Children's ideas about

ECOSYSTEMS

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
ECOSYSTEMS

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

There has been little research into children's ideas of ecosystems as such. However, research into children's understandings of component ideas provides some insights into their ecological concepts, and studies of children's conceptual reasoning inform the findings about particular concept areas in this domain.

The research findings are summarised under the following headings:

Progression in children's reasoning
Nutrition and Energy flow
Food chains and webs
Populations and Competition between organisms
Environment
Decay
Cycling of matter through the ecosystem
Pollution
Gas exchange
Respiration.

Progression in children's reasoning

Leach et al [1] describe pupils' reasoning about ecological phenomena from ages 5-16. These findings corroborate descriptions of children's thinking in a number of domains reported by many researchers from Piaget onwards [2].

There is a trend from the egocentric (self-centred) thinking of very young children, through anthropocentric (human centred) reasoning, to reasoning including a wider range of factors in older students. Teleological reasoning (an event is predetermined in order to fulfil a need, for example 'there are a lot of rabbits so that foxes will not get hungry') is common in young children. With age it becomes less pronounced, but persists to some extent in senior school students. The following progression in children's thinking related to ecosystems was identified by Leach et al.

Younger children, age 5-7, tend to think only in terms of individual organisms which people keep (pets, zoo animals, house plants) and which need humans for their survival. Older junior pupils (7-11) extend their thinking to wild organisms as individuals, though some may think that these are fed and cared for by people. Most pupils over the age of thirteen have a concept of populations of organisms in the wild, but their 'explanations' of relationships are merely descriptions of nature (birds live in trees, foxes eat rabbits). It is not until much later that students think in terms of populations of organisms in the wild competing for scarce resources. There are not distinct stages of reasoning in the conceptual development of any one child or group of children. A child may use different types of reasoning in different contexts.

Nutrition and Energy flow

The main points of children's ideas about food and nutrition, as they relate to understanding of ecosystems, are quoted here. Fuller information about the research in this area is given in the Nutrition Research Summary and in the Growth Research Summary.*

Many children associate the word 'food' only with what they identify as being edible [3]. Few pupils associate substances such as starch with 'food' [4]. Pupils of all ages identify food as necessary to promote growth and health, but do not recognise that it is the source of material to become either part of their bodies in growth and repair, or the source of energy. When they do relate food to energy, many pupils of eleven or twelve years old consider that food is converted directly into 'goodness' or 'energy' and that it vanishes completely in the process [5].

A universal and very persistent conception amongst children and adults is that plants get their food from the soil. Many pupils think that 'food' for plants is anything taken in from the environment, including water, minerals, fertilisers, carbon dioxide and even sunlight [3 4 6 7 8]. 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. Few pupils have any understanding that photosynthesis makes food which provides energy for the plant's life processes.

---

* *See Nutrition Research Summary*
See Growth Research Summary

Many children express the idea that plants make food for the benefit of animals and people rather than as essential for the plant itself. (This is an example of teleology.) [9]. Children do not recognise that photosynthesis is the process by which energy from the environment becomes available to plants and then to animals.

Many children think of light as 'food' for plants or as a reagent in photosynthesis. Over half of a sample of secondary school children thought that light is made of molecules [10]. Most children do not understand energy transfers in living things. Most pupils believe that plants get the energy needed for all their processes directly from the Sun, and they use the words 'heat' and 'light' interchangeably in this context. Nearly 80% of a sample of thirteen-year olds thought that plants use heat from the Sun as an energy source for photosynthesis. Most consider that the sun is one amongst many sources of energy for plants, others being soil, minerals, air and water.

Gayford [11] reports that 17-18 year-old Biology students considered that energy flows, or is transported, from place to place in biological systems, and that it can be stored like a material. They thought that energy was 'formed' or 'used' in biological processes, rather than thinking in terms of energy conversions.

Food Chains and webs

Some studies relating to children's ideas about interdependency in food chains and food webs have focussed on children 'getting the right answer' to exam-type questions rather than on the conceptual basis of children's understanding.

Senior [12] analysed the responses of fifteen year-old students to Assessment of Performance Unit (APU) questions about the manipulation of populations of organisms in food webs. He found that students were not comfortable with the arrow notation used in school science to indicate a trophic relationship, and so they fail to understand the underlying principles of the relationship and to complete the activities correctly. Schollum [13] identified a similar difficulty for pupils dealing with food chains; they were better able to answer problems about food chains if lines rather than arrows were used to link populations.

Few students relate their ideas about feeding and energy to a framework of ideas about interactions of organisms. Only half of a sample of University Biology students asked about the statements 'life depends on green plants' and 'the web of life' explained these 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 many students still think teleologically, for example, nearly a quarter of the students expressed views suggesting that other organisms exist for the benefit of humans [14]. A subsequent study on 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. Only 25% of biology students and 7% of non-biologists suggested that this is because animals cannot make their own food. Some students thought that carnivores could exist if their prey reproduced plentifully, without apparently relating this to the source of the preys' food! [15].

Students' understanding of ecological relationships depends on their concepts of 'plant' and 'animal', and on their knowledge of habitats and physical principles. Even after teaching, 13-15 year-old Nigerian students were not convinced that producers exist in aquatic habitats, since they had little experience or information about specific habitats with plants living under water [16]. Leach et al's subjects recognised the existence of aquatic plants but some said that sunlight and carbon dioxide could not get through the water to the plants, so they did not acknowledge them as producers [1].

Bell et al found that pupils' limited recognition of 'producer' and 'consumer' was tied to their meaning of 'plant' and 'animal'. Once the scientific extension of the words 'plant' and 'animal' were established by teaching, pupils could apply the terms 'producer' and 'consumer' appropriately [17].*

Several studies [18] [19] [20] involving subjects ranging from twelve-year olds to undergraduate zoology students, have found that most students interpret food web problems in a limited way, focussing on isolated food chains. This focus on linear food chains, rather than recognition of cycles of matter or interdependency with other organisms and systems predominates in their thinking about ecosystems.

Smith and Anderson [5] noted that many eleven and twelve year-olds, who accept that populations in a food web are related, may still see predation as a 'specific eating event' for the benefit of the eater alone. 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.

---

* *See Living Things Research Summary*

Communities, populations and competition between organisms

Adeniyi [16] found that students' meanings of ecological terms were related to everyday usage rather than to scientific definitions. For example, a quarter of the students used the term 'community' to mean a group of people living together with similar ideas. Another quarter did not distinguish between the meaning of 'community' and 'population'. He revealed a range of ideas about pyramids of number and biomass, amongst his Nigerian students. Several ideas were anthropocentric (for example, there are more herbivores than carnivores because people breed them) or they implied teleological predestination (for example, the number of producers is large to satisfy the consumers). 'Stronger' organisms were considered to have more energy, which they use to feed on weaker organisms with less energy. Some students saw energy adding up through an ecosystem, so a top predator would have all the energy from the producers and other consumers in the chain.

Leach et al [1] found that although nearly half of children at all ages between five and sixteen could select pictures of organisms to construct a balanced community which contained a producer and primary and secondary consumers, few at any age used the idea of interdependence to explain their selection. At age 5-16, 22% used the idea of interdependence. Most based their choices of their description of the status quo in nature, or used teleological reasoning. The pupils were asked to predict which population of organisms would be largest, and why. Although most pupils, at all ages, chose producers, a significant number chose primary or secondary consumers. Again, the explanations for the choice were mostly just descriptions of nature (for example, rabbits have many babies) or teleological, with little evidence of reasoning about interdependence or energy flow. There was some progression in reasoning with age.

In the context of seasonal change, children made some links between populations, ranging from simple food or shelter links at age eleven to sophisticated energy flows in food webs by some students at age sixteen. When set questions based on food webs, children responded differently according to which organisms were 'removed' from the hypothetical web. Pupils made least links between the removal of a top predator and the rest of the food web, and most links between the removal of producers and the rest of the food web. They seemed more able to trace links up through the trophic levels than down.

Griffiths and Grant [20] reported that a fifth of fifteen year-olds thought that a population higher on a food chain is a predator on all the organisms below it. Many of these pupils thought that a change in the population of one species would affect only those species related to it directly as predator or prey, while others thought that a change in the size of prey population would have no effect on its predator population. These authors suggest that the introduction of the food chain concept as a precursor to food webs is a reason for children failing to use ideas about interdependency to explain relationships in complex ecosystems.

Environment

Leach et al [1] investigated children's ideas about what various organisms need to stay alive and healthy, and the source of these requirements in the environment. Most children recognised plants' need for soil, water and sunlight in their habitat. The need for air, oxygen or carbon dioxide was identified by a small minority of pupils; less than a third of sixteen year-olds noted the need for carbon dioxide or oxygen. The needs of consumers were identified as water, food and shelter and many pupils at all ages identified food and shelter links between organisms in communities. However, younger children (up to thirteen) seemed to think in terms of the needs of individual organisms rather than populations. Many pupils at all ages seemed unable to conceptualise organisms and their environments independent of human involvement, and many younger pupils thought that all organisms are fed by people.

Most pupils, at ages 11-16, were able to mention some features of organisms that are related to a specific habitat, and some were able to make predictions of the habitat of organisms with particular features.

Several studies of ideas of adaptation have suggested that students use teleological and anthropomorphic reasoning to explain the relationship between an organism and its environment [21 22 23 24].*

Decay

Recent research in Portugal [25], USA [5] and England [1] indicates a remarkably similar progression in children's concepts about decay. The research questions related to the 'disappearance' of dead animals or fruits on the surface of the soil. (See Figure 1). The youngest children think that dead things just disappear or they have human-centred notions which do not allow for ideas about continuity of matter after death. All these studies found that most children conceptualise decomposition as the total or partial disappearance of matter. The concept seems resistant to change, with 70% of 11-13 year-olds giving responses implying a lack of conservation of matter, even after teaching about the topic. (See Figure 2.)

* *See Living Things Research Summary*

Progression in children's thinking about decay

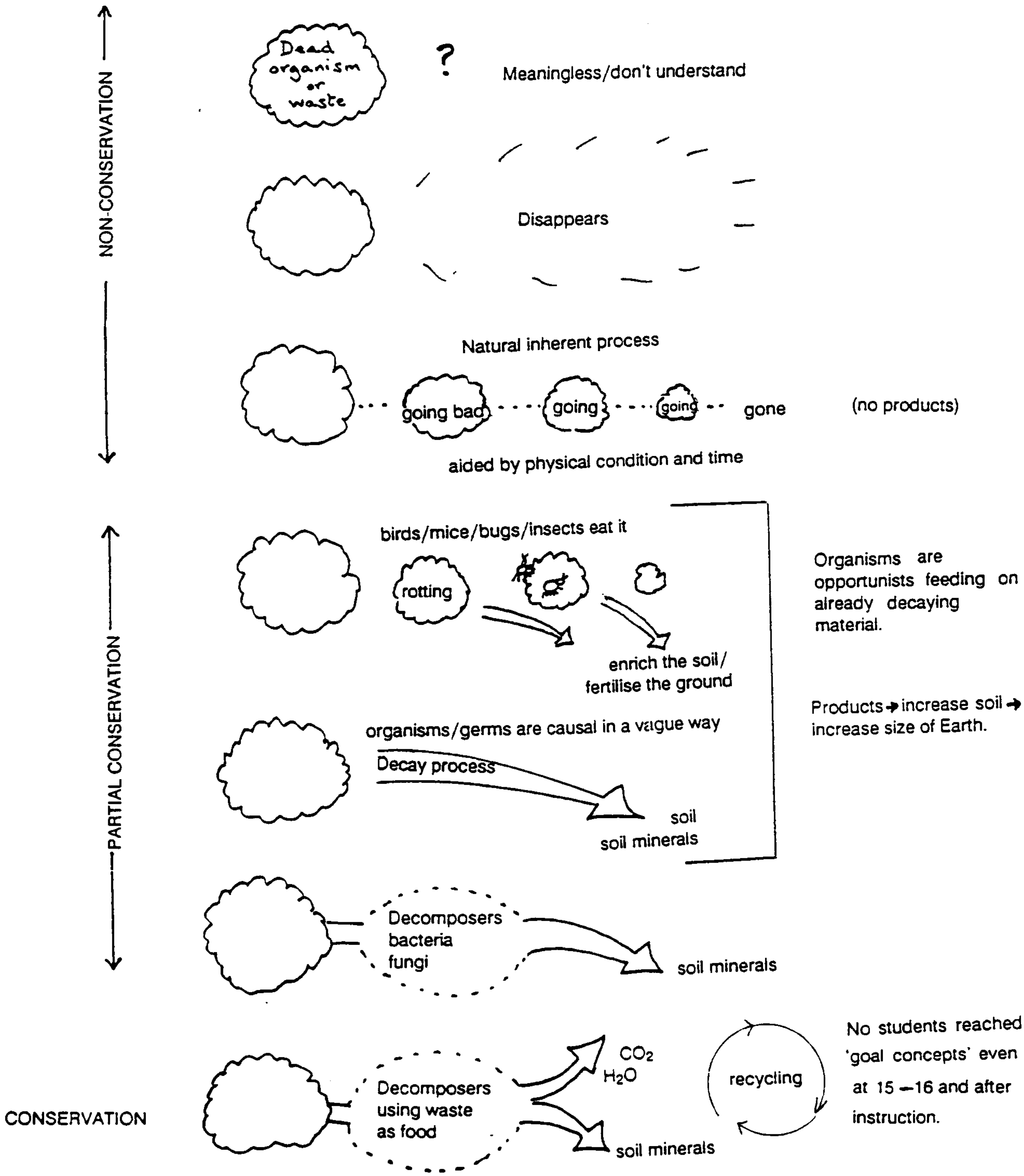

Figure 1

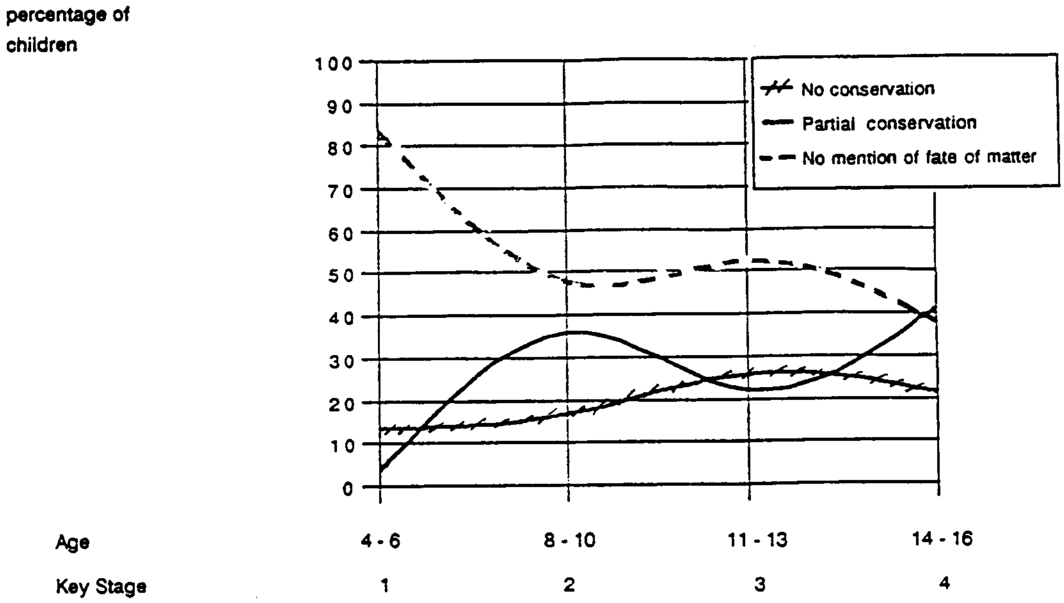

Figure 2: Issues of conservation relating to decay of apple

They were not aware that material from dead organisms becomes part of the non-living environment nor that microbes initiate the process of decay. They tended to think that it is insects which break up material once it has started to rot of its own accord. A later concept is that bugs or germs eat the partly rotted matter. They think that rotted material 'enriches' or 'fertilises' the soil but do not identify it as part of the soil. After tuition, up to 65% of 15-16 year-olds use the words 'bacteria', 'fungi' or 'decomposers' but are not clear about their role. Although progression is characterised by an increasing number of factors being used to explain phenomena, there is little evidence that pupils at fifteen or sixteen have an understanding of how various physical factors relate to the action of microbes. (See Figure 3.)

Some Swedish children expressed the belief that all dead material decays to form soil. and that the Earth is thus getting bigger all the time. This idea recapitulates historical notions [26]. Very few children seem to be aware of ideas about organic matter changing to mineral matter during decay, or of any other recycling [25].

Generally, pupils are unaware of the role that micro-organisms play in nature, especially as decomposers and as recyclers of carbon, nitrogen, water and minerals [1].

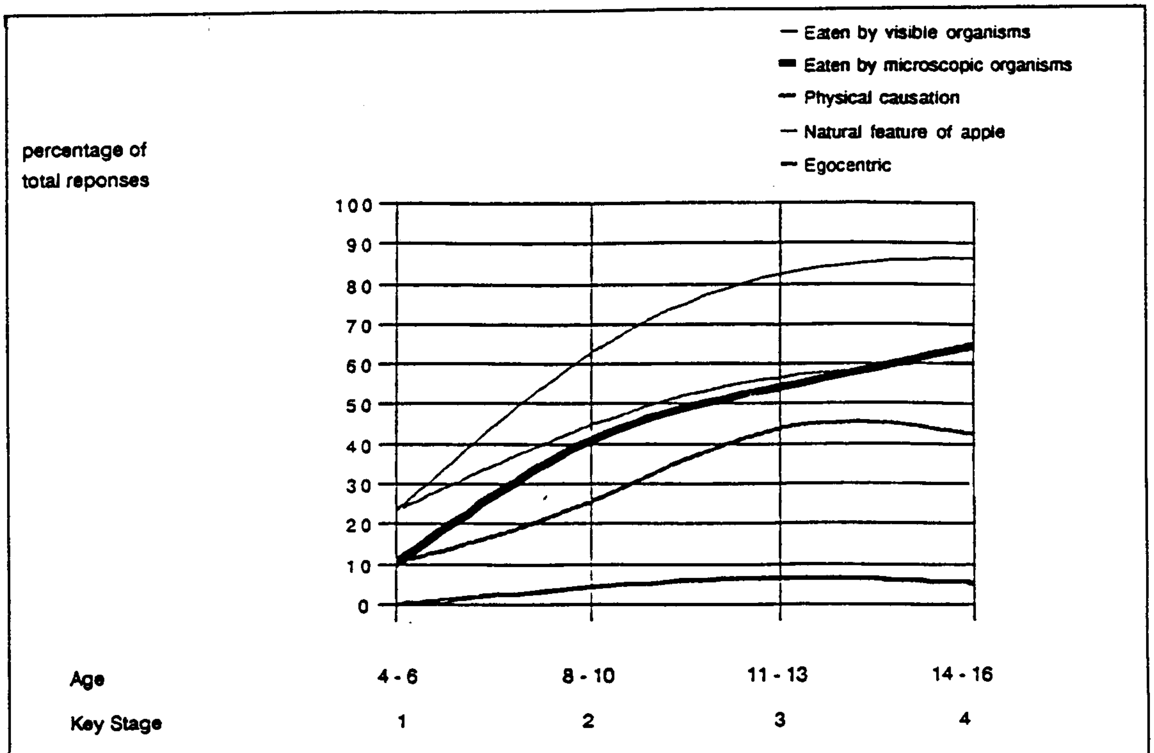

Figure 3: suggested causations for decay of apple. (It should be noted that there is an increasing tendency to offer more than one possible factor relating to the decay process with age.)

Cycling of matter through the ecosystem

Children's understanding of the cycling of matter through the ecosystem and of the component processes of photosynthesis and cellular respiration requires a level of commitment to conservation of matter in chemical changes. This depends on their concepts of matter, states of matter, chemical change and energy. Children's ideas on these topics are reviewed in the Research Summaries of the relevant domains.*

Smith and Anderson [5] found that almost all of their twelve year-old sample were aware that some kind of cyclical process takes place in ecosystems. However most tended to think in terms of sequences of cause and effect events, with matter being created or destroyed in these events, and then the sequence starting again. Some recognised a form of recycling through soil minerals, but failed to incorporate water, oxygen and carbon dioxide into matter cycles. Their ideas about gas balance are noted below. They saw no connection between the oxygen/carbon dioxide cycle and other processes involving the production, consumption and use of food, and their understanding of the matter cycling process remained fragmented. Following instruction there was little change, with only 4% of pupils achieving the 'goal conception' that matter is converted

* *See Materials, Solids, Liquids and Gases, Chemical Change, Particles, Energy Research Summaries*

back and forth between organisms' bodies and substances (carbon dioxide, water and minerals) in the environment. A few pupils had picked up the idea of food being converted but they thought of it being converted into energy!

Leach et al [1] report that, even at age sixteen, few pupils have a view of matter that involves conservation in a variety of contexts such as photosynthesis, assimilation of food, decay and respiration. Moreover, pupils did not appear to distinguish food, matter and energy. No pupils in this study presented an integrated view of a consistent amount of matter cycling, though a few older pupils showed evidence of conserving matter in decay and in photosynthesis.

Pollution

A recent American study [27] indicates few changes in knowledge about ecological crises, from age 9-16. However, it identified some progression in children's ideas of pollution. Nine year-olds regard pollution as something which is directly sensed by people, and affects people or other animals. They do not consider that harm to plants constitutes an environmental problem. Their responses indicate that air can somehow circulate pollution.

Thirteen year-olds have a more conceptual understanding of ecological crises including a concept of cumulative ecological effects. They do not have to sense it for it to be there and unseen chemicals like acid rain are considered pollutants. These students' responses include the idea that pollution kills (rather than harms) animals (particularly fish) and also plants. Human populations, factories and cars are considered to be possible sources of ecological crises.

By sixteen, students have a greater number of relevant concepts and meaningful connections between them. They believe that pollution can affect everything. Biodegradable materials are considered less harmful to life than non-biodegradable, and the concentration of pollutants is considered to be important. At this age, the students recognise that environmental issues are complex and they relate economic concepts to cause and effects of ecological crises.

Several important misconceptions were held by at least half of the large sample of students interviewed. They included:

- anything natural is not pollution
- biodegradable materials are not pollutants
- the oceans are a limitless resource

- solid waste in dumps is safe
- the human race is indestructible as a species.

The researchers also found little evidence that pupils used science concepts, learnt elsewhere in the curriculum, to inform their understanding of ecological issues.

Gas exchange and balance

Various studies of children from 9-16 have revealed that they think either that air is not used by plants, or that plants and animals use air in opposite ways [3, 8, 28, 29]. 'Oxygen' is often used synonymously with 'air' [16]. Children display a better understanding of what happens to oxygen than of what happens to carbon dioxide [30].

Anything about gases going in and out of organisms is considered as breathing [27]. Barker [3] found that children aged nine 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 teleologically and anthropocentrically: it is thought to happen so that humans' oxygen supply is replenished [13].

Leach et al found that by thirteen most pupils stated that animals need oxygen and a few stated that plants need carbon dioxide. By sixteen, more pupils held these ideas and some were aware of the role of carbon dioxide in photosynthesis.

Arnold and Simpson [31] devised a test for sixteen year-old students, who had been taught the topic, to identify conceptions regarding gas exchange which indicated interference between the concepts of photosynthesis and respiration. 46% of students did not understand that increased photosynthesis decreased carbon dioxide in a closed system. Specific distractors identified the following misconceptions:

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

Eisen, Stavy et al [15, 29] investigated students' understanding of the importance of photosynthesis in the ecosystem in maintaining oxygen levels. Most (82%) of 13-15 year-olds knew that plants release oxygen in photosynthesis and that this oxygen supports a range of living things. However, only about half of the students at each age level indicated that animals could not live without plants because of their oxygen need, and only about 10% mentioned the oxygen cycle in relation to the sun as the origin of life. The same questions posed to older students produced similar proportions of responses from 'non-biologists', although those who had studied advanced courses in Biology were able to give more satisfactory explanations. (Even so, only 25% of the 'biologists' and 7% of the non-biologists suggested that animals could not exist in a plant-free world because they were not autotrophic.)

Wandersee [32] tested 1405 students aged 10-18 by a written test. When asked about the flow of gases during photosynthesis, 62% of the youngest children, rising to 85% of the college students knew that carbon dioxide flows into the leaf during photosynthesis. The figures for oxygen flow were similar except for the youngest students, only 51% of whom knew the correct direction. Most students seemed to think that the two gases always flow in opposite directions. However, questions set in the context of a diagrammatic replication of Priestley's experiment, where a mouse and an illuminated plant were placed in a sealed container, indicated that many students had difficulty in applying their knowledge of gas exchange to an 'ecosystem'. Although an increasing proportion through the age groups (38% to 67%) suggested that both the plant and the mouse would live, many thought that both would die or that only the plant would live. In explaining their answers, the percentage of students who used the word 'air' decreased with age (26% to 4%) while there was a corresponding rise in the proportion using 'carbon dioxide' and 'oxygen' (18% to 58%) to justify their choice of answer.

Respiration

Although students may have notions about gas exchange and consider any gas exchange as a kind of breathing, few at any age have a coherent concept of respiration. Respiration and breathing are thought, by most students, to be synonymous [33]. Children learn from an early age that they breathe oxygen and oxygen is often equated with air [16].

Gellert [34] and Nagy [35] found that young children know that air is necessary for life but appear to have a limited idea of what happens to inhaled air, often thinking that it remains in the head. Both researchers found that half of 9-10 year-olds associated lungs with breathing and some pupils recognised that an exchange of gases with the air is important to all parts of the body. However, young secondary pupils are unlikely to relate the need for air or oxygen with the use of food.

Leach et al [1] note an absence of ideas about the physiological role of the gases. By age eleven, pupils recognise that animals need air or oxygen. Pupils mentioning oxygen said that it was needed to breathe or to keep the animal alive. No pupils mentioned the release of energy from food in connection with the need for oxygen. Responses indicated that pupils had no ideas about the physiological role of breathing, seeing the process as an end in itself. Arnaudin and Mintzes [36] found one third of school children and one quarter of college students thinking of 'air tubes' connecting the lungs and heart, with up to a third of all their sample suggesting that air is simply inhaled into the lungs then exhaled without links to the heart and circulatory system.

Asked explicitly 'What is respiration', the 13-15 year-olds studied by Stavy et al [29] referred only to gas exchange by inhaling and exhaling air. Most merely said 'we breathe in order to live'; a few had ideas about oxygen: 'oxygen revives the cells', 'oxygen activates the heart and causes blood to circulate'.

Anderson et al [37] studied ideas about respiration held by American college non-biology majors. The students identified oxygen as a need of animals and carbon dioxide as a need of plants. They used the everyday language meaning to identify respiration with breathing. They did not link food, oxygen, carbon dioxide and energy into any coherent view about respiration. They exhibited a lack of knowledge about respiration, unlike than the range of alternative ideas contradictory to the science view which they offered about photosynthesis.

A notion evident from several studies is that plants do not respire, or they respire only in the dark [28, 29, 33, 38]. Pupils who refer to respiration in plants do not perceive it as an energy conversion process; many think that photosynthesis is the energy-providing process for plants. Many children believe that respiration in plants occurs only in the cells of leaves since only leaves have gas exchange pores [33].

Children tend to believe that energy is used up by living things in general, and that plants use up energy in growing. They think that energy is created or destroyed in different life processes [11, 28, 39]. Even advanced Biology students aged 17-18 do not think in terms of energy transfer. Of Gayford's sample, 79% did not consider that biological processes such as respiration involve energy conversions. They think that respiration actually forms energy which is used later in synthetic reactions. Also, 74% though that 'ATP has high energy bonds which release energy', a view probably arising from the teaching of out-dated ideas.

Global warming and ozone depletion

Boyes and Stanisstreet [40, 41] found some scientifically acceptable ideas about global warming, already present amongst eleven year-olds. These include the notion that an increase in the Greenhouse Effect will cause changes in weather patterns. Other ideas, generally held by the science community, take time to become established over the period of secondary schooling; an appreciation of the mechanism of global warming by the retention of solar energy is an example.

A number of 'misconceptions' are identified amongst 11-16 year-old pupils. Some of these persist in the oldest school students and amongst undergraduate students. The idea that the use of lead-free petrol will reduce global warming is an example. The results also reveal underlying themes in children's thinking. Confusion between ozone layer depletion and the Greenhouse Effect is one such theme. It seems that students are aware of a range of environmentally 'friendly' and 'unfriendly' actions, and know about a range of environmental problems, but they do not link particular causes with particular consequences. Rather, children appear to think in a general way that all environmentally 'friendly' actions help all the problems.

In a study of primary school children, the same research team [42] found that most children were aware that generating electricity from renewable resources, using recycled paper and replacing trees by planting would reduce global warming. Although the majority of children realised that a reduction in automobile use would diminish the Greenhouse Effect, the preponderance of this idea was lower in older primary school children. More than half of the children thought that keeping beaches clean or protecting wild species would reduce the Greenhouse Effect, although the frequency of these ideas was lower in the older children. Furthermore, the most common misconception, held by 87% of the pupils, was that the use of lead-free petrol would reduce global warming.

Like the older students studied by Boyes and Stanisstreet, primary school children confuse the causes of global warming, ozone layer depletion, and atmospheric lead pollution by leaded gasoline. The researchers suggest that it will require specific efforts to disentangle these important environmental issues in the minds of children, especially since the problems are intangible and so not readily open to experiential learning. They suggest that this education should begin early, before misunderstandings become embedded concepts leading to entrenched attitudes.

References

1. Leach J, Driver R, Scott P, Wood-Robinson C
1992
Progression in conceptual understanding of ecological concepts by pupils aged 5-16.
Centre for Studies in Science and Mathematics Education, University of Leeds.

2. Piaget J
1929
The child's conception of the world.
Routledge and Kegan, London.

3. Barker M
1985
Teaching and learning about photosynthesis.
Science Education Research Unit, University of Waikato, Working Papers No.220-229

4. Pascoe HT (ed.)
1982
Pupils' learning problems in certificate biology.
Course Proceedings, National Inservice Course: 1981 Aberdeen College of Education, Biology Department.

5. Smith EL, Anderson CW
1986
Alternative student conceptions of matter cycling in ecosystems.
Paper presented to National Association of Research in Science Teaching.

6. Bell BF, Brook A
1984
Aspects of secondary students' understanding of plant nutrition.
Children's Learning in Science Project, Centre for Studies in Science and Mathematics Education, University of Leeds.

7. Barker M, Carr M
1989
Teaching and learning about photosynthesis.
International Journal of Science Education 11(1)48-56

8. Simpson M, Arnold B
1982
Availability of prerequisite concepts for learning biology at certificate level.
Journal of Biological Education 16(1):65-72

9. Roth KJ, Anderson CW
1985
The power plant: Teachers' Guide.
Institute for Research on Teaching, Michigan State University, East Lansing, Michigan, USA.

10. Simpson M
1983
The molecell rules, OK?
Aberdeen College of Education Biology Newsletter 42:7-11

11. Gayford CG
1986
Some aspects of the problems of teaching about energy in school biology.
European Journal of Science Education 8(4):443-450

12. Senior R
1983
Pupils' understanding of some aspects of interdependency at age fifteen.
Unpublished MEd Thesis, University of Leeds.

13. Schollum B
1983
Arrows in science diagrams: Help of hindrance for pupils?
Research in Science Education 13:45-49

14. Brumby MN
1982
Students' perceptions of the concept of life.
Science Education 66(4):613-622

15. Eisen Y, Stavy R
1988
Students' understanding of photosynthesis.
The American Biology Teacher 50(4):208-212

16. Adeniyi EO
1985
Misconceptions of selected ecological concepts held by some Nigerian students.
Journal of Biological Education 19(4):311-316

17. Bell B, Barker M
1982
Towards a scientific concept of animal.
Journal of Biological Education 16:197-200

18. Webb P, Boltt G
1990
Food chain to food web: A natural progression?
Journal of Biological Education 24(3):187-190

1990
The concept of photosynthesis and pupils' ideas on the concept of 'cycles'.
In: Voorbach MT, Prick LGM: Teacher Education 6, Research and Developments in Teacher Education in the Netherlands (in press).

20. Griffiths AK, Grant BAC
1985
High school students' understanding of food webs: Identification of a learning hierarchy and related misconceptions.
Journal of Research in Science Teaching 22(5):421-436

21. Jungwirth E
1975
Preconceived adaptation and inverted evolution (a case study of distorted concept formation in high school biology).
Australian Science Teaching Journal 21:95-100

22. Engel Clough E, Wood-Robinson C
1985
How secondary students interpret instances of biological adaptation.
Journal of Biological Education 19:125-130

23. Caravita S, Tonucci F
1987
How children know biological structure/function relationships.
Proceedings of the Second International Seminar on misconceptions, Ithaca, NY, USA.

24. Caravita S, Tonucci F
1987
Investigating pupils' conceptualisation in the biological domain: Structure/function relationships.
European Conference for Research on Learning and Instruction.

25. Sequeira M, Freitas M
1986
Death and decomposition of living organisms: Children's alternative frameworks.
Paper presented at the 11th Conference of the Association for Teacher Education in Europe (ATEE).

26. Helden G
Personal communication.

27. Brody MJ
1992
Student science knowledge related to ecological crises.
Paper presented to AERA, San Francisco, USA, 1992.

28. Arnold B, Simpson M
1980
An investigation of the development of the concept of photosynthesis to SCE 'O' grade.
Aberdeen College of Education.

29. Stavy R, Eisen Y, Yaakobi D
1987
How Israeli students aged 13-15 understand photosynthesis.
Unpublished manuscript, Tel Aviv University.

30. Bell B
1985
Students' ideas about plant nutrition: What are they?
Journal of Biological Education 19(3):213-218

31. Simpson M, Arnold B
1979
The concept of photosynthesis at 'O grade - what are the pupils' difficulties?
Scottish Association for Biological Education Newsletter 4:38-40

32. Wandersee JH
1983
Students' misconceptions about photosynthesis: A cross-age study.
In: Helm H, Novak JD (eds.) Proceedings of the International Seminar: Misconceptions in Science and Mathematics. 20-22 June 1983, Cornell University, Ithaca, NY, USA:441-446

33. Haslam F, Treagust DF
1987
Diagnosing secondary students misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument.
Journal of Biological Education 21(3):203-211

34. Gellert E
1962
Children's conceptions of the content and functions of the human body.
Genetic Psychology Monographs 65:293-405

35. Nagy MH
1953
Children's conceptions of some bodily functions.
Journal of Genetic Psychology 83:199-216

36. Arnaudin MW, Mintzes JJ
1985
Students' alternative conceptions of the human circulatory system: A cross age study.
Science Education 69(5):721-733

37. Anderson CW, Sheldon TH
1990
The effects of instruction on college non-majors' conceptions of respiration and photosynthesis.
Journal of Research in Science Teaching 27(6)

38. Driver R et al
1984
Science in schools at age fifteen: Report No2 Assessment of Performance Unit.

39. Smith EL, Anderson CW
1984
Plants as producers: A case study of elementary science teaching.
Journal of Research in Science Teaching 21(7):685-698

40. Boyes E, Stanisstreet M
The 'Greenhouse Effect': Children's perceptions of causes, consequences and cures.
University of Liverpool. Submitted for publication 1992.

41. Francis C, Boyes E, Qualter A, Stanisstreet M
Ideas of elementary students about reducing the 'Greenhouse Effect'.
University of Liverpool. Submitted for publication 1992.

42. Boyes E, Stanisstreet M
Students' perceptions of global warming.
University of Liverpool. Submitted for publication 1992.

MODELLING THE ECOSYSTEM

Children's Prior Ideas

From an early age, children can draw linear 'who eats what' food chains. However, few pupils understand the integration of chains into webs and cycles even at the end of secondary school, nor that food chains and webs are intended as models of all feeding relationships in a habitat.

Children have a notion of food passing along a food chain, like passing a parcel, but not of food being assimilated into bodies at each stage.

Plants are seen as an important source of food for animals, but most children do not regard them as the only or ultimate source.

Most students over thirteen know that animals cannot survive without plants, but lack an understanding of why plants are crucial. Few can relate the importance of plants in the ecosystem to the Sun as the source of life.

Few children recognise that plants grow in water and are a source of aquatic food chains.

A very prevalent notion in children's thinking is that of predestination; they think that food chains exist in order to provide for people and large animals.

Some children think that a predator feeds on all the organisms below it in the food chain.

Some children's concept of food chains includes the idea of energy building up through the food chain, so a top predator receives all the energy from the lower levels. Some think that the bigger animals at the top of the chain are more energetic.

(See Ecosystems Research Summary)

The Challenge for Pupils

The global ecosystem is far too vast and complex to allow thinking about all aspects at once. Thus the challenge for pupils is to develop models to help them to think about it in manageable ways. This is a good opportunity to look at the importance of models in science. Pupils may meet models of separate instances of biological relationships, from which they need to develop a series of widely applicable generalised models. (See Using Models in the Introduction, page 25.) There are a number of powerful conventional models for describing ecological relationships which children need to make their own. Those usually included in lower secondary school work are food chain and web, pyramid of numbers and pyramid of biomass. These lead on to pyramid of energy at a later stage. In all these cases, the challenge lies in applying the conventions to a diversity of phenomena.

The idea of food as a material and its assimilation (and its energy content), underlies an understanding of the significance of food chains. Children need to understand that food becomes body material, which serves as food for the next organism in the chain and so on. (See Assimilation Learning Guide in 'Nutrition'.) From the experience of tracing food chains, children will notice that all start with a green plant; they need to recognise this generalisation and to consider why it should occur. (See both the Plant Nutrition Learning Guide and the Energy and Photosynthesis Learning Guide in 'Nutrition'.)

Pupils may have difficulty in recognising that in a food chain diagram one word or picture represents a whole species or group of species.

Pupils need to bring quantitative ideas about populations into their thinking about food chains. Preoccupation with the conventions of drawing diagrams (food chains horizontally, pyramids vertically) may interfere with grasping the concepts. Pupils need to recognise that a pyramid of numbers assumes a snapshot view of an ecosystem. They need to imagine a closed ecosystem within which the numbers of organisms could, theoretically, be counted. (They must, however, be aware that their own sampling of an ecosystem is not likely to be effective in demonstrating a pyramid of numbers, due to the problems of sampling.) Having met the model they need to apply it to a variety of ecosystems.

It is a particular challenge for pupils to accept that living things are composed entirely of matter. (See All Materials Learning Guide in 'Materials'.) Children need to understand that 'biomass' is not just a qualitative description of body material but also a quantitative value, and that all the biomass of all the organisms at a trophic level can be 'added together'. Children need to reach an understanding that matter 'must go somewhere', either into the next trophic level or into the environment. (See Conservation of Matter Learning Guide in 'Materials'.) Appreciating the significance of the pyramid of biomass depends on these principles of matter which are difficult to grasp. It is a massive jump to thinking about energy, so it is not appropriate to introduce pyramids of energy until a later stage.

Children's Prior Ideas

Children may think of materials appearing and disappearing.

How pupils perceive a change may determine whether or not they regard material substance as being conserved. If the pupil's view of a change is dominated by the apparent 'disappearance' of some materials, they are unlikely to think mass is conserved.

If children regard gases as 'weightless' they are unlikely to conserve overall weight or mass in reactions that involve gases.

Many children may predict a loss of mass or volume during reactions.

Pupils do not appreciate the quantitative aspects of chemical change, particularly the conservation of overall mass/substance.

By age twelve, many children are aware that some kind of cyclical process takes place in ecosystems such as plants rotting and helping other plants to grow. However, they tend to think in terms of sequences of events with matter being created or destroyed, at least partially, in these events.

Some children regard soil, water and food as factors necessary for growth rather than as sources of matter.

Some children have a notion of food passing along a food chain, like passing a parcel, but not of food being assimilated into bodies at each stage, and being a transfer of matter through the ecosystem.

Few children are aware of ideas of matter from the bodies of organisms changing into mineral matter and becoming part of the non-living environment. They do not relate respiration to the cycling of matter.

They see no connection between the oxygen/carbon dioxide cycle and other processes involving the production, consumption and use of food.

They conceptualise decomposition as the total or partial disappearance of matter.

(See Ecosystems Research Summary)

The Challenge for Pupils

Pupils will probably become familiar with the concepts of plant nutrition, animal nutrition, respiration and decay through teaching of separate topics. Having met these topics in isolation, they face the difficult challenge of bringing them together into an overall view of the cycling of matter. This involves recognising that everything making up living things, food and the environment is material. It also involves recognising that matter can be changed but not destroyed or created. Children may need to work from the ideas that all the matter on the Earth has been here, in some form, since the Earth was formed, and that this is the finite resource of matter for all living things. They also need to acknowledge the continuity of material between living things and the non-living environment. There is a particular challenge in recognising gases as forms of matter, since many stages in matter cycling involve the atmosphere. (See All Materials and Conservation of Matter Learning Guides in 'Materials' and Gases Learning Guide in 'Solids, Liquids and Gases'.)

Pupils need to think about the sort of cycle that they are considering so as to be aware that material is cycled. (See Cycles in the Introduction, page 23.) Pupils will need considerable help in relating their ideas of food and body substances, material and energy. (See Food Learning Guide in 'Nutrition'.) Because pupils may not clearly differentiate between matter and energy, they need first to make this distinction, so as to focus only on matter when they think about cycling. An established concept of matter cycling is an essential basis for the later understanding of cycling of elements considered separately (C, N, 0, S, and so on). Having established the cycling of matter, pupils will be in a position to superimpose the flow of energy which is associated with the synthesis and breakdown of compounds through the matter cycle, at a later stage of their studies.

Pupils need to revisit photosynthesis (and the subsequent syntheses) in plants to recognise that this is the main stage, in the cycling of matter, at which matter of the non-living environment becomes the matter of living things. (See Plant Nutrition Learning Guide in 'Nutrition'.)

Children need to move from their knowledge of 'eating events' to an understanding of the origin of the material that is eaten. This involves visiting the idea of assimilation and recognising that this is the stage at which the body material of one organism (the eaten) becomes the body material of another (the eater). (See Learning Guide: Interdependence, and Assimilation Learning Guide in 'Nutrition'.)

Understanding the role of respiration in the cycling of matter again involves recognising the commonality of food and body material. Although respiration is defined in terms of food, pupils need to realise that this 'food' is the body material of an organism. They need to recognise that respiration is the stage in matter cycling at which matter of living things becomes matter which returns to the non-living environment. (See Learning Guide: Respiration.)

The challenge of fitting 'decay' into the cycling of matter, depends on realising that material does not 'disappear' when bodies or excretory products decay. Pupils need to recognise that the chemical interactions involved in decay are the respiration processes of microbes, and that decay is one route for the conversion of the matter of living things to environmental matter. (See Decay and Recycling Learning Guide in 'Microbes'.)

Children's Prior Ideas

Young children think of living things only as separate individuals which are dependent on human care.

Even though some older children may think about wild organisms as members of populations and may be able to describe relationships between organisms observed in nature, they tend to think of inter-relationships only in terms of simple food chains or provision of shelter. Their thinking is descriptive rather than explanatory. They do not think in terms of interdependence of several components of an ecosystem (animals, plants, gases, food, minerals).

Although secondary school students are able to draw and manipulate food chain and food web diagrams, they often think of the components as individual organisms. They focus on linear food chains in predicting the effects of a change in one component, and do not recognise the far reaching effects on the whole food web and whole ecosystem.

Some children think that a predator feeds on all the organisms below it in a food chain.

Most students over thirteen know that animals cannot survive without plants, but lack an understanding of why plants are crucial. Few can relate the importance of plants in the ecosystem to the Sun as the source of life.

Although children recognise that organisms need materials (soil, water, food, air) from their environment, they may not see these materials as sources of matter for growth and repair (or as sources of energy).

(See Ecosystems Research Summary)

The Challenge for Pupils

Children come to secondary school science knowing about the needs of organisms for food and shelter: a rabbit eats grass, a bird nests in a tree. Although they use this simple but limited model of interdependency, it needs to be made explicit to them - they need to be aware that they are thinking about one organism depending on another, for example a rabbit depending on grass. They need to become aware that interdependence is an important idea which will be used in many other biological contexts, and that they will be revisiting and elaborating the idea throughout their course. Children need to move in several directions from their 'one-to-one dependency' model. They may think of dependency as social interaction within a species, so they need to extend their thinking to one species being dependent on another. Then there are various levels of dependency - a bird depending on a tree for a nesting site is a less intimate dependency than interactions in food chains. Also, there are many individuals and many species simultaneously depending upon each other in a number of ways. The major challenge for pupils is to shift from their descriptive understanding of dependency in any context, to an explanatory understanding. In science, we explain the simple ideas of dependence in terms of the 'big ideas' of matter and energy. Recognising that organisms, like the non-living environment, are composed of matter, is essential to adopting this wider view. (See All Materials Learning Guide in 'Materials'.) Conservation of matter and continuity of matter between the environment and organisms, and between organisms, depends on this. (See Learning Guides: Cycling of Matter and Modelling the Ecosystem, and Conservation of Matter Learning Guide in 'Materials'.) Although it is very difficult for pupils to grasp these concepts, an early and explicit introduction to interdependence at the material level, may help them to see the significance of interdependence. Having been introduced to the notion of interdependence through materials, pupils face the challenge of keeping this idea in mind, while studying Nutrition (see all Learning Guides in 'Nutrition'), Respiration (see Learning Guide: Respiration), Growth (see all Learning Guides in 'Growth'), Decay (see Decay and Recycling Learning Guide in 'Microbes'), and so on. Bringing these ideas together at the end of the course of study will help pupils to establish an explicit model. The model of interdependence needs to be used for understanding cycling of specific elements, population dynamics and flow of energy in more advanced stages of study.

Children need to build upon their understanding of interdependence between individuals to progress to thinking about populations interacting and then to more complex systems. The idea of interdependence needs to be associated with the idea of a system in which change in any part affects the whole, and brings it to a new equilibrium. Pupils need to clarify the terminology used for ecosystems. For example, the ecological sense of 'population' and 'community' must be distinguished from the sociological sense. Experience of studying organisms in their environments introduces pupils to ecology, but enables only a limited appreciation of ecosystems as so many aspects are not observable. In thinking about ecosystems it is usual and useful to start by studying a 'closed' system such as a small distinct pond. However, pupils need to realise that no ecosystem is closed - all are 'open' in that in all ecosystems energy exchange and gas exchange are global, even if no other materials are exchanged outside the immediate system. They need to recognise that focussing on localised ecosystems is only a way of dealing with a convenient but arbitrary portion of the global system. Different parts (for example the school field, deserts, the oceans) are considered in different circumstances. Revisiting the concept of the global ecosystem at the end of a science course will enable pupils to integrate their ideas not only of living systems (see all Learning Guides in 'Ecosystems', 'Nutrition', 'Growth' and 'Microbes') but also of materials and energy.

POLLUTION

Children's Prior Ideas

Some children think of pollution as only those aspects which are directly sensed by people and which directly affect people and other individual animals.

Pupils may have a rudimentary idea of the cumulative effects of pollution, some of which cannot be directly sensed. However, they have an 'all or nothing' concept of pollution killing, rather than harming, organisms.

Children tend to think in overall terms of environmentally 'friendly' or 'unfriendly' effects. They do not distinguish the problems caused by different pollutants: they think that the greenhouse effect, ozone depletion and atmospheric lead pollution are interchangeable in terms of their causes and effects.

Older secondary school students have some understanding of the widespread and differentiated effects of pollution. They consider that biodegradable materials are less harmful to life than non-biodegradable materials. Many consider that biodegradable materials are not pollutants.

Pupils of all ages on the whole are confident that the human species is indestructible.

(See Ecosystems Research Summary)

The Challenge for Pupils

Pupils are familiar with the word 'pollution' but they need to recognise that it is not a precisely defined term. Their own sense of pollution being 'bad' or 'a problem' and being produced by people may present a useful starting point for developing the notion. The challenge for pupils in moving to a more sophisticated concept involves thinking in terms of matter and energy; it involves confronting many different ideas from a number of domains. (See Gases Learning Guide in 'Solids, Liquids and Gases', Gas Exchange in Plants Learning Guide in 'Nutrition', and Fossil Fuels Learning Guide in 'Energy'.) A pupil's concept may be limited to a personalised view: 'pollution affects me and other individual people'. Pupils may like to think about specific instances of individual actions and trace causes and effects into the ecosystem. They need to extend their thinking to a range of examples and to apply the idea of pollution to new contexts as they meet them.

It may be difficult for children to accept that there is a spectrum of meaning of 'pollution' from mildly irritating annoyances (which are a matter of opinion) to lethal situations. Children should have the opportunity to discuss the nature and extent of the potentially harmful effects of a range of materials and energy sources in the environment. Such discussion may lead to recognising that 'pollution' depends on the extent or concentration of a potential pollutant, and that a 'useful' or 'harmless' substance can be a pollutant if present in excess, whereas some substances are harmful (polluting) if present in the smallest quantity.

Pupils need to have a sound understanding of the full range of materials, and also to appreciate that the materials we call 'chemicals' are not a separate class of materials, if they are not to be vulnerable to a simplistic 'chemicals cause pollution' idea. (See All Materials Learning Guide in 'Materials'.) Moreover, they also need to accept that energy can be a pollutant and this idea may seem strange, given the importance of energy.

Pupils' concept that pollution is caused by people can be built upon to consider not only man-made substances and energy sources, but also the imbalance of 'natural' substances in the environment arising directly or indirectly from human activity.

Understanding environmental crises depends on some appreciation of the dynamic equilibrium of ecosystems. (See Learning Guides: Interdependence and Competition.) Pupils may be able to accept that 'pollution' consists of <u>changes</u> - increased lead, increased nitrate, increased noise, and so on, and that the changes upset the ecosystem. It involves recognising, as pollution, an imbalance of something which in itself may not be harmful. This may be a convenient way into the dynamics of the ecosystem.

There is a further challenge for pupils in moving from a simple notion of 'bad' or 'harmful' to a value judgement based on risk-benefit analysis.

Pupils need a clear conceptual understanding as a basis for considering the wider social implications. They need to bring scientific understanding, not just information, to underpin the debate about ethical and economic implications of pollution.

ECOSYSTEMS

COMPETITION

Children's Prior Ideas

Children do not regard food as a scarce resource for animals: young children think it is provided by people. They attribute to animals human decision-making about food and suppose that any animal can choose from a wide range or readily available food.

Because children do not regard food as scarce they do not consider competition for food. Even when they have been introduced to food chains and webs, pupils think in terms of linear chains and so do not consider competition between species for the same food resource. Pupils think that a change in population will affect only those species directly related to it as predator or prey.

Children's understanding of competition depends on the context they are considering; they can more readily understand competition between predators for a food source, than competition between prey in 'avoiding being eaten'.

(See Ecosystems Research Summary)

The Challenge for Pupils

An initial challenge for pupils is to recognise that, globally, resources are finite and that within any ecosystem they are scarce. (See Learning Guide: Interdependence, and also Conservation of Matter Learning Guide in 'Materials' and Harnessing Energy Transfer Learning Guide in 'Energy'.) Making the step from 'finite resources' to 'scarcity' involves thinking proportionally in terms of supply and demand. The more organisms in an ecosystem the more demand there is on the supply of all resources. The concept of 'competition' assumes that the ecosystem under consideration is 'closed'. (See Learning Guide: Modelling the Ecosystem.)

To identify 'demands' pupils have first to think about organisms' needs at the individual level. Looking at food resources from the point of view of the eater is necessary to understand that each kind of animal <u>can</u> eat only certain foods and therefore has specific requirements. Pupils need to recognise the fiction in children's stories and cartoons about animal characters choosing from the range of foods that people eat.

Having identified the specific demands of individuals, pupils have to recognise that many individuals are making demands on the same resource. The challenge then is to bring together the notion of the specific need and the limited supply of the particular resource. The proportionality relationship between need and supply is one which needs addressing. Pupils need to understand that 'same mice, more owls' is the same proportional relationship as 'fewer mice, same owls'. Children may require practice in manipulating such ideas, as they can reason proportionally in some contexts more easily than in others.

Pupils may develop the idea of biological competition from the consideration of supply and demand, but the meaning of the word 'competition' may then need discussion. Children associate 'competition' with sporting events, quizzes or examinations, where the human contestants or competitors are engaged in <u>trying</u> to do better than their opponents. While this can introduce the ecological term 'competition', it does produce a false concept of the relationships between 'competing' organisms. Pupils need to be introduced to a number of examples of competition between organisms for resources, to recognise that it does not involve actual fighting or 'trying' to out-do 'rival' organisms. They then need to think of other examples of competition which may occur in the ecosystems which they study.

In ecology, as in other domains, pupils need to be inducted into certain conventions. They need to recognise that a name (for example 'the rabbit' or 'a bird') may refer either to an individual or to a species. Similarly in a diagram of a food chain a picture of one fox represents all foxes (within an ecosystem). Furthermore, whenever 'competition' is considered, pupils need to distinguish 'competition between species' from 'competition within species'. For example, food web problems focus on competition between different species such as owls and kestrels competing for mice. Germination problems may focus on competition between different seedlings of the same species, for water and light.

Children's Prior Ideas

The word 'respiration' is perceived, by most students of all ages, as synonymous with breathing.

From a young age, children know that people and animals need air in order to breathe. They may know that they breathe oxygen and they believe that oxygen is 'good'. Oxygen is often equated with air. They tend to think of carbon dioxide and gases in general as strange and harmful.

Some pupils think that anything concerned with gases going in and out of organisms is breathing.

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, in order to replenish the humans' oxygen supply.

Most children think of breathing as an end in itself, somehow necessary to keep an organism alive. They do not link oxygen with food and energy release, nor with the metabolic source of carbon dioxide.

Although pupils have a range of ideas about most processes of living things, few have any spontaneous notions about respiration.

When asked about plant respiration pupils suggest that:
- plants do not respire
- plants respire only in the dark
- plant respiration is photosynthesis.

Even senior students do not necessarily associate biological processes, such as respiration, with energy transfer.

(See Ecosystems Research Summary)

The Challenge for Pupils

It is a difficult challenge for pupils to distinguish the technical meaning of respiration from their more familiar meaning of breathing, given its connection with 'artificial respiration'. This is not merely a superficial matter of words, but it incorporates a more significant challenge. The challenge is to move from a mechanistic description of what is happening in 'breathing' to an explanatory account of why respiration is important. Pupils need to recognise that breathing in mammals and a variety of gas exchange processes in other organisms are just adjuncts to the universal process of respiration in all cells of all living things.

Pupils may like to compare all aspects of respiration with the analogous process taking place in a fire or in a car. This may help to identify respiration as chemical interaction. It involves thinking about the 'purpose' of the respective processes of combustion and respiration. However, pupils must beware of extending the comparison to thinking of the fire or car as living. (See Living and Non-Living Learning Guide in 'Living Things'.) Considering the difference between respiration and combustion (notably the rate and the obviousness and the 'uses' of the energy released) may help to obviate this problem.

Pupils will need to be told the scientific meaning of the term respiration so that they may be able to assimilate it into their developing ideas across all aspects of science. To make sense of respiration, pupils need to not only distinguish energy from matter, but also to appreciate the relationship between them. This is a major challenge for which pupils need to draw upon their ideas from several domains.
(See All Materials and Material Substances Learning Guides in 'Materials',
Food Learning Guide in 'Nutrition',
Chemical Interaction and Oxidation Learning Guides in 'Chemical Change',
Recognising Energy Transfer, Harnessing Energy Transfer and Conservation of Energy Learning Guides in 'Energy'.)