

Children's ideas about

NUTRITION

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.

Children's ideas about NUTRITION

Before reading this summary of children's prior ideas, it may 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 understandings.

Introduction

Only a small amount of research has studied what children understand by 'food' and the processes of feeding in animals. There is, however, an extensive literature on children's concepts of plant nutrition and of the interaction of photosynthesis and respiration in plants. Few studies have examined children's ideas about the importance of these processes in matter cycling and energy flow in ecosystems, though notions about the interaction of producers and consumers in food chains have been investigated.

The concept of feeding as a characteristic of living things has been identified in children's thinking. Understanding the difference between plant and animal nutrition depends on children's concepts of 'animal' and 'plant'. Research findings about the concepts 'living', 'animal' and 'plant' are reviewed in the Research Summary: Living Things.

Studies of children's concepts of food and of nutrition in animals and in plants are covered in this Research Summary, under the following headings:

- Food: what it is
- Dietary components
- Human digestion and assimilation
- Plant Nutrition
- Photosynthesis
- Gas exchange in plants
- Food chains and ecological cycles
- Progression
- The major studies and their implications for teaching.

Food: what it is

Any discussion of 'food' is fraught with the semantic problem that the word 'food' has different meanings in everyday and technical situations. There are no ready alternative

words to offer pupils in either context. The school science definition of food as organic compounds which organisms can use as a source of energy for metabolic processes is not consistently used even by science educators. Studies in Scotland and in New Zealand found that even the word 'food', even when used in science lessons, is used in a variety of ways by both teachers and textbooks, and food is considered in three different contexts: human nutrition, photosynthesis and ecology, with different meanings for each¹. It is not surprising that pupils construct alternative concepts of food which make sense to them in trying to integrate the various meanings presented through school lessons.

Children and most adults consider food as that which is fit for human consumption, that is food is something that is eaten. This might be extended to mean anything useful taken into an organism's body, including water, minerals and, in the case of plants, carbon dioxide or even sunlight. When referring to starch in the context of plant nutrition, a typical child's comment was 'starch is not food because it is made not eaten'² and Simpson and Arnold found 'starch' to be the most frequently misclassified item in their study of pupils' concept of food cited by Barker¹. Eisen and Stavy³ asked advanced high school and university students 'What does food mean to you?'. The responses included the following:

	<i>Biology students</i>	<i>Non-Biology</i>
Essential materials	24%	29%
Energy source	40%	27%
Materials for building the body	14%	14%
Both energy and building materials	11%	6%

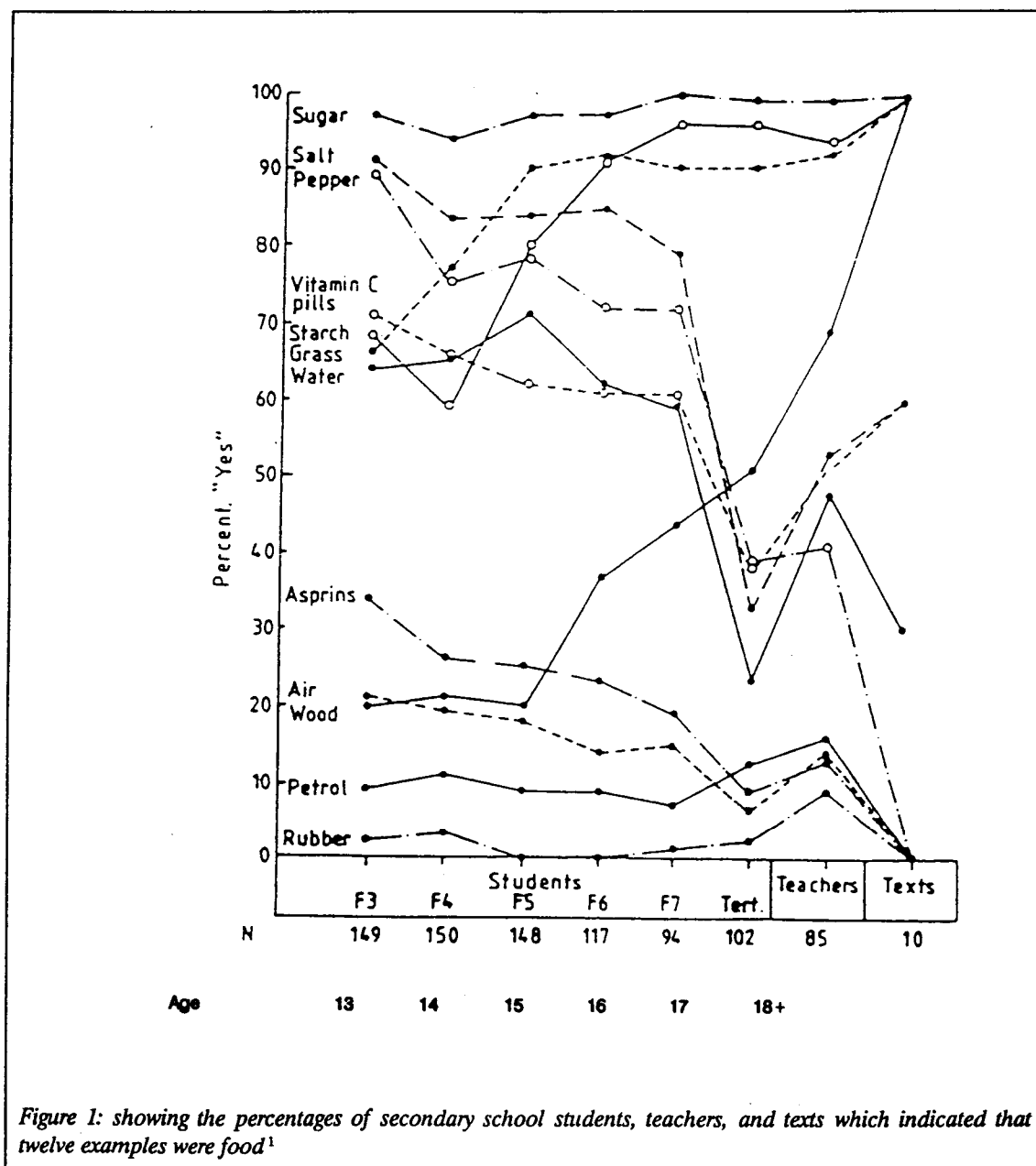
(The difference between the two groups is not statistically significant.)

Children often give a non-functional explanation of the importance of food; they say that it is needed to keep animals and plants alive, without understanding the role of food in metabolism. School pupils (aged 13-14) 'do not grasp, or are unaware of, the....meaning of the word 'food' as a material that serves as a substrate for respiration....'⁴.

Food is associated with material for growth, rather than as an energy source, especially in relation to plants. Children do not recognise that plants need an energy supply as they do not appear to be energetic in the sense of running around. Since the 'energy-rich' definition of food is not used by children, the distinction of minerals being 'nutrients' but not 'food', as presented by teachers, is meaningless.

In New Zealand, Barker investigated students' concepts of food by interviewing 28 pupils aged from 8 to 17, then by surveying a larger number of students, from age ten to

university undergraduates, by written questionnaires. The graphs below summarise the results from secondary school students and teachers. Figure 1 shows which items were considered to be food. Junior secondary pupils discriminated between those items which are taken orally by humans or familiar animals and those which are not. Aspirins are recognised as 'medicine' not 'food'. Those students who have studied biology for several years produced responses nearer to those of the biology teachers sampled. Figure 2 shows that among older secondary school students the use of edibility and palatability as criteria of food was replaced by the energy criterion. Barker concludes that any learner's concept of food is fluid and context-dependent, depending on who or what is considered as the eater, whether materials are considered in isolation or in combination, or even whether food is considered metaphorically.



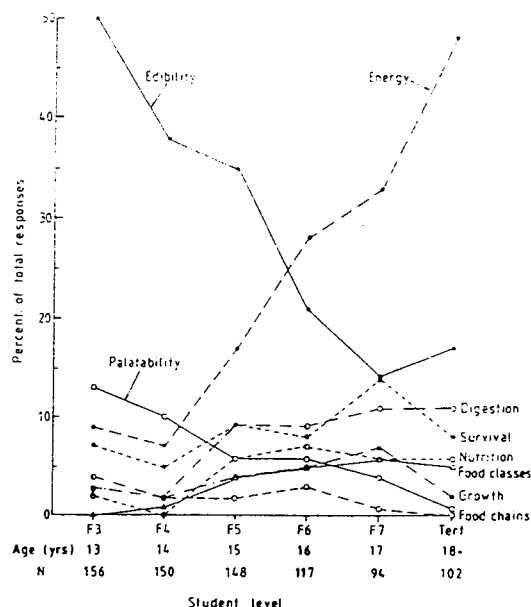


Figure 2: showing the percentages of students who used nine criteria when they were writing an answer to the question "Why are some things, and not others, described as 'food'?"¹

Dietary components

From an early age children know that eating has many consequences: growth, health, strength and energy. But for pupils these are vague concepts anyway. Carey⁵ quotes two studies, by Wellman and Johnson⁶, and by Contento⁷ of children's ideas of nutrition. Pre-school children thought that consumption of anything, even water, would lead to body weight gain, and that differences in height as well as differences in girth are a direct consequence of the amount consumed. These children thought that some diets are more wholesome than others in ensuring health and growth. From the age of eight most children differentiate different kinds of diets as making people fat or strong⁶. Five year-olds knew that fruits and milk are good for them but did not know why. They knew of vitamins as pills to make people strong and healthy but only three out of 34 5-11 year-olds realised that ordinary food contains vitamins.

Lucas, in his survey of 1033 adults, found that they were familiar with the names of dietary components but not their functions: 37% thought that proteins provide most of the energy needs of the human body and 19% thought vitamins do⁸. Proteins are more clearly identified with food; most of a sample of 1405 students from aged 10-19 selected proteins as the product of photosynthesis, presumably relating these substances to food and to growth⁹. As mentioned above, food is associated with material for growth, rather than as an energy source. Some pupils referred to plants getting vitamins from the soil⁹. This suggests that they thought of vitamins as being the same as minerals. Teachers will

be aware from their own experience that children have difficulty in understanding that a foodstuff, such as bread, contains various kinds of food components or nutrients, such as starch and vitamins. They hold the notion that bread is starch, cabbage is vitamin C, cheese is protein and so on.

Research by Brinkman and Turner suggests teaching did not change certain ideas of Dutch and English teenagers about fat in the diet. A small number of students (about 10%) think that it is not necessary for your health to eat fat. Fat tends to be associated with unhealthy food. A substantial number (about 30%) deny that 'you can obtain energy from fat'. About half deny that regular meals can cause over consumption of fat; they think that excess fat can only come from snacks⁴⁷.

Arnold has postulated 'interference' between the concepts of cell and molecule ¹⁰.* Simpson ¹¹ followed up this work by an investigation on 249 14-15 year-old Biology students in six schools, who had all been taught about food and digestion. They were asked to identify items on a list as being 'made of atoms and molecules', and/or 'made of cells'. Three quarters of the pupils accepted that carbohydrates and proteins are made of molecules but a large minority thought that they are also made of cells. Only half of those students also studying Chemistry, and a mere third of non-Chemistry students, thought that a biscuit is made of molecules and nearly a fifth thought it is made of cells. From examination of all the items on the list it seems that pupils regard those associated with living things as being made of cells but not molecules, whereas those which are studied in Physics and Chemistry, including energy, are made of molecules and not cells. Proteins and carbohydrates are seen as falling in both categories.

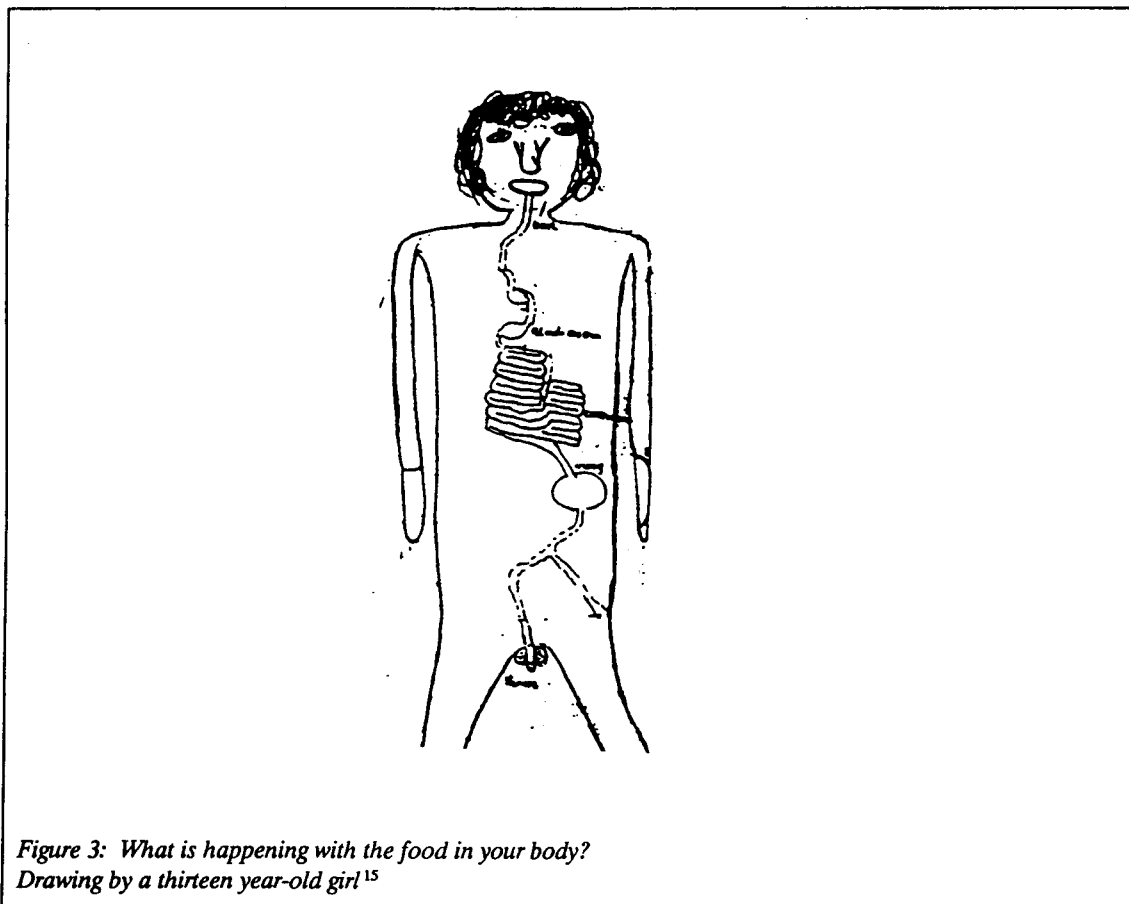
Pupils have difficulty in developing concepts of 'carbohydrate' and 'starch'. Arnold and Simpson found that many pupils think that carbohydrate is a gas (54% of eleven year-olds, 30% of thirteen year-olds). Even more think that carbon is a gas¹².

Human digestion and assimilation

Carey's review of a number of studies ⁵ provides insight into young children's ideas of the human digestive system. Gellert ¹⁶ asked 96 children aged 4-16 to list what was inside them, then gathered detail from further questioning. The youngest children knew that they had food inside them, and by nine most children listed several organs including the stomach. Fraiberg states that up to about nine a child imagines his body as a hollow skin bag which is all 'stomach'. It is a reservoir in which blood, food and wastes are somehow contained ¹³. Older children and adults realise that there is a food bag inside the body but the everyday use of the word 'stomach' to refer to this bag and to the

* See Research Summaries: *Materials and Living Things*

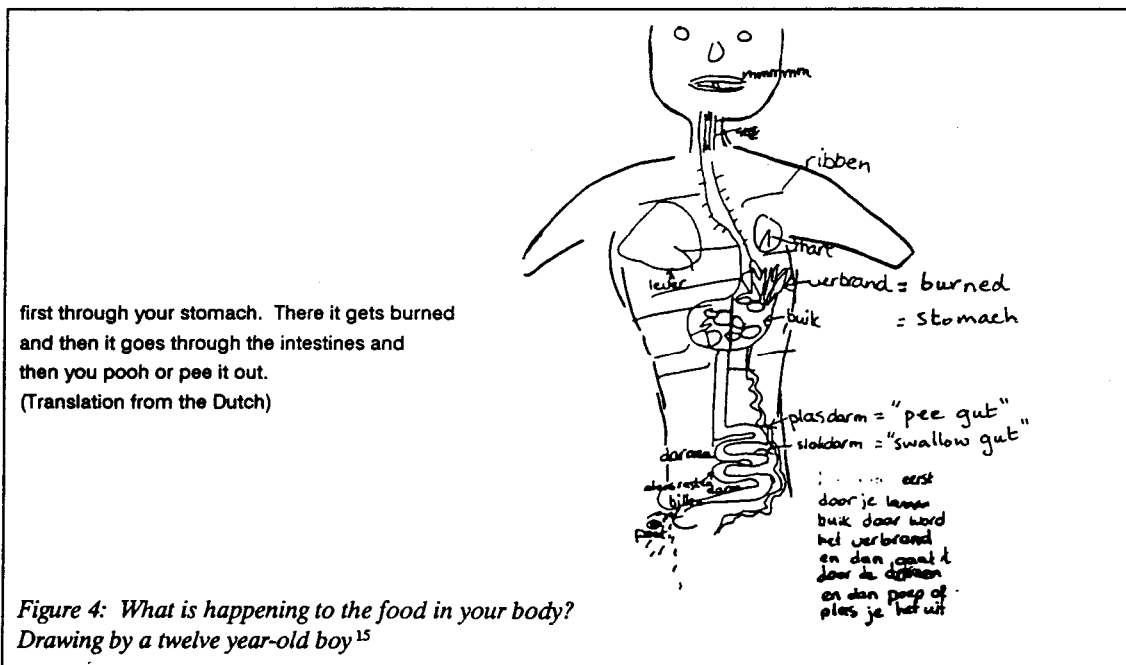
abdomen causes confusion. When the stomach is drawn as an internal organ it is usually shown larger and lower than it really is¹⁴. Intestines are drawn, but the liver is rarely shown. Many children draw or describe the digestive system as being double with two outlets, one for faeces and one for urine (Figures 3 and 4)¹⁵. The youngest children relate the stomach to breathing, blood or strength and energy^{5 14}. From about seven they begin to know that the stomach helps to break or digest food, and later that food is transferred elsewhere after being in the stomach. Gellert found that by eleven most children had a fairly correct outline of anatomy and the overall function of systems. She attributed the initial ideas to sensations of heartbeat and swallowing, and later ideas to TV (even in 1962 in the USA) and hospital experience (her sample were in-patients)¹⁶.



Top primary age children say that lumps of food are broken down, juices or acid dissolve food, and that 'goodness' is somehow extracted. These descriptive ideas were found to be expressed in a similar way by 34% of Simpson's sample of thirteen year-olds. Children under nine think that food vanishes after it is eaten¹⁶. Older children suggest that food turns into 'goodness' or 'energy', again suggesting that the amount of food matter is not conserved. Only three of 34 subjects, aged 9-11 knew that food is changed in the stomach and brings about its effects by being broken down into altered substances that are carried to tissues throughout the body.

A very common concept amongst children is that digestion is the process which releases usable energy from food ¹⁷. This arises from linking the two acceptable ideas 'energy is obtained from food' and 'digestion is the breakdown of food' to construct an unorthodox idea ¹⁸.

'Burning' of food may be located precisely in the stomach, with the use of flames shown in children's drawings, Figure 4 ¹⁵.



At thirteen, children's ideas of the sequences of digestion are very confused, both in terms of the anatomical route and the processes. Routes may include the trachea, heart, kidneys in some children's minds. The sequence of processes may start with breaking into soluble particles, releasing energy, followed by swallowing ¹⁷. These ideas are obviously not naive intuitive notions but constructions derived from an overload of information: pupils have been taught a lot of unfamiliar words or familiar words in a new context.

Simpson found that 58% of thirteen year-olds thought that enzymes are made of cells ¹⁷. Teachers will be familiar with pupils thinking that enzymes are creatures, something like germs, a notion encouraged by advertisements.

Top primary children think that defaecation is necessary to make room for more food ^{5 17}. By thirteen most children say that some of our food is useless or harmful so must be eliminated.

Plant nutrition

During the 1980s a considerable amount of research was done on children's ideas of plant feeding, and consistent patterns in children's thinking were noted in several different countries. Several of these research projects have used their findings about children's ideas develop teaching schemes which are discussed in the later section 'The major studies and their implications for teaching'.

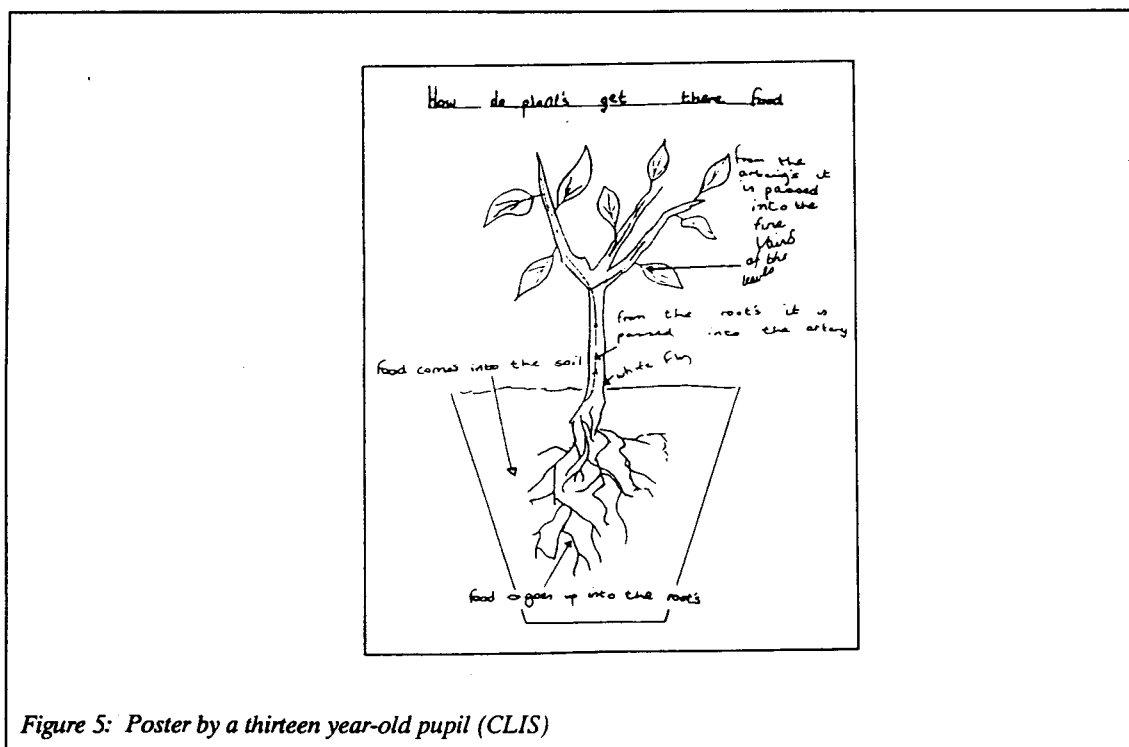
Many writers begin by noting the conceptual demands of the topic of plant nutrition. Arnold sums up the demands made by the abstract and complex concept of photosynthesis by pointing out that pupils are expected to understand that:

'an element, carbon, (which is solid in pure form) is present in carbon dioxide (which is a colourless gas in the air) and that this gas is converted by a pigment (chlorophyll) in a green plant into a sugar (a solid, but here invisibly in solution) when hydrogen (a gas) from water (a liquid) is added using light energy which is consequently converted to chemical energy'.

Pupils do not possess the prerequisite concepts of living things, gas, food and energy which are required to build an understanding of photosynthesis²¹.

Barker and Carr comment 'how unlikely and counterintuitive is the concept of photosynthesis'. A sequence such as that above has 'the makings of a fairy story. How much more plausible is the probability that plants suck up food from the soil'²².

Source of food



Bell¹⁸ reviewed the work of Simpson and Arnold^{23 24} Roth, Smith and Anderson²⁵ and Driver et al²⁶ as well as her own work with the CLIS Project^{27 28}. The universal and very persistent intuitive conception, identified in all studies with subjects of all ages, is that plants get their food from their environment, specifically from the soil; the roots are the organs of feeding. As an example, half of Simpson and Arnold's sample of 344 Scottish 12-13 year-olds and a third of the 627 14-16 year-olds, and over 70% of Roth's 229 American eleven year-olds held this heterotrophic view, that is, that plants feed in a similar way to animals. Driver et al and Bell and Brook analysed hundreds of fifteen year-old students' responses to questions administered in the Assessment of Performance Unit surveys^{26 28}. A fifth of the responses attributed growth of a tree to the food it had taken in, most referring to the soil. Only 8% indicated that a tree makes its own tissues from constituents it takes in from its environment.

In other studies large numbers of children claimed that plants take in organic food substances from the soil, that is starch and sugar²⁹ or protein⁹. They believe that plants have multiple sources of food²⁰.

showing the percentages of students in four groupings according to what they wrote in a paragraph about plants and their food. Some students, ST, subscribed to the teacher's science view that food is produced within a plant. Others, Sch, held the children's science view that food is absorbed material. A third group, SchT, expressed both views, and a fourth group, So, expressed neither view.

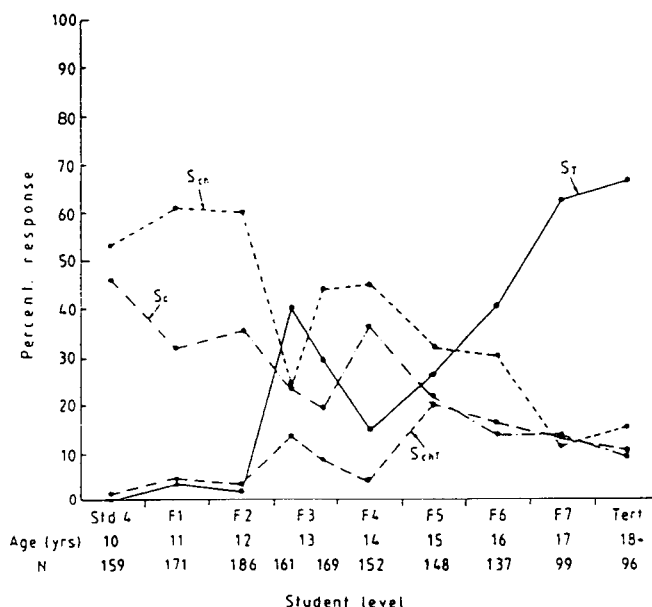


Figure 6: From Barker, source of food for plants

Barker's graph, figure 6,¹ shows the move from the naive view to the school science view, with teaching. This also indicates that children are able to hold the heterotrophic

view concurrently with taught ideas about photosynthesis, without apparent conflict^{18 20}. The view that plants' food is the material that they absorb is resistant to change even in the face of continued instruction¹. Children know that plants do absorb materials from the soil and they regard these as food.

Food substances for plants

Children understand that plants absorb water from the soil and that water is essential to growth; they assume that it is the main component of growth material³⁰.^{*} (The validity of this assumption depends on one's understanding of growth, and whether dry mass, or fresh mass is being considered. The pupils and the researcher or teacher may be thinking at cross purposes on this issue.) Having learnt that plants take in carbon dioxide, water and minerals, pupils regard these as the food of plants. When food is associated with energy, these inorganic substances are assumed to contain and supply energy^{28 1}. Half of 12-13 year-olds (in a sample of 344), knowing that plants absorb carbon dioxide, think that it is absorbed through the roots²⁴, whereas some pupils think that water is absorbed through the leaves³⁰. Many children think that water and carbon dioxide support the processes of drinking and plant breathing, respectively, and that they remain unchanged during these processes²⁰.

Some children think that the sunlight, absorbed by plants, is food. Pupils know that plants take in minerals from the soil and think either that these are food for the plant or that they contribute directly to photosynthesis³¹. It is suggested that everyday reference to fertilisers as 'plant food' may promote this idea.

Photosynthesis

There is evidence that children construct alternative meanings for technical words such as 'photosynthesis' and 'chlorophyll' after the words have been introduced during teaching. Some children think of photosynthesis as a substance not a process², or they think of photosynthesis as the plant's kind of respiration³¹. There is very little understanding of the role of energy in plant metabolism. Pupils think that all the food acquired by plants builds up as the plant grows. They have little understanding that the food provides energy for the plant's life processes²⁴. Barker explored the proposition, as presented in many school text books, that 'during photosynthesis, energy is stored up in food'. He found that 60% of thirteen year-olds agreed with the statement, but that less than half of these gave a reason considered to be scientifically valid. Many reasons implied rote learning of the statement with little understanding of energy. In Barker's work 54% of thirteen year-olds, in free-response writing, described photosynthesis in terms of food-making, 19% in terms of producing carbohydrates and only 3% in terms of storing energy¹.

^{*} See Research Summary: Growth

Photosynthesis is not seen as important to plants themselves; many children think that it is something that plants do for the benefit of people and animals particularly in relation to exchange of gases²⁰.

There is an intuitive disbelief that increase in weight and growth is due mainly to the incorporation of matter from a gas. Even fifteen year-old students (35% of biologists and 6% of non-biologists) failed to mention carbon dioxide as being the source of increasing weight of growing seedlings, although most (74% and 45% respectively) knew that carbon dioxide is absorbed. Studies of younger students indicate the same conceptions. The difficulty experienced by learners in linking the carbon dioxide absorbed to increase in mass during growth, may be due to children's difficulty in conceiving of a gas as a substance^{20,4}.

Children consider chlorophyll variously as a food substance, a protection, a storage product, a vital substance like blood, something that makes plants strong, something that breaks down starch. Some children, with a notion of its function in photosynthesis, think that chlorophyll attracts sunlight or absorbs carbon dioxide. Some hold the anthropocentric view that it is just there to make leaves green and attractive^{28,24,9,1}. The role of chlorophyll in absorbing light energy is seldom appreciated by students, even after teaching¹. Only 29% of 12-13 year-olds and 46% of 14-16 year-olds in the Aberdeen study understood chlorophyll in terms of a converter of light energy to chemical energy.

Sunlight is considered by many children to be a reagent along with carbon dioxide and water²². Light was considered to be made of molecules by well over half of Simpson's sample¹¹.

Most children of eleven think that plants always need light to grow, and apply this idea to include germination²⁵. Teachers will be aware of the persistence of this idea even in the face of evidence to the contrary from germinating seeds and mature plants kept in The dark^{28,9,*}. Barker found that 26 out of his sample of 28 pupils, shown a picture including a tree and the sun, said that plants get their energy from the sun. However, the interviews showed that most did not understand the energy transfer, and most used the terms heat and light interchangeably. Nearly 80% of thirteen year-olds thought that plants use heat from the sun as the energy source for photosynthesis. Most pupils considered that the sun is one amongst many sources of energy for plants, others being soil, minerals, water, air and wind¹.

* See Research Summary: Growth

showing the percentages of students who selected items in response to the question "Where does a green plant get its energy from?" The percentages of students who selected "sun" only are also shown

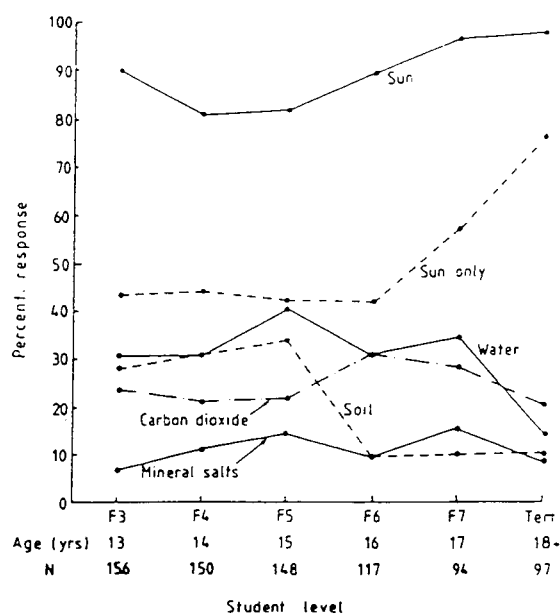


Figure 7

Barker's study revealed many instances where students failed to distinguish correctly between the material and non-material components of photosynthesis. This reinforces other findings regarding gas as a non-substance, and sunlight energy changing into material food.

Gas exchange in plants*

The relationship between photosynthesis and respiration is difficult for children to understand. Children learn from an early age that they breathe oxygen, and oxygen is accepted as part of the natural order of things. Children display a much better understanding of what happens to oxygen than of what happens to carbon dioxide¹⁸ and oxygen is often equated with air³³. Interviews with eleven year-olds revealed that they thought either that air is not used by plants, or that plants and animals use air in opposite ways^{24,34}. Anything about gases going in and out of organisms is considered as breathing or respiration, respiration being thought synonymous with breathing. Barker's interviews with children from age nine confirmed that they hold the 'plant breathing - animal breathing' model: that animals breathe in oxygen and breathe out carbon dioxide, whereas plants breathe in carbon dioxide and breathe out oxygen. Plant breathing is often viewed anthropocentrically: it is thought to be so that human's oxygen supply is replenished¹. From their analyses of a large sample of fifteen year-olds responses to Assessment of Performance Unit questions, Driver et al found that only a third understood gas exchange in plants, only a half used the idea that oxygen is required for respiration of plants and less than a third used the idea that green plants

* See Research Summary: *Ecosystems*

take in carbon dioxide. Even fewer appreciated that this occurred only in light¹⁸. A notion evident from several studies is that plants do not respire, or they respire only in the dark. Many children believe that respiration in plants occurs only in the cells of leaves since only leaves have gas exchange pores³⁵.

Arnold and Simpson devised a test for sixteen year-old students, who had been taught the topic, to identify interference between the concepts of photosynthesis and respiration³⁶. Looking for conceptions relating to gas exchange they found that 46% of students did not understand that increased photosynthesis decreased carbon dioxide in a closed system. The following misconceptions were identified:

- 25% believed that water plants absorb carbon dioxide at night,
- 25% that photosynthesising leaves produce high carbon dioxide levels
- 18% that pond weed produces bubbles of carbon dioxide in light.

Children tend to believe that energy is used up by living things in general, and that plants use up energy in growing. Their concepts of energy in living things include the ideas that plants make direct use of solar energy for vital processes^{30 31} and that energy is created or destroyed in different life processes^{21 37 38}.

Food chains and ecological cycles*

The integration of concepts of feeding and energy within an ecological perspective is not evident in the thinking of many students. Only half of a sample of University biology students asked about the statements 'life depends on green plants' and 'the web of life' explained the statements in terms of food chains. Only a minority of these mentioned harnessing solar energy or photosynthesis as the reason why green plants are crucial in the food chain. Even at this stage of education, nearly a quarter of the students expressed views suggesting that other organisms exist for the benefit of humans³⁹. A subsequent study of students from age thirteen up to University level revealed very similar proportions of these same ideas. Most students knew that animals could not exist in a plant-free world, but some thought that carnivores could exist if their prey reproduced plentifully, without apparently relating this to the source of the prey's food! About half of the students at each age level indicated that animals could not live without plants because of their oxygen need, but only 10% mentioned the oxygen cycle in the context of the sun as the origin of life⁴.

A study of Nigerian pupils revealed a range of ideas about pyramids of number and biomass. Several ideas were anthropocentric (for example, there are more herbivores than carnivores because people breed them) or they implied predestination, (for example, the number of producers is large to satisfy the consumers). 'Stronger'

* See Research Summary: *Ecosystems*

organisms were considered to have more energy, which they use to feed on weaker organisms with less energy. Some saw energy adding up through an ecosystem, so a top predator would have all the energy from the producers and other consumers in the chain³³.

A study of 12-13 year-olds' conceptualisation of cycles revealed that they thought in linear terms about food chains, rather than recognising cycles of matter or interdependency with other organisms and systems⁴⁰. In a sample of fifteen year-old students, 95% interpreted food web dynamics in terms of one food chain only, and 18% of this sample thought that a population higher on a food chain is a predator on all the organisms below it⁴¹.

Pupils tend to regard food which is eaten and used for energy as belonging to a food chain; the food which is incorporated into the body material of eaters is seen as something different and not recognised as the material which is the food of the next level. The lack of the concept of conservation of matter underlies many of the conceptual problems in this area⁴².

Progression

A few studies have attempted to identify progression in students' ideas, particularly regarding plant nutrition.

Stavy and Eisen found that fewer students in the 9th grade (about fourteen years old) than in the 8th grade knew the 'correct' answers to many of their questions. Despite 'learning' orthodox scientific information in the 8th grade, pupils reverted to their naive concepts later. Those advanced students who had not continued with biology reverted in even greater numbers³⁴.

Wandersee concluded that, with few exceptions, students' concepts of photosynthesis continued to change as they moved through the educational system, but certain prior conceptions were resistant to change and continued to be held⁹.

Barker's interviews and surveys indicated developmental trends in several concepts related to photosynthesis. He expressed several of these as graphs (see figures 1, 2 and 6). He also identified three trends in concepts of plant gaseous exchange: a trend towards identifying the gases correctly, a trend towards focusing on leaves rather than on the whole plant, and a trend away from human centred view¹.

The major studies and their implications for teaching

The major research projects studying children's concepts of food and nutrition are those based at the Children's Learning in Science Project (CLIS) in Leeds University, at the Science Education Research Unit (SERU) of Waikato University, New Zealand, at Aberdeen College of Education, at the Institute for Research on Teaching (IRT) of Michigan State University, USA and at Tel Aviv University, Israel. All of these research teams have gone on to apply their finding to teaching strategies. Other studies have contributed to understanding children's concepts in this domain but have not developed teaching programmes.

Conceptual barriers encountered in practical work

The traditional practical work intended to teach pupils about photosynthesis serves to confuse rather than elucidate the subject. Several researchers have documented what many teachers realise: pupils miss the point in the sequence of recipe procedures for testing leaves for starch. The decolorising of leaves and the reappearance of colour, which often looks olive green rather than the theoretical blue-black, all compounds the confusion about chlorophyll, starch, iodine and the factors involved in photosynthesis. The food in leaves has no visible reality. Even if the starch test is understood, pupils have difficulty in relating this to sugar as the product of photosynthesis^{22 21}. Many students do not obtain the expected results so there is little possibility of the intended ideas about plant nutrition being constructed by students as a result of doing practical work. In addition, this use of practical activities may work against the learning of a way of carrying out investigations, for example, problem solving³². Because of the complex procedures, the use of controls in these 'experiments' both distracts pupils from the intended conceptual outcomes and hinders an understanding of experimental design²². 'Few people would suggest abandoning practical activities in science lessons. It may be that some of the intended outcomes of these activities are unrealistic....if we desire the outcome of conceptual learning about plant nutrition, the practical activities as conducted in lessons may not promote these outcomes.'²

The CLIS team at Leeds analysed over 700 responses, from thirteen year-olds and fifteen year-olds, to three questions relating to plant nutrition in the Assessment of Performance Unit surveys. Following these findings, a programme of research, trials and case studies in three schools by a team of teachers and researchers led to the development of a teaching scheme, applying constructivist principles. The CLIS 'Approaches to Teaching Plant Nutrition' is a six double-lesson unit intended for thirteen year-olds. It starts with the pupils' own ideas and opportunities for testing their theories by their own experiments. The teaching scheme acknowledges the difficulties inherent in the traditional practical approach by presenting the school science view with practical evidence, avoiding the traditional sequence of repetitive 'experiments'. It ends

The work of the SERU group at Waikato University included a survey of over a thousand school students and interviews with 28 pupils. The extensive findings relating to concepts of food and photosynthesis are reported in a series of working papers. In these, Barker points out that there is no consensus and consistency amongst teachers and textbook writers on the definition of food and feeding. 'Perhaps as teachers we need to re-examine our reasons for stressing that photosynthetic products and not reactants should be considered as plant food, and even whether this point is fundamental to our view of photosynthesis.' Barker also writes that we should reconsider our objectives in teaching photosynthesis, relegating the trophic theme and emphasising the origin of the energy-rich products of which plants are made (sugar, starch and cellulose) especially focusing on wood rather than on food. He applied these principles to developing a teaching package 'Where does the wood come from?' based on the generative learning model of Osborne and Wittrock and using constructivist strategies. The package was used and evaluated in an action research trial with one class of fourteen year-olds and was then adopted for wider use ^{1 22 30 44}.

Arnold and Simpson at Aberdeen have studied the concepts held by over a thousand Scottish pupils, by interview or a multi-choice questionnaire. They recommend that the digestive system should be taught emphasising the overall sequence and function while reducing the mass of detail. Working from a philosophy of hierarchical learning they produced a book of pupil exercises to help establish the prerequisites for difficult biological concepts including photosynthesis and respiration ^{10 11 12 17 19 21 23 24 34 36 43}.

The team at Tel Aviv investigated the concepts of 33 pupils aged 13-15 by interview and questionnaire, then gave a similar questionnaire to 188 advance students at high school and University. Eisen, Stavy and Barak-Regev report on the outcomes of a course in photosynthesis for thirteen year-olds developed on the basis of this research. Their course focuses on chemistry and on the role of photosynthesis in the ecosystem by introducing the cycles of materials in nature. They also deal with the relationship between photosynthesis and respiration. They take the historical parallel into account in their teaching schemes (see below). After the unit was taught, students were tested by questions in four domains within the subject. Pupils who had studied this unit scored significantly better than students from a regular course in their avoidance of misconceptions. An interesting finding of this study is that the control group showed a lower percentage of misconceptions than samples in the authors' previous research using the same questions. They attribute the improvement to teachers' raised awareness of pupils' likely misconceptions, resulting from publications and INSET in Israel, suggesting that this awareness has an effect in itself, even without the elaboration

of new strategies ^{34 29 44}.

The IRT team at Michigan studied a sample of over 200 eleven year-olds. Pupils took pre-tests, were observed during their normal lessons, then post-tested. The same research group gave similar questions to a sample of 105 University students, most of whom were majoring in education and taking a subsidiary biology course having done at least one biology course at high school. Both samples held the same 'misconceptions', and for both levels of student the researchers developed teaching schemes based on comparing students' concepts with goal concepts, and identifying the critical barriers. Constructivist strategies are employed to help students attain the goal concepts. Limited success has been achieved with these special instruction modules, but some prior concepts appear to be very resilient to change ^{20 25 37 42}.

Haslam and Treagust took a sample of 483 13-17 year-old pupils in Perth, Australia. They used interview and paper-and-pencil test results to develop a two-tier multiple choice research instrument. They recommend that such an instrument could be used either as a pre-instructional diagnostic test or as a formative evaluation, but they have not developed a teaching scheme as such³⁵.

Many concepts held by children reflect those held by eminent scientists in the past. Children do not possess prior knowledge directly comparable with ideas about photosynthesis but they have prior views about plant materials and activities analogous to those held by earlier philosophers and scientists. Barker's teaching strategy, clarifying reactants and products before introducing energy, parallels historical development⁴⁴. The historical parallel is used yet more explicitly in Eisen and Stavy's scheme⁴⁵. Wandersee gave 1405 students, aged 10-19, a paper-and-pencil 'Photosynthesis concept test'. Certain questions were based on theories from the history of science. This has not been developed into a course but Wandersee suggests that such diagnostic tests, mirroring historical ideas, may serve as an heuristic device for students to discover their own conceptual weaknesses as a starting point for restructuring⁹⁴⁶.

A summary of the historical development of this subject, abridged from Barker¹ and from Wandersee⁴⁶ is appended in the Additional Materials.

References

1. Barker M
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NUTRITION

FOOD: WHAT IT IS

Children's Prior Ideas

Children know that food is necessary for life and activity but the meaning of 'food' is not consistent in children's thinking and they have different concepts of food in different contexts. (This inconsistency also applies to adults, including teachers and textbook writers.)

In the everyday context, children and most adults think of food as something that we eat. Food is thought of as a solid as distinct from a drink.

Pupils of all ages identify food as material to promote growth and health and activity. They do not recognise that it is the source of material to become either part of their bodies in growth, or the source of energy.

When they think about other organisms they extend their 'eating' and 'growth' notions of food, to include anything useful taken into an animal or plant.

Children, from an early age, know that what we eat consists of components called proteins, fats, vitamins and so on, but they do not understand the respective functions of these substances, and do not recognise them as groups of materials.

They do not distinguish the foodstuff that we eat, for example bread, from the component, for example starch. They hold the notion that bread is starch, cheese is protein, and so on.

Many pupils either think that food chemicals are made of cells, or they do not accept that they are made of molecules.

(See Nutrition Research Summary)

The Challenge for Pupils

The challenge involves moving the focus from 'eating food' towards recognising, distinguishing and then integrating the materials-supply and energy-supply aspects of food. Children can develop these general concepts from the idea of 'food' as a bulk substance. For a more sophisticated conceptual framework, children need to recognise that food materials, being like all other materials, consist of molecules of chemical substances. (See 'Materials'.)

The first step lies in pupils recognising the diverse meanings of the word 'food'. Starting from children's own ideas of what food is, elicited from poster sessions or creative writing, pupils and teacher can share the problem of the definition of food. They should realise that there is no scientific consensus, and be alert to the particular meaning used in each context they meet. Children need to refine their everyday ideas to construct increasingly sophisticated scientific concepts of food.

Children need to distinguish between their ideas about both growth and energy in relation to food and try to keep them separate at first. In sequencing the teaching, it might be preferable to focus first on the material for growth coming from food, later on the energy theme, and then on integrating these.

From earlier stages and other areas of the curriculum, children will be familiar with the need for food, and with types and components of food. Consideration of growth could re-open the topic. The questions 'Where does your skin come from?' or 'Where does wood come from?' provide useful starting points. (See 'Growth'.) A sequence for teaching the materials theme could proceed from these questions. (See Nutrition: Science Map.) The traditional food tests could be used to highlight the similarities and differences between foodstuffs of plant and animal origin, and to raise the issue of the chemical substances in 'food' becoming the chemical substances in 'bodies'.

So far as the energy theme is concerned, the abstract nature of energy makes this one of the most difficult challenges pupils will face. (See 'Energy'.) It might be introduced by food calorimetry. The traditional burning peanut experiment may be followed up with a question to relate energy in a peanut to the energy needs of a person eating peanuts. The 'burning peanut' should be seen as an analogy, and the rapid release of energy by combustion compared with the slow release of energy by respiration. An energy route through the topic of nutrition will revisit many of the same items as a materials route, but with a different emphasis. (See Nutrition: Science Map.)

A number of Teaching Schemes have been produced based on research into children's ideas, and developing sequences such as those above. (See Resources in Additional Materials.) Teaching Schemes which maintain the traditional separation of plant nutrition from animal nutrition may not allow such sequencing. In this case, children could be given an explicit opportunity to make the link between plant and animal nutrition, so that they can recognise that these are two alternative strategies for addressing the common biological problem of obtaining 'food' for growth and energy.

Children enjoy data search and analysis in relation to their own diet. If used at the end of the topic when pupils have come to some understanding of the distinction between growth and energy, it is a vehicle for applying their understanding of the uses of food.

NUTRITION

DIGESTION

Children's Prior Ideas

A young child appears to imagine his or her body to be a hollow bag, which is all 'stomach' containing food, blood and wastes.

Older children realise that there is a food bag inside the body, but use the word stomach to apply both to this and to the abdomen.

Secondary school children generally have some notion of the digestive system going through the body and know that food is broken down there. They tend to think that it all passes out of the body in the 'broken down' form.

Many think that the same system has two outlets, one for faeces and one for urine.

Young children hold non-conservation ideas of food vanishing. These persist in older children as ideas of food turning into 'goodness' or 'energy'.

Many children think that digestion is the energy-releasing process. Some think that the energy is released by burning in the stomach.

Many pupils think of enzymes as cells or creatures which break up food.

The Challenge for Pupils

Children need first to confront their everyday notions and then to accept that digestion is not an end in itself but an intermediate stage between eating and building up new body substances or releasing energy. Children can tackle the challenge at two levels:

- (1) working from the range of everyday words connected with digestion, they can refine these into scientific meanings.
- (2) for a much deeper level of understanding they can begin to develop the concepts of conservation of matter and of matter being rearranged. (Digestion provides a context for children to revisit these ideas in order to gradually build up the concepts.)

Understanding of digestion depends on previously established concepts of solids, liquids and solubility. (See 'Solids, Liquids and Gases', and Dissolving Learning Guide in 'Water'.)

'Designed' models such as those suggested below may help children to concentrate on the matter aspects of food; this may help children to avoid the idea that digestion releases energy. (See Introduction: Using Models.)

Different colours of poppit beads or canticubes make useful models. Without any initial mention of food or digestion, children could be given a chain of beads in a particular sequence and the problem of creating certain specified new sequences as quickly as possible. Their solutions involve breaking the chains into small units and then reassembling them. The children could then discuss such matters as how pig-muscle protein or peanut protein could become human toe-nail protein, by analogy with the beads, to help approach the need for digestion. Even without an established particle view children can use a 'breaking down and building up' model.

A popular way of modelling various aspects of digestion and absorption involves the use of Visking tubing to represent the gut wall. As with all models, it is necessary for the pupils to be clear what each component represents, especially as Visking tubing is used elsewhere in the science course to represent something different, namely a cell membrane. It is a challenge for children to understand the scale of the digestive breakdown. (See Learning Guide: Assimilation.)

The bead model could be extended as an application exercise at the end of the teaching sequence on digestion. Pupils could use things like sieves, tubes and chicken wire, with their beads, to extend the model of the digestion and absorption processes as far as possible. This could complement making realistic diagrams or models of the structure of the human digestive system, and lead to discussion of different types of physical models and their purposes. Use of video materials will help pupils to sort out what is realistic representation and what is analogous modelling.

Pupils who are using a particle model in their thinking about materials (see Particle Model Learning Guide in 'Particles') will be able to apply their ideas about atoms and molecules in accounting for digestion. They will be able to envisage insoluble substances becoming soluble in terms of larger molecules being broken down into smaller ones.

NUTRITION

ASSIMILATION

Children's Prior Ideas

Young children hold non-conservation ideas of food 'vanishing'. These persist in older children as ideas of food turning into 'goodness' or 'energy'.

Most pupils believe that plants always need light in order to grow, but very few realise that the new material of growing plants is derived from photosynthesis.

The Challenge for Pupils

The concept of assimilation is often marginalised in teaching but it is central to understanding much of biology. It is important to realise that it occurs in both animals and plants.

The challenge for children in understanding nutrition lies in accepting that what we eat, or what plants make, actually becomes skin, bone, blood, wood, leaves, and so on, and accepting that the body is made from food. Attaching the word 'biomass' is a useful step towards building the concept. They need to believe that 'biomass', like all other materials, consists of substances which are the product of chemical interactions and which can be reactants in further interactions. Pupils may approach the concept through consideration of questions about the origins of these body materials. (See Learning Guide: Food - what it is; 'Growth' Learning Guides; Material Substances Learning Guide in 'Materials'; and Chemical Interaction Learning Guide in 'Chemical Change'.)

Although the analogy of a car and petrol is useful for the fuel/energy aspects of nutrition, it is not transferable to the matter aspect. However, it may be useful for children to consider the limitations of the car analogy, and to use another analogy for assimilation, such as demolition of an old building and the use of the materials to make a new house. The poppit bead or centicube model can be extended. (See Learning Guide: Digestion.)

A child's concept of assimilation may be global, with the materials conceptualised as bulk units. This is a step in the direction of a more sophisticated molecular concept, once the child has developed a notion of atoms and molecules. There is an underlying challenge of establishing a particle theory. (See Particle Model Learning Guide in 'Particles'.) However, children with an already formed particle concept will not automatically relate it to assimilation. They will have to be helped to integrate the ideas. If beads or blocks are used as models for representing component small molecules, care must be taken to clarify what the model units represent, especially if the same model units have been used elsewhere to represent cells or atoms.

NUTRITION

PLANT NUTRITION

Children's Prior Ideas

A universal and very persistent prior conception is that plants get their food from the soil and that the roots are the organs of feeding.

Even when students have accepted taught ideas about photosynthesis, they still believe that plants obtain some food from the environment. They believe that plants have multiple sources of food.

Children think of water, minerals, fertilisers, carbon dioxide and sunlight as food for plants. Many believe that carbon dioxide is absorbed through the roots, and others think that water is absorbed through the leaves.

Many children think that water and carbon dioxide are for plant drinking and plant breathing respectively, and that these substances remain unchanged.

Pupils assume that water is the main component of new material as the plant grows and do not believe that carbon dioxide is the main source of weight of the solid material of growing plants.



Photosynthesis is often regarded as the way plants make food for the benefit of animals and people, rather than as essential for the plant itself.

(See Nutrition Research Summary)

The Challenge for Pupils

Children need to establish the scientific meaning of 'plant' and the distinction between plants and animals, (see Living Things) before they can distinguish the nutrition of plants from that of animals.

It is an enormous challenge for children to accept that gases and liquids can be chemically changed into solids and that the solids are interconvertible. (See Nutrition Research Summary, page 8.) It may be advisable to concentrate on the matter changes before dealing with energy changes and before introducing the term photosynthesis. This delays the energy issue until children have some form of understanding of the materials story from which to tackle energy ideas. It also avoids the necessity of defining the end point of photosynthesis. (See The Teacher's View.)

The notion that plants get their food from the soil is intuitively sensible, historically supported and horticulturally reinforced. There is little chance of totally displacing it, but the conflict between this and the scientific concept of photosynthesis can be exploited to help children reconstruct their ideas towards the scientific view. Acknowledging children's ideas that plants get something from the soil is a useful starting point to build from.  **THINK LINK** 

Children's own ideas of how plants get their food can be elicited, acknowledged and discussed. The many meanings of 'food' could be reviewed and the problems of terms shared with children. It may be advisable to agree to avoid using the word 'food' in explaining plant nutrition. This could be in the nature of a game, with penalty points for anyone resorting to the word 'food'!

A few published teaching schemes present strategies to help students restructure their understanding of plant nutrition. (See Resources in Additional Materials.)

The term photosynthesis is confusing to many children, possibly due to its introduction at an early stage of school or from other sources, before they can attach meaning to it. A fresh approach to plant nutrition, avoiding the initial use of the word 'photosynthesis' may be appropriate.

An analogy with a factory may help children to understand plant nutrition; the materials taken in from the environment are the 'raw materials' for making the product 'food'. (Children should realise that a living plant is a unique food factory in that its raw materials are simple inorganic substances. People in a factory or at home who 'make food' make it from substances which are already foods, that is organic materials.) They enjoy developing such analogies to their limits through group discussion, posters, drawings and creative writing. The factory idea helps to integrate the chemistry of synthesis with the anatomy of the plant. The idea of the power supply of the factory is a useful lead into the energy aspects of photosynthesis. (See Learning Guide: Energy and Photosynthesis.)

NUTRITION

ENERGY AND PHOTOSYNTHESIS

Children's Prior Ideas

Many children think the word 'photosynthesis' means a substance rather than a process.

Children do not recognise that the food made in photosynthesis is plants' energy source and the energy source for animals.

Many children think that light is a reagent in photosynthesis, and they often think it is made of molecules. Most pupils believe that plants always need light in order to grow, including during germination.

Most children use the words 'heat' and 'light' interchangeably and they think that plants can use the heat from the sun as the energy source for photosynthesis. Most consider that the sun is one amongst many sources of energy (soil, minerals, water, wind, air) for plants. A common conception is that plants make direct use of solar energy for their living processes, without the intermediate process of photosynthesis.

Pupils' concepts of chlorophyll include thinking of it as a food substance, a protection, a storage product, a vital substance like blood, or something that breaks down starch. Many pupils believe that chlorophyll actively attracts light; few understand its role as an energy converter.

(See Nutrition Research Summary)

The Challenge for Pupils

Concepts of the conservation of energy, transformation of energy and the distinction between energy and matter, all underpin an understanding of photosynthesis. These are all extremely difficult for pupils, even at the end of secondary school. For a start, children have to accept that light is energy! Yet, despite the problems, children may be helped to construct concepts which are, at least, stepping stones to a comprehensive scientific understanding.

It may be helpful to approach through the materials route, establishing the idea of plants as food-making factories, before introducing the role of sunlight or the word 'photosynthesis'. (See Learning Guide: Plant Nutrition.)

However, pupils have firmly held prior ideas about energy, derived from earlier school work or media sources. It is important to work from these ideas towards integrating 'energy' into the materials story. Children need to refine their ideas, that light is needed for healthy plant growth, that energy is a sort of material reagent and that something from the sun 'powers' the plant, towards a concept that light energy from the sun 'powers' the plant food-factory and that the 'food' provides the material for growth.

Children may have traced the transfer of energy through physical systems. They may be able to extend their ideas to thinking of sunlight energy being used to build up large food molecules, which can release the energy at a later stage. (See Respiration and Food Chains Learning Guides in 'Ecosystems'.) In relation to the burning peanut experiment, children can consider the question 'How did the energy get into the peanut?' as well as 'Where does it go?'. It is impossible to experience or observe photosynthesis directly, and research shows that much of the traditional practical work has little effect on developing pupils' concepts of photosynthesis. Children can only come to know the scientist's theory by being told it, along with the derivation and use of the word 'photosynthesis'. Memorable experiences, such as standing under a large tree in bright sunlight, may help to impress children with the scale of photosynthesis and the importance of light and green-ness.

The significance of photosynthesis may be approached by giving pupils the experience of standing under a large tree on a bright summer day. They are then struck by the green-ness of a large leaf area and they can begin to think about the millions of green leaves in the world and their effect in making food material and their effect on the atmosphere.

Children are impressed by starch prints, on leaves, of stencilled names or preferably of a photographic negative. This is a case where children are more likely to appreciate a careful teacher demonstration resulting in a clearly recognised photograph, than the doubtful results of their own laborious procedures. (See Additional Materials.) Getting inside a giant model leaf (available at certain environmental centres) can begin to develop ideas of light absorption. Pupils may apply this goal idea in creative writing. They could write stories about the consequences of disasters, such as massive oil well fires, or nuclear winter, which block out sunlight. Discussion of their stories may provide pupils with the opportunity to address their notions of plants deliberately 'helping' the world by capturing energy.

NUTRITION

GAS EXCHANGE IN PLANTS

Children's Prior Ideas

Children, from an early age, know that they breathe something called oxygen and believe that oxygen is 'good'. Oxygen is often equated with air, both being 'good', whilst they tend to think of carbon dioxide and gases in general as strange and harmful.

Pupils think that anything concerned with air, oxygen or carbon dioxide going in and out of organisms is breathing. Respiration is perceived as synonymous with breathing. Photosynthesis is thought of as plants' kind of respiration.

The common view is that animals breathe in oxygen and breathe out carbon dioxide, whereas plants breathe in carbon dioxide and breathe out oxygen. Few pupils appreciate that their 'plant breathing' model applies only in the light.

Many children believe that plants' gas exchange is purposeful and human focused, in order to replenish the humans' oxygen supply.

Pupils' ideas of plant respiration include

- 'plants do not respire'
- 'plants respire only in the dark'
- 'plant respiration is photosynthesis.'

(See Nutrition Research Summary)

The Challenge for Pupils

A major challenge for children lies in thinking of air as a mixture of different gases, each with its own properties and role in living processes. Notions of movement of gases and their proportions in the air present additional problems. Pupils need to consider each gas separately, and each process separately, before integrating the ideas into the concept of balance. (See Air Gases Learning Guide in 'Air')

This is an area in which children would benefit by bringing their ideas into the open and by discussing them. It needs careful intervention by the teacher with questions to guide discussion and to prevent consensus from reinforcing their prior conceptions. The prior idea that plants promote gas balance for the benefit of humans could be addressed in this discussion.

Selected experiences may help pupils towards understanding gas exchange, but it is unlikely that many will move far towards this difficult goal. This is a challenge which may need to be addressed many times throughout the science course, as children develop ideas about gases and their nature.

Children who have developed the idea of a two way process of gas exchange, can apply the idea and predict the different overall effect in different circumstances. As a check on their predictions, they could use bicarbonate indicator to provide a fairly direct indication of increase or decrease of carbon dioxide. However, some children find it difficult to relate changes in the liquids to gaseous carbon dioxide, and to accept that these experiments can show nothing about oxygen changes.

The traditional (and often 'cheated') demonstration of oxygen production by pondweed under a funnel rarely produces a convincing result, since only a small volume of a mixture of gases is collected. Children are more readily convinced that illuminated plants produce gas, by observing individual cut strands of Elodea producing bubbles. This may be a place where they have to take on trust the fact that it is oxygen that is produced in light. Children's lack of knowledge about the solubility of carbon dioxide, can lead to incorrect interpretations of the lack of bubbling in dim conditions.