Children's ideas about

LIVING THINGS

RESEARCH SUMMARY

This is a brief outline of research setting out the main prior ideas and understandings which teachers might expect to meet among pupils.

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Before reading this summary of children's prior ideas, it would be helpful to look at the Science Map and The Teacher's View so as to have a useful overall perspective from which to view children's understanding.

Introduction

The research into children's concepts of living things, which is covered in this Research Summary, is presented under the following headings:

The concept of 'living'
The concept of 'animal'
The concept of 'plant'
The process of classification
The concept of 'species'
Cell theory
Adaptation
Organisation of the body: Structure and function
Implications for teaching.

It would be helpful to consult the Research Summaries in other domains of 'Life and Living Processes' for those aspects of the papers reported here, and of other articles, which outline children's ideas on particular life processes.

The concept of 'living'

Research on children's ideas of 'living' has been in progress ever since the 1920s. We can define 'living' by contrasting living things either with inanimate objects, which have never been alive, or with dead organisms, which were once alive. However, these two aspects have not always been distinguished in the research.

Animism

The pioneering studies about children's ideas of 'living' were carried out by Piaget [1]. He observed that children tend to regard many inanimate objects as capable of sensations, emotions and intentions, and he called this view 'animism'. He found that young children said that such things as the sun, cars, the wind, clocks and fires 'know where they are' and 'could feel a pin prick'. When asked what is and is not alive, they judged these same objects to be alive. He showed that children younger than ten years old interpret physical phenomena in terms of intention on the part of inanimate objects, for example 'the sun is hot because it wants to make people warm'.

Piaget identified five stages in the development of the 'life concept' in children:

Stage 0	No concept.
Stage 1	Age 6-7....things that are active in any way, including falling or making a noise, are alive.
Stage 2	Age 8-9....all things that move, and only those, are alive.
Stage 3	Age 9-11....things that appear to move by themselves, including rivers and the sun, are alive.
Stage 4	Over 11....adult concept: only animals are alive, or animals and plants are alive.

Carey [2] has studied childhood animism and suggests that there is no evidence for the universal progression through the stages defined by Piaget. Her criticisms are based on several concerns, the main one of relevance to teaching being that the word 'alive' as used by children and investigated by Piaget does not label the adult concept of 'living thing'. Children may appreciate that living things are distinct from inanimate objects, but they do not have a concept of 'living things' which subsumes animals and plants into a single category. As they do not have this concept to correspond to the word 'alive', the word 'alive' has some other meaning for them. The meaning of the word 'alive' changes with the age of the child. If this is so, studying the development of the meaning of 'alive' is not the best way to study the child's developing concept of life. Carey suggests that the Piagetian procedure induced self-conscious theories about 'life' on the part of the children, rather than tapping into and diagnosing their prior concept of life. In Carey's own experiments, only 13% of children aged less than ten years old volunteered physiological criteria for life, but most of another sample of similar age were able to assign given attributes, such as 'has babies', correctly to living things.

Carey reviewed the work of Piaget and of Laurendau and Pinard and others, in relation to her own research data, suggesting that progression in the concept of 'living' is linked to the child's developing conceptual framework about biological processes. Young children (4-7 years) have little biological knowledge, but there is a marked increase in the knowledge of 9 and 10 year-olds. The younger children therefore explain bodily functions of living things and the activity of inanimate objects using a 'naive psychology' of human behaviour entwined in intentional causal reasoning, for example: spinach makes Popeye strong because he likes it, the Sun shines in order to keep us warm. As the biological knowledge of the child grows the idea of biological function independent of human intentional causality develops, and animistic reasoning declines.

Piaget's work prompted a number of other studies, in various countries and cultures, which have produced an extensive literature on animism. In 1969 Looft and Bartz [3] reviewed the literature up to that date. The research showed that animistic notions are present in populations of all age ranges and great cultural differences. They are prevalent in the thinking of many different college student samples, though students who had studied biology gave fewer animistic answers than those who had not. However, the subjects were not usually informed that they were expected to give scientific answers, so many may have answered metaphorically. A recent study by Inagaki and Hatano [4] suggests that young children use animism metaphorically as a model to explain phenomena.

The words 'living' and 'life' may label different concepts. Klingberg found that the question 'Is (a certain object) living?' produced different responses from the question 'Has it life?' (reported in [3]). These semantic distinctions have not always been acknowledged in designing research studies and have given rise to much discussion of the detailed results.

Criteria for life: the characteristics of living things

Following the 'animism' debate, research in the 1970s attempted to delve into the biological criteria that children use in deciding whether something is alive.

Smeets [5] found that eleven year-old children used biological words as criteria for things that they considered as living, but that they did not distinguish the meanings of these words from other usages. For example the majority seemed to consider the following pairs of words identical in meaning: destruction/dying, seeing/knowing, contact/feeling, presence of ears/hearing, production of noise/talking, expanding/growing. Looft [6] reported that although 39 out of 59 seven year-old children correctly classified sixteen items as living or non-living, this ability is not indicative of a biological grasp of the implications of the life concept. Over half of the 39 understood the need for nutriment, but few applied a concept of breathing or of reproduction in defining living things, even when asked questions such as 'does a frog breathe or need air?'.

By the late 1970s and early 1980s, work on children's concepts of living things became more related to the educational context but the same issues were still being discussed. Bell (formerly Stead) [7,8,9] has pointed out that commonly used words such as 'living', 'dead' and 'animal' may be used to label different concepts by different people.

Stead (Bell) found that all but one of her sample of 9-15 year-olds used biologically accepted characteristics of life to justify their categorisation of examples as living things. Many used a combination of these attributes. However, she reports that only five out of 32 pupils had a concept of living similar to that of a biologist, despite up to four years of formal biology teaching. Most children over-extended the scientifically-accepted concept of living: they considered fire, clouds, sun, candle, river, car, and so on, to be living.

This over-extension usually resulted form the use of only one or a few critical attributes, for example 'a cloud is living because it moves'. Some pupils considered that an item could be living at some times (for example, a bike when moving) and non-living at other times, and many acknowledged that they were unsure of their categorisations.

These findings have been replicated in further work by Bell and by researchers and teachers using questions based on her research schedules. Surveys across a range of ages, by Bell et al, have shown the prevalence of different ideas about 'living'.

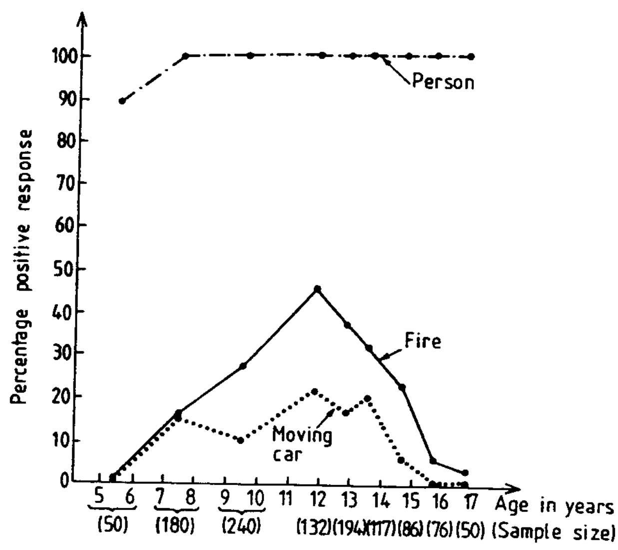

Figure 1: Representative sample response to 'is it living?'. (16 and 17 year-old pupils were studying biology)

Arnold and Simpson [10] investigated the concept of living things, amongst Scottish pupils from age 10-15 including biology and non-biology students. From the primary years all pupils could use the term 'living thing' in context and could give appropriate examples.

When classifying eighteen examples and non-examples of living things there was no steady improvement from age 10-15, and non-biology certificate pupils performed better than biology pupils. This suggests that school biology experience had not improved the students' concept attainment and is further evidence for the trends described by Bell. Of the non-certificate (lower attaining) pupils aged fifteen, 28% included at least one of the following as living: fire, milk, water, cloud, energy, car. Only 9% correctly classified all eighteen items. The four most popular attributes chosen to identify living things were eating/drinking, moving/ walking, breathing, growing. There was little progression evident in the responses from primary to junior secondary pupils, although the older pupils gave the best results. Only 36% of 14-15 year-olds included respiration as a criterion of life although many had studied biology.

Leach et al confirm this [11]. These researchers found that a few infant children are unfamiliar with the word 'alive'. When they do recognise the word, most children at this age and many up to eleven do not consider plants to be alive. They did not point out the grass and the tree when asked to find something alive in a picture, but searched amongst these for drawings of animals.

The results of Stavy and Wax [12] from a study of 5-16 year-old children in Israel are similar. They found that almost all children recognised animal examples as living, but only 30% of six year-olds, and 70-80% of 12-15 year-olds regarded particular plants as living. Almost all children attributed growth to plants, but apparently did not consider this a pre-requisite of life: 100% of 8-11 year-olds stated that plants grow but only 69% of them regarded plants as living.

Stavy and Wax attribute their results in part to the Hebrew language, where the word for 'life' is similar to that for 'animal', but not to that for 'plant'. Also the words for 'growth' and 'death' in animals are different from those applied to plants. However, in view of similar findings from English speaking pupils in various countries, this proposed explanation may need to be questioned.

Tamir et al [13] studying 424 Israeli pupils aged 8-14 also found that there was no significant difference between grade levels in children's ability to classify sixteen pictures into living and non-living categories. Over 99% of the children classified all the animal pictures as living; 82% of the responses correctly classified the plant illustrations as living, with the tree and the mushroom less frequently considered alive than the herbaceous plant. Also, 80% classified the inanimate examples as non-living, with natural things like a river or the sun more frequently being considered alive than man-made objects. Thus 20% of item responses were incorrect, and this may represent far more than 20% of individual children failing to correctly classify at least one item.

Embryos provided interesting responses. Only half the children considered eggs to be alive whereas 60% classified seeds as alive.

A progression from the ideas of the younger to those of the older students became apparent in the criteria they gave for classifying examples. Overall, the most popular criteria as indicators of life were movement for animals, and growth and development for plants and embryos. About half the reasons were based on life processes with more emphasis on biological processes and less on usefulness to man by the older children.

Most of the children who classified inanimate items as alive believed that they have a different kind of life, and about half thought that plans have a different kind of life from animals. The differences were related to supposed differences in movement, sensation and consciousness. These findings are evidence that life has many meanings for children; it is not a uniform concept.

Tamir et al also investigated the notion of continuity of life. Although most pupils could put pictures of seed germination or chick embryology in the correct sequence, and 85% said that the seedling was alive, only 66% said that the seed was alive. They believed in the possibility of living organisms to develop from non-living, stating: 'seeds are dead, when we put them in soil they get food and begin to live' or 'larvae change into pupae which are dead and then we get butterflies'. However, most of the children did understand the continuity of life explicitly stating 'if the seed were not alive it would not be able to grow' or expressing the idea that living organisms originate from other living organisms. In some cases the latter idea did not prevent children from believing that eggs and seeds are not alive. A difference was apparent in a class of agricultural school students within the sample where only one classified eggs and seeds as non-living, suggesting that their agricultural experience had an impact on their understanding of the life concept.

Lucas, Linke and Sedgwick [14 15] used an unfamiliar object, in a photograph, to elicit concepts of life from nearly a thousand Australian children aged 6-14. The object was actually a lump of dough photographed on a sandy background. Children were asked to write down how they could find out whether the object was alive, with cues about how to proceed: what would you look for? what would you do to it? what would it do?. The overwhelmingly common responses (86-100% varying with age grades) was in terms of the behaviour of the object. The behaviour most children chose was some sort of movement, with an increase in this response through the primary grades and a decline through the early secondary years. However, analysis of the children's range of responses revealed that even young children's ideas of life are based on more than movement. Children at all grade levels applied a variety of criteria, including consulting expert advice. At all grade levels more than 40% of pupils suggested a criterion based on external structure; an increasing proportion at higher grades used an aspect of internal structure, such as blood or cells; a substantial proportion used physiological functions, such as heartbeat or respiration. These types of response had not been elicited by the restricted questioning of the earlier 'animism' studies.

Brumby [16] studied 52 British University biology students' perceptions of the concept of life. She set four different problems, one of which was similar to that of Lucas et al but her stimulus material was an actual strange weathered stone, rather than a photograph. Her other questions related to evidence of whether fire is alive, to evidence for life on Mars and to explaining the expression 'the web of life'.

Most students referred to similar criteria as those used by young children such as growth and movement. The traditional 'seven characteristics of life': movement, respiration, sensitivity, growth, reproduction, excretion and nutrition, dominated their explanations. These were applied in an unsophisticated way and without reference to principles of scientific experimentation, suggesting that the seven characteristics had been rote-learned. Some responses included references to cells or organic chemicals, but there was hardly any mention of a self-replicating molecule. Brumby suggests that the 'learning' of fragmentary 'facts' had overwhelmed the curiosity and wonder of children as they become tertiary students and did little to help an understanding of the world around them.

Anthropomorphism and personification

Anthropomorphism means attributing human attributes, thoughts, emotions and intentions to non-human things. It is not always clear whether children, giving anthropomorphic responses, think that other organisms or objects really think like humans or whether they are using anthropomorphism in a metaphoric sense.

Inagaki and Hatano [4] point out that children readily distinguish people from other living and non-living things and that they do not readily accept that humans are a kind of animal. However, children recognise a gradation in similarity between humans and other things, ranging from the close similarity with other mammals, grading through vertebrates, invertebrates, plants and minerals. Inagaki and Hatano investigated the use of 'personification metaphor' by young children. They concluded that when a particular response of an organism, whether it be a tulip or a rabbit, is similar to that of a human, children use human characteristics to make predictions about the organism, but this is not the case when the attribute under consideration is different between the organism and a human. They contend that children are able to differentiate between humans, non-humans and inanimate objects, but they use personification as a metaphor to help generate predictions.

Death

A number of studies of children's concept of death, reviewed by Carey [2], have suggested that children progress to an intuitive biological conceptualisation at about 9 or 10. Very young children consider death in terms of human experience, relating it to notions of sleep and departure, separation and punishment. They see it neither as final nor as inevitable. Primary school children accept the finality of death as an event that happens to people due to an external agent. Around age 9 or 10, children begin to understand death as an inevitable biological process of the body ceasing to function. Despite different cultural references to myths and religious beliefs, children in all studies indicated the same progression of concepts of death.

A study by Sequiera and Freitas [17] confirmed the stability of Portuguese primary school children's concepts of death and decomposition even after the teaching of these concepts.* These children tend to conceptualise death in terms of a human/animal model referring to tiredness of the body, or the stopping of human/animal organs (mainly the heart). Some children tend to define death using a theological or deterministic approach, or refer to affective causes (sadness, lack of friends). Cell-based explanations were only found amongst the oldest children studied (12-13 year-olds) and then only in 40% of the responses. Few children considered death in relation to all living organisms.

The concept 'animal'

Carey points out that very young children have concept 'animal' that does not include inanimate objects, although the concept is different from the adult concept 'animal'.

Leach et al, however, found some infant school pupils unfamiliar with the word animal.

Stead (Bell) [18] and her colleagues report that to many students animals are only the large land mammals, such as those found as pets, on farms or in zoos. Their range of examples of animals is narrower or more restricted than that of a scientist. She found that only four out of 39 fifteen year-old pupils categorised pictures of animals and non-animals in the way a biologist would. Only about half the pupils categorised a fish, boy,

* *See Research Summary: Microbes*

frog, snail, snake or whale as an animal. Reasons for identifying something as an animal included: four legs, large size, land habitat, fur and noise production. About half of the children used the criterial attributes of living things to specify items as animals. They did not seem to recognise that these attributes do not distinguish animals (in either their restricted sense or in the biological sense) from other living things. Some mentioned feeding, but in the same way as it is used as an attribute of living things, rather than emphasising the heterotrophic nature of animal feeding.

Surveys of pupils', tertiary students' and teachers' understanding of the word 'animal' produced the responses shown in Figure 2 and Figure 3. All these people were asked to respond as they would in a science lesson context.

IS IT AN ANIMAL?	11 year olds (N = 49)	Primary teacher trainees (N = 34)	Experienced primary teachers (N = 53)	University biology students (N = 67)
Cow	98%	100%	100%	100%
Boy	57%	94%	96%	100%
Worm	37%	77%	86%	99%
Spider	22%	65%	86%	97%
Grass	0%	0%	0%	0%

Figure 2: Percentage responses of various samples to 'is it an animal?'

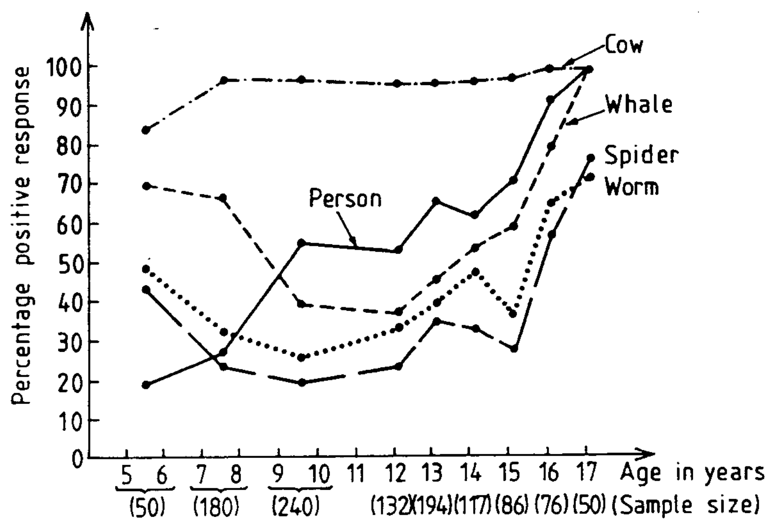

Figure 3: Representative sample response to 'is it an animal?'

The U-shaped curves for a whale, worm and spider have been replicated in a number of formal and informal surveys. One explanation for this is as follows. Five year-olds have a relatively simple idea of classification, whereby living things consist of plants and animals (and humans). Older children learn about insects, arachnids, sea-mammals, and so on. For some of these the concept of 'animal' becomes restricted to land mammals and they regard 'insects', 'mammals', 'birds', 'fish' and 'humans' as parallel sets to 'animals' rather than as sub-sets. Some older students adopt the scientific classification of subordinate sets, although the everyday restricted use of 'animal' affects the responses of some older respondents. Many people of all ages are reluctant to agree that a person is an animal; in everyday usage 'animal' is often contrasted with 'person', as in 'No animals allowed in this shop' and to describe a person as an animal is an insult.

Bell and Barker [9] report that traditional teaching about consumers and about animals as consumers did not appreciably affect pupils' understanding of either concept as shown in Figures 4a.

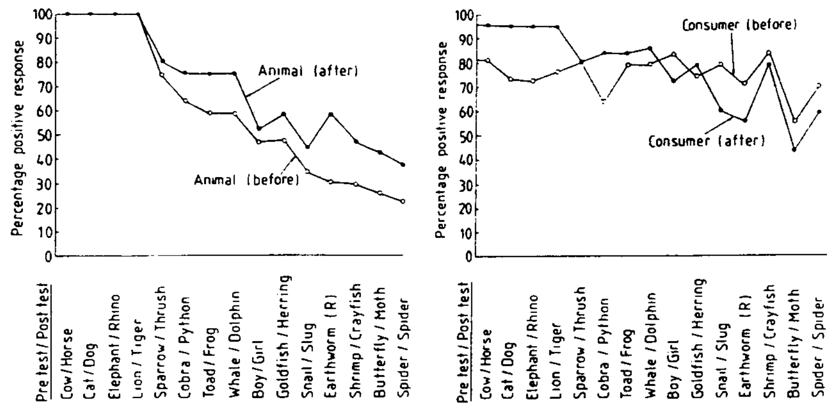

Figure 4a: Stability of thirteen year-old pupils' views despite teaching.

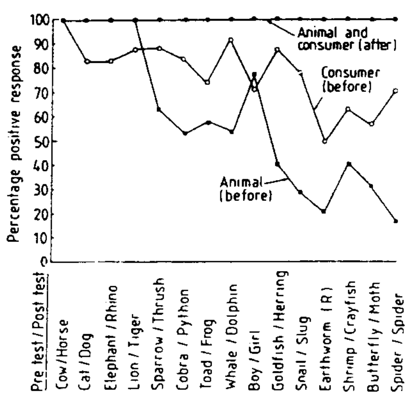

Figure 4b: Changing thirteen year-old pupils' view about 'is it an animal?' and 'is it a consumer?'

Pupils came to believe that only large mammals, (that is, 'animals' in their terms) are consumers. However, teaching activities directed at extending the concept of 'animal' were successful. A parallel class of pupils was specifically taught the biologist's view of 'animal' before they were taught about consumers. After this focussed teaching all these children correctly identified a range of creatures as both animals and consumers, as shown in Figure 4b.

Trowbridge and Mintzes [19] report restriction of the concept 'animal' in the thinking of school and university students, consistent with Bell's findings. Asked to name five animals, most students gave large four-legged terrestrial examples. Of all responses 81% were mammals, 10% birds, 5% reptiles and 4% fish. These students stated similar attributes to those reported by Bell, also confusing the attributes of living things and of the animal kingdom, indicating difficulty with the idea of hierarchical classification. Some suggested that humans are not animals.

Tema [20] based her study on Bells' work, and set out to investigate the conceptions held by rural and urban African pupils in relation to the concept 'animal'. Despite their culturally different backgrounds most students showed some similarities with Bells' pupils in their conceptions of 'animal'. However, many of the rural children regarded as an animal any creature which is not human or a plant. They used a human-centred reference point, and defined an animal by its lack of human abilities like talking and cooking. Many used religious arguments for the distinction between animals and humans.

The concept 'plant'

Stead (Bell) [21] established, from interviews with 29 children aged 9-15, that they have a much narrower meaning of the word 'plant' than the biologist's meaning. Only four children used generalised criteria such as 'grows in the ground', 'has leaves', 'has roots', 'is green', to categorise all the instances of plants. Others used criteria which excluded particular examples from the category 'plant'. Bell found children, from all age groups, who considered that a tree is not a plant, because it is large and hard, although 'it was a plant when it was little'. Some children suggested that a plant is something that is cultivated, hence grass and dandelions were considered weeds and not plants. Almost half of the sample did not consider a carrot and a cabbage to be plants, but vegetables, and over half did not consider a seed to be a plant. These results indicate that many pupils do not view 'weeds', 'vegetables', 'seeds' as sub-sets of the set 'plants' but as comparable sets.

The ideas of many fifteen year-olds were as restricted as those of ten year-olds despite science teaching.

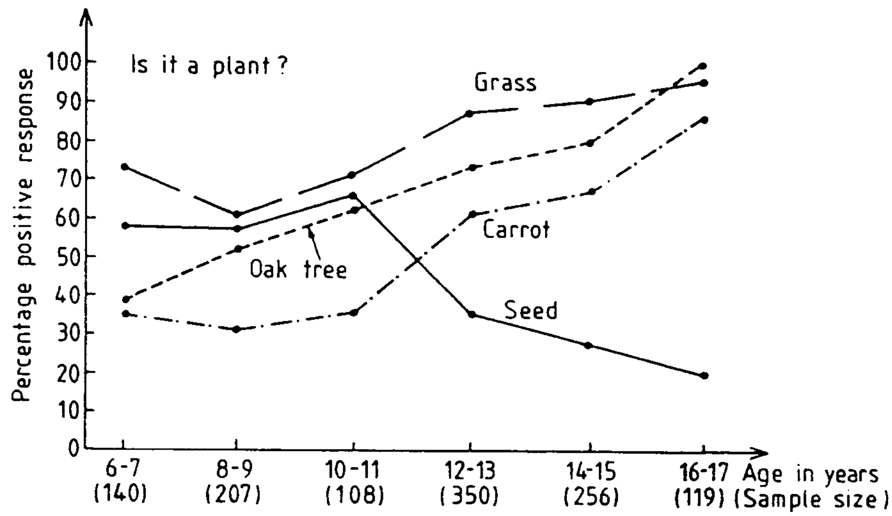

Figure 5: Results from a survey which investigated the views of the concept 'plant' at several age levels.

Leach et al confirm that pupils choose 'plant', 'tree' and 'flower' as exclusive groups. However, they were willing to assign trees and flowers to the category 'plant' when they were given a restricted number of categories in a classification task.

Children's concepts of plants can also be inferred from their identification of items, including plants, as living or non-living (see 'The concept of living' above).

The process of classification

Distinguishing living from dead, or living from inanimate things, and grouping living organisms involves classificatory skills. Children's ideas of classification in dealing with a range of items have been investigated by Piaget and many others. Bell pointed out that children's classification indicates a lack of understanding of superordinate classes (for example plant, animal) and subordinate classes (for example flowering plant, mammal, insect). Many biological sub-sets are seen as comparable sets to the set 'plant' or 'animal'.

Leach et al report that most seven year-olds can assign organisms to groups of their own choice, but their groups are of differing status and not hierarchical. Young children can use only two groups at the same time, whereas older children use a number of groups at the same time to assign organisms. By age thirteen most children, when asked, can use the group 'animals' to include groups such as bird, and by sixteen most students use hierarchical classification more spontaneously.

Ryman [22] found that English twelve year-old children encountered difficulties in classifying organisms into taxonomic categories, more so with plants than with animals. Some difficulties arose from adaptations to similar environments within a taxonomic group which mask fundamental similarities and prevent children from generalising examples of organisms into that group. Moreover, pupils may learn a 'school science' way of classifying and be able to classify organisms in the school science context, but they retain their intuitive ideas about concepts such as 'flower' and 'animal' for use in everyday life. The label 'insect' was understood to apply to small, crawly things, including spiders and centipedes.

The categories 'flowering plant' and 'vertebrate' were found to be used in the scientific sense by less than half of the thirteen year-olds surveyed by the Assessment of Performance Unit [23]. Even fewer (18%) of the sample of about 800 children could apply the term 'reptile' correctly. Many held incorrect views about reptiles having slimy skin.

Askham [24] reports that children (aged 9-12, in California) used mixed strategies in classifying plants outdoors in a botanic garden. They focussed on individual features of the plants such as the shape of leaves, the flowers, the colour, rather than on the whole plant. The latter would be necessary to find the totality of resemblances and differences required to arrive at a formal scientific classification. Leach et al also found that children of all ages focussed on more obvious features such as number of limbs or habitat, rather than on more fundamental differences such as physiology, when classifying living things.

Trowbridge and Mintzes report similar findings to those of Ryman with groups such as 'insects' being used as 'garbage cans' for animals whose group name was not known. Many students relied on everyday, rather than the taxonomic meaning of class names, such that jellyfish and starfish were classified as fish, and turtles with amphibious habits were classified as amphibians. This 'amphibian' classification of turtles and of penguins was found by Braund amongst many of the children he studied [25].

The concept of species

Leach et al report that pupils from 5-16 recognised that rottweilers, poodles and alsatians should all be put into one group called 'dogs' but they showed little understanding of the basis of this grouping. At age sixteen a few pupils referred to genetic information, but even these showed little knowledge of the genetic basis of the concept 'species'.

Cell theory

Arnold [26] has shown that pupils seem to suffer from interference between the concepts of 'cell' and 'molecule'. Eleven year-old Scottish pupils were asked to draw their ideas of molecules. Most drawings resembled cells, with features such as nucleus and membranes discernible. Children seem to have a generalised concept of 'very small units that make up larger things' which Arnold has called the 'Molecell'. Pupils aged 14-15 were asked to indicate whether certain items are made of cells and/or molecules. As well as living organisms themselves, things associated with living things were thought, by a large minority of pupils, to be made of cells. It seems that those items studied in biology lessons, including proteins, carbohydrates and water, are thought to be made of cells.

An overwhelming majority of pupils indicated that living organisms are not made of molecules, but that energy, heat and so on, are. It seems that they confined the concept 'molecules' to things encountered in physics and chemistry.

Dreyfus and Jungwirth [27,28] report similar confusion about orders of magnitude and levels of organisation amongst sixteen year-old Israeli students. Their responses suggested that they thought that molecules of protein are bigger than the size of a cell and that single celled organisms contain intestines and lungs. The pupils had been taught about cells in the previous year and superficially 'knew' a number of correct statements about them. However, over a third or responses revealed 'inadequate' alternative ideas about cells as follows:

> Everything, including enzymes, is floating in water inside a cell.
>
> The cell membrane functions just like a sieve; only liquids can pass through; it recognises, selects and rejects substances by a conscious process.
>
> The nucleus supervises the cell in a conscious way 'like a brain'.
>
> Hereditary information is only considered in those events related to reproduction.
>
> Some cells specialise in making protein, others specialise in producing energy; the main energy source is protein; there is a lot of energy in water which is an energy source for the cell; cells only need energy when moving; energy is transferred from cell to cell by the blood stream.

Many pupils do not equate meat with muscle, nor know that meat is made of cells and of proteins. Many students expressed self-contradictory ideas: the information encoded in the nucleus of all cells of an organism is identical/during cell division different information is transmitted to different cells. The cell is the basic unit of every living things/only parts of the body are made of cells, others are not.

Dreyfus and Jungwirth categorised the origin of pupil errors. Apart from ideas derived from non-school experience, many misconceptions arose from overgeneralisation of school knowledge, or from the literal use of words which teachers had meant metaphorically. For example, useful analogies such as 'giant protein molecules' and 'microbes eating substances' can lead to those misunderstandings mentioned above.

Adaptation

Adaptation is a term used with a number of different meanings. All of the research has found that most students regard adaptation in terms of individuals changing in major ways in response to their environment, in order to survive. They see adaptation in a naturalistic or teleological sense: to satisfy the organism's need or desire in order to fulfil some future requirement. In Engel-Clough and Wood-Robinson's study [30], two thirds of 12-14 year-olds and half of 16 year-olds gave teleological interpretations of examples of adaptation. Only 10% of the whole sample gave scientifically acceptable explanations. The rest merely restated the questions in some tautological form. Students show confusion between an individual's adaptation during its lifetime and inherited changes in a population over time. In other words, they believe in the inheritance of acquired characteristics. This Lamarckian belief is clear from many surveys of students both before and after instruction in genetics and evolution [29 30 31 32 33].

Deadman and Kelly found that 11-14 year-old boys were aware that animals in the past were different from animals of the present, yet somehow related. They had some idea of evolutionary change over time, but little notion of the time scale involved. Most pupils regarded evolution as a series of episodes, often related to specific environmental changes in the past, such as the Ice Age [29].

Brumby found that only 18% of students, even after studying 'A' level Biology, could correctly apply a process of selection to evolutionary change. Most gave a Lamarckian interpretation that individuals can adapt to change in the environment if they need to, and that these adaptations are inherited. Brumby [34] considers that pre-existing Lamarckian ideas can block the understanding of a Darwinian explanation.

Organisation of the body: Structure and function

Carey [2] has reviewed a number of studies, including those of Crider, Gellert and Nagy, about children's concepts of the organisation of the body.

The studies show that by age ten, but not by age seven or eight, the child understands that the body contains numerous organs that function together in maintaining life. For instance, the ten year-old knows something of the mechanisms by which eating and breathing support the body's functioning. This knowledge is by no means perfect, and early adolescence brings further changes in the child's conceptualisation of these mechanisms. Ten year-olds do not understand food is broken down into nutrients and wastes in the course of digestion.* The nervous system is thought of in pyschological rather than physiological terms by ten year-olds.** Nonetheless, by secondary school age, children begin to view the body as a biological machine. They may have ideas that the circulatory, respiratory, and digestive systems are related, and they are beginning to conceptualise the relations between the brain and the body.

Crider has identified a progression in the child's concept of the body. Very young children do not distinguish between the properties of the whole body and of its constituent parts. When the young child comes to know some internal organs, each is assigned a static function: the heart is for love, the brain is for thinking. By eight or nine the child has built a coherent system; the functioning of all the organs is conceptualised in terms of the movement of tangible substances such as food, air and blood. The organs are containers with channels of all sorts (for example, blood vessels) connecting them. The final stages of building a metabolic and cellular understanding of the body, with recognition of transformation of bodily substances, is achieved by a few children, according to Crider, by the age of eleven.

Gellert showed that by eleven years old, over half the children used the term 'circulation' indicating blood flow, and referred to the heart as a pump. There was no evidence that even the older children (sixteen year-olds) realised that blood returns to the heart in a complete circulation. After age nine, most children recognised that air is breathed into the lungs and somehow gets around the body.

Nagy found that children say that internal organs (for example the heart, stomach and brain) are made of bones, skin, flesh and food, the same answers they gave when asked what the whole body is made of.

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* *See Research Summary: Nutrition*

** *See Research Summary: Responding to the Environment*

Caravita and Tonucci [35 36] found that young children gave egocentric explanations for parts of the body: 'my hair is for washing'. By the end of primary school, they explain the functions of organs or apparatus in terms of causal chain relationships. These authors confirm Carey's contention that a shift occurs naturally in children's thinking between the ages of 7 and nine, from a holistic, human centred view to a view which recognises different functional parts working together. However, even older pupils have difficulty with this integration in respect of biological structures, and further progress depends on effective experiences and instruction. The authors point out that most biological relationships are not at all obvious and are a construction based on abstract knowledge.

Caravita and Tonucci found that the response of children to the living world is emotionally driven, reinforcing findings of other workers such as Paterson [37]. Dreyfus and Jungwirth, in particular found that some strongly held alternative conceptions derive from affective attachments, especially in disadvantaged children. Like other workers, Caravita and Tonucci found that children do not relate muscles to meat. Young children expressed only the static, supporting, function of the skeleton; older children recognised that the skeleton is necessary for movement but only 20% could draw muscles appropriately across joints. Discussion and manual experience with models revealed better understanding than the drawings did.

Implications for teaching

'There can be little question that animistic-like responses exist; the question which remains unanswered is what do they mean?' [3]. A number of authors have said that teachers should realise that their pupils do not have the same concepts as teachers do when they use the words 'living', 'animal' and 'plant'. Having a clear concept of the scientific meaning of these words is essential for understanding other biological ideas. Examples are: microbes are living things, organisms can arise only from pre-existing living organisms, the significance of autotrophic and heterotrophic nutrition.

The opinions of researchers about how to achieve the scientific concepts are sometimes contradictory. Arnold and Simpson, [10] writing in 1979, regretted that the old-fashioned 'characteristics of life' had been left out of modern syllabuses. 'Variety' rather than 'unity' of living things was stressed. They advocated bringing back the teaching of the characteristics of living things. Beronsky, Ondraka and Williams [38], in 1977, reported that deliberate instruction on life characteristics improved the identification of living and non-living. However, Brumby, [16] in 1982, noted that students had learnt the 'seven characteristics' as by rote and could not apply them in classifying and operating criteria. She suggests that rote learning of the characteristics of living things inhibit students' application of the concept of life to solve a real-life problem. Bell [8] reached a similar conclusion about the use of MRS GREN mnemonic. As well as teaching the characteristics of living things it is necessary to consider the absence of these characteristics from non-living things.

Consideration of non-examples of classes is part of the strategy recommended by Trowbridge and Mintzes to develop skills of discrimination and generalisation as a training in classification [19].

Bell et al in the LISP Project in New Zealand have produced materials in the form of games and quizzes, to specifically address the concept of living, animal and plant, and the relationship between them. Such specific teaching has clarified the concepts and facilitated the learning of further concepts such as 'consumer' [8,39]. (See Figure 4).

Dreyfus and Jungwirth [40] worked with 14-15 year-old pupils, attempting to change their concepts of the cell membrane using a 'cognitive conflict' strategy. At the end of the series of lessons, they decided that this approach was not appropriate in this case, where the pupils' prior ideas were derived from school knowledge and not from personal experience. The pupils have neither a commitment to their prior ideas nor access, at their scientific level, to a correct alternative explanation. Dreyfus and Jungwirth recommend teaching only the results and implications of the functioning of the cell membrane, and not its biophysical and biochemical processes.

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LIVING AND NON-LIVING

Children's Prior Ideas

Young children associate the idea of 'living' or 'alive' with all moving things.

As they get older, they associate 'living' with things that appear to move by themselves, including clouds, the sun and fire. This 'animism' persists in the thinking of many secondary school pupils.

Many children, even at secondary school age, do not regard plants as living; very few consider that seeds are alive.

Children who do not believe that seeds and eggs and pupae are alive, nevertheless believe that live seedlings, chicks and butterflies can arise from them.

Some children use growth as a criterion for life; however, many children who know that plants grow, deny that plants are alive.

Some children refer to breathing as a criterion for life.

Older pupils who have been taught the 'seven characteristics of life' can often quote them, but many are unable to apply them systematically as criteria for life.

(See Living Things Research Summary)

The Challenge for Pupils

Children are likely to use knowledge of themselves to evaluate whether unfamiliar objects are living; they use the idea of a human being as a metaphor for 'living'. This accounts for animistic ideas being so widespread in childhood, and persisting into adolescence. It is easy to see how children come to see fires and clouds as 'alive' - they do seem to have 'a life of their own'! Language and folk culture often reinforce these animistic ideas - with such expressions as a 'living flame' and so on. By adulthood, however, most people can distinguish between the scientific notion and more colloquial use of the word 'living'.

Distinguishing living from non-living, at both a theoretical and a practical level, is an enormous challenge for experts, let alone children. The problem is that there is no single criterion distinguishing life and it is worthwhile sharing this problem with pupils. Moreover, the characteristics which define life are not easily observable. In helping children to recognise 'living things', the teacher needs to choose examples which clearly demonstrate some or all of the characteristics of life. In order to help pupils to develop their own concept of 'living', a display of examples is useful for pupils to classify as 'living', 'dead' and 'never-lived'. Non-living items, such as a bunsen flame and a clockwork toy animal, which show some life-like characteristics, and living items, such as a seed and a potato, which appear inert, should be included in the display. Discussion of pupils' classifications helps them to learn what aspects of their biological knowledge are relevant in deciding whether something is 'alive'. Alternatively, a questionnaire with pictures of examples and non-examples of living things could be the stimulus for discussing these criteria. (See Additional Materials.)

The mnemonic MRS GREN, summarising the seven characteristics of life, (Movement; Respiration; Sensitivity; Growth; Reproduction; Excretion; Nutrition) may be useful if clearly reinforced with a range of applications. Research shows, however, that this can become a mere 'mantra' if offered superficially. The real challenge is to recognise the commonality of living things and how it can be interpreted in terms of the list of characteristics applied to actual examples. It needs to be acknowledged that not all living things show all the characteristics all of the time. Children find it difficult to think of something as being alive if they cannot observe it moving, eating or growing. As a group discussion to extend their concept of 'life' pupils could take sides to present evidence as to whether or not an item is alive. They can be shown an unusual piece of rock, sponge or other amorphous object and be told it was found in an exotic place (a desert island, Mars, or a jungle). The children can then consider how they would find out if <u>is</u> alive, if it was once alive but is now dead, or if it has never been alive.

Pupils also need to appreciate that (most) living things are made of cells. This is necessary for understanding that metabolic processes underlie the manifestations of the seven characteristics. (See Learning Guide: Cells.) Only living things can make their own new body material according to a self-replicating 'blueprint'. If pupils can begin to approach this idea as the criterion of life, Nutrition, Growth and Reproduction can be understood as the more fundamental of the seven activities defining living things. (See Learning Guides Assimilation in 'Nutrition' and Materials and Mechanisms in 'Growth'.)

ANIMAL/PLANT/HUMAN

Children's Prior Ideas

Children and adults tend to think of animals only as large, furry, four-legged, land mammals.

Pupils tend to think of 'insects', 'birds', 'fish' and 'humans' as alternative sets to 'animals' rather than subsets of 'animals'.

Most pupils think of plants as small herbs, deliberately cultivated and rooted in the ground. They contrast 'plant' with 'tree', 'weed' and 'vegetable'.

People do not think of themselves as animals; rather, humans are contrasted with animals. However, children recognise gradation in similarity between humans and other things, ranging through mammals, vertebrates, invertebrates, and plants to minerals.

(See Living Things Research Summary)

The Challenge for Pupils

There is a three-fold challenge in approaching this goal.

The first is a linguistic one: pupils need to apply the words 'animal' and 'plant' in a more precise way than in everyday speech and to extend their concepts to include a fuller range of examples. Pupils can be helped to appreciate that the words have different meanings in everyday life and in science. It is not that one is wrong and one is right, but that it is a matter of recognising the usage appropriate to the context. Pupils find it fairly easy to adopt the scientific concepts but they will need to be reminded whenever the scientific meaning of the words is being assumed. The more common a word is in everyday usage the more likely children are to fall back to using it in its lay meaning. These are concepts for which a diagnostic questionnaire is very useful to open up discussion. (See Additional Materials.)

The second challenge for the pupils is to recognise the differences in nutrition as the criterion for distinguishing animals and plants. Stepping stones to this recognition arise from discussion of obvious differences between animals and plants which can be related to their different nutrition: differences in movement, speed of response, colour, and general anatomy.

Thirdly, pupils need to accept that the terms 'plant' and 'animal' are not merely descriptive, but that they are used to name two kingdoms within the taxonomy of living things (see Learning Guide: Classification). Most of the living things familiar to children are either a plant or an animal and classification into one or other group, exclusively, needs to be practised. Children may be offered a range of activities to challenge their own concept. Categorising many specimens of living things as plants or animals helps to clarify the criteria for grouping organisms into their respective sets.

Further activities for categorising animals and plants, for example worksheets, crosswords, card games and quizzes, could reinforce the concepts of 'animal' and 'plant'. (See Additional Materials.)

Accepting that humans are animals involves more than a semantic shift. Most pupils have an emotional resistance to regarding themselves and other people as animals, which may be based in cultural and religious traditions. In respecting this, it may be helpful to balance the evidence that people are animals, in the biological sense with evidence for the uniqueness of the human species as a special kind of animal.

Children's Prior Ideas

Very young children do not classify systematically, using the same criteria for every member of a group of organisms. They use only one superficially visible criterion at a time. Older children do use a system, but often tend to classify organisms according to visible adaptations which may have arisen from similar environments rather than recognising what scientists see as fundamental similarities.

When children use words such as 'insect', 'fish', 'amphibian', 'moss', they are thinking of more extensive groups than those defined by the scientific meanings of the these words.

Whatever their meanings of the words, pupils tend to think of 'insects', 'birds', 'fish' and 'humans' as alternative sets to 'animals' rather than as subsets of animals. Similarly they think of 'flowers' and 'trees' as alternative sets to 'plants'.

However, relatively young pupils can be taught to classify hierarchically, and by about the age of sixteen many do so spontaneously.

(See Living Things Research Summary)

The Challenge for Pupils

Pupils will approach the systematic classification from experience of grouping objects and living things for various purposes. Grouping of organisms on criteria such as habits, habitat or usefulness leaves some scope for negotiation and opinion about the limits of the categories, and allows for the allocation of an organism to more than one group. However, pupils must recognise that the 'natural systematic classification' has been created to accommodate <u>all</u> species of organisms in order to make sense of the diversity of life. This has involved the establishment of non-negotiable, hierarchical, non-intersecting categories agreed throughout the scientific community.

The challenge in applying the general idea of classification in the form of the systematic biological classification involves the pupils coming to share the meanings agreed within the scientific community. They need to recognise that, although the 'natural system of classification' aims to reflect natural similarities and differences amongst living things, it is a human creation operating by consistent rules. Unlike many classifications they may use, this is not an area where it is valid for pupils to construct their meanings for categories or create their own groupings. The shared meanings can only be communicated by an 'expert'. The teacher will need to clarify the scientific meanings of terms such as 'mammal', 'fish', 'insect', 'moss' and so on.

Pupils need to realise that similarities as well as differences must be considered in assigning organisms to sub-sets. They also need to think about the predictive value of the system - for example, if a particular organism is classified in the class 'reptiles' and we are all agreed on the characteristics of reptiles, we have a general idea of this particular organism's characteristics.

Pupils using keys, need to recognise that a key is only a tool for identifying those organisms which have been written into the key. This should be distinguished from the 'systematic classification' which includes all organisms and to which keys relate.

LIVING THINGS

SPECIES

Children's Prior Ideas

Pupils recognise the unity of certain species, for example dogs, cats, humans, and know that organisms produce offspring of their own kind. However, they show little knowledge of the genetic basis of the concept 'species'.

(See Living Things Research Summary)

The Challenge for Pupils

Pupils confront a vicious circle when they try to grasp the concept of 'the species'. The concept of the species underpins any understanding of taxonomy, adaptation, inheritance, evolution and extinction. At the same time some concepts from these areas of study help to define the term 'species'.

This goal may appear easy to achieve merely by attaching the word 'species' to children's intuitive notions of different 'kinds' of living things. However, to a pupil, the words 'fish', 'alsatian', 'poodle', 'mouse', 'grass', 'daffodil', may all signify 'kinds' of living things of the same status.

The challenge is to realise that applying a species label to a particular group of individuals is not just a naming exercise; it is a recognition of fundamental similarities within a group which enable it to perpetuate itself as the same 'kind' through the consecutive generations without 'mixing' with other groups.

Discussion based on pupils' everyday experience of pets and gardens, and on their knowledge acquired from the earliest children's books may serve as a starting point to approach a scientific understanding of 'species'. Children know that familiar animals and plants produce offspring of their own kind. Part of the challenge is to understand that members of a species <u>cannot</u> breed with members of other species or produce offspring of a different species from themselves. The rare exceptions to this rule provide newsworthy or bizarre examples of sterile offspring, such as the mule, reinforcing the definition of a species as a self-perpetuating unit. Application of the 'species rules' to dogs helps to reinforce the concept. Pupils may consider questions such as: 'Can a poodle and an alsatian breed together?', 'Can a poodle and a cat breed together?', 'How can your recognise a dog as a dog and as distinct from a cat?', 'Is this 'dogness' perpetuated when different varieties breed together?', 'Which is a species - 'dog' or 'poodle'?'.

LIVING THINGS

CELLS

Children's Prior Ideas

Secondary school pupils are familiar with the word 'cell' but many think that it applies to any small unit discussed in relation to living things. They often confuse the concepts of 'cell' and 'molecule'.

Many pupils think that only certain parts of the human body and other living things, are composed of cells.

Many children think that cells consist of amorphous jelly.

Some pupils, however, believe that single cells contain organs which are miniature replicas of the organs of multicellular creatures. They may think that the parts function in a conscious and deliberate way - the nucleus controlling the cell, the membrane selecting substances, as a person could control and select.

There is little evidence of children understanding that chemical interactions occur in cells.

Many children think that enzymes are living organisms. They think that enzymes are involved only in digestion.

(See Living Things Research Summary)

The Challenge for Pupils

This is an area where issues of size and scale need to be addressed. Children need to think about their large bodies each being composed of millions of tiny cells. Building block analogies are often useful (for example, house bricks or Lego bricks). However, there are pitfalls; if bricks represent cells in one analogy and represent molecules in another context, pupils' confusion of scale will be compounded. It is important for pupils to realise what the brick stands for in each context.

It is difficult for children to transfer a macro view of the processes of life, as observed in themselves and other creatures, to the processes of life at an invisible cellular level. If pupils have taken on board the seven characteristics of life and they can accept that a cell is alive, the challenge is to make the logical link of accepting that a cell can perform the life processes. The need is then to look at the details of how particular cells perform these processes. It would be useful for the teacher to diagnose the ideas which children hold about processes and systems within a cell, and to acknowledge those which are useful analogies.

A conventional approach to teaching this concept is to study an organism such as Amoeba, perhaps using video sequences. Even if pupils develop some <u>knowledge</u> about the life processes of this organism, they do not necessarily transfer it to a <u>belief</u> in the autonomy of cells of their own body.

Pupils need to recognise that cells have an infrastructure; video sequences of acellular organisms and of cells in tissue culture may be helpful to establish this recognition.

Having established the notion of a cell being composed of parts and performing all the processes of life, children need to address the issue at the level of materials. It is helpful to sequence schemes of work, such that pupils meet cell processes after they have established certain concepts about materials. They need to believe that cells, like all other things, are made of materials and that these materials consist of substances. (See Material Substances Learning Guide in 'Materials'.) This involves concepts of scale; children need to realise that cells, however microscopic, are made of molecules far more tiny.

From a study of Materials, pupils may have developed a notion that some substances can co-exist without interacting, and that under certain conditions some substances interact. These concepts are needed for understanding the stability of cell structures and the dynamics of living processes. (See Chemical Interactions Learning Guide in 'Chemical Change'.) These difficult and sophisticated ideas are not easily accessible to pupils but may be approached in the study of the chemistry of particular processes, for example respiration (see Learning Guides Respiration in 'Ecosystems' and Assimilation in 'Nutrition'). If pupils realise that chemical interactions occur in living cells and not just in test tubes, they are starting to approach the goal.

Children's Prior Ideas

The majority of pupils regard adaptation only in terms of *individuals* changing in major ways in response to their environment. They do not recognise adaptation in the context of species.

Young children often reason in a teleological sense, seeing a wide range of diverse biological phenomena as part of some sort of 'grand plan'. For example, they may suggest that certain organisms exist in order to feed other organisms.

This reasoning often persists into adolescence. When pupils are introduced to new ideas about evolution and adaptation in science lessons they may 'fall back' on their teleological reasoning, drawing inferences such as 'giraffes consciously adapted to their need for food from high trees by developing long necks through successive generations'.

It may be that everyday language, such as that used on television nature programmes, reinforces teleological language. Students may not believe conscious adaptation, but they lack the language to express their complex conceptions.

In addition, some children and older students stating that individuals can adapt during their lifetime if they need to, think that these adaptations are inherited, resulting in adaptation of a species. That is, they appear to hold the Lamarckian view of the inheritance of acquired characteristics.

(See Living Things Research Summary)

The Challenge for Pupils

The initial challenge facing pupils is to use the word 'adaptation' in a biological sense of an individual 'becoming suited to survival in the environment'. A wide range of examples of changes during the lifetime of people and familiar animals and plants can be discussed - for example tanning when sunbathing, increase in blood count at altitude, plants developing large leaves in the shade - and recognised as changes in response to current conditions.

A greater challenge arises in extending the idea of adaptation from adapted individuals to consider a population or species being adapted to its conditions. Having a 'snapshot view' of a species, that is thinking of a species as a lot of adapted individuals at one point in time, may be as far as many pupils will be able to extend the idea.

However, in order to link the adaptation of individuals with the survival of a species pupils need to be aware of individuals reproducing and providing the next generation; they need to be aware of life cycles; they need to think about adaptation to the surroundings increasing the chances of survival of an individual; they need to have in mind the inheritance of characteristics from parents. (See Learning Guides in 'Reproduction and Inheritance'.) All these ideas come together in thinking about the survival of a species. Moreover this is a case where pupils need to bring time into their thinking, recognising that a life cycle takes time and that a number of cycles amount to continuation of a species through time. Pupils may begin an integration of all these ideas towards a concept of survival of a species, but it is likely to be a static 'snapshot' view of a species.

In due course pupils will need a more dynamic concept of adaptation to account not only for survival but also for the evolution of the species. This involves a very much more difficult challenge: pupils need to think about individual variation alongside ideas about adaptation, life cycle and evolutionary time scale. Consequently, in the early secondary years it is a sufficient goal to establish some of the contributing concepts of natural selection.

Pupils are familiar with the notion of extinction of major groups such as dinosaurs. Their suggestions of possible causes of extinction of dinosaurs may be provide a basis for understanding extinction in terms of fitness of individuals for the environment. Technological analogies of obsolete designs being discarded, and new models being developed from the best of early designs may help pupils to understand extinction and evolution. However, it is important that pupils do not infer deliberate intention in the case of evolutionary selection.

TIME SCALE

Children's Prior Ideas

Pupils tend not to include a time dimension in their thinking.

Children have difficulty in appreciating the extremely long time scale of geological processes; suggestions about the age of soil vary from 'as old as the Earth' to 'about five years'.

Pupils may be aware that animals of the past were different from animals of the present, yet somehow related. They have some idea of evolutionary change over time but little notion of the time scale involved.

(See Rocks Research Summary)

The Challenge for Pupils

Pupils take account of time only when hours, weeks and days are involved. They have difficulty in linking personal experience of the time it takes for things to happen with the exceedingly long time involved in geological and evolutionary events. (See Introduction: Size and Scale in Mass, Length and Time.)

Pupils might be better able to think about this expanse of time if they have personal experiences 'scaled' to represent long time periods. For example, the one hundred metre track on the athletics field could represent forty-five million years: then the last 50,000 years (since humans appeared) would 'occur' in the last 1.00 mm of 'time'.

The very slow rate of geological processes is matched by the slowness of many evolutionary changes to living things. Pupils find it hard to imagine the time involved in the changes that have given rise, for example, to the evolution of the giraffe's long neck. Pupils will need to come to terms first with the time scale for a single life cycle and then with the very large number of generations which have existed in the past.

Pupils do not readily accept that any living thing could have existed before humans particularly as they often think that plants and animals are dependent on humans for care. Moreover, portrayal of dinosaurs together with 'stone age' man in films and comics only serves to reinforce their view.

Locating the origins of humans and other species on a Time Chart is an exercise which bears repeating whenever this is appropriate. (See Additional Materials: Time Chart.)

Ideas about the beginning of the Universe and of mankind have religious significance for some pupils and therefore they need to be treated sensitively.

LIVING THINGS

STRUCTURE AND FUNCTION

Children's Prior Ideas

Young children think of the function of any biological structure in relation to themselves (egocentrism) or to people in general (anthropocentrism). For example, 'flowers are coloured so that they look pretty', 'meat is for eating', 'trees give us shade'.

Pupils find it difficult to integrate the many pieces of information they have about living things to achieve a structure/function relationship.

(See Living Things Research Summary)

The Challenge for Pupils

Once the concept of the cell has been established (see Learning Guide: Cell), pupils need to relate it to the ideas of tissue, organ and system in thinking about a wide range of living things. They will need to extend their awareness of well-recognised tissues and organs like bone and heart to include less obvious examples like skin and blood. They also need to include plants in their thinking and recognise wood as a tissue and roots as organs, for example.

The distinction between tissue and organ is not always a clear one, particularly when the same word, for example, muscle, is used to describe both tissue and an organ. It may be that an analogy with an object being made of materials is a helpful one for pupils trying to relate tissues to organs. Alternatively a house and its rooms and contents may provide a useful analogy. However, it is important that any analogy is carefully chosen so as to avoid confusion with analogies used in different contexts.

Before attempting to relate structure to function, pupils face the challenge of distinguishing between the two. They need practice in applying the word 'structure' whenever they think about any whole living thing or part of it. Then they need to think about the 'job' that the organism or part performs, and learn to apply the word 'function'. Technological analogies may be useful. However, in technology, a structure is deliberately designed to serve a particular function. It is important that pupils do not infer a similar intention in the evolution of biological structures and functions.

Pupils need to analyse a structure/function relationship, using examples from all levels: cell, tissue and organ. They need practice in asking and answering questions, such as:

'How does the shape of the sweet pea flower help the flower to do its job?'
'How does the shape of a seagull's wing enable the bird to fly?'
'How does the green-ness of an oak leaf help the plant to do the job of making food?