
13. I. where do you think they've gone?
14. P. into the water - type of sugar
15. I. why do you think you can't see them anymore?
16. P. (8.0) oh (8.0) I don't really know to be honest
17. I. would you like to tell me about colour again? you were rather keen on the colour when you were dissolving - what
18. P. it's gone a different colour - it's gone - it 'asn't stayed um pure like it was last time - it's just gone --it's not very much changed but it's just gone a - a greyey tint - not much
19. I. um hum - well we'll just put that away a minute let's just think about one of these granules of sugar here's some here

((on I's finger)) let's just think about one of them there's one sugar granule and we just want to think about it going into the water - would you like to draw for me what you think happens to it in the water as you were stirring it - what do you think happens first to it?

20. P. er it'll all break up - like that and gradually as stir it the spoon gets to it un it'll all break up
21. I. you think it'll break up?
22. P. yeah an' then it'll if yer stir it a bit more it'll dissolve into the water
23. I. suppose then you took some snapshots of it at different times here ((last diagram)) you can't see it anymore we'll say - what happens to it between when it's like that and you can't see it - just show me
24. P. on there it'll get - it'll be much smaller then here it'll be a few dots - there'll be a few bits of granules and then here there's nothing there because the spoon's stirring it up and breaking it up and it's all dissolving
25. I. I see
26. P. an' it'll get smaller and smaller here as it goes
27. I. suppose that you were Superman urm and you were looking into this ((beaker in diagram)) - you are looking into there ((actual beaker)) - now you know Superman has X-ray eyes so he can see the fine detail in there - you were telling me the sugar went into the water - where do you think the sugar is - in the water there now?
28. P. whereabouts - in the water?
29. I. yes - if you had X-ray eyes where do you think it would be in the water?
30. P. I think it would probably be at the bottom
31. I. I see - just put 'at the bottom'
and suppose we looked at drops - suppose Super-Mark looked at these drops what would super-Mark see inside there if he had X-ray eyes?
32. P. inside the drop?



33. I. yes
34. P. just - probably (1.0) - tiny really - really tiny little bits that you couldn't see out with bare eye just right - right tiny little bits just water in around but - an' if you stirred it a bit more it would probably go away but if you saw it just like I did it it 'ud be very tiny little drops
35. I. I mean now it's gone into the water - we are talking about put 'really tiny drops there' would you?
36. P. tiny drops
37. I. really tiny drops you said did you - these are drops are they or bits?
38. P. bits
39. I. is it bits? yes um hum really tiny bits in there an er let's suppose you could - er Super-Mark looked inside one of these granules - we've drawn it bigger to make it clear - what detail do you be inside each of these granules?
40. P. I don't know really I think you could probably see through them
41. I. so you'd think they'd be plain



42. P. plain - shall I write plain?
43. I. write it inside here - the box
44. P. plain
45. I. fine thank you

PHASE 3: WEIGHING DISSOLVED SUGAR

1. I. Imagine that you have two articles - bricks, stones anything and I said to you 'which is the heaviest of those two stones -

those two jars - anything how would you find out which was the heaviest?

2. P. er (1.0) put them on some scales - put them on some scales and do a - see the reading - which one's heaviest? It's probably this one ((glass jar)) because this one's in a tupperware and this is a big glass bottle so this 'll be the heaviest

3. I. I notice you are lifting them up in your hands how does that help you?

4. P. erm you can tell difference between these because one of them all weigh your hand down and the other one probably won't weigh your hand down as much - you can see - you can tell the difference - which is the heaviest - that one's the heaviest 5. I. why do you think things like this do weigh your hand down? what

6. P. because these are made out of - type very - probably these are made out of plastic er type stuff and it's right light

7. I. I see - I was just thinking if you had any two stones or any two 'anythings' they all weigh down a bit don't they - now why do you think they weigh down a bit in your hands?

8. P. because you couldn't really tell because your hands aren't very aren't as accurate as the scales

9. I. no

10. P. you could be wrong 'cos these could be the lightest and this one could be the heaviest so they could be wrong - with your hands

11. I. but they are both weighing down - what I am asking you is why do you think they do weigh down on your hands? what is the

12. P. the content of the sugar - how heavy the sugar is and how heavy the glass is - how big the glass is made - and this one's quite heavy but not as heavy as this

13. I. right - well let's try the scales then and er we'll see - let's just stop this swinging ((adjusts balance)) ((balance explained)) so if we put these two things on

14. P. yeah that one's the heaviest

15. I. now let's use some water instead right put those on and find out which is the heaviest of those two

16. P. that one by a tiny little bit 'cos it's not dead on

17. I. OK this side is heavier so let's take some out of this one what can you tell me about those two beakers of water now?

18. P. they 'ad different amounts of water in them each that - that one 'ad the most in at first until you took some out 'cos it went up there and that one didn't 'ave as much in but now you took some out they both got the same amount and they'd going and they dead on the marker say they both weigh the same

19. I. OK then - take them off and I would like you to weigh a couple of packet's of sugar - would you weigh those one on each side what can you say about those two packets of sugar?

20. P. that one's just over

21. I. this one is a bit heavier than that one isn't it se we'll take a bit out of this one still heavier isn't it ((takes more out)) ((re-weighs))

22. P. just about yes right

23. I. both about the same aren't they ok well suppose then we were to put these back on - put these two beakers back on - what would you expect if those two weigh the same and these two weigh the same?

24. P. they'd be the same - in the middle

25. I. OK we'll do that and see what happens - quite right - in the middle Can you open this one ((packet of sugar)) and put the sugar in the beaker please (12.0) it will come out that's ok it will come out if you tip it. Tip it right up that's it. that that's right. there we are stir that up and tell me what you think is happening in there

26. P. that's gone all murkey. can't see through it now

27. I. hum hum. keep stirring

28. P. the granules are breaking up gradually

29. I. hum

30. P. I can see right through it now. at the beginning when I first started to stir it I couldn't see through it at all I can see through it now and it 'as all gone

31. I. right thankyou. now suppose we take this beaker and put it back on this side ((yellow)) would the yellow side be heavier than the red side or would it be lighter or would they both be the same. which

32. P. er: (6.0) I think (1.5) I think this one ((red)) I think will be a bit a bit heavier I think it will be just a bit heavier

33. I. hum hum what makes you think that Mark?

34. P. because this one's got umm: well. we've added the sugar to it as well. this one's got no sugar in an' its got the sugar on the side
35. I. yeah
36. P. so I think this red one'll probably be heavier because it's got the more on it so I think this one'll be heavier
37. I. You think that will be heavier
38. P. yes
39. I. hum hum
40. P. yeah
41. I. so in that case you think that this ((yellow i.e. S in W)) is lighter for some reason don't you
42. P. yeah I think that one's lighter
43. I. what's going to make it lighter do you think
44. P. cos it's only got that on it it hasn't got the sugar either
45. I. hum hum. so where's the sugar then now?
46. P. in the water
47. I. hum hum and if you put sugar in water it makes it lighter is that what you are saying?
48. P. yeah I think yeah I think this one ((red)) will be heavier
49. I. hum hum (3.0) and how does that happen do you think that when you put sugar in water it gets lighter
50. P. I think cos when you put the sugar in the water there's nothing left on there then there's just the water if you put it on
51. I. hum hum
52. P. then with this one there's just water in there there's nothig else
53. I. hum hum
54. P. so I think that this one probably will be heavier
55. I. I see. right thanks

PHASE 4: VOLUME OF DISSOLVED SUBSTANCE

1. I. what do you think would happen to the water?
2. P. it would rise because we said it would dissolve and the bits would make it rise
3. I. hum hum (.) well what would happen when we first put it in do you think?
4. P. when I first put it in?
5. I. when you just put it in
6. P. you get the for it to dissolve it become a murky colour first and then gradually it 'ud rise a bit higher
7. I. hum hum
8. P. and I think that's what would happen (.) it would rise
9. I. so just after we put it in what's going to happen did you say?
10. P. it'll go a murky colour and then it'll dissolve and then it'll rise
11. I. well you put it in and we'll see what happens (.) dead on five at the moment (3.0) now its 5.2 about
12. P. yeah
13. I. yeah (.) well why do you think it has gone up?
14. P. 'cos with this (.) this is probably the crystal is probably heavier than the water and it's making the water rise cause it's it's an extra thing in it
15. I. um:
16. P. so it's making the water rise
17. I. now just ((sometime)) before you put one of those into this dish here (.) where has it gone now?
18. P. you can just see it (.) just there you can just tiny very see it just dissolving
19. I. now suppose we left that one in here until you couldn't see it anymore what do you think would happen to the water?
20. P. it would rise a bit more
21. I. hum hum
22. P. I think it would probably rise a bit more and get higher and higher
23. I. yeah (.) and why do you think that is?
24. P. because when it's dissolving the water'ud (.) the sugar would add to the water and the water would get higher 'cos the sugar's adding to it
25. I. I see
26. P. so I think it'ud probably get higher
27. I. hum hum (.) thanks very much

Interview with Fle

I.D. No.:	6605	School-year:	10
Gender:	F	Ability:	average
Age:	15.3	Curriculum:	Biology

PHASE 1: GAINING INTEREST AND ATTENTION

1. I. One of the first things I would like you to have a look at is these ((large sugar crystals)) If you would like to pick one up and er touch it feel it - perhaps you would like to tell me first of all what you would call something that looked like that?
2. P. crystals
3. I. I see
4. P. made from sugar
5. I. and what made you think it was a crystal?
6. P. it was the shape really
7. I. I see - anything in particular - I mean - these stones have got shape haven't they?
8. P. when you see a crystal it's usually shaped like this - it's shaped a bit like a diamond as well
9. I. have you any idea what gives it a shape like that?
10. P. it's been cut
11. I. so you have the idea that manufacturers cut them?
12. P. yes
13. I. I see - did you notice anything else besides its shape?
14. P. it's clear - it feels like when you've been touching something in your hand like dust like a film of dust in your hands I thought it was sugar
15. I. I see and um er would you describe them as being hard or soft or what
16. P. hard
17. I. um hum some materials like this are soft ((polythene)) others are hard some in between - have you ever thought about hardness and softness what might cause it?
18. P. no not really
19. I. does anything spring to your mind at the moment as to why some things like that are hard and other things are soft?
20. P. how they are made really this might have been soft then it's all been compacted together or frozen like that

PHASE 2: 'DISSOLVING'

1. I. Here the same thing in a smaller form I'm sure you'll recognise that
2. P. sugar
3. I. yes - would you take half a teaspoonful of that put it into there and give it a stir and er tell me what - just put a piece of paper underneath to see what' going on - keep stirring - perhaps you could pretend you're a radio commentator giving a commentary on what' happening inside
4. P. well the sugar's sunk to the bottom when you stir it it's moving around it's dissolving I think I don't know it's twirling around when you stir it then when you leave it it sinks back to the bottom
5. I. keep stirring - you're talking about dissolving - erm what do you think happens to things when they dissolve? what goes through your mind?
6. P. they um well like it's hard to explain they um they just like break up an' dissolve and get thinner they dissolve breaking up
7. I. you imagine them breaking up
8. P. yes
9. I. have you thought why something so hard as sugar should break up in water? what do you think causes something so hard to
10. P. just think it'd be something inside the sugar you know or what the sugar's made of and everything just dissolves - gets so thin and just dissolves away
11. I. hum hum so what's happened now do you think?
12. P. it's all gone
13. I. where would you say it has gone?
14. P. in the water

15. I. you still think it's in the water do you even though you can't see it? what makes you think it is still in the water even though you're unable to see anything there?

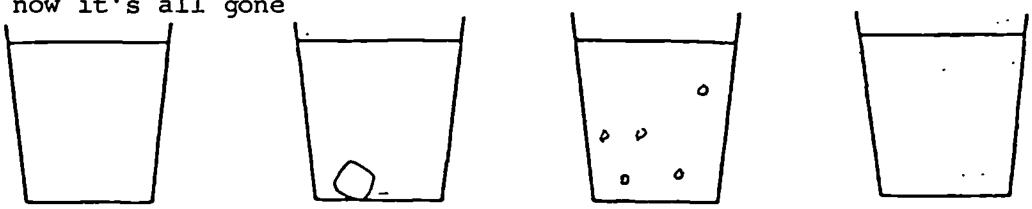
16. P. because it can't 'ave evaporated and it couldn't 'ave gone anywhere else - only in the water

17. I. now these words you use are rather interesting 'gone into the water' urm what do you imagine water is like that sugar can go into - as you put it?

18. P. um well it's liquid really and just like when the sugar's put in it's by itself and then when its put into the water it being mixed in with something its like mixing in with the water getting thinner thinner so it dissolves and there's nothing else there so its just in with the water - gone with the water - all separated there's not a piece by itself so it's all over the water

19. I. hum hum - I see - now suppose that this ((diagram)) represents one of these little crystals of sugar and it's going into thw water - by the time it's reached here we can't see it any more - I wonder if you would like to draw for me what happens to this crystal between the time that it's here and it has completely gone there

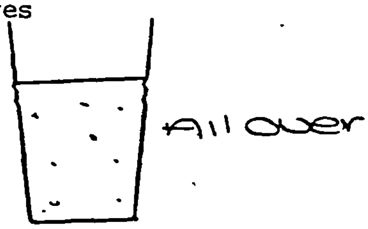
20. P. now it's all gone



21. I. just imagine for a moment there' a person called Super Fleur who has Superwoman qualities and can see inside there now - if we look at this we can't see the sugar in there but you have told me you are convinced there is sugar in there - but if you had X-ray eyes like Superwoman you'd be able to see what it's like inside there would you like to show me where you'd expect the sugar to be?

22. P. shall I just draw little dots

23. I. draw whatever you think the sugar is - yes



24. P. all over

25. I. where did you get that idea from - that it's all over?

26. P. well if it's all broken up so its not like settled anywhere if it'd been settled we'd 'ave seen it really - so it's all mixed in everything

27. I. um hum does it strike you as strange that it could be all over or not - you've used this word settled and things very often settle don't they - so what convinces you that it's all over? - rather than

28. P. I think if it'd been settled the - well if one crystal 'ad 'ave been settled they'd all 'ave been settled and they'd all go down to the bottom and you'd see them again and the crystals would be all down there and not diffused or whatever

29. I. interesting - are you suggesting that when they get together they form crystals again?

30. P. not form crystals but they'd be in the same place and you'd see them more but they all might be broken up there

31. I. so why are you suggesting we can't see them at the moment?

32. P. because they're all broken up and like when it was crystal it was all together now it's been broken up water passes through it so we can't see it any more

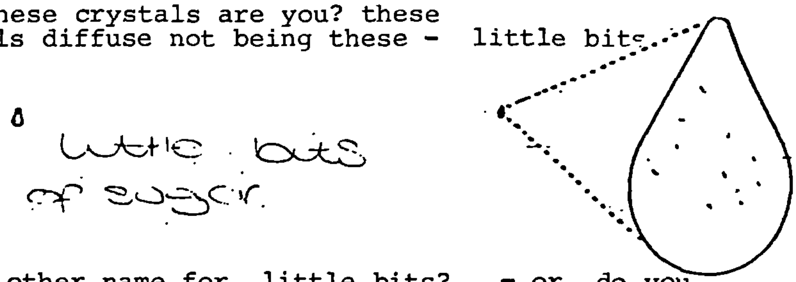
33. I. um hum is that because of its size you can't see it? - you said it's all broken up or is there any other reason

34. P. I don't know actually um I don't think of it's size I think it's the water as well not getting into the cube but surrounding the cube dissolving it it might be because of its size 'cos it's got smaller

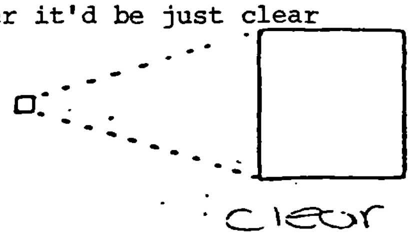
35. I. have you any idea of the size of these things?

36. P. no

37. I. well you mentioned 'all over' just write all over at the side imagine now that we just looked at a drop of the liquid in there now and with your Super Fleur eyes magnifying many millions of times what do you think you would see inside a drop - would you draw something?
38. P. er crystals all over scattered all over
39. I. so you're calling these crystals are you? these
40. P. no well the crystals diffuse not being these - little bits sugar



41. I. have you used any other name for little bits? - or do you imagine little bits do you?
42. P. yes
43. I. hum hum now suppose again with your Super Fleur eyes you looked at one of these granules - you looked inside it - magnified again many millions of times urm what do you think the sugar would be like inside?
44. P. I just think it would be clear actually you know with just like I think it would be clear not crystals or solid or form - its not like its got little bits all over it'd be just clear
45. I. clear?



46. P. you know the odd dot in a place or two but not dots all over
47. I. so you imagine it like jelly - a lump of jelly clear
48. P. um clear
49. I. well just write clear would you underneath there - thank you that's very interesting. Well you have more or less answered the next thing I was going to ask - I have asked a number of people about this and we generally get something like this or one or two other things. From what you said I suppose this is the nearest to what you were saying
50. P. um
51. I. and then when it's dissolved in water any of those?
52. P. ((points))
53. I. um hum

<u>PHASE 3: WEIGHING THE DISSOLVED SUGAR</u>

1. I. suppose we have two objects ((shown)) It's like you to tell me how you'd compare their weights - you might see them both advertised at 15p and you want value for money how could you decide quickly which was the heaviest?
2. P. pick them up - I'd say this was the heaviest 'cos that's got holes in
3. I. there you are using something about your knowledge of the inside. You said pick them up and usually when you pick things up you do this - what are these really doing in your hands?
4. P. well - which is the heaviest you'll lift that up more that the lightest like a weight when you put a weight on the scale if you've got the heaviest the weight goes down the lightest stays up
5. I. and what makes it go down?
6. P. because the weights bigger and heavier
7. I. so your impression of weight is a sort of heaviness idea is it?
8. P. um
9. I. this will take you back to primary days a bit er it is the simplest one that I could carry around schools - when these two marks are opposite one another it means we've got the same weight on each side - if this side is heavier it moves over there and so on - would you like to weigh those two - so which is the heavier of those two?
10. P. this is about the heaviest
(further balance instruction)

22. P. I think it might not go back exactly on three but lower and therefore down
23. I. um hum - and it'll go down a bit because - you said what?
24. P. because the sugar's spread out more and diffused it's not one solid shape
25. I. so you have the idea that when things are diffused they don't take up as much space as when they're in one place - is that what you are telling me?
26. P. um:
27. I. right thanks

PHASE 5: WEIGHT REVISITED

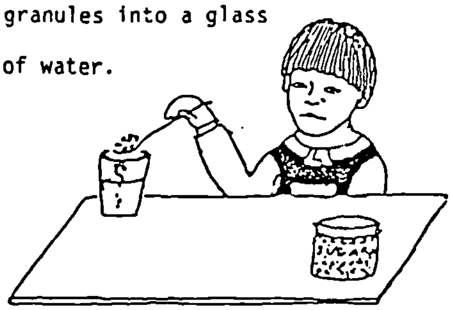
1. I. Just have a look at this before you go - we had these two beakers one with sugar in and one with water - lots of children tell me what you told me that this one becomes lighter - when the sugar's dissolved - in actual fact it stays the same as you can see so what do you think is going on here - why is it so many people tell me that er
2. P. people - I don't know what's happening but I think people can't see the sugar - must have dissolved - can't see it anywhere else and that's all compact so they think that might be heavier - this one
3. I. so what do you think the reason is now that you've seen the two are the same - why do you think they are the same?
4. P. well the sugar's in the water - it does - it's even dissolved - it still stays as heavy - it makes the water just as heavy - that's the weight of the water
5. I. um hum - I see

APPENDIX 3.3 THE SURVEY TASKS [1]

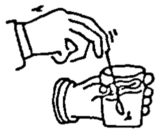
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar granules into a glass of water.



2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.

What do you think has happened to the sugar granules?

____

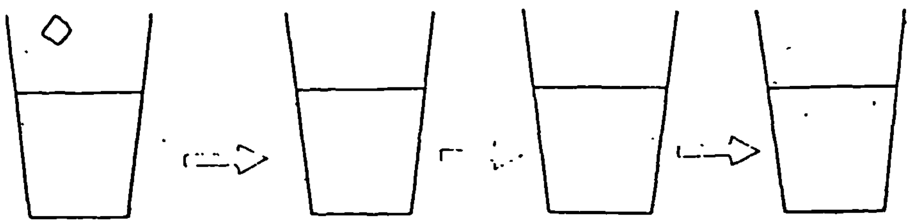
____

____

Why can't Liz see the sugar granules?

____

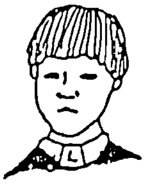
Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



Thank you for your ideas   Boy ☐   Girl ☐   Age____ ____

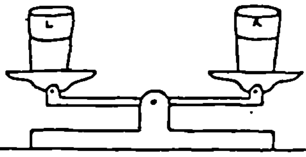
1. The original task sheets have been reduced by 20% in these reproductions.

A-3.3.2

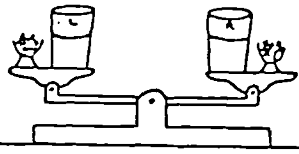


Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

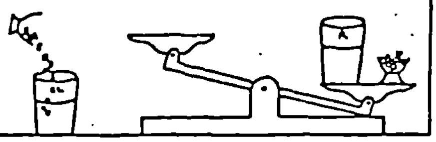
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



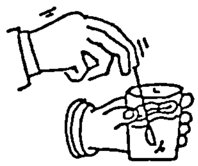
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



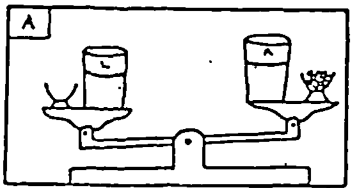
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

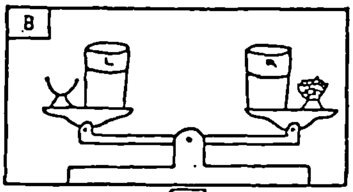


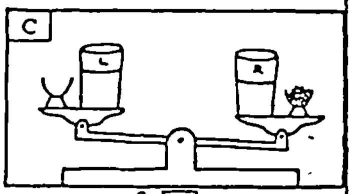
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☐ B ☐ C ☐

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because..

....

....

....

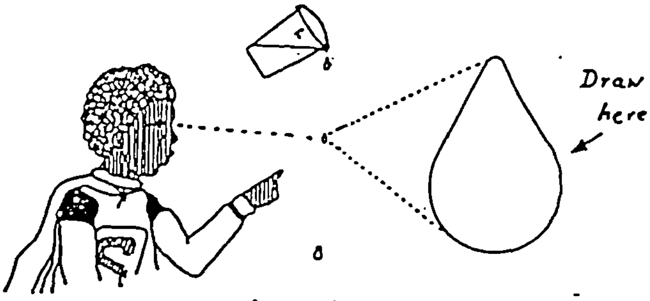
Thank you for your ideas. Boy ☐ Girl ☐ Age ____ ____

Rob is pretending he is Superman,

he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

Draw the tiny detail you think that Superman Rob can see inside one drop.

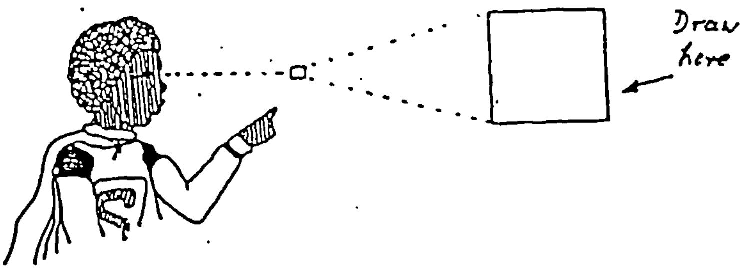


Describe your picture of the 'inside' of the drop.

____

____

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

____

____

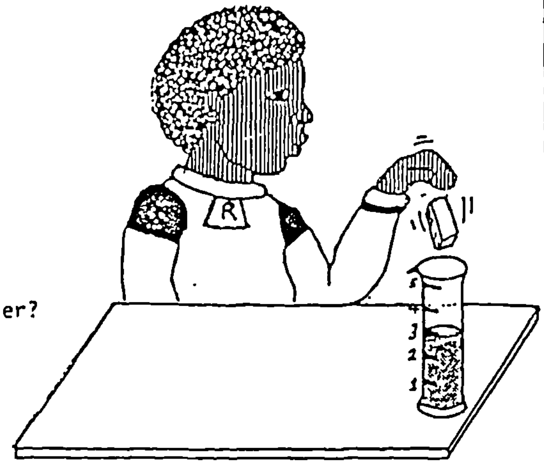
____

Boy ☐ Girl ☐ Age ___ ___

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering what will happen to the water if he puts a large sugar crystal into it.



What do you think will happen to the water?

____

____

Why do you think that?

____

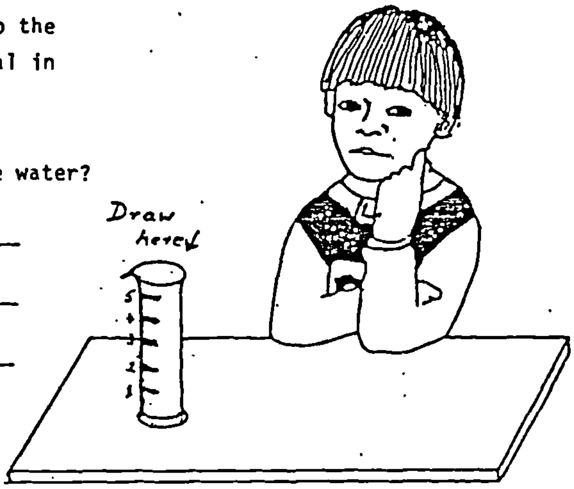
____

Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)

Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water until it cannot be seen.

What do you think will happen to the water?



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____

____

Why do you think that?

____

____

____

Thank you for your ideas.

Boy ☐ Girl ☐ Age_____ _____

APPENDIX 3.4 EXAMPLES OF COMPLETED SETS OF SURVEY TASKS FROM A BOY AND GIRL IN EACH YEAR GROUP.

Pupil I.D. No.	Gender	Age	School year	Curriculum	Date tasks completed
Rac 2030 (3.030)	F	8.2	3	Primary Science	14.05.85
Nei 2055 (3.055)	M	8.5	3	Primary Science	16.05.85
Mag 3046 (5.306)	F	9.0	5	Leeds Middle School Science	17.10.85
Pau 3107 (5.107)	M	10.0	5	Junior Science	14.05.85
Emm 4072 (7.072)	F	12.0	7	Leeds Middle School Science	9.11.84
Har 4001 (7.001)	M	11.10	7	Leeds Middle School Science	18.10.84
Mar 6013 (10.013)	F	14.8	10	C.S.E./'O'level Biology,Physics Chemistry	30.04.85
Ric 6141 (10.141)	M	15.2	10	C.S.E./'O'Level Biology,Physics Chemistry	11.06.85
Car 7014 (12.014)	F	17.2	12	'A' level Chemistry Biology	15.03.85
Jon 7042 (12.702)	M	17.3	12	'A' level Biology Computer Science	11.06.85

Survey responses from Rac

I.D. No.: 2030 (3.030)　　School-year: 3

Gender: F　　Curriculum: Primary science

Age: 8.2

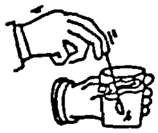
2030_3

Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

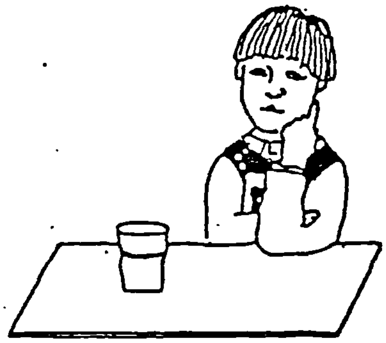
1. Liz is putting a spoonful of sugar into a glass of water.

2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



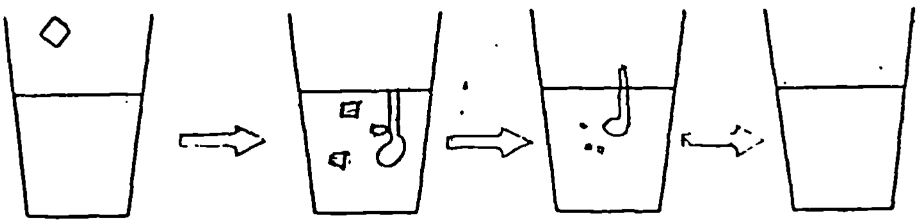
What do you think has happened to the sugar granules?

I think when she stirri because it has brok up.

Why can't Liz see the sugar granules?

Because in has brok up.

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



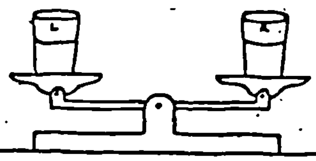
Thank you for your ideas　　Boy ☐　Girl ☑　Age 8 2

2030g

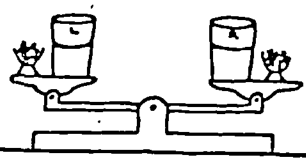
30

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

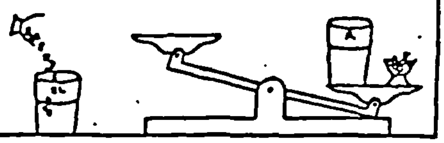
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



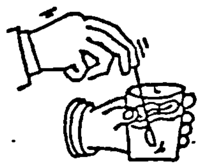
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



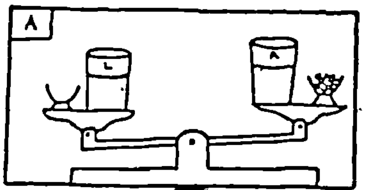
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

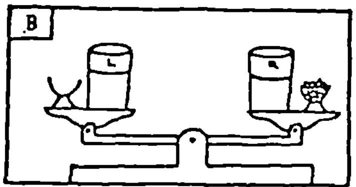


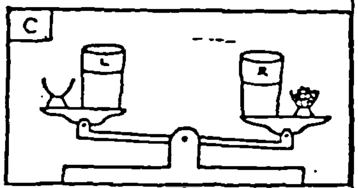
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☑ B ☐ C ☐

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because...the....mug......has.....the.....s.ager.. ..in....and.......it......has......got.....the...egg....cup..on. ..top.....saw......A......must....by......the......efes.....

....

Thank you for your ideas. Boy ☐ Girl ☑ Age 8 2

A-3.4.3 (Rac)

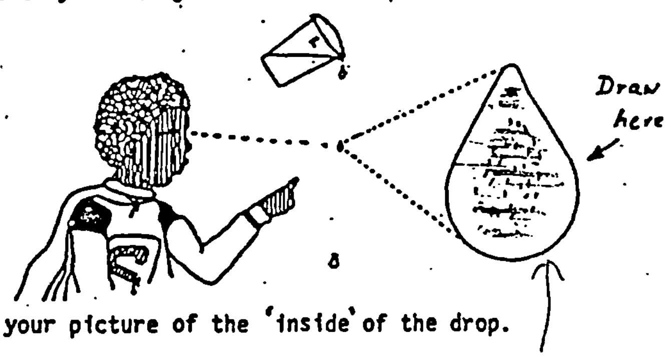
2030g

Rob is pretending he is Superman,

~ he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

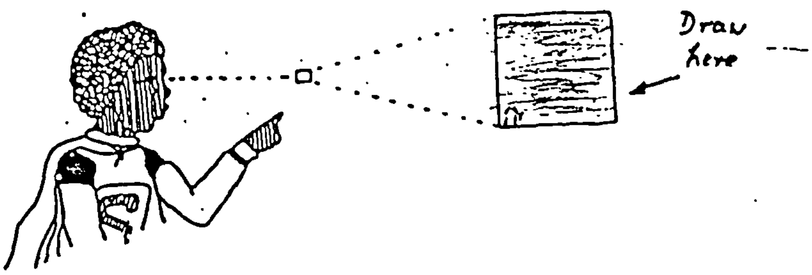
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

In my drop if you look carefli you can see th suger

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

I have drorn the suger in one corn at the botm

2030g Boy☐ Girl☐ Age 8 2

2030g

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering <u>what will happen to the water</u> if he puts a large sugar crystal into it.

What do <u>you</u> think will happen to the water?

It will go up to

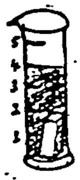
4.

What makes you think that will happen to the water?

I think it will just will go up to 4.

Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)

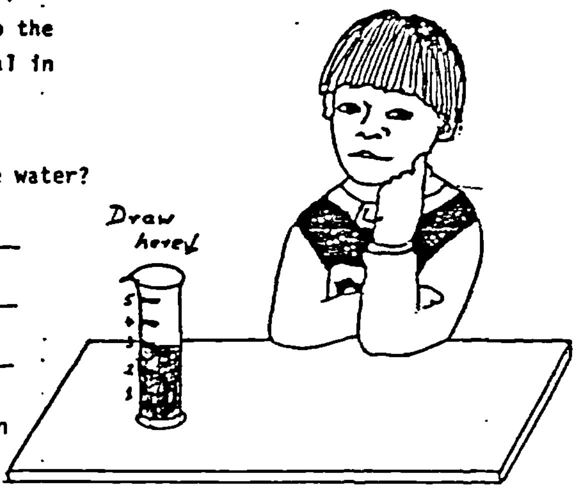


Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water <u>until it cannot be seen</u>.

What do <u>you</u> think will happen to the water?

It will go donw

to 3.



What makes you think that will happen to the water?

I think the water will go back from where it starid

Thank you for your ideas. 2030g Boy ☐ Girl ☑ Age 8 1

Survey responses from Nei

I.D. No.: 2055 (3.055)

School-year: 3

Gender: M

Curriculum: Primary science.

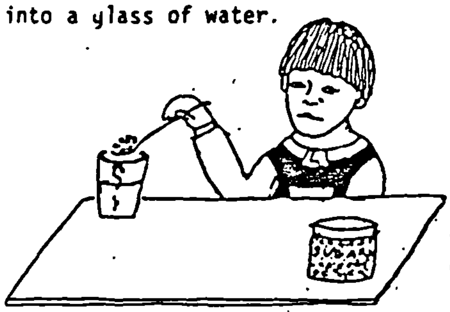
Age: 8.2

2055b

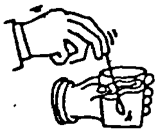
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar into a glass of water.

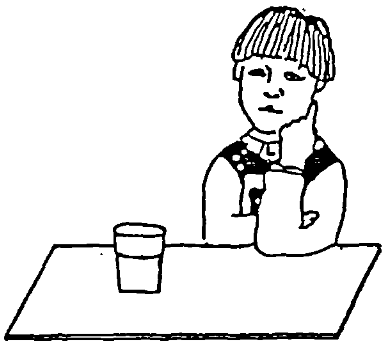


2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



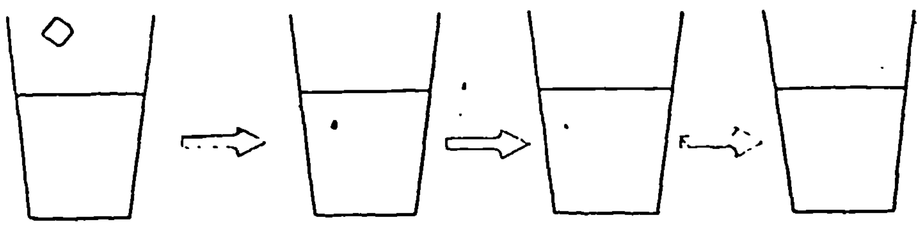
What do you think has happened to the sugar granules?

I think the sugar granules have grown smaller

Why can't Liz see the sugar granules?

because they have grown smaller

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



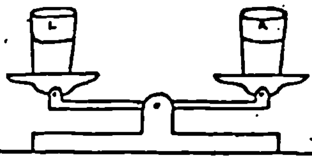
Thank you for your ideas

Boy ☑ Girl ☐ Age 8 5

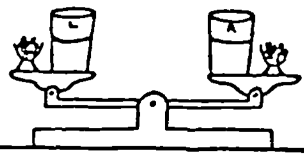
(2055b) 55

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

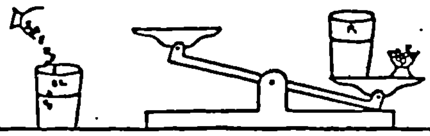
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



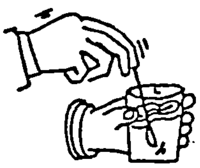
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



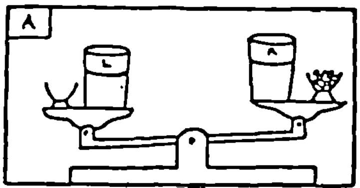
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

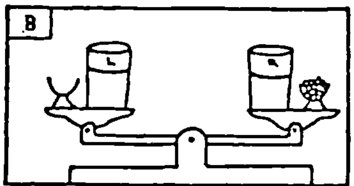


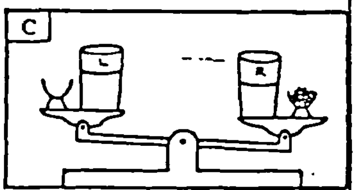
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☐ B ☑ C ☐

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because..the..granules.....are...still...there because...there.....still...in...the....water.......

....

....

Thank you for your ideas. Boy ☑ Girl ☐ Age 8 5

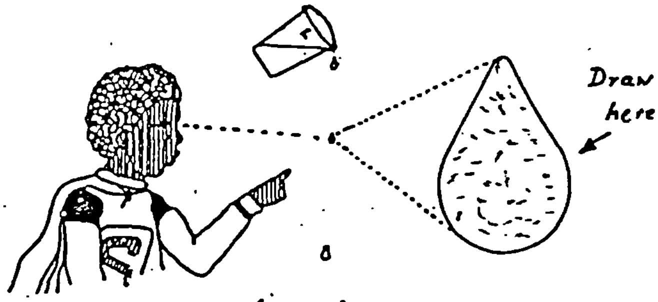
2055b

Rob is pretending he is Superman,

~ he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

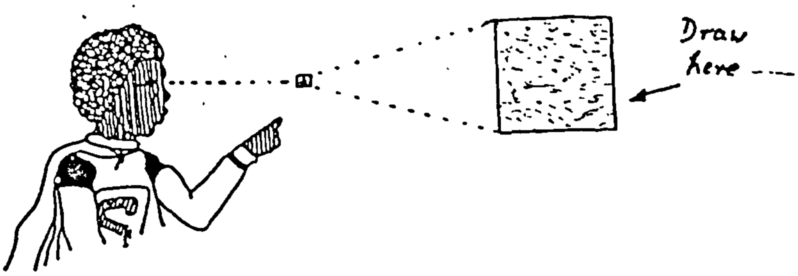
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

Granules OF sugar

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

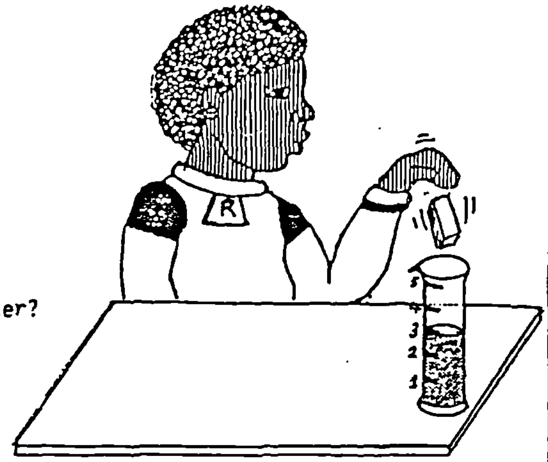
2055b. Boy☐ Girl☐ Age 8 5

2055b

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering <u>what will happen to the water</u> if he puts a large sugar crystal into it.



What do <u>you</u> think will happen to the water?

it will go salty

or sweet

What makes you think that will happen to the water?

because the crystal will disolvs in

the water

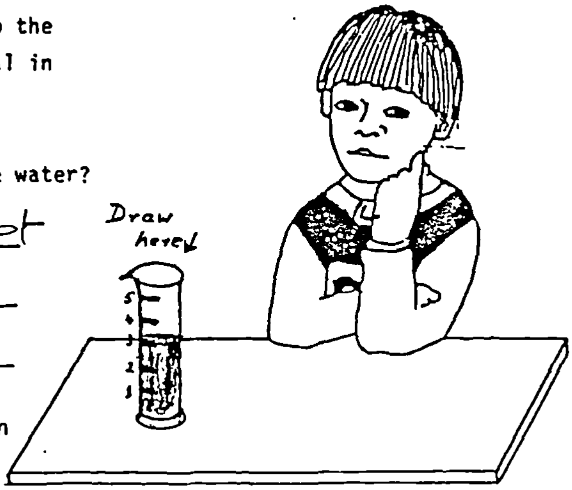
Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)

Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water <u>until it cannot be seen</u>.

What do <u>you</u> think will happen to the water?

it will go sweet



What makes you think that will happen to the water?

because the crystal disuvs

Thank you for your ideas. 2055b Boy ☑ Girl ☐ Age 8 5

Survey responses from Mag

I.D. No.: 3046 (5.306)

Gender: F

Age: 9.0

School-year: 5

Curriculum: Leeds Middle School Science.

30469

Liz is playing with sugar and water.

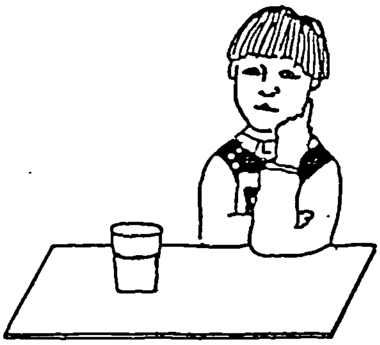
Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar into a glass of water.

2. She is very busy stirring.

When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



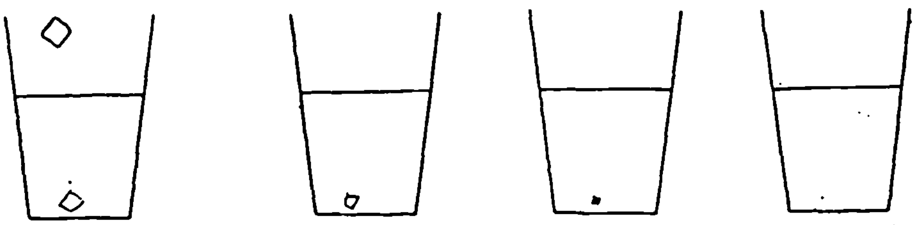
What do you think has happened to the sugar granules?

They've gradually ~~getting~~ got smaller and smaller until you can't see it anymore (dissolving).

Why can't Liz see the sugar granules?

Because they've got so small you can't see them.

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.

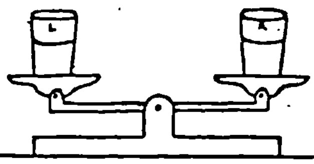


Thank you for your ideas Boy ☐ Girl ☑ Age 9 2

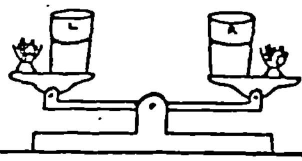
30465

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

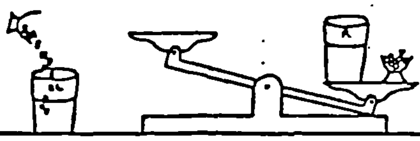
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



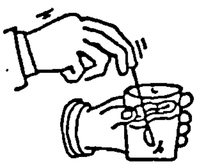
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



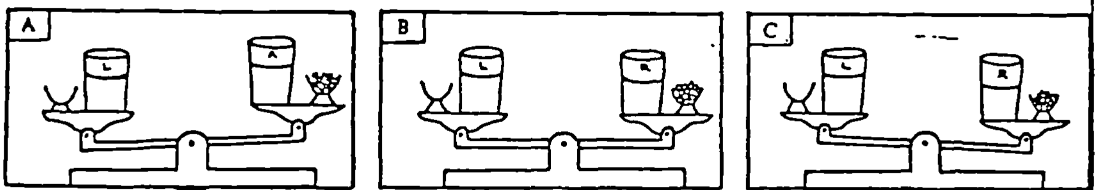
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.



4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:



A ☐ B ☑ C ☐

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because...all...I...am...doing...is...putting ..the...sugar...into...the...mug, it's...only...in...a...... ...different...z...place. Even...though...the...suger..... seems...gone...its...only...got...smaller, there's only...more of it. its the same weight.

Thank you for your ideas. Boy ☐ Girl ☑ Age 9 2

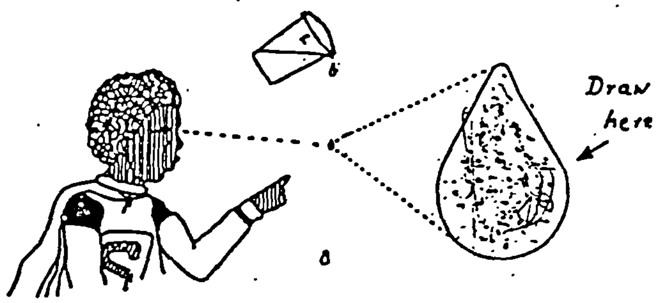
3046g

Rob is pretending he is Superman,

he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

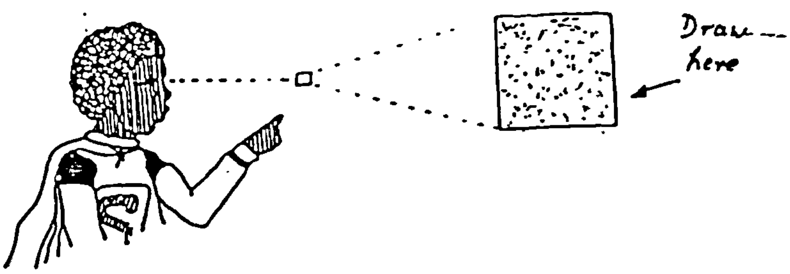
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

I think it's made up of lots of those sugar granules and the water.

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

Again I think it is made of bubbles and smaller sugar granules than the one above, so small you can hardly (cannot) see it.

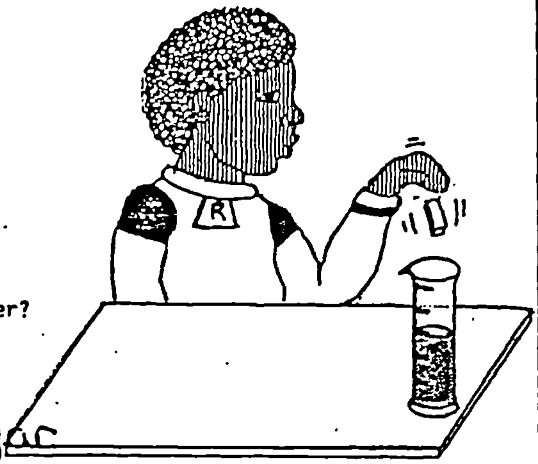
Boy☐ Girl☑ Age 9 2

3046g

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering what will happen to the water if he drops a large sugar crystal into it.



What do you think will happen to the water?

It will go higher when you put in sugar

Why do you think that?

Because there is a force from the sugar forcing the water up.

Draw the water after Rob has put the crystal into the measure

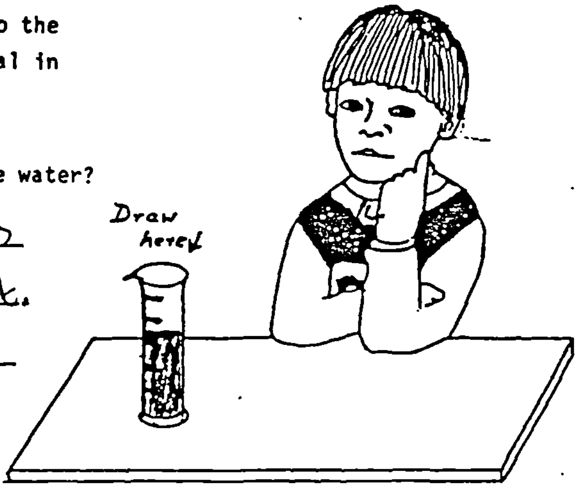
(Shade with your pencil to show where the water is)

Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water until it cannot be seen.

What do you think will happen to the water?

The water will go back a LITTLE bit.

~~b~~



Why do you think that?

Because some of the force has gone so the water can return a bit.

Thank you for your ideas.

Boy ☐ Girl ☑ Age 9 2

A-3.4.1(Pau)

Survey responses from Pau

I.D. No.: 3107 (5.107)

School-year: 5

Gender: M

Curriculum: Junior science

Age: 10.0

3107b

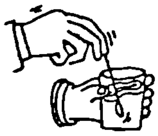
157

Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

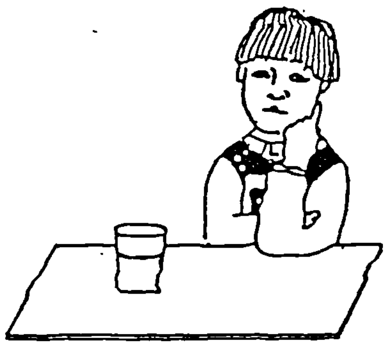
1. Liz is putting a spoonful of sugar into a glass of water.

2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



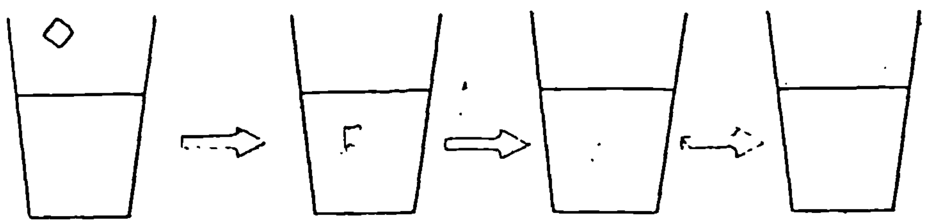
What do you think has happened to the sugar granules?

I think the sugar granules have disolved in the water.

Why can't Liz see the sugar granules?

Because they have disolved

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



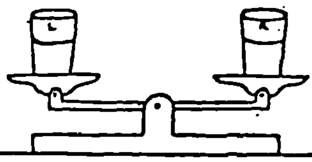
Thank you for your ideas

Boy ☑ Girl ☐ Age 10

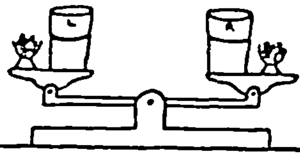
3/076

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

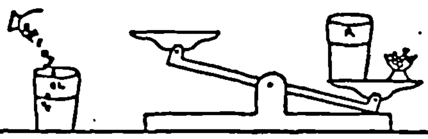
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



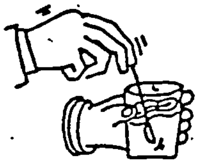
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



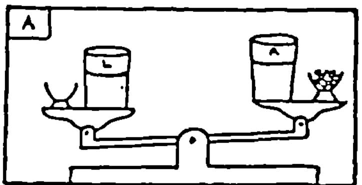
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

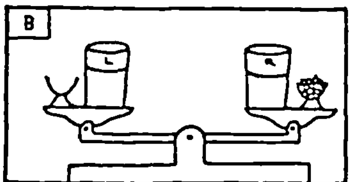


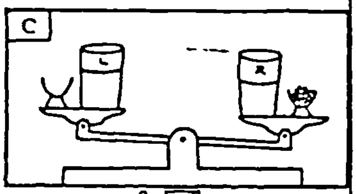
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☐ B ☐ C ☑

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because...when the sugar granules disolve there will not be any more granules left so the granules will be like thin air. But Robs granules will still be there

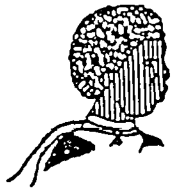
Thank you for your ideas. Boy ☑ Girl ☐ Age 10

A-3.4.3(Pau)

31076

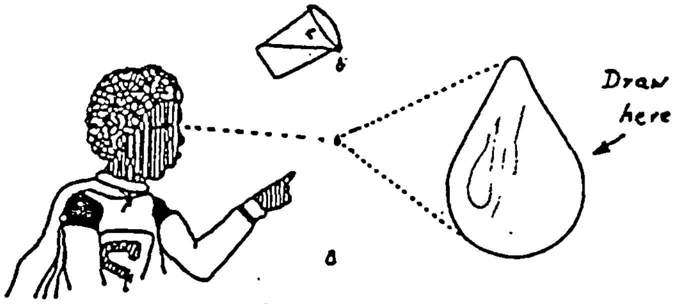
Rob is pretending he is Superman,

he can see the detail inside tiny objects.



Imagine that a drop from Liz's mug is magnified many thousands of times.

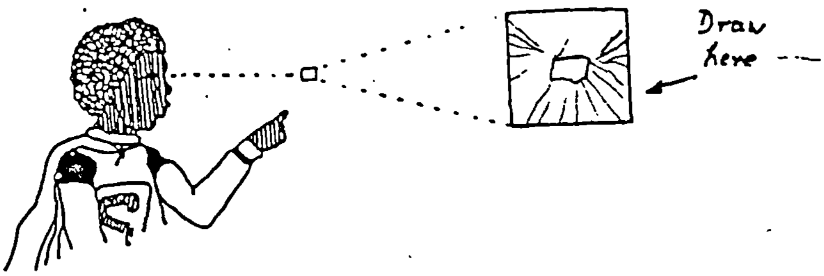
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

My picture is just a reflection of light because there is nothing inside clear water

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

I think that the granule will be like a tunnel going in and in till it gets to the centre

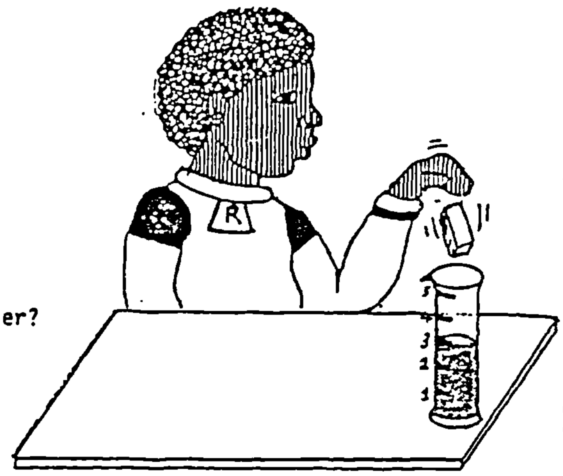
Boy ☑ Girl ☐ Age 10

31076 | 15

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering <u>what will happen to the water</u> if he puts a large sugar crystal into it.



What do <u>you</u> think will happen to the water?

I think the water will rise

What makes you think that will happen to the water?

well when my brother was doing his homework he had to see how much the bath water would rise if he put his hole body in it

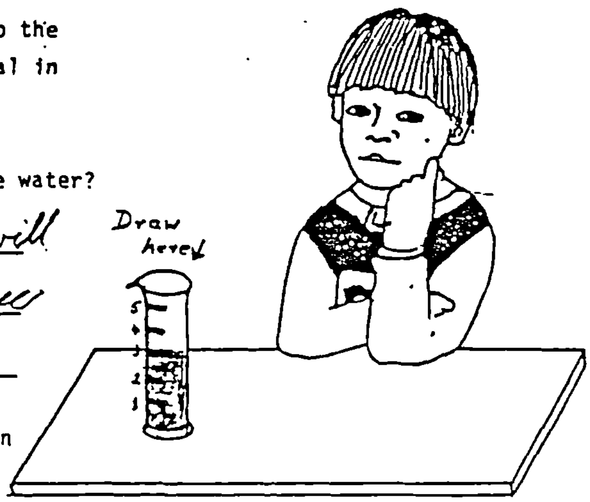
Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)

Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water <u>until it cannot be seen</u>.

What do <u>you</u> think will happen to the water?

I think that the water will go back to the same stace



What makes you think that will happen to the water?

Well if there is nothing in it it will just be the same.

Thank you for your ideas. 31076

Boy ☑ Girl ☐ Age 10

A-3.4.1(Emm)

Survey responses from Emm

I.D. No. 4072 (7.072)

Gender: F

Age: 12.0

School-year: 7

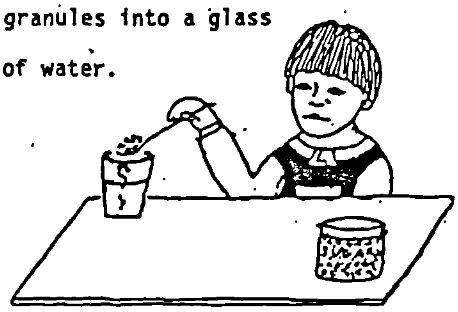
Curriculum: Leeds Middle School Science

4072g

Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

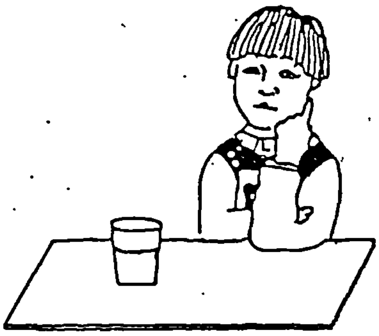
1. Liz is putting a spoonful of sugar granules into a glass of water.



2. She is very busy stirring.

When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



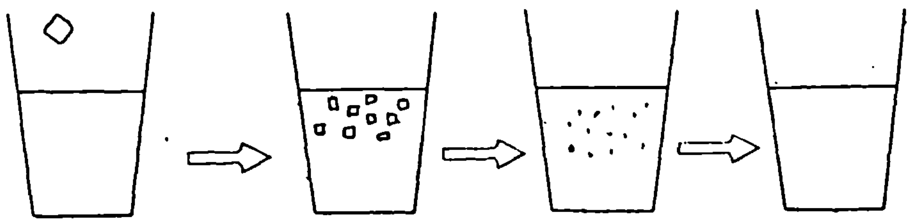
What do you think has happened to the sugar granules?

The Granules have Disouled into the water.

Why can't Liz see the sugar granules?

Becaus they Have melted away.

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



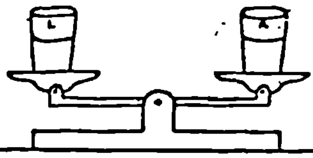
Thank you for your ideas

Boy ☐ Girl ☑ Age 12 0

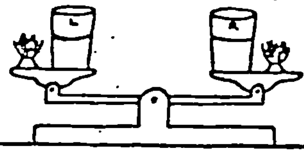
(4072g) 72

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

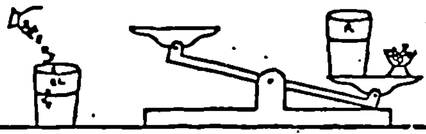
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



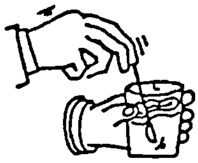
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



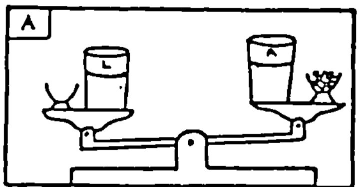
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

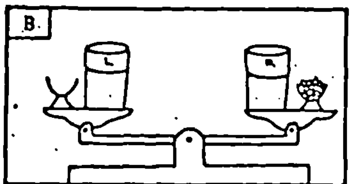


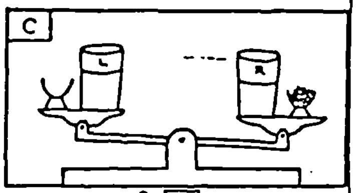
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☐ B ☐ C ☑

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because...when...you...put...Some.thing...in......
...water....that...Disolves....Bacomas....lighter....Bacaus..
...it...melts..away...but...Robbis...granuales...Havenot......
...Dissapeard...

Thank you for your ideas. Boy ☐ Girl ☑ Age 12

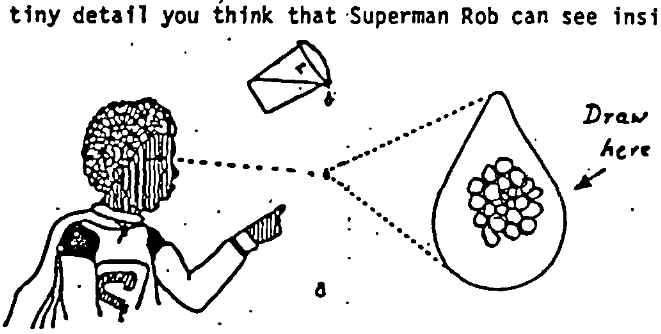
4072g

Rob is pretending he is Superman,

he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

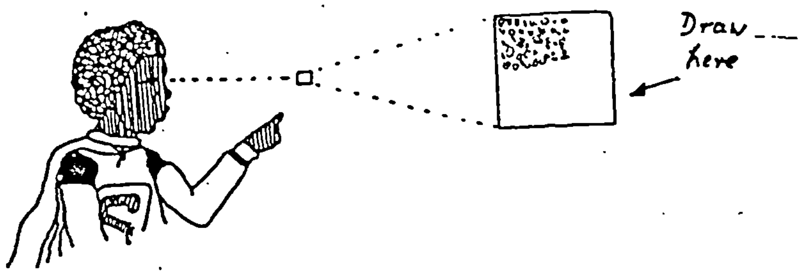
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

The Drawing is about the tiney granuwal that have ~~Dee~~ Disolved into tiny bits. Also the water cells

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

Tiny little pices of Sugar that makes up the granule.

Boy☐ Girl☐ Age 12

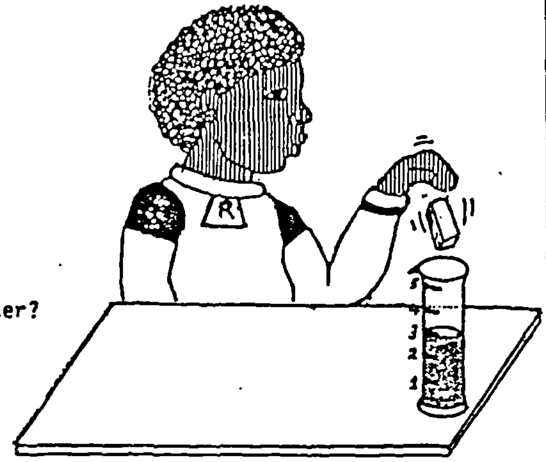
A-3.4.4(Emm)

4072g

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering <u>what will happen to the water</u> if he puts a large sugar crystal into it.



What do <u>you</u> think will happen to the water?

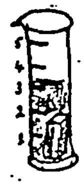
the water will rise a little.

Why do <u>you</u> think that?

I think this becaus the crystal will push up the water.

Draw the water after Rob has put the crystal into the measure

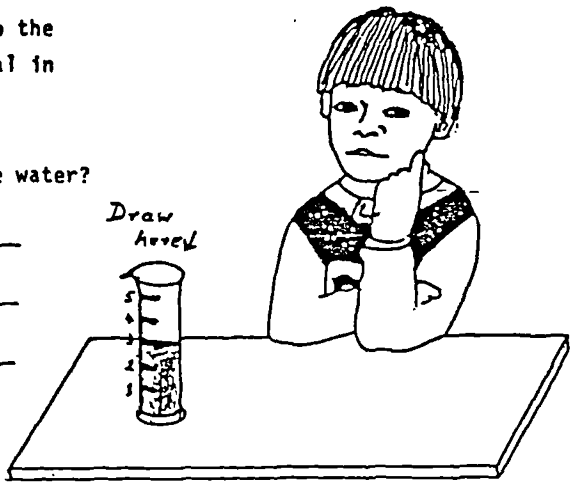
(Shade with your pencil to show where the water is)



Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water <u>until it cannot be seen</u>.

What do <u>you</u> think will happen to the water?

I think the water will go back to the origonal size.



Why do <u>you</u> think that?

becau I think this becaus the crystall has disolvd

Thank you for your ideas.

Boy ☐ Girl ☑ Age 12

Survey responses from Har

I.D. No.: 4001 (7.001)

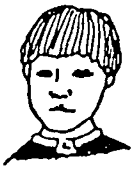
Gender: M

Age: 11.10

School-year: 7

Curriculum: Leeds Middle School Science.

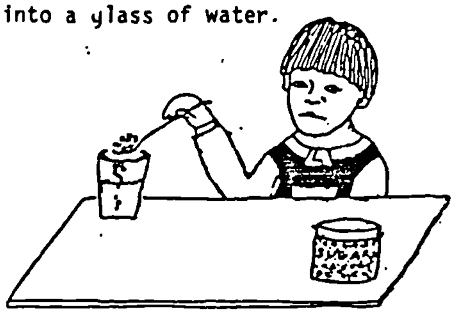
4001b



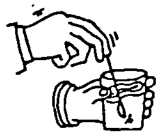
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar into a glass of water.

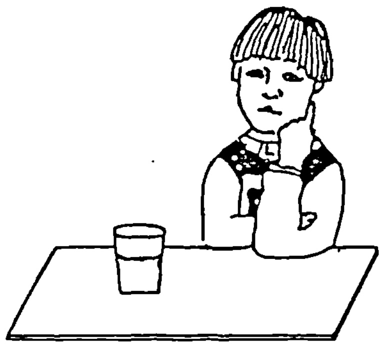


2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



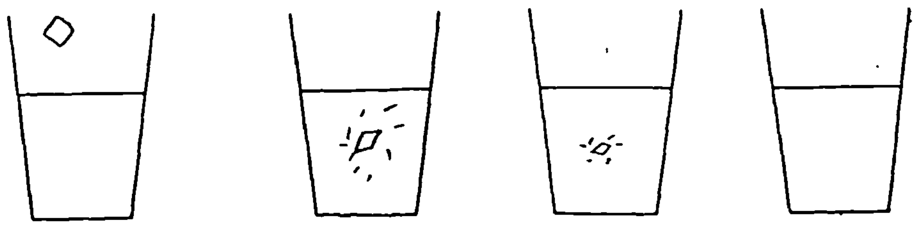
What do you think has happened to the sugar granules?

The sugar granules have dissolved in to the water.

Why can't Liz see the sugar granules?

Liz can not see the granules because they are too small and some will have dissolved.

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



Thank you for your ideas

Boy ☑ Girl ☐ age 11 10

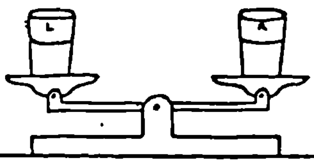
A-3.4.2(Har)

4001b

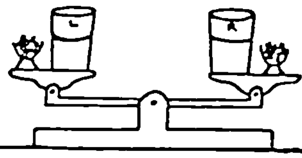
1

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

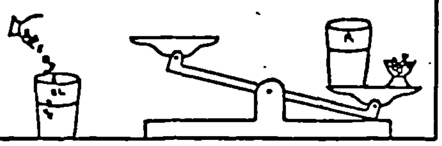
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



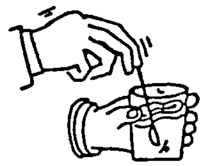
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



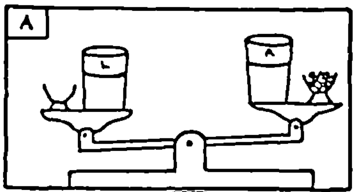
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

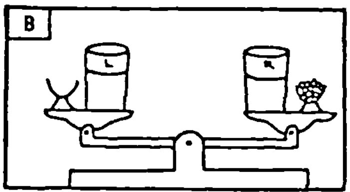


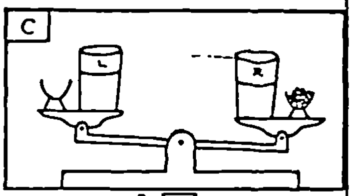
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☐ B ☐ C ☑

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because... the granules have disolved and therefore will not weigt as much as before they had disolved

....

....

Thank you for your ideas. Boy ☑ Girl ☐ Age 11 10

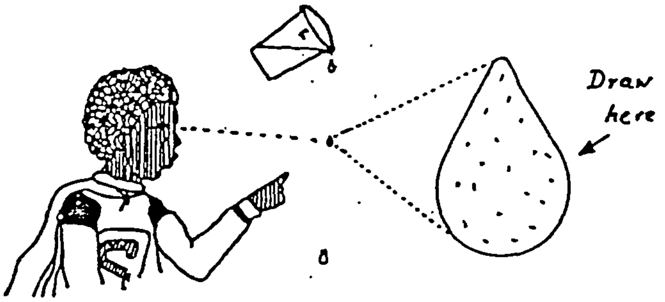
4001b

Rob is pretending he is Superman,

he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

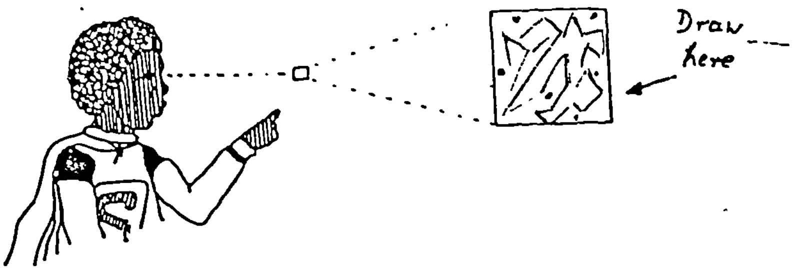
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

there will be little bits of sugar that were nearly disolved but not quite and would be very small.

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

there will be a few lines and a few little bubbles the lines will be from the outside and there will be bubble from the [illegible]

4001b. Boy ☑ Girl ☐ Age 11 10

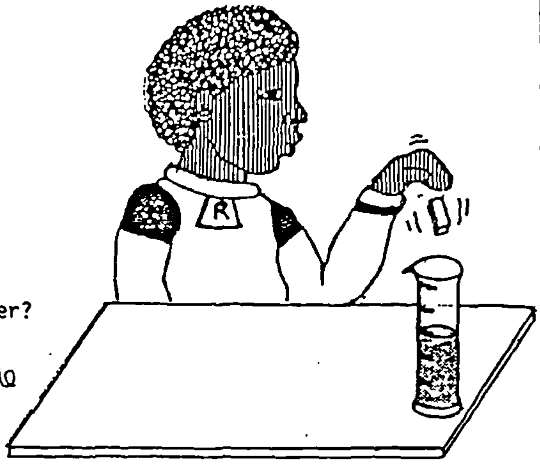
4001b

1

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering what will happen to the water if he drops a large sugar crystal into it.



What do you think will happen to the water?

the water will rise a little bit higher.

Why do you think that?

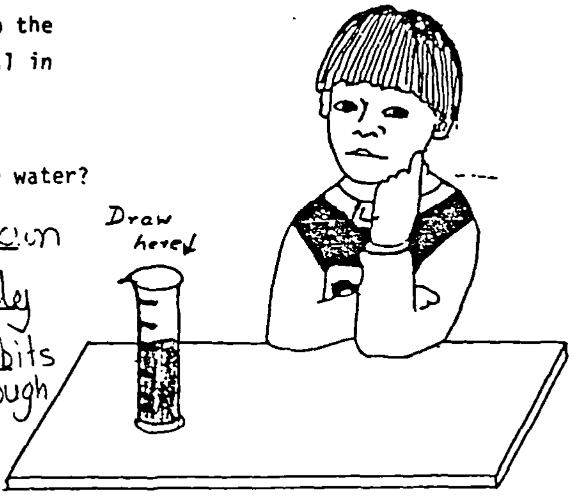
I think this because there will not be as much room for the water so it will rise to make more room for itself.

Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)

Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water until it cannot be seen.

What do you think will happen to the water?



the water will come down again but not completely because there are still bits of sugar in it even though they are not visible.

Why do you think that?

I think that because there will be more room for the water again but not quite as much as before because there is still some sugar in it.

Thank you for your ideas.

4001b Boy ☑ Girl ☐ Age 11 10

A-3.4.1(Mar)

Survey responses from Mar

I.D. No.:6013 (10.013)

Gender: F

Age: 14.8

School-year: 10

Curriculum: C.S.E./'O'level Biology Chemistry Physics.

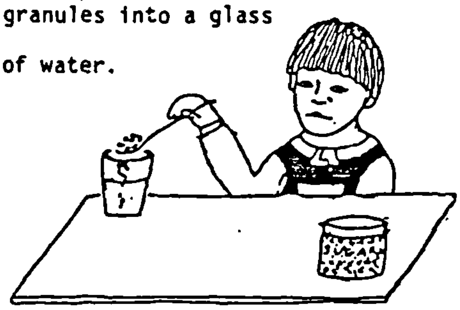
60139

13

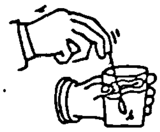
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar granules into a glass of water.

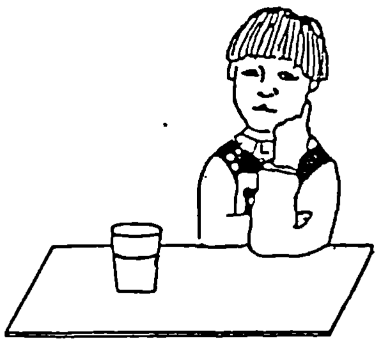


2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



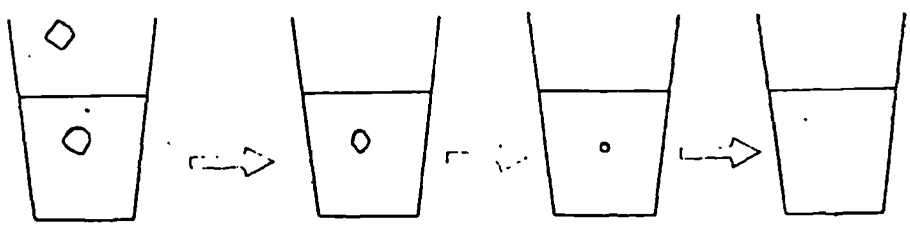
What do you think has happened to the sugar granules?

They have dissolved into the water

Why can't Liz see the sugar granules?

Because they are soluble and have dissolved completely so they are no longer there to be seen They are now in the water

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



Thank you for your ideas

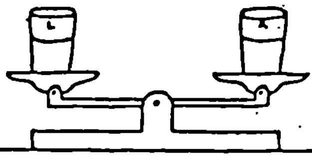
Boy ☐ Girl ☑ Age 14 8

6013g

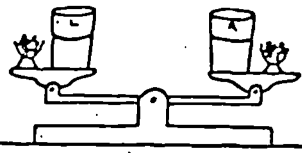
13

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

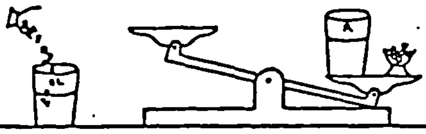
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



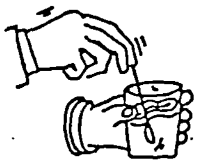
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

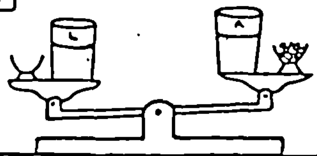


4. Liz stirs the water until she cannot see the sugar granules.

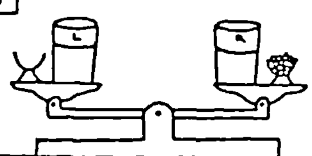


5. If Liz puts her mug and egg-cup back on the scales, do you think the scales will look like pictures A, B or C below:

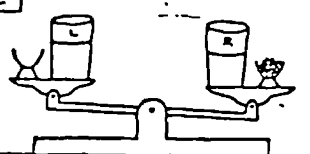
A



B



C



A ☐ B ☐ C ☑

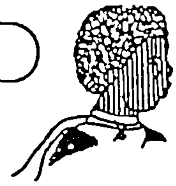
Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because... the sugar in Liz's cup had dissolved and so it was no longer there as it got smaller and smaller and lost its weight and so Robs sugar was still there and still had its origonal weight as it couldn't dissolve in anything

Thank you for your ideas. 6013 BPC Boy ☐ Girl ☑ Age 14 8

6013g

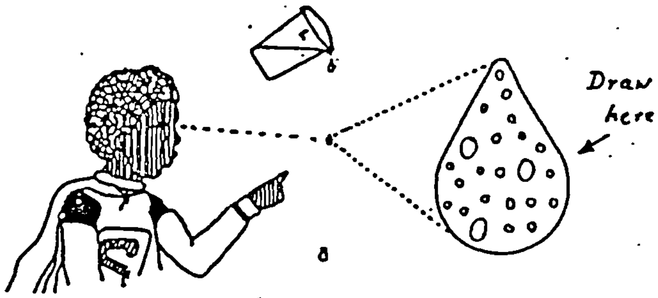


Rob is pretending he is Superman,

~ he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

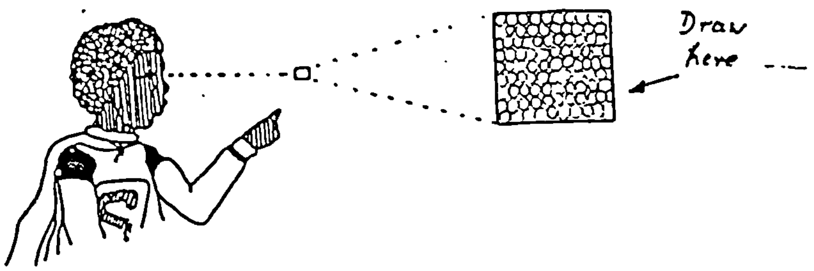
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

There is lots of small water molecules with a few large sugar molecules mixed in with the water molecules

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

There would be lots of tiny sugar molecules stuck together and so the granule has a proper shape. The molecules are so close together that the granule appears to be completely full with no holes in it

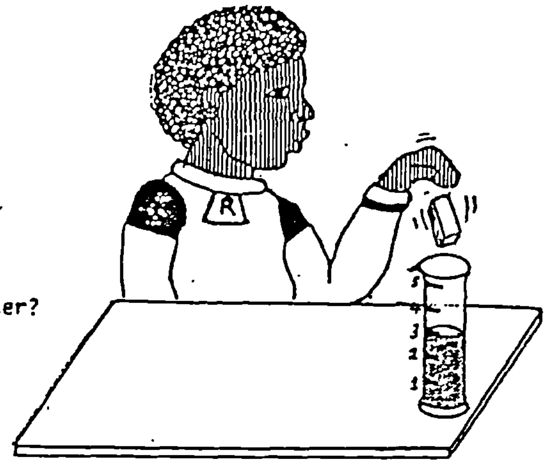
Boy☐ Girl☑ Age 14 8

6013g 6013g.

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering <u>what will happen to the water</u> if he puts a large sugar crystal into it.



What do <u>you</u> think will happen to the water?

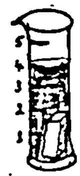
The water would rise.

Why do <u>you</u> think that?

Because the granule would not dissolve immediately and so it will take up some of the space in the cylinder causing the water to rise to make room for it.

Draw the water after Rob has put the crystal into the measure

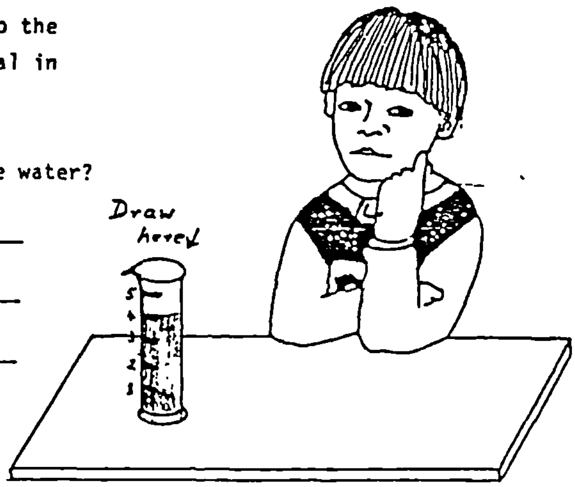
(Shade with your pencil to show where the water is)



Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water <u>until it cannot be seen</u>.

What do <u>you</u> think will happen to the water?

It would stay the same.



Why do <u>you</u> think that?

Because the granule would have dissolved and its molecules would have taken up the space where it was before and so the level of the water would stay the same.

Thank you for your ideas.

Boy ☐ Girl ☑ Age 14 8

A-3.4.1(Ric)

Survey responses from Ric

I.D. No.: 6141 (10.141)

Gender: M

Age: 15.2

School-year: 10

Curriculum: C.S.E./'O'level
Biology
Physics
Chemistry

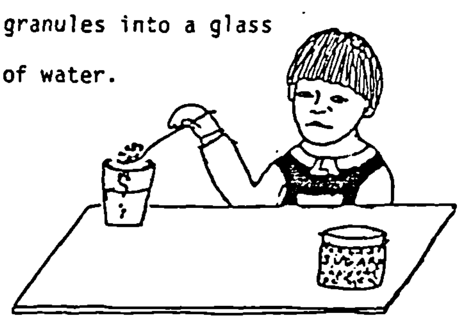
6141b

14

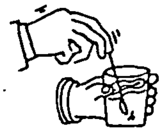
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar granules into a glass of water.

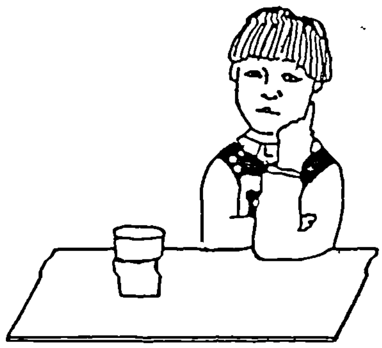


2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



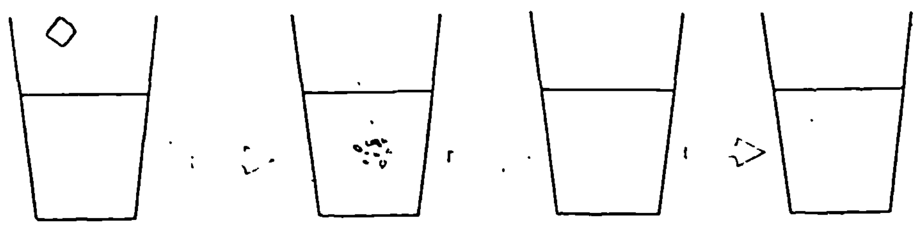
What do you think has happened to the sugar granules?

The granules have dissolved in the water, it would have worked better in warm water.

Why can't Liz see the sugar granules?

because they have become the same colour as the water when they were dissolved.

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.

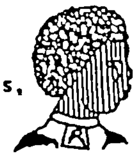


Thank you for your ideas

Boy ☑ Girl ☐ Age 15 2

A-3.4.2(Ric)

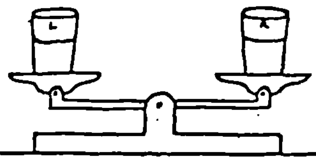
6141b



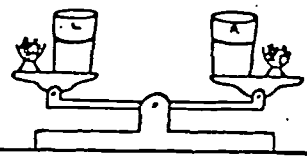
1-t

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

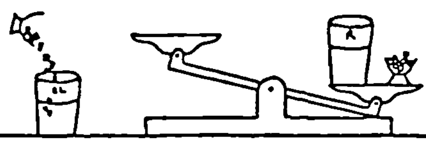
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



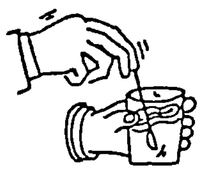
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



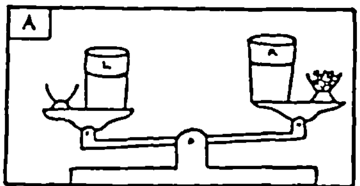
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

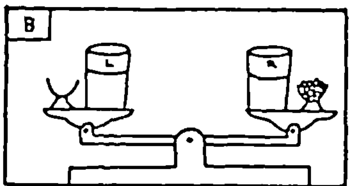


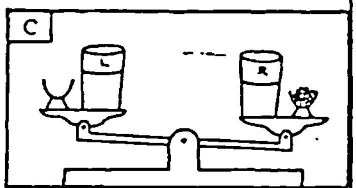
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do you think the scales will look like pictures A, B or C below:







A ☐ B ☑ C ☐

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because the sugar granules are still present in the water but they cannot be seen

Thank you for your ideas. Boy ☑ Girl ☐ Age 15 2

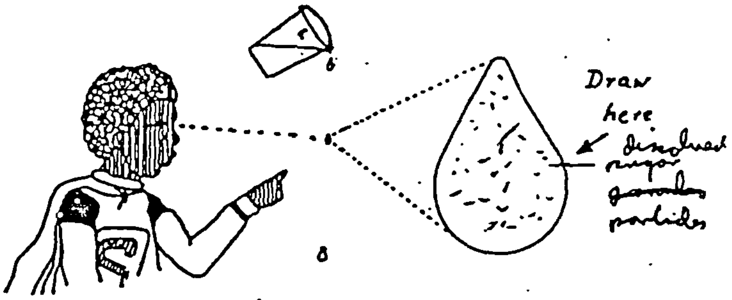
6141b.

Rob is pretending he is Superman,

~ he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

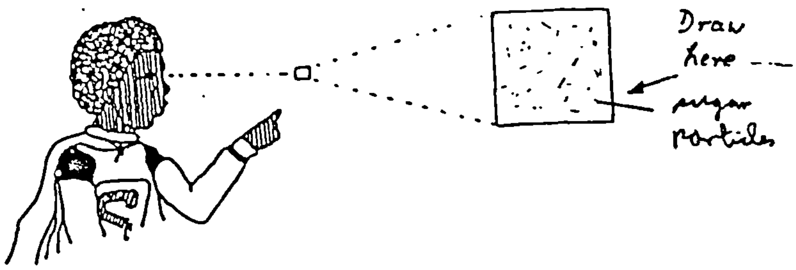
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

There are thousands of minute dissolved sugar ~~granules~~ particles inside the drop.

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

There are thousands of minute sugar particles inside the granule

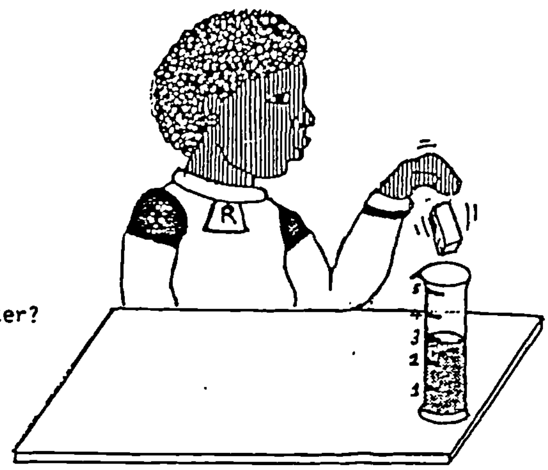
Boy ☑ Girl ☐ Age 15 2

(6141b)

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering what will happen to the water if he puts a large sugar crystal into it.



What do you think will happen to the water?

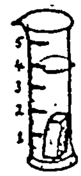
The water level will rise

Why do you think that?

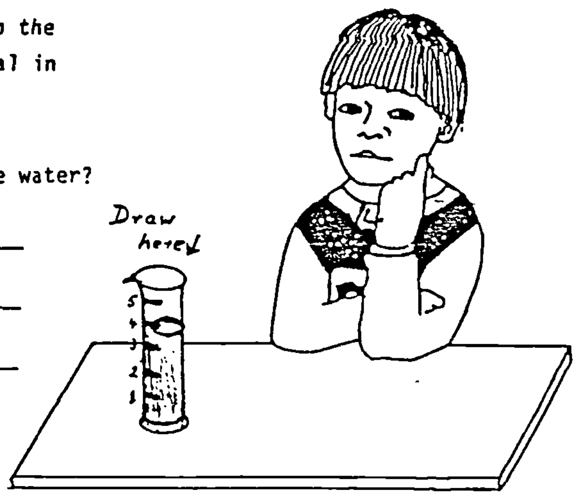
More particles are going in via the sugar so more particles will be present

Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)



Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water until it cannot be seen.



What do you think will happen to the water?

Nothing

Why do you think that?

Because the same number of particles are present in the water.

Thank you for your ideas.

Boy ☑ Girl ☐ Age 15 2

A-3.4.1(Car)

Survey responses from Car

I.D. No.: 7014 (12.014)   School-year: 12

Gender: F   Curriculum: 'A' level Chemistry Biology.

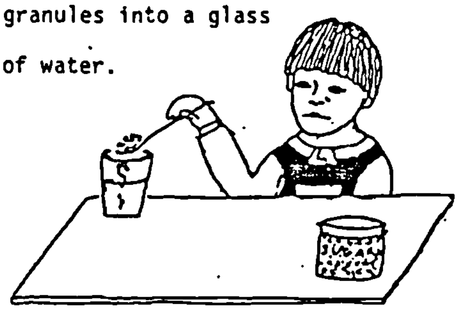
Age: 17.2

7014g

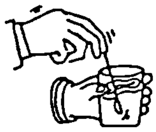
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar granules into a glass of water.

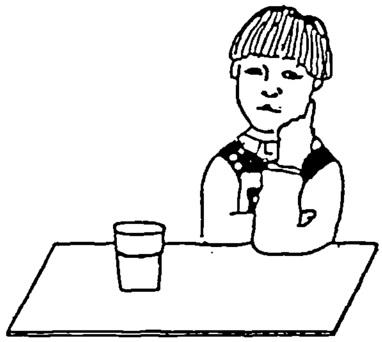


2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



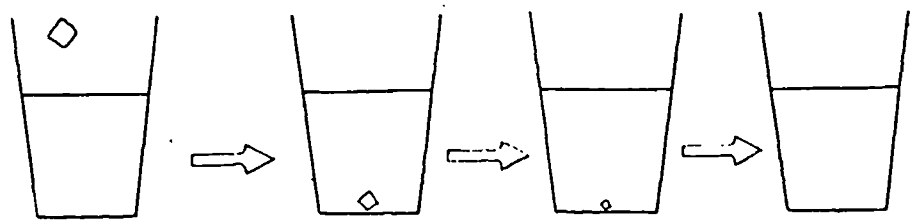
What do you think has happened to the sugar granules?

The sugar granules have dissolved in the water, i.e. the crystals are soluble in the water.

Why can't Liz see the sugar granules?

They have dissolved in the water i.e. they have passed from solid to aqueous state.

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.

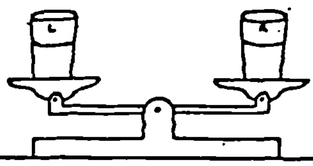


Thank you for your ideas   Boy ☐ Girl ☑ Age 17 2

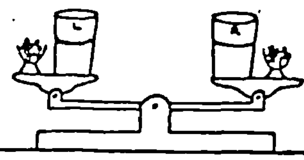
70/145

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

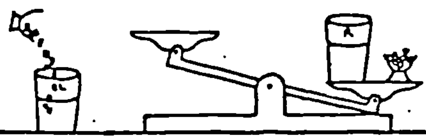
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



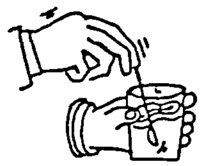
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



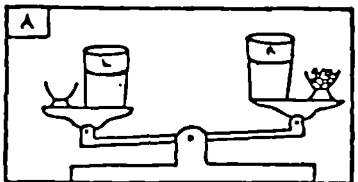
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

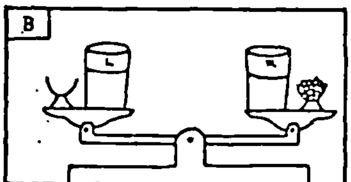


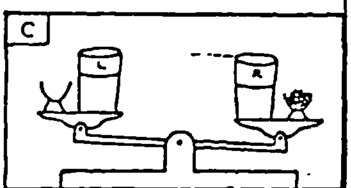
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do you think the scales will look like pictures A, B or C below:







A ☐ B ☐ C ☑

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because the solid on the right hand side of the scales with a beaker of liquid weighs more than the solid which is dissolved in the beaker of water on the left hand side of the scales.

Thank you for your ideas. Boy ☐ Girl ☑ Age 17 2

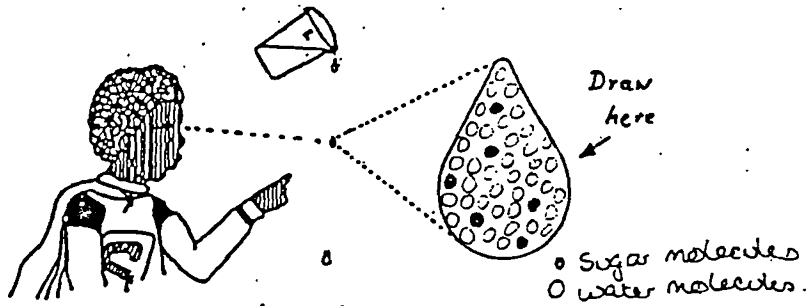
70145

Rob is pretending he is Superman,

~ he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

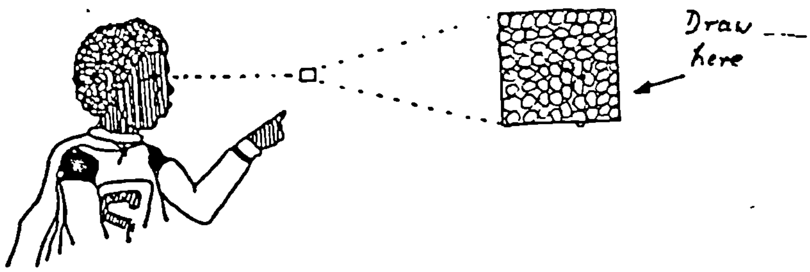
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

In the drops are many molecules held together by attractive forces, the molecules are spaced well apart so the liquid is free to move. There are less sugar ~~crystals~~ molecules than water molecules because the solution is not fully saturated with sugar.

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.



Describe your picture of the 'inside' of a granule of sugar.

Lots of particles in the granule are very close together, so the solid is unable to move like a liquid the particles are only allowed to vibrate. This is a very strong characteristic of solids.

Boy ☐ Girl ☑ Age 17 2

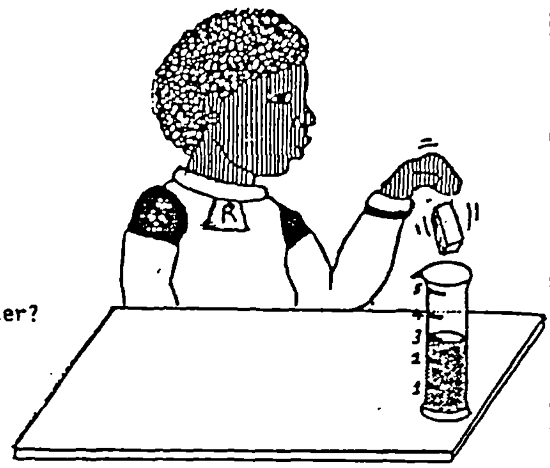
A3.4.4(Car)

70145

Rob is playing with a medicine measure.

He has put some water in it.

He is wondering what will happen to the water if he puts a large sugar crystal into it.



What do you think will happen to the water?

The water level will rise

Why do you think that?

Because as soon as the crystal has been put in it has had no time to dissolve so as it is solid it displaces some of the water.

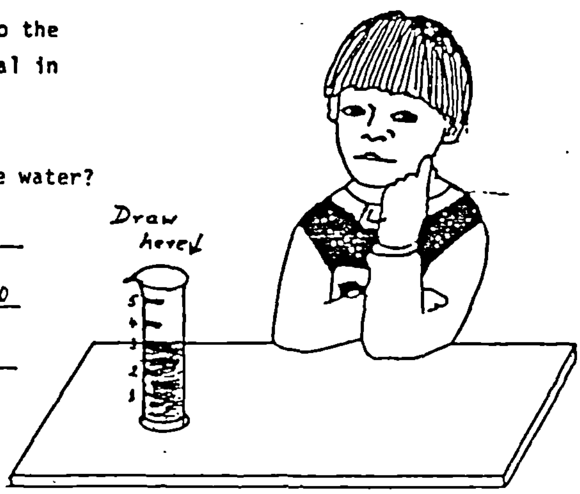
Draw the water after Rob has put the crystal into the measure

(Shade with your pencil to show where the water is)

Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water until it cannot be seen.

What do you think will happen to the water?

The water level will drop to just above the original level.



Why do you think that?

This is because there is no large solid to displace the water only small particles.

Thank you for your ideas.

Boy ☐ Girl ☑ Age 17 2

A-3.4.1(Jon)

Survey responses from Jon

I.D. No.: 7042 (12.072)

School-year: 12

Gender: M

Curriculum: 'A' level
Biology
Computer Science.

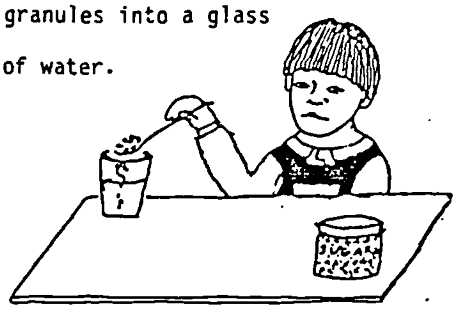
Age: 17.3

7041b

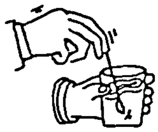
Liz is playing with sugar and water.

Please follow what she is doing and then give your ideas.

1. Liz is putting a spoonful of sugar granules into a glass of water.

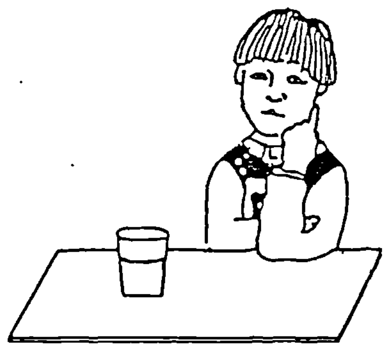


2. She is very busy stirring.



When she stops stirring she cannot see any sugar granules.

3. Liz is wondering what has happened to the sugar; she can't see it anymore.



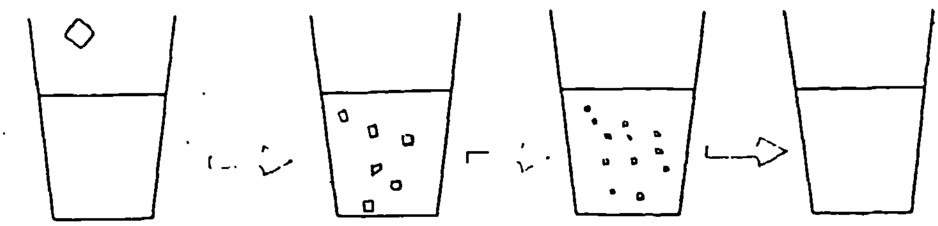
What do you think has happened to the sugar granules?

The Sugar granules have dissolved in the water.

Why can't Liz see the sugar granules?

Because they have dissolved in the water. The particles become smaller and therefore cannot be seen

Please draw some pictures or 'snapshots' of a sugar granule in water up to the time when it cannot be seen.



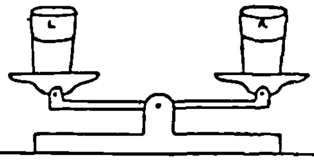
Thank you for your ideas

Boy ☑ Girl ☐ Age 17 3

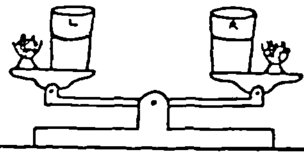
7042b

Liz and Rob are playing with new scales, mugs and egg-cups, please follow what they do.

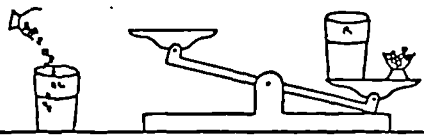
1. They pour water into their mugs and the scales balance. They say, "The mugs are the same weight".



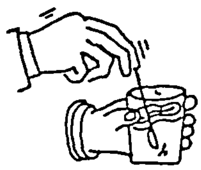
2. Then they fill their egg-cups with enough sugar granules to make the scales balance again.



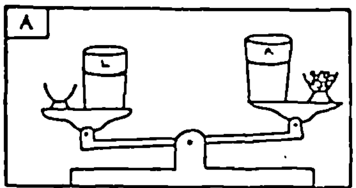
3. Liz takes her mug off the scales and pours her sugar into her mug. Rob leaves his alone.

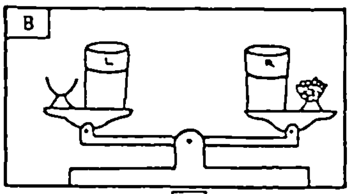


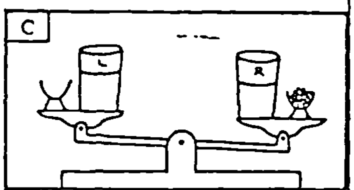
4. Liz stirs the water until she cannot see the sugar granules.



5. If Liz puts her mug and egg-cup back on the scales, do <u>you</u> think the scales will look like pictures A, B or C below:







A ☐ B ☐ C ☑

Please tick(✓) one box

Please say why you chose this answer:

I chose this answer because... the particles have dissolved into the water and energy has taken place resulting in a loss of mass.

Thank you for your ideas. Boy ☑ Girl ☐ Age 17 3

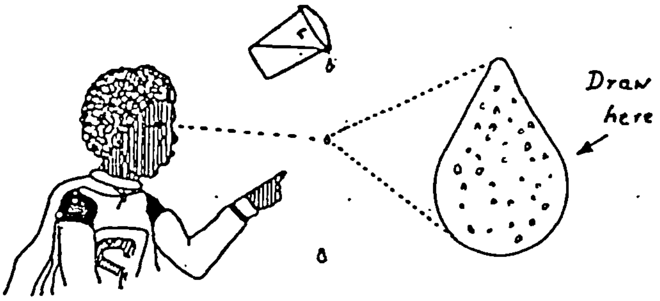
7042b

Rob is pretending he is Superman,

— he can see the detail inside tiny objects.

Imagine that a drop from Liz's mug is magnified many thousands of times.

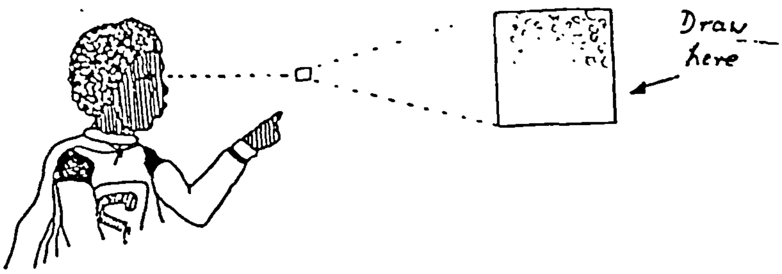
Draw the tiny detail you think that Superman Rob can see inside one drop.



Describe your picture of the 'inside' of the drop.

The inside of the drop would consits of many tiny particles floating around in the water.

If Superman Rob could see inside a tiny granule of sugar, draw the detail that you think he could see.

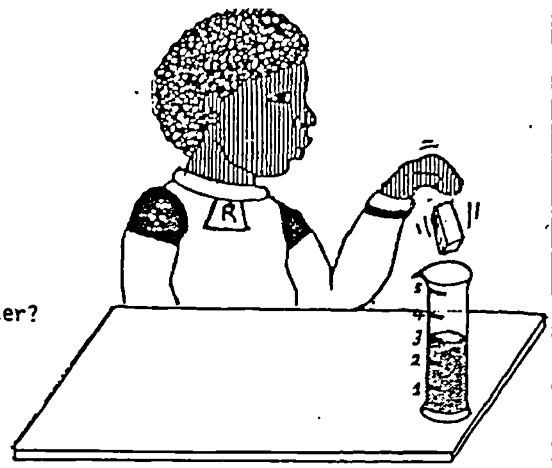


Describe your picture of the 'inside' of a granule of sugar.

Many thousands of compact particles would be seen

Boy ☑ Girl ☐ Age 17 3

(70426)



Rob is playing with a medicine measure.

He has put some water in it.

He is wondering what will happen to the water if he puts a large sugar crystal into it.

What do you think will happen to the water?

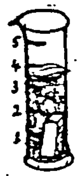
The water will rise.

What makes you think that will happen to the water?

By inserting the crystal, it will displace some of the water causing the level to rise

Draw the water after Rob has put the crystal into the measure

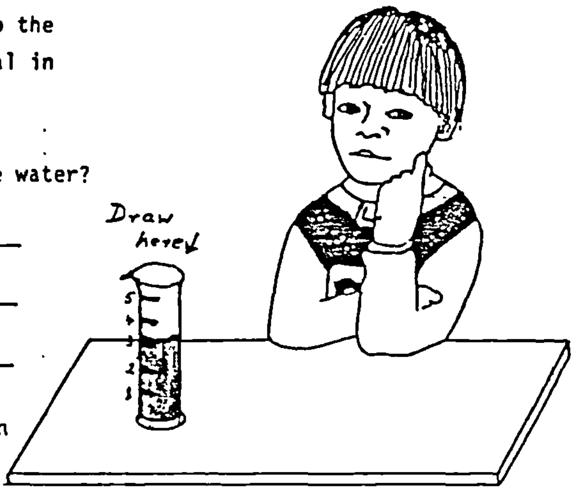
(Shade with your pencil to show where the water is)



Liz is wondering what will happen to the water if Rob leaves the sugar crystal in the water until it cannot be seen.

What do you think will happen to the water?

The water level will drop ~~less~~



What makes you think that will happen to the water?

The crystal will dissolve & there will be a smaller surface area ∴ less water will be displaced & the level will fall

Thank you for your ideas.

Boy ☑ Girl ☐ Age 17 3

APPENDIX 3.5 LETTER TO HEADTEACHER REQUESTING PERMISSION FOR PUPIL PARTICIPATION IN THE RESEARCH PROJECT.

Dear

I am writing to ask whether you would be willing to help with some small scale educational research during the 1984-5 academic year.

My research will be supervised by Dr. Rosalind Driver of the Centre for Studies in Science Education at the University of Leeds. The project involves the investigation and documentation of ideas and explanations that pupils use about some simple scientific phenomena. It is anticipated that the information obtained should be useful for teachers and curriculum developers.

The study would require that six pupils, from each of the ...and ... years, should be available for individual interviews lasting about thirty minutes. These six pupils, three boys and three girls, would be selected from the high, average and low ability pupils in each year-group. Also, I would like to administer a written task, lasting about thirty minutes, to two or three classes that together cover the whole ability range in the two year-groups mentioned above. The children selected for interview would not be required for the written task.

If you would like to discuss this matter further, could you suggest a date and time when it would be convenient to visit your school.

I appreciate that this is a difficult time to make such requests but I would value a tentative offer of assistance even though it may be necessary to withdraw at a later stage.

Yours sincerely,

(Brian Holding)

APPENDIX 3.6 CHECKLIST OF MATERIALS FOR SURVEY TASKS

1. Duplicated task sheets.
2. Pencils.
3. Large sugar crystals.
4. Number cards.
5. Boiled water.
6. Waste container.
7. Plastic jug.
8. Paper towels.
9. Granulated sugar.
10. Spoons
11. Plastic tumblers.
12. Plastic table cloth.
13. Egg cups.
14. Dropping pipette
15. Measuring cylinder
16. Weighing scales.
17. Cloth cover.

Specific task materials:

Task sheet 1:	tumbler, water, granulated sugar and spoon.
Task sheet 2:	scales, 2 tumblers, 2 egg cups, dropping pipette, spoon, granulated sugar and water.
Task sheet 3:	one large sugar crystal per pupil.
Task sheet 4:	measuring cylinder, large sugar crystal, water.

APPENDIX 3.7 VERBAL INTRODUCTION TO SURVEY TASK

The following kind of introduction was used, though clearly it had to be modified accoding to the age of the pupils.

Hello girls and boys!

(A comment on some current event e.g. weather, day, classroom etc.)

Well, I expect you are wondering what all this is about. (Researcher points to task sheets and the table full of equipment.)

You'll be glad to know it is not a test. So, what is it all about? Well, I am a collector. Do any of you collect things? Badges? Rubbers? Stamps? (Some children's responses taken). I am collecting young people's ideas about things you may learn about in your lessons sometime. In a few minutes I'm going to ask you about your ideas because I think they can help us to understand,a little better,what happens when we learn about things. So, would you please answer these questions, writing down the ideas that come to you as you think about the things I am going to show you.

We will read through the tasks, a page at a time. I will introduce you to two busy people, Liz and Rob, and will show you with this equipment all the things they do.

Any questions?

Let's make a start, let me introduce Liz...

(Proceed to demonstrate each task, reading aloud with the pupils.)

APPEXDIX 3.8 CHECKLIST OF MATERIALS FOR INTERVIEW TASKS

1. Tape recorder, batteries, battery eliminator.
2. Pupil's names.
3. Diagram tasks and folder.
4. Pencils.
5. Large sugar crystals
6. Granulated sugar.
7. Boiled water.
8. Waste container.
9. Plastic jug.
10. Paper towels.
11. Plastic table cloth.
12. Plastic tumblers.
13. Polythene bags containing 5g. sugar.
13. Plastic dishes.
14. Hand lens.
15. Plastic spoons
16. Dropping pipette.
17. Weighing scales.
18. Measuring cylinder.

Specific task materials:

Phase 1: Large sugar crystals, plastic dish, hand lens and water.

Phase 2: Tumbler. granulated sugar, water, spoon, pencil, outline diagram sheets and white card.

Phase 3. Objects for weighing, scales, 2 tumblers, 2 sugar bags, plastic spoon, pipette and white card.

Phase 4: medicine spoon, medicine measure, measuring cylinder, large sugar crystals, pipette and white card.

APPENDIX 3.9 CODED INTERVIEW DATA

Key to coded data

Column A GENDER: 1 Male, 2 Female

Column B CURRICULUM: 4 Science, 30 Physics, 200 Chemistry, 1000 Biology 1200 Biology & Chemistry, 1030 Biology & Physics, 230 Chemistry & Physics, 1230 Biology,Chemistry & Physics.

Column C YEAR GROUP: 3 year-3, 5 year-5, 7 year-7, 10 year 10, 12 year-12

Column D SCHOOL: 1 - 15.

Column E RESPONSE CATEGORIES for 'stirring sugar and water' 1 no response, 2 copied text, 3 unintelligible, 4 tautology, 5 unrelated, 6 unique, 7 dissolved, 8 disappeared, 9 gone into 10 gone to bottom, 11 melted, 12 mixed, 13 evaporated, 14 disintegrated, 15 absorbed, 16 reacted.

Column F RESPONSE CATEGORIES for additional statements to those in Column E: 1-16 as for column E, 17 broken down or up, 18 broken to molecular size, 19 smaller and smaller 20 smaller to molecular size, 21 molecules mix, 22 granules in spaces, 23 molecules in spaces.

Column G RESPONSE CATEGORIES for 'why dissolved sugar not seen': 1-16 as for Column E, 17 molecules in spaces, 18 reduced to molecular size, 19 size beyond sight, 20 change of state, 21 transparent sugar.

Column H RESPONSE CATEGORIES FOR 'diagram of granule dissolving' 1-6 as for column E, 7 surface action, 8 fracture, 9 surface action and fracture, 10 unchanged.

Column J RESPONSE CATEGORIES for 'predicted weight/mass' when dissolved': 1 weighs more, 2 weighs same, 3 weighs less, 4 no response.

Column K RESPONSE CATEGORIES for 'reason for response in Column J' 1-6 as for column E, 7 sugar gets heavier, 8 weight permanent, 9 sugar (substance) still there, 10 nothing added or taken away, 11 same amount on both sides, 12 parts equals whole, 13 molecules permanent, 14 sugar loses its weight, 15 sugar not there, 16 particles lose weight.

Column L RESPONSE CATEGORIES for 'diagram of inner constitution of solution': 1-6 as for Column E, 7 continuous & no sugar, 8 continuous and sugar, 9 continuous 'bits' of sugar and water, 10 continuous 'bits' of sugar only, 11 molecular particles of sugar & water, 12 molecular particles of sugar only.

Column M RESPONSE CATEGORIES for 'name of particle': 1-6 as for Column E, 7 atom, 8 molecule, 9 particle, 10 crystal, 11 granule, 12 bits, 13 pieces, 14 cubes, 15 grains, 16 drops, 17 bubbles, 18 parts, objects, lumps, 19 specks,dots 20 sugar, 21 cells, 22 no particles.

Column N RESPONSE CATEGORIES for 'diagram of inner constitution of solute': 1-6 as for Column E, 7 regular array of molecules, 8 random distribution of molecules, 9 reguar array of uniform 'bits', 10 random distribution of irregular 'bits' 11 continuous.

Column P RESPONSE CATEGORIES for 'name of particle in sugar crystal' 1-22 as for Column M.

Column Q RESPONSE CATEGORIES for 'predicted volume with undissolved sugar in water': 1-6 as for Column E, 7 volume increase, 8 volume unchanged, 9 volume decrease.

Column R RESPONSE CATEGORIES for 'reason for response in column Q': 1-6 as for Column E, 7 volume, 8 weight, 9 force, 10 prior observation, 11 absorbed.

Column S RESPONSE CATEGORIES for 'predicted volume with dissolved sugar in water': 1-6 as for Column E, 7 even greater volume, 8 same volume, 9 somewhat less volume, 10 original volume, 11 less than original volume of water.

Column T RESPONSE CATEGORIES for 'reason for response in S': 1-6 as for Column E, 7 more volume as particles, 8 more bulk volume, 9 more substance, 10 more weight, 11 more force, 12 same volume as particles, 13 same bulk volume, 14 substance still there, 15 same weight, 16 same force, 17 less volume as particles, 18 less bulk volume, 19 dissolved but still there, 20 less weight, 21 less force, 22 no extra volume as particles, 23 no bulk volume visible, 24 no substance visible, 25 no weight left, 26 no force left, 27 soaks up water, 28 no volume as particles.

Column U TEACHER RATING OF PUPIL ABILITY (Interview data only) 1 high, 2 average, 3 low.

ID No	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T	U
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APPENDIX 3.10 CODED SURVEY DATA

Key to coded survey data(as for interview data - see p. A-3.9.1)

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2010	2	0004	03	11	07	01	09	07	2	09	03	01	10	12	8	05	10	01
2011	1	0004	03	11	08	01	19	03	1	01	03	01	03	03	7	05	08	01
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2014	1	0004	03	11	09	01	01	07	2	09	10	20	10	20	7	01	08	01
2015	1	0004	03	11	11	08	11	07	3	15	07	22	10	13	7	01	03	01
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ID No	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T
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APPENDIX 3.11 QUESTIONNAIRE FOR TEACHERS ABOUT RELATED CURRICULUM TOPICS

C O N F I D E N T I A L

Pupils concerned:

1. Familiarity with terminology

*Would the pupils have previously used the terms listed below?

☐ solvent	☐ solution	☐ solute	☐ atom
☐ dissolving	☐ melting	☐ crystallising	☐ molecule
☐ weight	☐ mass	☐ volume	☐ particle

2. Familiarity with measurement

*Would the pupils have had previous experience of the instruments listed below?

☐ double pan balance ☐ single pan balance

*Would the pupils have had previous experience of measuring

☐ the volume of a liquid using a measuring cylinder?

☐ the volume of a solid by displacement?

3. Familiarity with diagrammatic representation

*Would the pupils have previously seen 'particulate' diagrams that represent the items below?

☐ a solid	☐ a liquid	☐ a solution
☐ melting	☐ dissolving	

4. Familiarity with certain experimental work

*Would the pupils have previously:

☐ recovered a solid solute from a solution?

☐ separated a mixture of soluble and insoluble substances?

☐ done an experiment that illustrated the conservation of mass?

Date.................... Signed...................................

* Please tick(✓) the appropriate boxes

Thank you for your assistance. (Please return in the enclosed s.a.e.)

Appendix 4.1

Calculation of chi-square for the proportion of conservers by year-group classification.

	3rd-year	5th-year	Row
Number of pupils conserving weight/mass	73	54	127
Number of pupils not conserving	39	55	94
column total	112	109	221

Overall proportion of conservers $= \frac{127}{221} = 0.575$

If no. of conservers is independent of year group,
then expected no. of conservers in the third-year $= 0.575 \times 112$
$= 64.4$
and expected no. of conservers in the fifth-year $= 0.575 \times 109$
$= 62.7$

it follows that expected no. of non-conservers,
in the third-year $= 47.6$

in the fifth-year $= 46.3$

Now $\chi^2 = \frac{(O_i - E_i)^2}{E_i}$ where O_i = observed frequency

E_i = expected frequency

O	E	O - E	$(O - E)^2$	$(O - E)^2/E$
73	64.4	8.6	73.96	1.15
54	62.7	-8.7	75.69	1.21
39	47.6	-8.6	73.96	1.55
55	46.3	8.7	75.69	1.63
221	221.0	0		$\chi^2 = 5.54$

APPENDIX 4.2

PERCENTAGE OF PUPILS OFFERING THE REASONS SPECIFIED FOR CONSERVING OR NOT CONSERVING WEIGHT/MASS OF DISSOLVED SUGAR

Year-group / Reason		3	5	7	10	12
Sugar becomes heavier in some way	% Boys	2	5	5	3	5
	% Girls	4	6	10	4	-
Assertion that sugar maintains same weight	% Boys	20	23	19	20	9
	%Girls	15	25	29	15	2
Sugar still there so weight still there	% Boys	14	9	17	30	35
	% Girls	17	9	4	18	26
Nothing has been added or taken away	% Boys	-	2	1	11	7
	% Girls	-	4	4	4	2
Same amount of sugar there	% Boys	-	2	7	4	21
	% Girls	-	-	-	11	26
'Bits' weigh same as whole	% Boys	-	-	-	6	-
	% Girls	-	-	-	6	-
Molecular particles are still there	% Boys	-	-	1	1	5
	% Girls	-	-	-	3	5
Assertion that sugar loses weight	% Boys	5	20	19	14	7
	% Girls	10	23	19	21	21
Sugar not 'there'	% Boys	14	29	21	1	2
	% Girls	15	19	23	15	7
Particles loose weight	% Boys	-	-	-	5	2
	% Girls	-	-	-	4	12
Unintelligible, copied text, unrelated types of response	% Boys	28	6	5	4	-
	% Girls	37	15	11	-	-
No response	% Boys	17	2	4	1	2
	% Girls	2	-	-	-	-