K of 2

~~X18530~~

Leeds National Curriculum Science Support Project

X18881

IMPORTANT NOTE:

The 'Ecosystems' domain brings together all aspects of life and living processes. All areas of study of living things can be put into the context of ecosystems, since all living things exist as members of ecosystems, interacting with other living things and with the non-living environment. Ecology is not an 'add-on' subsidiary to the study of the processes of isolated living things.

Ideas about materials and about energy underly an understanding of living processes and ecosystems. This domain relates to the 'Materials' domain in having a focus upon the continuity of matter between non-living and living things. It also refers to the 'Energy' domain in having a focus upon energy transfers accompanying living processes.

This Project has developed a coherent view of the natural world as a whole, having a view of living processes and ecosystems consistent with the views of materials and energy presented in these domains.

ECOSYSTEMS

The following sections have been designed for use in association with one another. The Learning Guides are supported by the Research Summary, the Science Map and The Teacher's View. It will also be helpful to refer to the Science Map and The Teacher's View when using the Research Summary.

CONTENTS

Science Map

This map shows those ideas which make up a sound basis for understanding Ecosystems to work towards in the early secondary years. This is proposed as a coherent framework in itself which at the same time provides an appropriate basis for development. Critical ideas around which understanding is structured are identified in the map as shaded boxes and these goals make up the right hand column of the Learning Guides.

Learning Guides

These guides are the nucleus of the materials. They are folded so that children's prior ideas from the Research Summary are set alongside goals from the Science Map and they describe the challenges pupils face when it comes to restructuring their ideas. They also suggest interventions which could be used in teaching schemes to help pupils reach the goals. Related extracts from the National Curriculum are included. The Learning Guides in this domain are:

INTERDEPENDENCE

POLLUTION

COMPETITION

MODELLING THE ECOSYSTEM

RESPIRATION

CYCLING OF MATTER

Research Summary: Children's Ideas

This is a brief outline of research into children's ideas, setting out the main prior ideas and understandings which teachers might expect to meet among pupils. These ideas make up the left hand column of the Learning Guides.

The Teacher's View

This section outlines those aspects of a deeper understanding which the teacher needs to have in mind whilst working with pupils.

ECOSYSTEM

SCIENCE MAP

Living things depend upon one another and upon the materials in their environment. (See Learning Guide: Interdependence)

All the living things and the materials on the Earth, because they are interdependent, make up the 'global ecosystem'. Within the global ecosystem we can focus on smaller ecosystems. (See Learning Guide: Interdependence)

An environment can only support a certain number of living things. There is a competition between living things for the resources of the environment. (See Learning Guide: Competition)

Competition exists between individuals in a species and between different species.

Each species has features which enable it to survive in its usual environment, but not all individuals of a species are identical.

Those living things which are best suited to obtain the scarce resources survive and reproduce. Those less suited are less likely to survive and reproduce.

When one animal hunts and kills another for food, it is called a 'predator' and the food animal is called its 'prey'. The 'prey' is a resource for the 'predator'.

A big population c predators tends t decrease the populatio of its prey, by eating i The smaller populatio of prey then tends t decrease the populatio of its predator, b starving it.

The Sun is the major source of energy for the Earth and all life on it.

Green plants transfer light energy into energy which they can use for living processes, or which can be passed on to other living things. (See Energy and Photosynthesis Learning Guide in 'Nutrition')

Energy is transferred when one living thing feeds on another. In food, energy is associated with materials.

Food substances interact with oxygen in the cells of living things. The 'new' substances formed are carbon dioxide and water. This process is called 'respiration'. During respiration energy is transferred. (See Learning Guide: Respiration)

Although some of th energy transferred i respiration enables lif processes, most of th energy is transferred t the environment an 'lost'.

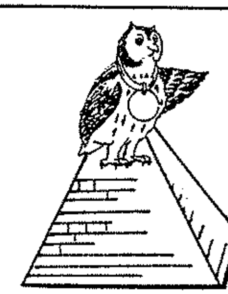
Each living thing needs it environment to provide shelter and a source of materials and energy.

Only green plants can transfer light energy and produce complex substances. They are called 'producers'.

A sequence of living things, each feeding on another can be represented as a 'food chain'. Every food chain starts with a green plant (producer). (See Learning Guide: Modelling the Ecosystem)

Animals eat complex materials from the bodies of other living things. They are called 'consumers'. This includes animals which eat plants (herbivores) and animals which eat other animals (carnivores).

A pyramid of number describes the decrease in number of individual at each level of a foo chain. There are fewe individual predator than prey in an ecosystem. (See Learning Guide Modelling the Eco system)



Certain changes to the materials and energy of the ecosystem, arising from the acitivities of human society, are harmful to life. These changes are examples of pollution. (See Learning Guide: Pollution)

Carbon, nitrogen, oxygen and hydrogen are the main elements making up the substances of which living things are made. The elements are available to living things in the raw materials carbon dioxide, water and nitrates.

Green plants take in simple substances from the environment and convert these substances into body material (biomass). (See Learning Guide: Cycling of Matter)

In daylight, photosynthesis uses up carbon dioxide and produces oxygen; but all the time plants are respiring, using oxygen and producing carbon dioxide. The overall effect is an exchange of gases with the air. (See Gas Exchange in Plants Learning Guide in 'Nutrition')

Plants and animals use oxygen and give out carbon dioxide in respiration. In a well-balanced ecosystem, the processes of photosynthesis and respiration maintain the constant composition of the air.

Material is transferred from the body of one living thing to another, when one living thing becomes the food of (is eaten by) another. (See Learning Guide: Cycling of Matter)

A pyramid of biomass describes the decrease in total body material a each level of a food chain. (See Learning Guide Modelling the Eco-system)

Pollution can affect the survival of living things both by the poisonous effects of the pollutants themselves and by the lack of raw materials for living processes.

If any substances from living things build up faster than they can be recycled to raw materials, they may lead to pollution.

Carbon dioxide and water and simple substances containing nitrogen are products from respiration and decay.

Material from the bodies of living things is returned to the environment when living things break down complex substances to simple substances in respiration. (See Learning Guide: Cycling of Matter)

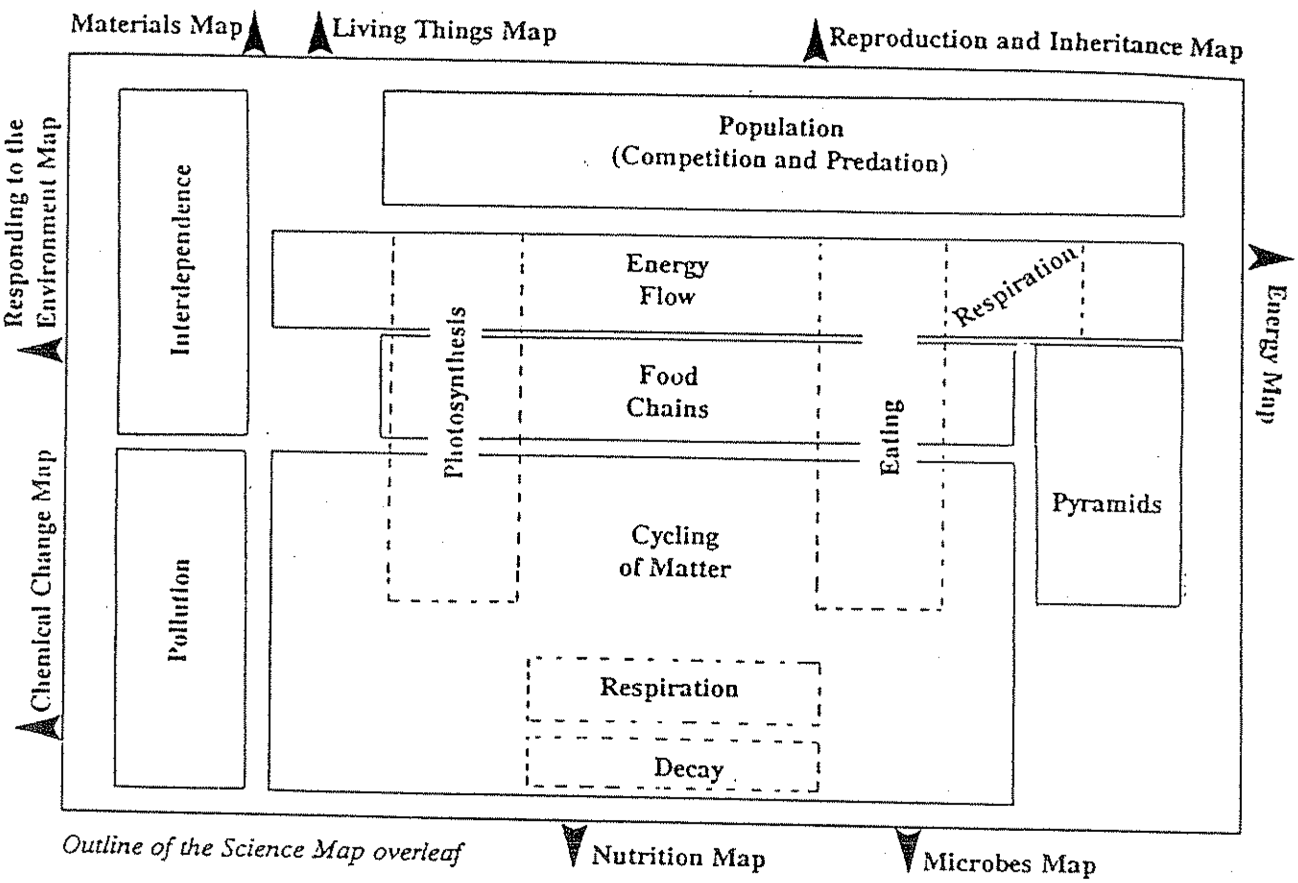
Material from the bodies of living things is returned to the environment by the process of decay. (See Learning Guide: Cycling of Matter)

As a result of the chemical changes in living processes, waste products are produced. These substances are excreted into the environment.

5

ECOSYSTEMS

SCIENCE MAP



Outline of the Science Map overleaf

The map overleaf shows those ideas which make up a sound basis to work towards in the early secondary years. This is proposed as a coherent framework in itself which at the same time provides an appropriate basis for development. Critical ideas around which understanding is structured are identified in the map as shaded boxes and these goals make up the right hand column of the Learning Guides.

Aspects of a deeper understanding which the teacher needs to have in mind whilst working with pupils are outlined in The Teacher's View.

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 changes - 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.

Goal

Certain changes to the materials and energy of the ecosystem, arising from the activities of human society, are harmful to life. These changes are examples of pollution.

Related National Curriculum Programme of Study Key Stage 3

They should study the effects of human activity, including food production and the exploitation of raw materials, on the purity of air and water and on the Earth's surface. They should come to appreciate that beneficial products and services need to be balanced against any harmful effects on the environment. (Sc2 iii)

They should....be introduced to the classification of waste products of human activities as biodegradable and non-biodegradable.... (Sc2 iv)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

They should investigate how far everyday waste products, for example, *garden refuse, paper, plastic materials and cans* decay naturally and use this knowledge to improve the appearance of their local environment. (KS1 Sc2 iv)

They should study aspects of the local environment affected by human activity, for example, *farming, industry, mining or quarrying* and consider the benefits and detrimental effects of these activities. They should study the effects of pollution on the survival of living things. (KS2 Sc2 iii)

They should....consider the significant features of waste disposal procedures, for example in *sewage disposal and composting....* (KS2 Sc2 iv)

They should have opportunities....to consider current concerns about human activity leading to pollution and effects on the environment, including the use of fertilisers in agriculture, the exploitation of resources, and the disposal of waste products on the Earth, in its oceans and in the atmosphere. They should relate the environmental impact of human activity to the size of population, economic factors and industrial requirements. (KS4 Sc2 iii)

They should relate their scientific knowledge to the impact of human activity on (these) cycles and ecosystems and to the disposal of waste materials. (KS4 Sc2 iv)

Related National Curriculum Statements of Attainment

Pupils should:

Sc2 iv/2d know that some waste materials decay naturally but do so over different periods of time.

Sc2 iii/3b know that human activity may produce changes in the environment that affect plants and animals.

Sc2 iii/5c know how pollution can affect the survival of organisms.

Goals

A sequence of living things, each feeding on another can be represented as a 'food chain'. Every food chain starts with a green plant (producer).

A pyramid of numbers describes the decrease in number of individuals at each level of a food chain. There are fewer individual predators than prey in any ecosystem.

A pyramid of biomass describes the decrease in total body material at each level of a food chain.

Related National Curriculum Programme of Study Key Stage 3

Pupils should be introduced to pyramids of numbers and biomass as ways of quantifying relationships within food chains. (Sc2 iv)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

They should be introduced to the idea that plants are the ultimate source of all food in the living world. (KS1 Sc2 iv)

They should be introduced to the idea that green plants use energy from the Sun to produce food and that food chains are a way of representing feeding relationships. (KS2 Sc2 iv)

Pupils should consider energy transfer through an ecosystem and how photosynthesis initiates this process. (KS4 Sc2 iv)

Related National Curriculum Statements of Attainment

Pupils should:

Sc2 iv/4d understand food chains as a way of representing feeding relationships in an ecosystem.

Sc2 iv/7e understand pyramids of numbers and biomass.

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 <u>all</u> 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 <u>becomes</u> 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'.)

Goal

Food substances interact with oxygen in the cells of living things. The 'new' substances formed are carbon dioxide and water. This process is called 'respiration'. During respiration energy is transferred.

ʾelated National Cu·riculum Programme of Study ‹ey Stage 3

ʾupils should explore and investigate how flowering ·lants and mammals are normally organised at ellular and macroscopic levels. They should study fe processes....respiration, removal of waste.... articularly as they relate to human beings. They ıould study respiration....in plants.... (Sc2 i)

upils should discuss the use of fuel/oxygen 'stems as concentrated sources of energy in living ings.... They should consider energy from the ın,...,the origin and accumulation of fossil fuels ıd the use of biomass as fuel. (Sc4 ii)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

Pupils should be introduced to the major organs and organ systems of mammals and flowering plants. They should explore ideas about the processes of breathing.... (KS2 Sc2 i)

Pupils should extend their study of the major organs and organ systems and life processes. They should explore how the internal environments of plants and animals are maintained, including....solute balance, for example, ...*carbon dioxide*.... (KS4 Sc2 i)

Pupils should consider energy transfer through an ecosystem.... (KS4 Sc2 iv)

Related National Curriculum Statements of Attainment

Pupils should:

Sc2 i/2a know that plants and animals need certain conditions to sustain life.

Sc2 i/3a know the basic life processes common to humans and other animals.

Sc2 i/4a be able to name and locate the major organs of the human body and of the flowering plant.

Sc2 i/5a be able to name and outline the functions of the major organs and organ systems in mammals and in flowering plants.

Sc2 i/7a understand the life processes of....respiration....excretion....in animals.

Sc2 i/7b understand the life processes of....respiration....in green plants.

COMPETITION

Goal

> An environment can only support a certain number of living things. There is a competition between living things for the resources of the environment.

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

They should be made aware of the competition between living things and their need for food, shelter and a place to reproduce. (KS2 Sc2 iii)

They should explore factors affecting population size, including human populations. (KS4 Sc2 iii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc2 iii/4c understand that the survival of plants and animals in an environment depends on successful competition for scarce resources.

Sc2 iii/6d understand population changes in predator-prey relationships.

Sc2 iii/7d know how population growth and decline is related to environmental resources.

:lated National Curriculum Programme of Study
:y Stage 3

ıey should be introduced to the factors affecting : size of populations of organisms, including mpetition for resources and predation. (Sc2 iii)

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.

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

16

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*

Progression in children's thinking about decay

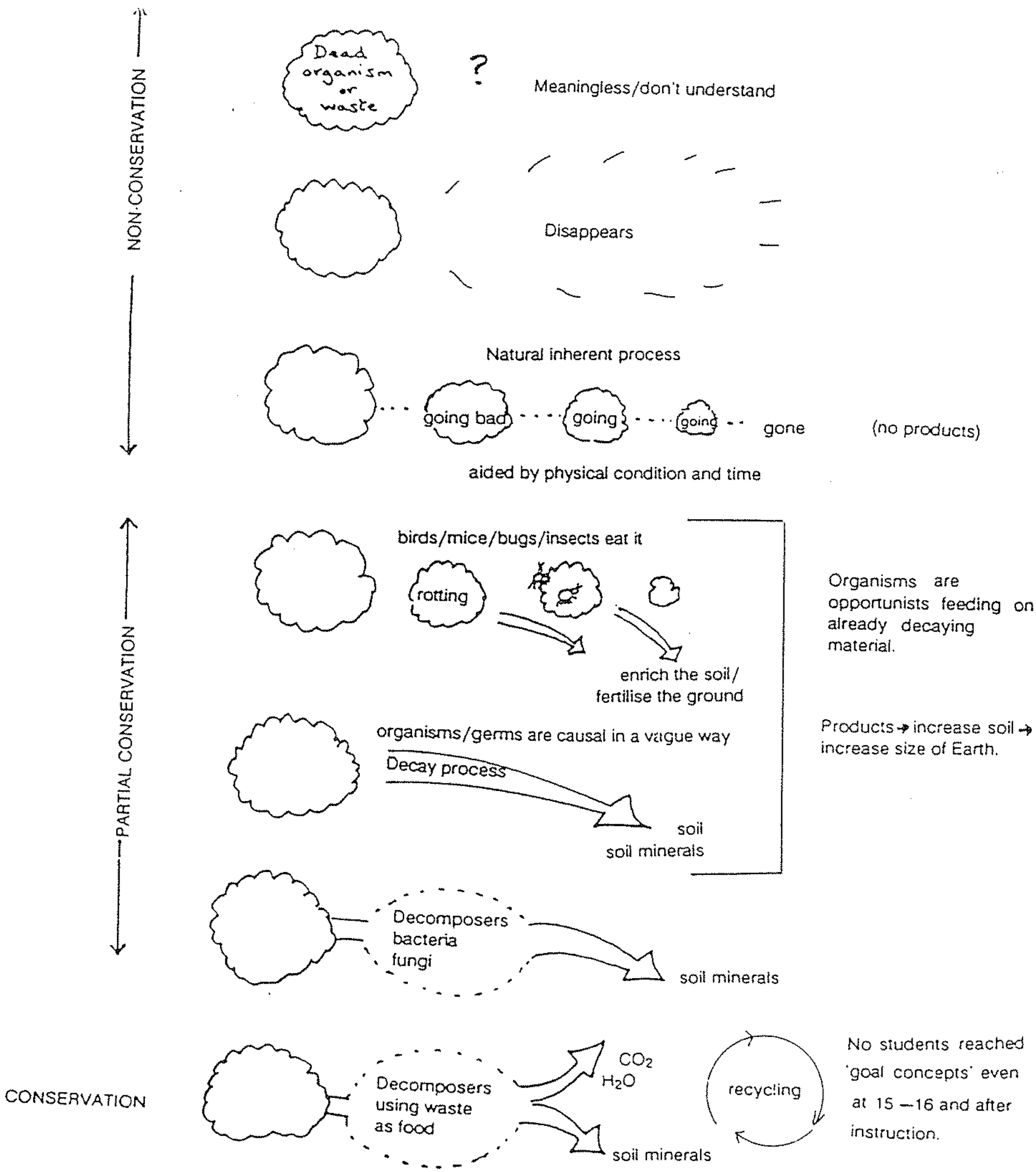


Figure 1

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*

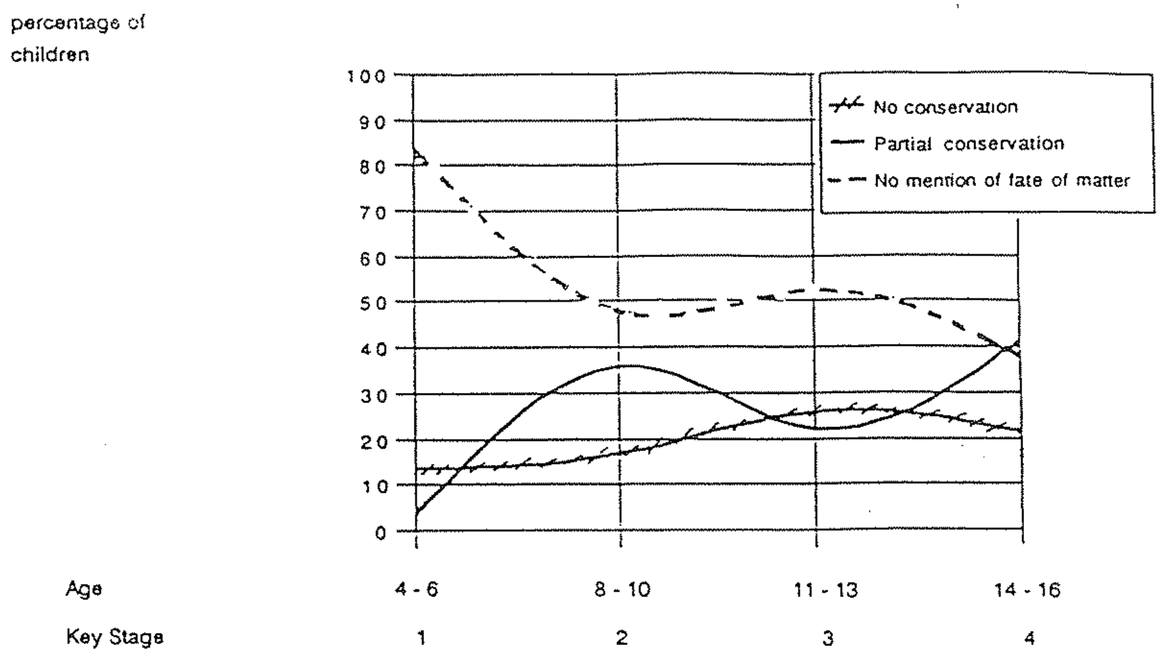


Figure 2: Issues of conservation relating to decay of apple

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].

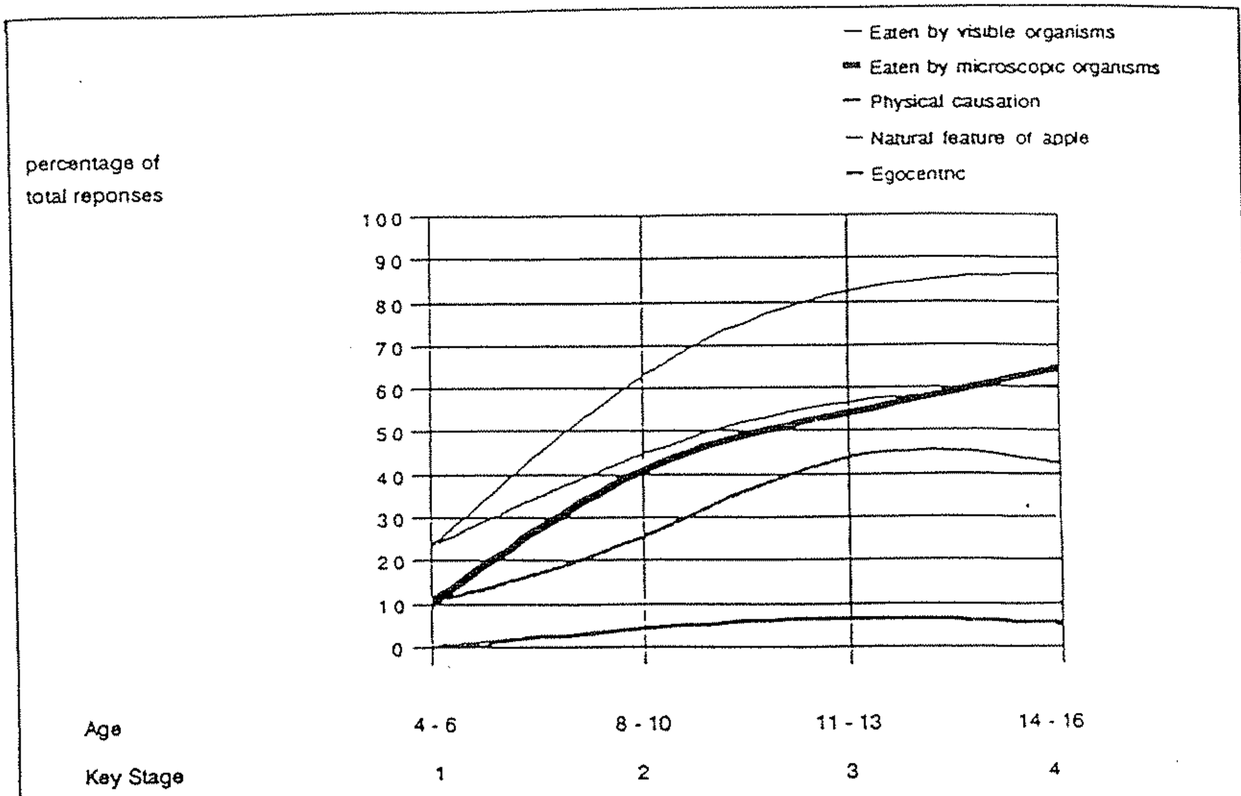


Figure 3: suggested causations for decay of apple. (It should be noted that there is an increasing tendency to offer more than one possible factor relating to the decay process with age.)

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

19. Boschhuizen R
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.

ECOSYSTEMS

THE TEACHER'S VIEW

This section outlines those aspects of a deeper understanding which the teacher needs to have in mind whilst working with pupils. Ideas in any aspect of science are constructed at ever increasing levels of sophistication and there are inevitably more sophisticated understandings than can be represented in these brief notes.

Ecosystems

The term 'ecosystem' refers to the interdependent system which includes all the living things and non-living components of a particular place. Thus it can be applied to the whole global ecosystem or to a certain sub-set, for example the 'desert ecosystem' or the ecosystem of a particular puddle. The study of ecosystems is known as ecology.

The distinction is often made between 'open' ecosystems which are continuous with other parts of the environment and 'closed' ecosystems which are self-contained. However, the distinction is not absolute but one of degree. No ecosystem, even an artificial one in a sealed container, is completely isolated (closed): all need initial components which have come from somewhere else and all need an external source of light energy.

However small the space it occupies, an ecosystem is a very complex entity, with many components existing in a series of dynamic equilibria. These components interact throughout the ecosystem. An equilibrium may shift its position but normally the balance of the ecosystem is maintained. If any component of an ecosystem gets out of balance such that the system cannot compensate, an ecological crisis may occur, resulting in harm or death to massive numbers of organisms.

An understanding of ecosystems depends on understanding concepts of animal and plant, respiration, photosynthesis, food, decay, matter, conservation of matter, energy transfer. It also depends on understanding the principles of systems, cycles, dynamic equilibrium, models and analogies. These ideas are discussed in the relevant domains and in the Introduction.

Discussion of ecology may, at different times, be focussed on individual organisms, on one species or on many species. Words such as 'an organism' or 'an animal' may refer

ECOSYSTEMS

LEARNING GUIDES APPENDIX: RELATED EXTRACTS FROM THE NATIONAL CURRICULUM PROGRAMME OF STUDY FOR KEY STAGE 3

References relating to the Learning Guides are underlined below:

Sc2 strand i - life processes and the organisation of living things

Pupils should explore and investigate how flowering plants and mammals are normally organised at cellular and macrospcopic levels. They should study life processes, feeding (including digestion and assimilation), respiration, removal of waste, movement, behaviour, growth, reproduction and sensitivity, particularly as they relate to human beings. They should investigate the requirements for photosynthesis in green plants, the resulting products (sugars, startch and oxygen) and the minerals required for healthy growth. They should study respiration, growth and sexual reproduction in plants. They should have opportunities to explore and investigate the uses of enzymes and microbes, for example, in the *baking, brewing and dairy industries*. Pupils should extend their study of the ways in which the healthy functioning of the human body may be affectd by diet, lifestyle, bacteria and viruses (including Human Immunodeficiency Disease (HIV)), the abuse of solvents, tobacco, alcohol and other drugs, and how the body's natural defences may be enhanced by immunisation and medicines. They should study the human life cycle, including the physical and emotional changes that take place during adolescence, the physical and emotional factors necessary for the well-being of human beings in the early stages of their development, and understand the need to have a responsible attitude to sexual behaviour.

Sc2 strand iii - populations and human influences within ecosystems

Pupils should study a variety of habitats at first hand and make use of secondary sources, to investigate the range of seasonal and daily variation in physical factors, and the features of organisms which enable them to survive these changes. They should be introduced to the factors affecting the size of populations of organisms including competition for resources and predation. They should study the effects of human activity, including food production and the exploitation of raw materials, on the purity of air and water and on the Earth's surface. They should come to appreciate that beneficial products and services need to be balanced against any harmful effects on the environment.

Sc2 strand iv - energy flows and cycles of matter within ecosystems

Pupils should be introduced to pyramids of numbers and biomass as ways of quantifying relationships within food chains. They should study the cycling of materials in biological communities and be introduced to the classification of waste products of human activities as biodegradable or non-biodegradable, and investigate ways of improving the local environment.

Sc3 strand iii - chemical changes

Pupils should be made aware of the range of sources of raw materials, including those derived from the air, rocks, fossil fuels and living things.

Sc4 strand ii - energy resources and energy transfer

Pupils should discuss the use of fuel/oxygen systems as concentrated sources of energy in living things, engines, heating systems and other devices. Pupils should survey national and global sources of energy. They should consider energy from the Sun, nuclear energy, the origin and accumulation of fossil fuels and the use of biomass as a fuel.

to one individual or to one species. It is important to be clear in which sense such expressions are used in any particular context.

Environment

The 'environment' refers to the surroundings of an organism or group of organisms. It applies to all the materials and to the energy, including other living things, in the surroundings. The environment supplies an organism with the requirements for its life. It may also include factors harmful to the organism. However, many aspects of the environment are neither 'useful' nor 'harmful' to an organism.

Habitat

The meaning of the word 'habitat' is distinct from 'environment': it means the particular location or type of place occupied by an individual or species. The word 'habitat' can be applied to a place of any size, for example, a whole ocean or an individual leaf which houses organisms.

Pollution

'Pollution' has been defined as: 'The introduction by man, into the environment, of substances or energy liable to cause hazard to human health, harm living resources and ecological systems, damage to structure or amenity or interfere with legitimate use of the environment'.*

'Pollution' refers both to the activities which introduce potentially harmful substances and energy into the environment, and also to the effect of the substances and energy. The substances and energy are called <u>pollutants</u>.

A particular substance or energy input may be a pollutant in one context but not in another. This would depend on the concentration of the potential pollutant and on how it interacts with other environmental factors. Some substances are harmful if they are present even in the minutest quantities. Others are only harmful above a certain threshold concentration. Even then the threshold at which damage is caused to species could vary with the species. Some species are more tolerant than others to certain pollutants. Sometimes two substances act synergistically, increasing the pollution beyond that due to the two substances separately. Some conditions, such as wind or water flow, may disperse a pollutant, either spreading its harmful effects more widely, or alternatively diluting it so that it is no longer a pollutant. The hot water effluent from a power station is advantageous in encouraging the growth of fish in some rivers. However, a similar outflow elsewhere may produce thermal pollution, causing aquatic

* *Royal Commission on Environmental Pollution 1984*

animals to suffocate due to the decreased solubility of oxygen, and causing increased growth of harmful bacteria.* Nitrate fertiliser is not a pollutant in fields of crops, but it may pollute rivers by promoting excessive growth of water weeds. There are innumerable other examples of variations in the extent of polluting effects of particular substances or energy sources. In some cases it may even be a matter of opinion, as in the case of noise pollution by music or visual pollution by litter.

Community and population

All the individual organisms of all the species living within a particular habitat form a community. A community consists of a number of populations. Each population consists of members of one species which can reproduce amongst themselves.

Competition

The resources of an environment can support only a limited size of community and so there is competition for these resources. Competition may be inter-specific, with members of different species competing for the same resources, or intraspecific between members of the same population. Competition does not necessarily imply that individuals fight or struggle directly with others for obtaining food, or a place to shelter. Competing individuals may not come into direct contact with each other. For example, it may be that if certain seeds germinate early and grow quickly they will shade the ground below and inhibit the growth of later seedlings. The early plants will have been more 'successful' in the competition for light.

Predators and prey

Predation is one form of competition. Different predator species compete for the same prey species as food. Different prey species compete for escape from the same predator species. The interaction between an individual predator and its individual prey can be regarded as an instance of competition. The predator and prey are competing for maintaining their place in the community, that is for survival. However, if a predator population competed so 'successfully' that it ate its whole prey population, the predator would die out, unless it had an alternative prey. In a well balanced community there is an equilibrium between predator and prey populations. The sizes of the populations tend to fluctuate in relation to one another. A larger predator population kills a large number of prey, which tends to reduce the prey population to a small size. Then there is not enough prey to feed the existing predator population and some individuals will starve, thus tending to reduce their population. With fewer predators, the remaining prey individuals are more likely to survive and reproduce and increase their population size. (Figure 1.)

---

* *See The Teacher's View in 'Water'*

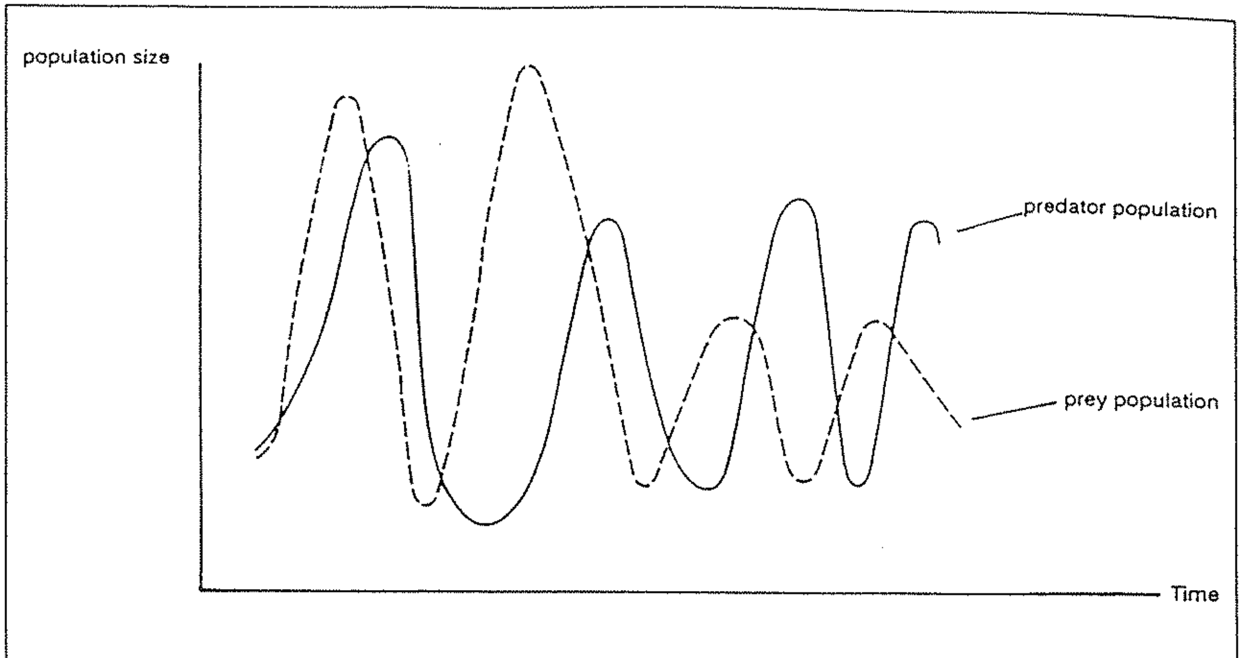


Figure 1: Fluctuations of predator and prey populations

The size of any population depends on birth rate, death rate and life span. The feeding relationships in a community consist of a complex web rather than discrete pairs of predator-prey species. Therefore, the explanation of population change above is a model rather than a realistic description of the complicated situation which occurs in most communities. However, in some situations the model makes quite accurate predictions about population size.

Respiration

All the processes of life involve energy transfers. They include, for example, movement of the whole or part of the body, movement of materials inside the body, conduction along nerve fibres, synthesis of materials in assimilation for growth and repair and reproduction. The energy for most of these processes is made available by respiration. (The energy for some processes originates elsewhere, for example the movement of water up a plant is mainly 'powered' by radiation from the Sun which evaporates water.) Food substances, like other fuels, can be thought of as concentrated sources of energy. In respiration, energy becomes available not directly from the food molecules but from the system which exists when food molecules interact with oxygen.

Respiration may be summarised by the overall equation:

(glucose) food + *oxygen* = *carbon dioxide* + *water* + energy (available for use)

This summarises a sequence of reactions by which 'food' substances are oxidised with the transfer of energy. The overall equation representing photosynthesis is the reverse of that for respiration, namely:

carbon dioxide + water + energy = *food (glucose) + oxygen*

However, the sequence of reactions making up photosynthesis is <u>not</u> the reactions of respiration in reverse.

Energy flow

The energy involved in synthesis of materials in one living organism is transferred when another organism eats, and then oxidises in respiration, substances from the body of the first organism.

Not all the energy from respiration is transferred to locations within the living organism. A lot of the energy is transferred to the environment, heating it. This energy is 'lost' from the ecosystem as it cannot be 'captured', that is, it cannot be transferred to building up new material or to other processes in living things. Thus energy flows through the ecosystem. Energy is not cycled.*

Matter cycling

Matter from the environment is incorporated into the materials of the bodies of living things (biomass) through the processes of photosynthesis, protein synthesis and assimilation.** Matter is passed from one organism's body to become the material of another organism's body through eating and assimilation.** Matter is returned to the environment from the biomass of living things through the processes of respiration, excretion and decay. Decay is the effect of the nutrition and respiration processes of micro-organisms which use biomass and excretory products as their 'food'.

The cycling of a single element may be traced separately. Carbon atoms and nitrogen atoms are involved in the ecosystem. The carbon cycle and the nitrogen cycle are models which explain and predict processes and compounds involving these respective elements. The cycles can be expressed in a variety of different diagrammatic layouts.

Gas exchange and balance

Gas exchange in the ecosystem is a balance between processes which use oxygen and

---

* *See The Teacher's View in 'Energy'*

** *See The Teacher's View in 'Nutrition'* produce carbon dioxide (respiration) and processes which use carbon dioxide and produce oxygen (photosynthesis).

Plants, like animals, respire all the time, absorbing oxygen and producing carbon dioxide. At night plants, like animals, take in oxygen and give out carbon dioxide. Green plants photosynthesise only in the day time when they are illuminated. The rate of photosynthesis varies with light intensity. In bright light the rate of photosynthesis exceeds the rate of respiration, so plants take in carbon dioxide for the excess photosynthesis and give out oxygen. The effect of photosynthesis masks the effect of respiration. At a certain dim light intensity, the rate of photosynthesis exactly balances the rate of respiration. At this point each process is using the by-product of the other process, so there is no overall gas exchange with the atmosphere.

The exchange of gases between living things and the atmosphere, through 24 hours (or perhaps a longer period of time involving seasonal change) results in overall constant composition of the atmosphere with respect to oxygen and carbon dioxide. However, if the balance of organisms and activities within the ecosystem becomes disrupted, the gas balance may be upset. Large scale deforestation decreases the total amount of carbon dioxide used in photosynthesis so there is an increase in the proportion of carbon dioxide in the air. This is distinct from the increased combustion of fossil fuels but contributes to the same 'greenhouse effect'.*

Models of feeding relationships

The feeding and energy relationships within an ecosystem may be represented by models: food chains, food webs, pyramids of numbers, pyramids of biomass, pyramids of energy. In each model, organisms are assigned to 'trophic levels' indicating their relative positions in a food chain. The trophic level indicates how many organisms the energy, originating from the Sun, has gone through.

Plants make 'food' from simpler substances, using light and energy, in photosynthesis. This constitutes autotrophic or producer nutrition. Animals take in ready-made organic material. This is heterotrophic or consumer nutrition.**

---

* *See The Teacher's View in 'Air'*

** *See The Teacher's View in 'Nutrition'*

The relationship between the terms applied to the 'levels' within these models are indicated below. The convention is that the arrows point in the direction that the food goes.

Example of food chain	*grass* →	*rabbit* →	*fox* →	*carrion crow*
TROPHIC LEVEL	trophic level 1	trophic level 2	trophic level 3	trophic level 4
TYPE OF LIVING THING	green plant	animal	animal	animal
MODE OF NUTRITION	autotrophic	heterotrophic	heterotrophic	heterotrophic
DIETARY TYPE	photosynthesing plant	herbivore	carnivore	'top' carnivore
FOOD USAGE	producer	primary consumer	secondary consumer	tertiary consumer

A food web of branching food chains, rather than several isolated food chains, is more representative of a real community. A web indicates alternative food sources and alternative grazers of predators of any organism.

The relationships in an ecosystem include decomposers feeding on dead organisms and waste products of the organisms from every trophic level. These may be considered in the terms of the scheme as shown above:

Example:	*mould*
TROPHIC LEVEL	trophic level 2, 3 or 4
TYPE OF LIVING THING	microbes: fungi, bacteria
MODE OF NUTRITION	heterotrophic
DIETARY TYPE	saprophyte
FOOD USAGE	primary, secondary, tertiary or quaternary consumer

(If a mould feeds on bread (a plant product) it is feeding at trophic level 2 as a primary consumer. If it feeds on a dead sheep, or on leather, it is feeding at trophic level 3 as a secondary consumer.)

A pyramid of numbers (Figure 2) represents the numbers of individual organisms at each trophic level in a particular community, at a particular point in time.

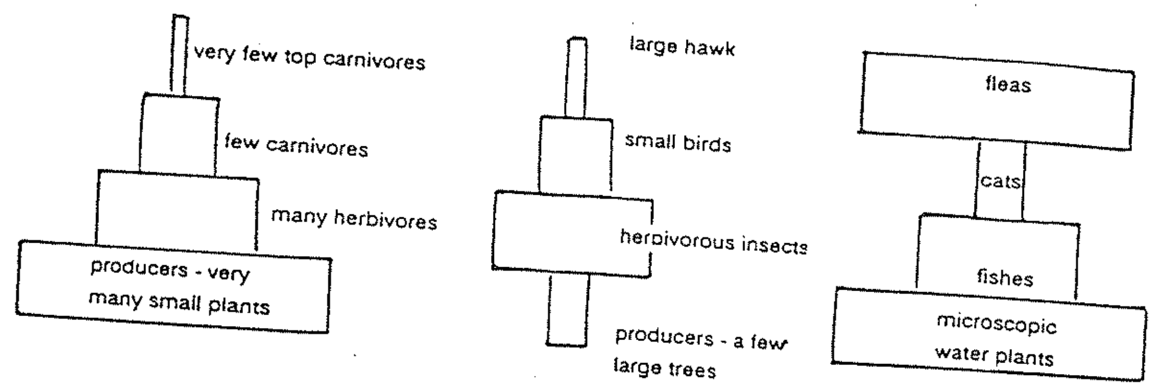


Figure 2: Pyramids of numbers

A 'pyramids of numbers' can vary from the pyramid shape, if a particular level consists of a few very large individuals or many very small individuals.

A pyramid of biomass (Figure 3) is a more coherent model since it emphasises the transfer of matter through the tropic levels, irrespective of the size of individual organisms. It represents a decrease in biomass through levels and raises the question of where matter has 'disappeared to' between one level and the next. The decrease in biomass is mainly accounted for by its conversion to carbon dioxide and water in respiration by the organisms at each level and subsequent 'loss' into the environment. Some of the decrease is accounted for by the feeding of decomposers which are not usually shown in the pyramid.

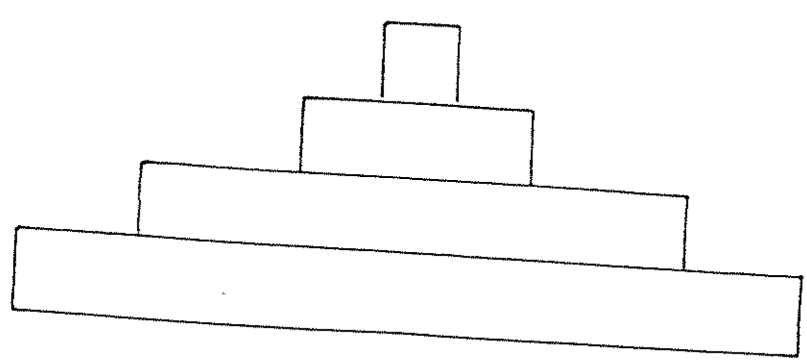


Figure 3: Pyramid of biomass

43

A pyramid of energy (Figure 4) is the most coherent model since it emphasises the transfer of energy through the ecosystem. The decrease in energy through the levels is accounted for by the inefficiency of energy transfer in respiration at each level. Much of the energy 'released' in respiration is 'lost'. It is dissipated in the process of heating the environment. Only about 10% of the energy at any level is transferred in association with the biomass to the next level. This decrease in energy availability at each level explains why food chains are rarely more than three or four links long.

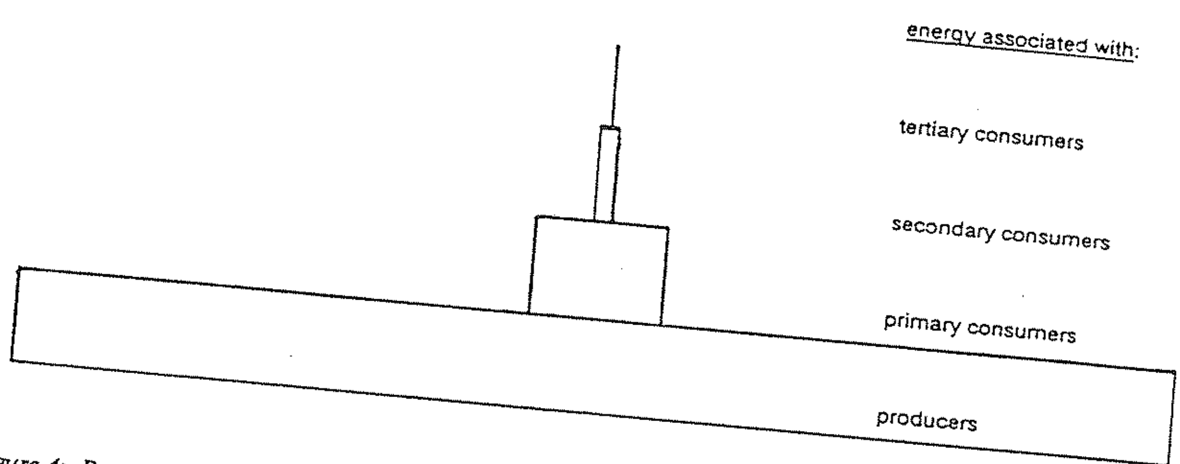


Figure 4: Pyramid of energy