THE DESCRIPTION AND MODIFICATION
OF CHILDREN'S VIEWS OF
PLANT NUTRITION

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ABSTRACT

This study lies within the constructivist tradition in science education which holds that the learner's prior knowledge is a key factor in concept development. The topic was photosynthesis, which was known to be difficult for students although little was known of their prior understandings about plant activities. A three phase research programme was designed to arrive at a description of these pre-teach views (Part 1) and to use this knowledge in an action research programme which modified children's existing knowledge more effectively than current classroom practice (Part 2).

Phase I comprised interviews with 28 pupils (aged 8 to 17 years). This lead to Phase II in which nearly 6000 pencil-and-paper survey responses were obtained from students from standard four (10-year-olds) to first year university (18+ years). The interviews and surveys showed that pre-teach children had a number of separate views about plant drinking, plant breathing, plant growth, how plants acquire energy, and plant feeding (these were collectively identified as views about 'plant nutrition'), but the children did not possess knowledge directly comparable with photosynthesis. As with earlier scientists' explanations, analogies and metaphors relating plants to animals were important in children's understandings. In contrast with what is known about children's prior knowledge generally, their views about plant nutrition were held with varying degrees of conviction and on some issues no views were evident.

Phase III approached classroom action research by evaluating three existing strategies. Each of these (the guided discovery, element analysis, and trophic conflict strategies) was found to be

deficient because children's prior knowledge was not considered and/or the scientists' view was not adequately addressed (i.e. food-making was considered at the expense of carbohydrate production or energy storage). A new strategy which explored the material aspects of photosynthesis (carbohydrate production)and which was based on the generative learning model was developed.

The new strategy resulted in a teaching package entitled "Where Does The Wood Come From?" which was trialled by an experienced and sympathetic teacher with a middle ability class of 26 fourth formers (14-year-olds). The class was observed throughout the four weeks of teaching, and individual students were also interviewed out of class at key times. After this unit, 71% of the students had acquired a view of photosynthesis as a carbohydrate-producing process. This contrasted with the usual guided discovery strategy, where a food-making view was the major outcome. Important observations were that the students perceived the unit as non-threatening, and that they underestimated the importance of their own ideas.

The study also documented some practical applications of the generative learning model (and constructivist theory generally) in the classroom. Investigations, surveys, a self-teach booklet, and a series of checkpoints were developed, and these features of the teaching package may have wider application. Also, it was suggested that the apparent similarities between children's views and those of earlier scientists may be used to facilitate classroom discussion and expose ideas. The findings of the action research resulted in suggested modifications to the generative learning model itself, especially its apparently sequential nature.

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INTRODUCTION

CHAPTER 1 PHOTOSYNTHESIS - AN INTRODUCTION

Photosynthesis thus eminently merits its distinction as the most important biochemical process on Earth.

(Daniel I. Arnon, 1982, p.22)

1.1 AN OVERVIEW OF THE THESIS

This study arose from an awareness of the learning difficulties which secondary school students encounter with the important topic of photosynthesis. Also, children's intuitive ideas about how plants function had received little attention from science education researchers, despite the fact that intuitive ideas were known to exert a fundamental influence on classroom learning.

Part 1 includes descriptions of interviews and surveys with children who had not been taught about photosynthesis. The children frequently possessed knowledge about a number of, to them, separate functions, i.e. 'plant drinking', 'breathing', growing', 'getting energy', and 'feeding', some of which are anthropomorphic expressions of components of photosynthesis. Not surprisingly, given the extreme biochemical complexity of photosynthesis, they almost never had an intuitive idea that green plants convert carbon dioxide and water into carbohydrates like cellulose (the major part of wood), sugar, starch, etc. and hence store energy as well as producing oxygen.

Part 2 deals with the modification of children's views about how plants function. Three existing strategies for teaching photosynthesis were rejected on the grounds that they either relied on knowledge which students at junior secondary school usually do not possess, or that they failed to take account of students' relevant existing knowledge. The novel strategy proposed uses a constructivistic approach based on the generative learning model of Osborne and Wittrock (1985) and incorporates the research findings of Part 1. The result is a teaching package entitled "Where Does The Wood Come From?" which focusses on the <u>material changes</u> of photosynthesis. The study documents classroom observations made when the package was being taught. Interviews with students (mainly 14-year-olds) before and after teaching also monitor conceptual change.

1.2 PHOTOSYNTHESIS - THREE MAJOR THEMES

Daniel Arnon, a scientist who contributed much to our understanding of photosynthesis, has described the formulation in the early 19th century of what continues to be the basis of our view of the process:

> "Numerous chemical analyses established that plants were made mostly of carbohydrates, whose chemical composition had the proportions of CH_2O, (carbohydrates - such as sugar, starch, and cellulose - are organic compounds composed of carbon, hydrogen, and oxygen). An overall equation for the chemical events in photosynthesis could finally be formulated: carbon dioxide plus water yields carbohydrates and oxygen.
>
> Some decades later, the implications of this equation were recognised. The carbon compounds and oxygen contain more chemical energy than the carbon dioxide and water from which they were formed, and this increase in chemical energy represents converted solar energy. Photosynthesis, it became clear, was a process of energy conversion in which light energy is trapped and converted into chemical energy".
>
> Arnon (1982), p.24-25.

Arnon's description of photosynthesis can be summarised by the definition of Hall and Rao (1981): "By the input of the sun's energy the energy-poor compounds, CO_2 and H_2O, are converted to the energy-rich compounds, carbohydrate and O_2". Arnon then goes on to discuss the wider implications of this process for our planet:

> "Virtually all living cells depend on solar energy, although most can use it only after it has been captured by photosynthesis, the hallmark of green plants. Through photosynthesis, solar energy is transformed and locked into organic compounds that make up more than ninety percent of each plant on Earth, from diatom to cabbage to apple tree. Plants, in turn, make possible all the varied food chains on land and in the waters. At the apex of these chains are higher animals (and human beings) that obtain the transformed solar energy either by eating plants or by eating other animals that feed on plants.
>
> But life's debt to photosynthesis does not end there ... a primitive form of photosynthesis that did *not* produce oxygen began about three billion years ago to change into the form dominant today, in which oxygen is a by-product ...
>
> As oxygen gradually became a permanent part of the atmosphere, it changed the character of life on Earth yet again. Oxygen gas, on absorbing ultraviolet radiation, formed an ozone layer in the stratosphere, shielding the Earth from deadly, short-wavelength solar radiation
>
> In short, all living creatures became dependent on photosynthesis for food, air, and protection from destructive radiation. Humans owe still other debts to photosynthesis, for we use wood and fiber for shelter and warmth and we power our industrial civilization by coal, oil, and natural gas - the ancient fossilized products of photosynthesis from millions of years ago. Photosynthesis thus eminently merits its distinction as the most important biochemical process on Earth".
>
> Arnon (1982), p.22

Two major themes emerge from these descriptions. A <u>biochemical</u> theme addresses the production of materials carbohydrates and a whole range of derived organic compounds like wood, fibre, coal, oil, and natural gas, and an <u>ecological energetic theme</u> addresses the question of solar energy and its transformation.

The present study focusses on classroom teaching and learning. Preliminary informal observations of classrooms and a study of school texts suggested that a third, <u>trophic theme,</u> is also important.

Photosynthesis is seen here as a food-making process. Arnon touches briefly on this theme when he talks of food chains. The trophic theme is, in fact, invariably a component of text-book accounts of photosynthesis in junior secondary school classes (section 6.1.3), and it is the major learning outcome at this level (section 8.2.2), but it should be noted that standard texts on photosynthesis at senior secondary and tertiary levels (e.g. Lehninger, 1975; Bloomfield, 1977; Whatley and Whatley, 1980; Tribe and Whittaker, 1982) make little or no mention of the trophic theme.

Figure 1 shows the relationships between these three themes and some of the questions which the present study discusses. The themes provide a framework for the analysis and presentation of data in chapters 4-8.[1]

1.3 PHOTOSYNTHESIS AND NEW ZEALAND SCIENCE SYLLABI

The concept of photosynthesis is either specified or alluded to in New Zealand science syllabi in use with students of every age from 5 to 17 years.

Although photosynthesis is not mentioned by name in the Primary to Standard Four (ages 5-10) Science Syllabus and Guide (Department of Education, 1978a), the trophic theme is established as one of the ideas on which students' experiences of plants can be based: "Green plants make their own food" (Level 2, 6 to 9 years, p.61). The 'food' is not specified, but trophic interdependence between man, plants and

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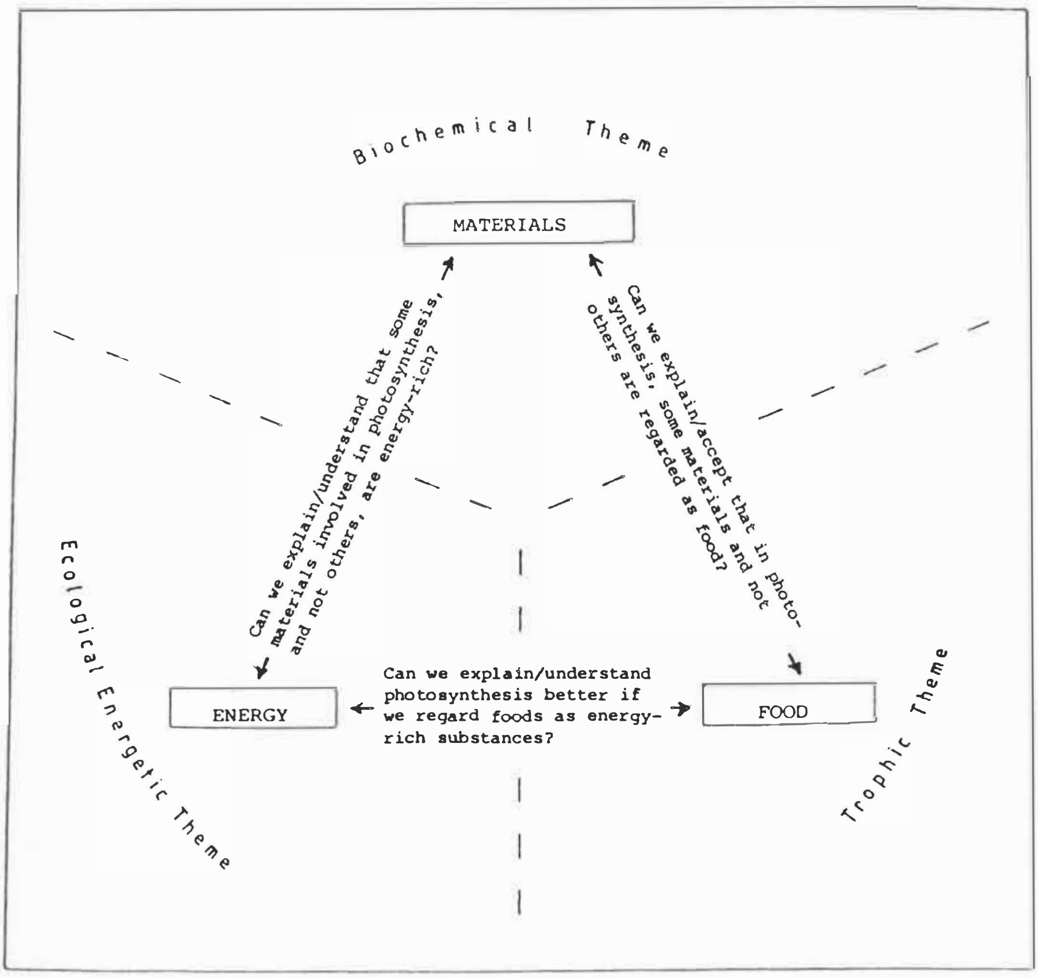
1 This structure was also used to prepare a reading list for teachers (Barker, 1985a).

Figure 1 : Three themes and three key concepts in teaching and learning about photosynthesis.



animals is the basis of six of the other ideas at this level, e.g. "All animals are dependent on green plants for food" (p.60). Older students are also expected to appreciate that "Fungi cannot produce their own food" (Level 3, 8 to 10 years, p.61). Timber and fibres are major topics elsewhere in this syllabus (p.68, 69) but the origin of these materials is not considered, even though photosynthetic requirements are mentioned: "Green plants require air, minerals, water, and light" (Level 1, 5 to 7 years, p.61). This idea is repeated at level 3 where light is now linked to energy: "Green plants convert light energy to chemical energy" (p.61).

The Forms One to Four (ages 11-14) Draft Science Syllabus and Guide (Department of Education, 1978b) highlights the trophic theme. A student in forms one and two (i.e. level 4) should be able to "classify green plants as producers" (p.22) and to "construct food chains of 3 organisms" (p.22) to express trophic interdependence of plants and animals. Photosynthesis is first mentioned by name, and a product material specified, in the content for forms three and four (i.e. level 5), where a student should be able to "describe the process of photosynthesis in simple terms of requirements (water, carbon dioxide, sunlight and chlorophyll) and products (glucose and oxygen)" (p.36). The ability to "relate the structure and arrangement of leaves and leaf cells to the (process) of photosynthesis ..." (p.36) is also an objective at this level. The concept of energy is prominent in this syllabus (p.34, 42), but energy is mentioned only once in connection with plants, in the context of community organisation rather than photosynthesis, i.e. a student should be able to "recognise that food chains represent the flow of energy through the community" (p.33).

The format and content of the School Certificate Science Prescription (1982) suggest a number of changes of emphasis in the treatment of photosynthesis at form five level (i.e. 15-year-olds). The topic is included under the heading 'Plants and Energy' and this section "aims to develop an understanding of how plants capture, store and release energy". An understanding of "the complementary nature of photosynthesis and respiration" is expected. Starch, not glucose, is now identified as the organic product. This, together with the expectation that "candidates will have carried out their own investigations", implies that the starch-iodine chemical test and an understanding of experimental controls are now expected. Indeed, the examination questions frequently invoke these skills. The School Certificate Biology Prescription (1978) has "photosynthesis and the carbon cycle : natural stores of sources of energy" as a topic. The School Certificate Horticulture Prescription (1984) specifies "plant nutrition - the intake and transport of essential elements from air, water, and soil..." but does not mention photosynthesis by name.

The University Entrance Biology Prescription (1976) for use in form six (16-year-olds) explores the energy theme but warns against teaching excessive biochemical detail: "Energy transformation in cells. The processes of respiration and photosynthesis explained with no more chemistry than is necessary to understand energy transformations in cells". Topics in the 'Ecological Principles' section are: "biogeochemical cycles contrasted with energy flow, food chains, pyramids of numbers, biomass and energy". The Biology prescription for University Bursaries and Entrance Scholarship Examinations (1970) implies that seventh formers (17-year-olds) should revise these topics. Photosynthesis is not mentioned by name.

In summary, these syllabi suggest an initial approach to photosynthesis through the trophic theme, followed by a consideration of the biochemical theme, and leading to a discussion of the ecological energetic theme.

1.4 PHOTOSYNTHESIS - LEARNING DIFFICULTIES

Published research, examiners' reports, comments from practising teachers, and students' responses all provide evidence that photosynthesis is a difficult topic for students. This section identifies some of these difficulties. Issues which relate photosynthesis to other topics are discussed, followed by an account of difficulties within the topic.

Two research studies rank the perceived difficulty of photosynthesis relative to other topics in biology. Finley, Stewart and Yarroch (1982) report on the responses of 100 randomly selected teachers in Wisconsin. The teachers were required to rank 15 biology topics which had been selected by the researchers from an initial list of 50 topics. Photosynthesis was ranked first in terms of importance and sixth in terms of difficulty. The five topics considered to be even more difficult than photosynthesis all had a strong component of biochemistry and/or genetics. This finding is supported by the work of Johnstone and Mahmood (1980), who used an index of perceived difficulty to investigate perceptions of photosynthesis relative to 14 other topics in the biology syllabus of the Scottish Certificate of Education Examination Board. They found that Scottish first year undergraduates, sixth form pupils, and teachers all ranked energy conversion in photosynthesis, respiration, ATP and ADP among the first four most difficult topics.

A number of workers report that students have difficulty relating photosynthesis to other topics where energy is involved. Brumby (1982), who investigated perceptions of the concept of life held by first year biology students at a British university, considered that "most students had not integrated their learning of photosynthesis, food chains and nutrition into an understanding of energy flow in the biosphere". Barrass (1984) suggests that many students in the United Kingdom who have achieved passes in external examinations in biology believe that respiration occurs in animals and photosynthesis occurs in plants, and that green plants photosynthesize in sunlight and respire at night. A New Zealand examiner's report (University Entrance Board, 1984) echoes this finding and also comments that only 4% of candidates who wrote an essay concerning photosynthesis and respiration as processes involving energy transfer in a cell gained a mark of 60% or better for that question. Stavy, Eisen and Yaakobi (1985) report that junior high school students in Israel often perceive photosynthesis as a type of respiration. A different type of integration problem has been found by Driver *et al.* (1983) who, in a study of British 15-year-olds' understanding of the topic 'air' (including gaseous exchange) report that students rarely connect plant gaseous exchange and growth.

Misconceptions in the area of chemistry may undermine learning in photosynthesis. Stavy, Eisen and Yaakobi (1985) cite misconceptions about elements, compounds, and the synthesis and analysis of compounds, and Mitchell and Gunstone (1984) discuss problems with conservation of matter. The latter researchers investigated the conceptions which 15-year-old Australian chemistry pupils had about stoichiometry. They gave 17 pupils (who had recently been taught about the atomic view of matter) a written item concerning possible changes in mass and numbers of atoms for a tree which had been growing in a sealed container for three years. Thirteen pupils considered that the total mass of the system and the number of atoms had both increased. Mitchell and Gunstone also found pupils using a non-conserving view of energy when discussing the equation for photosynthesis.

Difficulties within the topic photosynthesis have also been reported. Teachers often provide excessive biochemical detail when teaching photosynthesis (Auckland Regional Department of Education, 1982). Kirkwood[2] (personal communication) interviewed two experienced secondary school teachers who expressed misgivings about their own teaching of the energetics of photosynthesis. One commented:

> *At form six biology we're talking about energy relationships when we do photosynthesis. For instance, we're talking about sunlight energy and we talk of photons ... but I expect them to realise 'right, this is a photon, it's a quantum of energy, a packet of energy'. Hell's teeth, actually, the more you think about it you can see that the sixth forms don't understand a word. They haven't got that foundation. The coupling of energy to a molecule to link to another phosphate bond ... so that the energy that was there is now between those two atoms basically. That's a bit abstract for a sixth former, isn't it, but that's how to approach it. And then I say 'The electron is excited' and that must drive them nuts too, actually.*

The second teacher said:

> *Now there's been a lot of talk about what detail you go into about the biochemical pathways of photosynthesis, and really it's come down to the fact that the kids just simply have to appreciate that the energy is used to pull electrons off and hydrogens off and, um, pass it along a whole series of, um, molecules and it comes out their far end, all built up into a big one. But somewhere along the line they've got to get the idea that the, the electrons that have got excited by the light is what gives it the energy to keep going. So you <u>do</u> talk about excited electrons but what their concept is in their heads when you talk about excited electron ....! Um, you see, you use phrases ... to you they mean something and in the text books they always show them with an e with a little bit of zig-zaggy*

2 Interviews conducted as part of the Learning in Science (Energy) Project, Science Education Research Unit, University of Waikato, 1986)

> *stuff on them. And, I mean, what's the kids' picture behind their heads when they see e's with zig-zags on them?*

Experiments such as the starch-iodine test, which are invariably suggested in biology texts, also pose problems for pupils. Wood-Robinson (1984) notes that quite untenable conclusions are frequently drawn from these experiments. Difficulties with a further aspect, understanding experimental controls, are also noted in two examiners' reports: "Most candidates found the task of formulating an hypothesis and identifying a variable to suggest a control for experiments, beyond them" (School Certificate Examiner's Report in Biological Sciences, Department of Education, 1984). The University Entrance Board (1984) examiner's report states that only 12% of 16-year-olds correctly answered a multi-choice question involving the graphical representation of a controlled experiment to determine photosynthetic rate. This was the lowest percentage correct for any of the 30 multi-choice questions. Students' difficulties with the starch-iodine test and experimental controls are discussed further in section 10.3.1.

The important study of Bell (1985) encompasses many issues discussed so far. Two classes of students (14-year-olds) in England, being taught photosynthesis in a traditional manner by experienced teachers, were studied using classroom observations and individualised interviews. Bell reports that a number of factors appeared to impede learning:

- children's initial understandings about plants were never exposed or addressed.
- practical activities often failed to help students construct the 'right answer' but instead lead to confusion.
- the intended meanings of terms and concepts like 'food', 'energy change', 'synthesis', and so on, were never appreciated by students.

In summary, this section has suggested that students have difficulty relating photosynthesis to other topics such as respiration, energy flow, food chains, and growth, and their understandings are sometimes inconsistent with the conservation of materials and energy. Within the topic, accommodating excessive biochemical detail and coping with unfamiliar experimental situations also create learning difficulties.

Some of these confusions are apparent in the following four quotations from a pilot study of a class of 30 third formers who were invited to write a paragraph entitled "What Is Photosynthesis?":

Plants produce food by mixing chlorophyll with iodine to make a black substance called starch. (David, 13 years)

If plants are lucky enough to get CO_2 *and water that makes chloroyll (excuse spelling) which helps a plant quite a bit. Plants also make something we need. Out of their sugar intake they make starch.* (Rachael, 13 years)

Plants get their food from the soil, sun, etc. The food from the sun is more like a form called photosynthesis. (Lawrence, 13 years)

Roots are like mouths and they suck up matter from the ground and store it in the winter months so they can use it straight away. This process is called photosynthesis meaning photo - light synthesis - taking. (Marama, 12 years)

CHAPTER 2 ; PHOTOSYNTHESIS AND LEARNING THEORY

> *... logically meaningful material is always, and can only be, learned in relation to a previously learned background of related concepts, principles, and information which make possible the emergence of new meanings and enhance their retention.*
>
> (David Ausubel, 1968, p.128)

2.1 A REVIEW OF THEORIES OF LEARNING

The relative importance of ones "previously learned background" in influencing new learning is a key point of disagreement between the various traditions in cognitive psychology. Driver (1982) distinguishes three traditions which have influenced science education - developmental psychology, behaviourist, and constructivist psychology. According to Bell (1984), each of these traditions differs in its perspective of the learner's existing knowledge.

The developmental psychology tradition assumes that learning will be restricted by age-related cognitive development rather than by experience-related factors, i.e. existing knowledge. When this tradition is applied to science education, Piaget's stage theory of cognitive growth has been used as a criterion in the selection of appropriate classroom experiences and cognitive objectives, e.g. Shayer and Adey (1981). However, Driver (1978, 1983a) has suggested that other criteria may be more relevant.

The behaviourist tradition gives maximum attention to immediate external stimuli in instructional sequences and does not take into account the learner's existing knowledge. Instead, it assumes that increasingly complex sets of behaviour and skills can be built up through carefully constructed instructional programmes, e.g. Gagné (1970).

The constructivist psychology tradition asserts that a learner's existing knowledge is an essential component in learning. New meanings and understandings are always the outcome of a process of active cognitive construction, and they result from the interaction of a person s sense experience and existing knowledge (Kelly, 1955; Ausubel, 1968). The present study lies within this tradition.

The constructivist psychology tradition is manifest in a variety of disciplines, for example, in the area of reading comprehension where the existing ideas are referred to as 'schemata' or 'frames'. In science education the existing ideas have been variously labelled 'preconceptions', e.g. Smith and Anderson (1983), 'misconceptions', e.g. Helm and Novak (1983), 'intuitive theories', e.g. McCloskey (1983), 'alternative frameworks', e.g. Driver and Easley (1978), 'children's science', e.g. Gilbert, Osborne and Fensham (1982), and so on. Science educators see themselves as 'probing prior knowledge' (White, 1982) 'exploring students' views of the world' (Osborne and Gilbert, 1980a), or 'investigating layman's science' (Shanon, 1976). All of these approaches compare and contrast existing ideas with the consensual view of the scientific community, although they accord varying status to the existing ideas. The possible origins of these existing ideas have also been discussed (Osborne and Gilbert, 1980b; Sutton and West, 1982; Claxton, 1983; Driver and Erickson, 1983). For example, Claxton contrasts 'gut science (which manifests itself in spontaneous reactions and intuitive physical judgements) and 'lay science' (which is based on the everyday use of language and media images) with 'school science which derives from the symbolic and idealised world of the classroom.

The constructivist tradition is central to the generative learning model of Osborne and Wittrock (1985). This model has as its fundamental premise that "people tend to generate perceptions and meanings that are consistent with their prior learning. These perceptions and meanings are additional both to the stimuli and the learner's existing knowledge". The model claims to have implications for achieving conceptual change in classrooms, and Part 2 of the present study investigates this claim in the area of teaching and learning about photosynthesis.

2.2 ALTERNATIVE CONCEPTUAL FRAMEWORKS IN BIOLOGY

Children's existing ideas in chemistry, physics and biology have most frequently been referred to as 'alternative conceptual frameworks'. These frameworks have been reviewed by Gilbert and Watts (1983), Happs (1983), and Osborne and Freyberg (1985). This section briefly describes the relatively smaller number of studies in biology, which can be grouped into three content areas: taxonomy, growth and reproduction, and physiology.

Taxonomic studies have focussed on children's meanings for the terms most commonly used in broad classifications of the natural world. The concept of 'living' has been studied by Stead (1980a), Angus (1981), Tamir *et al.* (1981) and Brumby (1982). The work of Stead (1980c), which studied children's meanings for the term 'animal', drew on earlier work by Ryman (1974) and Boekaerts (1979), and was followed by Bell and Barker (1982). This latter research is the only case where a study mentioned in this section (Stead, 1980c) has been followed by classroom investigations into conceptual change, i.e. the modification of children's existing ideas. Stead (1980d) has also studied children's ideas about the concept of 'plant'.

Okeke and Wood-Robinson (1980) have investigated children's ideas about reproduction. This study also includes findings about growth, as does that of Schaefer (1979). Studies in the area of genetics (Kargbo, Hobbs and Erickson, 1980; Longden, 1982) and natural selection (Deadman and Kelly, 1978; Brumby, 1979) have also been carried out.

The area of physiology has received little attention, presumably because of the extreme conceptual complexity involved. When the present study was initiated no work was available into children's intuitive understandings about photosynthesis or animal nutrition, although Arnold and Simpson (1978) had contrasted children's and teachers' understandings of the term 'food'. Work which has been proceeding concurrently with the present study is discussed in the next section.

2.3 ALTERNATIVE CONCEPTUAL FRAMEWORKS IN PHOTOSYNTHESIS

Three studies on photosynthesis have been conceived in other than the constructivist tradition. Shayer (1974), working within the tradition of developmental psychology, described the cognitive demands of each sub-topic in the Nuffield O-level biology course, including photosynthesis. Having determined the facility which children of varying I.Q. have in working at the Piagetian level of concrete or formal stages of operation, the match between sub-topics like photosynthesis and these developmental stages was considered. Using the same model of cognitive stages, Gaskell (1973) proposed a sequence of topics, from the pre-operational to the formal level, leading towards photosynthesis. The study of Simpson and Arnold (1982a) lies basically within the behaviourist tradition. They produced a concept map for photosynthesis and researched children's views of four topics which they described as prerequisites for photosynthesis, i.e. 'living', 'food', 'gases' and 'energy'.

The four studies on children's existing ideas about photosynthesis within the constructivist tradition have largely focussed on the trophic theme (refer section 1.2). Simpson and Arnold (1982b), who used individual interviews and an open-ended written test with students aged 11-16 years in Scotland, found that the most erroneous idea which pupils of all ages had was that plants obtain their food through their roots. The pupils still held this view after teaching despite the fact that their teachers believed that the idea that 'plants make their own food' was relatively easy for pupils to follow. Simpson and Arnold also found that the role of chlorophyll in photosynthesis was poorly understood.

Roth, Smith and Anderson (1983) used a number of written diagnostic tests to investigate the 'misconceptions' held by 10-year-old students in Michigan before and after an eight week instructional period. They formulated a distinction between factual level and deeper level misconceptions. In the former category they noted that, after instruction, "about 80% of the students shared (the) belief that plants take in their food, most indicating soil as a source (72%), but some indicating water (25%) and air (5%) as additional or alternative sources". The inappropriate use of analogy was considered to be a possible source of these views: "Using an everyday definition of food and ... analogical reasoning rather than trying to deduce functions, students felt ... that plants, like people, can have multiple sources of food and that food is anything that plants need 'to live'". The authors saw the students' lack of thinking about internal processes as deeper level misconceptions. For example, the students made a simple direct link between a needed substance (light) and an observable effect (growth) and they did not seek out an interposed biological function. This caused them to overlook the significance of teaching about photosynthesis.

Wandersee (1983) gave a written diagnostic test comprising 12 tasks (experiments, phenomena, and situations) to American students from fifth grade through to college level. The tasks concerned a variety of subconcepts relating to photosynthesis and they exposed 31 'misconceptions'. Incorrect ideas about the definition and origin of food for plants were predominant, although 'misconceptions' about the functions of minerals, leaves, and chlorophyll were also noted.

The study of Bell and Brook (1984), whose conclusions were based on written and interview responses given by 15-year-old biology and non-biology students in England, generally substantiate the findings of the other three studies in the constructivist tradition. Bell and Brook highlight the fact that students may have alternative meanings for such scientific words as 'chlorophyll' as well as common words such as 'food', and that the students "appeared not to have linked together in a meaningful and in a scientifically acceptable way, the different aspects of plant functioning that they had learnt about."

Further and more detailed findings from these four studies are to be found in chapters 4, 5 and 6. Research which utilises children's views about plants and food as a basis for achieving conceptual change are described and evaluated in section 10.3.3.

In summary, no single conceptual framework, alternative to photosynthesis, is described in these studies. However, before teaching, children do possess views about plant activities and structures which can be related to photosynthesis. The present study refers to this collection of existing views as 'plant nutrition'.

2.4 THE RESEARCH DESIGN

Part 1 of the research was designed to provide a description of children's theories and explanations about plant nutrition, that is, about how and why plants utilise resources in their environment (water, air, soil, sunshine, etc.) and how these processes relate to the obvious physical features of plants (roots, branches, wood, leaves, etc.). These descriptions of plant processes were provided by pupils who had been taught about the topic of photosynthesis and also others who had not. Part 1 comprised two phases.

Phase I was qualitative in nature and comprised interviews with 28 pupils of age 8 - 17 years. The interviews were designed to elicit discussion about simple, natural situations involving growing plants. The analysis of the interviews was designed not so much to establish alternative conceptual frameworks but to document pupils' views about the presence or absence of functional links between environmental resources and the physical features of plants. The interviews are the indispensable basis of Part 1.

In Phase II, the quantitative surveys, certain commonly held views were selected from the Phase I data and used to prepare written tasks of various types. Nearly 6,000 of these tasks were completed by students aged 10-18 years. These surveys each functioned as separate probes, acting as a check on the reliability of certain of the findings in Phase I and also providing a measure of the relative extent to which views were present in the student community at large.

Part 2 of the research, which comprises Phase III, concerns the modification of children's views of plant nutrition. Part 2 utilises the findings of Part 1 in the devising and evaluating of a classroom strategy for teaching and learning about photosynthesis. Within the constructivist tradition, the strategy selects significant elements of children's cognitive structure and assists students to use these aspects of existing knowledge to build up a preliminary concept of photosynthesis which is consistent with the scientists' concept.

Throughout this research, meanings and understandings from various sources are exposed and interact. The terminology of Gilbert, Osborne and Fensham (1982) has been used as a means of identifying these sources. Thus:

Children's science refers to "those views of the natural world and the meanings for scientific words held by children before formal science teaching". This term was selected because the present research arose from a considerable body of earlier work at Waikato University (Freyberg and Osborne, 1982; Osborne and Biddulph, 1985) which employed the term.

Scientists' science refers to "the consensual scientific view of the world and meaning for words".

Teacher's science refers to "the viewpoint presented by the teacher to the pupil". Ideally, the view of science presented to children by the teacher will relate closely to scientists' science. Interaction between the teacher's science view and the science curriculum and its materials during preparation for teaching may or may not modify this view in the direction of scientists' science.

PART 1:

THE DESCRIPTION OF CHILDREN'S VIEWS

OF PLANT NUTRITION

CHAPTER 3 METHODOLOGY

If we are really serious about education, we must have precise ways both of measuring learning outcomes in individual students and of ascertaining whether they are consonant with our educational objectives.

(David Ausubel, 1968, p.565)

3.1 INTRODUCTION - NATURALISTIC AND PSYCHOMETRIC RESEARCH

Interviews are now widely accepted as part of the science education researcher's methodology (White, 1979; Sutton 1980a; Sutton and West, 1982). Because they are a means of generating detailed descriptive data from a smaller number of pupils, interviews are an essential feature of naturalistic research. Bell (1984) suggests three advantages for naturalistic research:

(1) It helps us to understand the mechanisms underlying cognition, rather than merely making predictions, as offered by quantitative (i.e. psychometric) research.

(2) The interactive nature of the interview provides an opportunity for the researcher to check her or his tentative interpretations of the subject's responses.

(3) Data collection can be undertaken in natural (i.e. everyday) situations and is not confined to the science classroom.

However, Pope and Denicolo (1984) consider that a conflict frequently exists. Naturalistic methods more faithfully elucidate the complexity and fluidity of cognitive structure, but psychometric methods (which generate quantitative data on selected parameters from larger numbers of pupils) are more appropriate if the objective is dissemination of tidy, tabulated results which will be perceived as having practical classroom utility. The present study, with its ultimate goal of classroom utility, adopted a combination of qualitative and quantitative approaches. Freyberg and Osborne (1982) and Carr (1985) report on the advantages in using this strategy.

Phase I, the interviews, proceeded on a grounded theory approach (Glaser and Strauss, 1967), i.e. with no pre-planned programme of categories for data analysis. The organisation of interview data into three broad categories (i.e. chapters 4, 5 and 6) emerged later and after independent validation. These categories were held to be consistent with naive cognitive structure (chapter 7) The findings of Phase II, the quantitative surveys, were interwoven with the presentation of the Phase I findings in chapters 4, 5 and 6. These survey data, often from large numbers of students over a wide age range, resulted in figures and graphs which emphasized key points from the interviews. This was especially useful in providing feedback to practising teachers during the research, reinforcing their sense of involvement once data-collecting had finished, and encouraging them to participate in Phase III.

3.2 PHASE I, QUALITATIVE RESEARCH - THE INTERVIEWS

3.2.1 The Interview Schedule

The interview schedule was structured along the lines suggested by Osborne (1980). Questions about photosynthesis, as such, were held back until later in the interview in order to make the schedule appropriate for pupils who were not familiar with the term, and to investigate whether or not those who had been exposed to the concept of photosynthesis made use of it in their responses to the earlier questions. It was possible to re-open some of the earlier questions if an interviewee had to be reminded of photosynthesis. The interview schedule (Figure 2) was used in conjunction with seven stimulus items, designated A to G (Figures 3-5, 8-11). The stimulus items were successively introduced to the pupil (for example, see '+A Foods' in Figure 2) and removed at a later point (for example, '-A').

Stimulus item A (Figure 3) comprised a deck of 12 cards on which were written the names of possible foods. These were progressively revealed to the pupil who placed each in turn in one of two columns under heading cards, 'FOOD' and 'NOT FOOD'.

Stimulus item B (Figure 4) was a printed sheet of 10 examples for pupils to categorise.

Stimulus item C (Figure 5) was a printed sheet and a number of small cards on which pupils could write the names of "anything that goes into or comes out of a plant". Small red arrows were provided which pupils could move around on the stimulus item sheet. The way the pupil used the arrow(s) to describe the movement of each substance was noted on a record sheet (Figure 6). Pupils chose to use the arrows in two ways. Sometimes a single arrow would be moved through a series of static positions (Figure 7). The interviewer noted these on the record sheet, joining each successive position with looped lines. On other occasions, a single arrow was moved slowly and continuously. This was recorded as a series of smaller arrow-heads. Later, the card on which the pupil had written the name of the substance under question was stuck onto the record sheet.

Figure 2 : The interview schedule.

Interview Schedule

Instruments

Phase I : The child's meanings for words (Osborne, 1980)

+A Foods	1.	I'm interested to find out your ideas about food. Let's look at some things and see whether they are food or not... Is (sugar) a food ?... What tells you that ?... Could it be a food ?
		O.K. Let's put (sugar) in the (food / not food) pile.
-A	2.	Can you tell me why all these ones are food, and all these ones aren't food ?
+B Examples	3.	Now let's look at these. Can you tell me which ones are the animals ? Which ones are the plants ? What tells you that ? What about the rest ? Which ones are the green plants ?

Phase II : The child's model of how things behave as they do

-B	4.	Let's think about food again. Does a (person) need food ? How does a (person) get its food ?
+C Plant	5.	Here's another picture. Can you tell me about it ?
-C	6.	Let's use the picture to talk about anything that goes into or comes out of a plant. We can write the names of things on these blank cards here, and we can use these arrows to show where things go. Can you think of something which a plant needs ? ... Well, write it on the card and show me where it goes with the arrows.
+D Boy/Tree/Sun	7.	Here's another picture. What's happening in this picture ?
	8.	What happens to a boy when he stands outside in the sunshine ?
	9.	And the tree ? What happens to a tree standing outside in the sunshine ?
-D	10.	Do the boy and the tree both need the sunshine ? What do they need sunshine for ?
+E Growing Plant	11.	Let's think about this picture now. What does it tell us ?
	12.	How did the plant increase in size over the five years ?
-E	13.	Where does the stuff that the tree is made of come from ?

Phase III (Part A) : The child's understanding of the scientist's view

	14.	A kid the other day told me that all life depends on the sun. Do you believe that ?
	15.	Do you know what happens to the sunlight when it reaches a plant ?
	16.	Would you say that plants can move ? Why do you think this is so ?
	17.	Why does a plant have leaves ?
	18.	What is the most common colour for leaves ? Why do you think this is so ?
+B Examples	19.	Could you say that any of these can make their own food ?
-B	20.	Could you say in a sentence or two what the word 'energy' means to you ?
+D Boy/Tree/Sun	21.	Let's go back to this picture. Is there any energy in this picture ?
-D	22.	A kid once told me that the world will run out of air in the end because of all the animals breathing the air in. Do you believe that ?

Phase IV : The child's outlook on science

	23.	Do you think that boys or girls like working with plants best ?
	24.	Have you got any favourite animals or plants around home ?
(+F Small Plants (+G Small Animals	25.	Which of these two books do you think (you/little kids) would like to work with the most ?
-F, -G	26.	Can you say whether plants or animals are more important ?
	27.	What do you think would happen to the world if plants only grew half as fast as they do ?

Phase III (Part B) : The child's understanding of the scientist's view

	28.	Do you know what "photosynthesis" means ?
+B Examples -B	29.	Have any of these pictures got anything to do with photosynthesis ?

Figure 3 : Stimulus item A, 'Foods'.
(Figures 3 and 4 are shown half actual size)

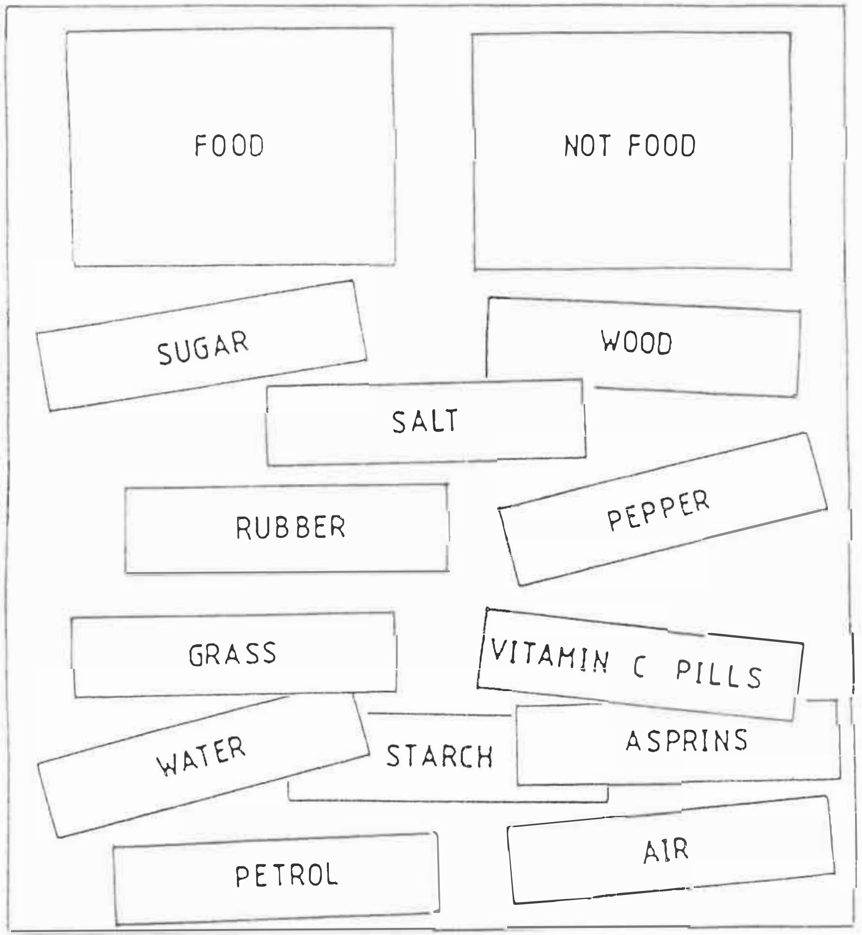


Figure 4 Stimulus item B, 'Examples'.

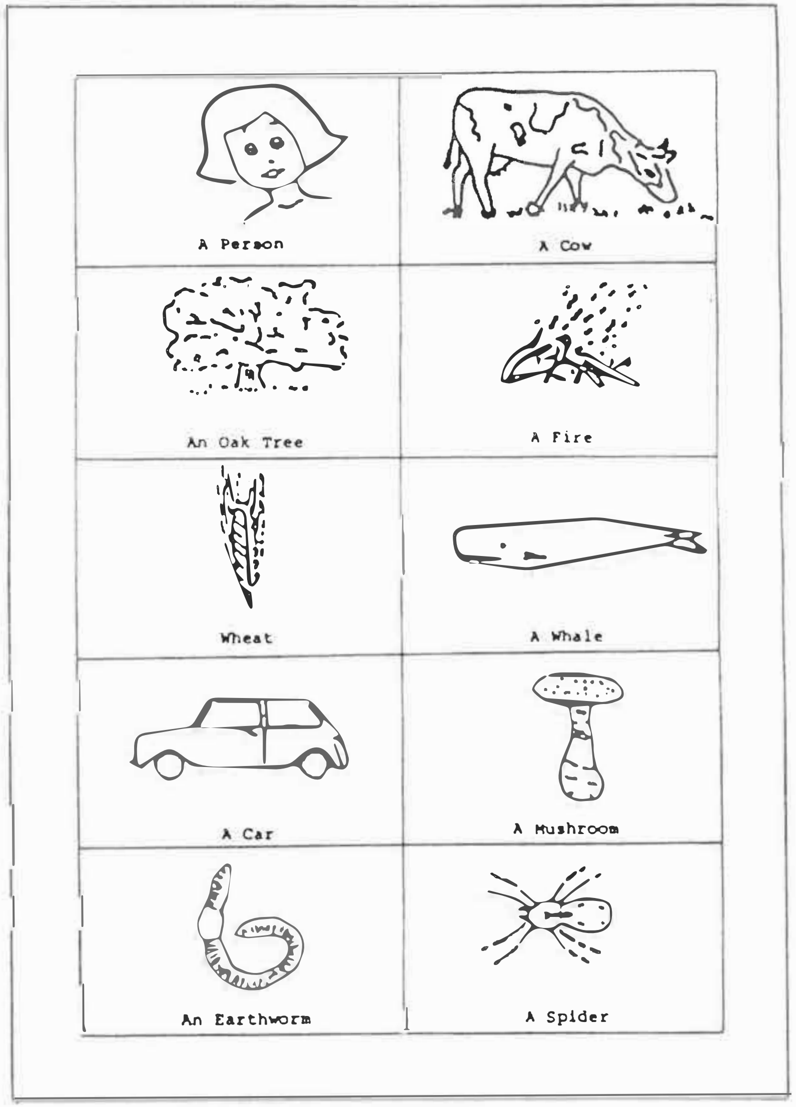


Figure 5 : Stimulus item C,'Plant'. (Samples of the arrows and cards used with the item are shown below.)

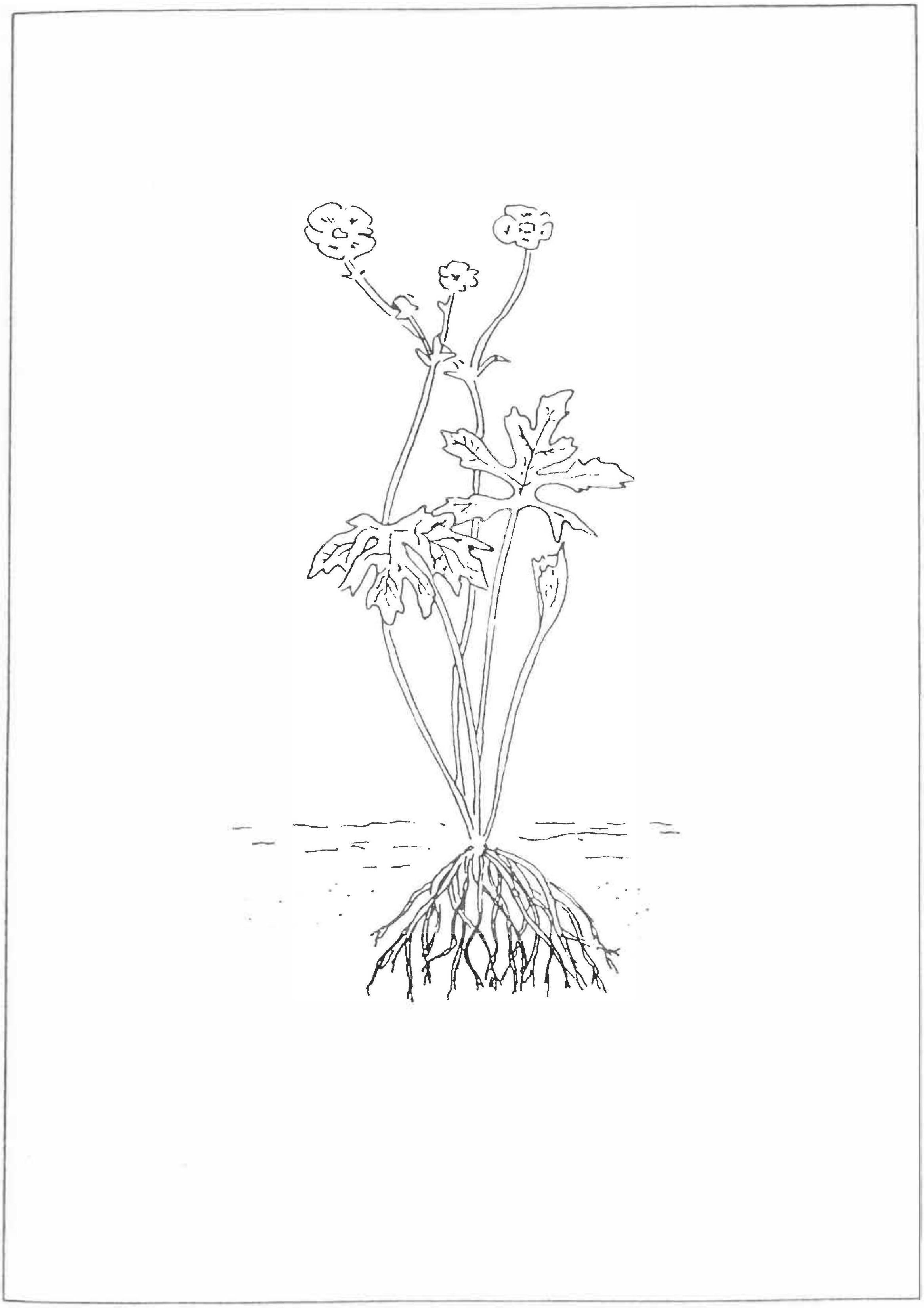


Figure 6 : The record sheet (one quarter actual size).

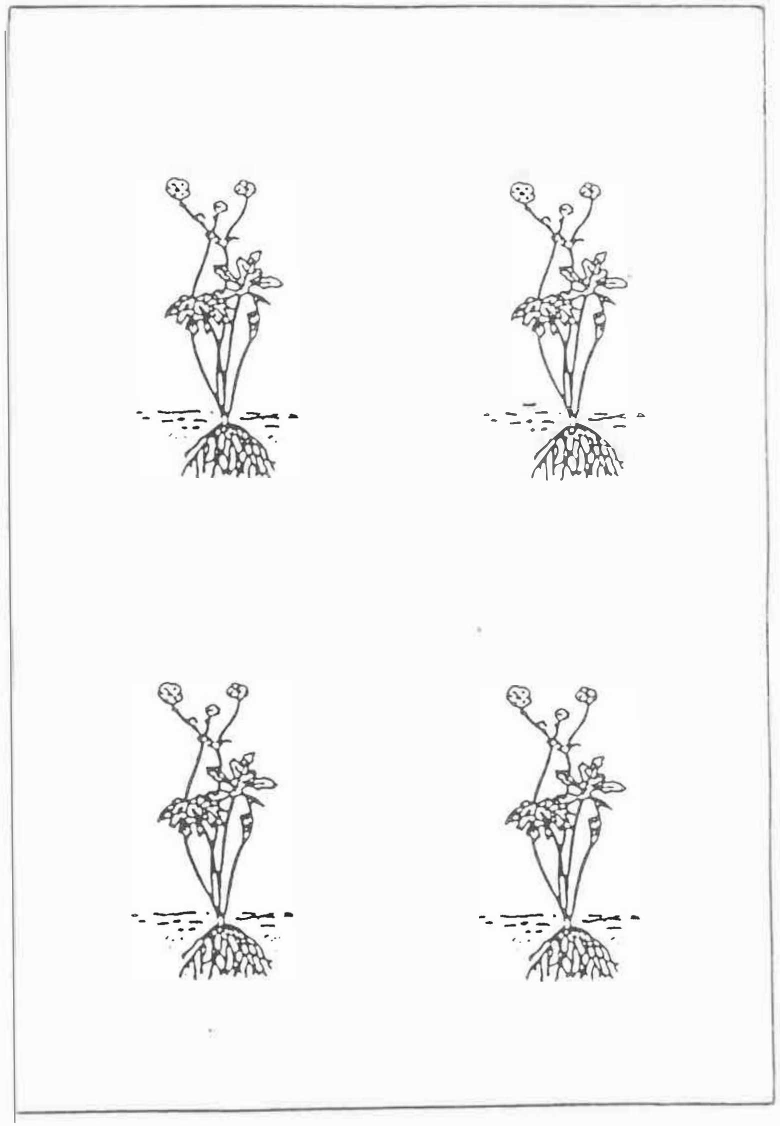
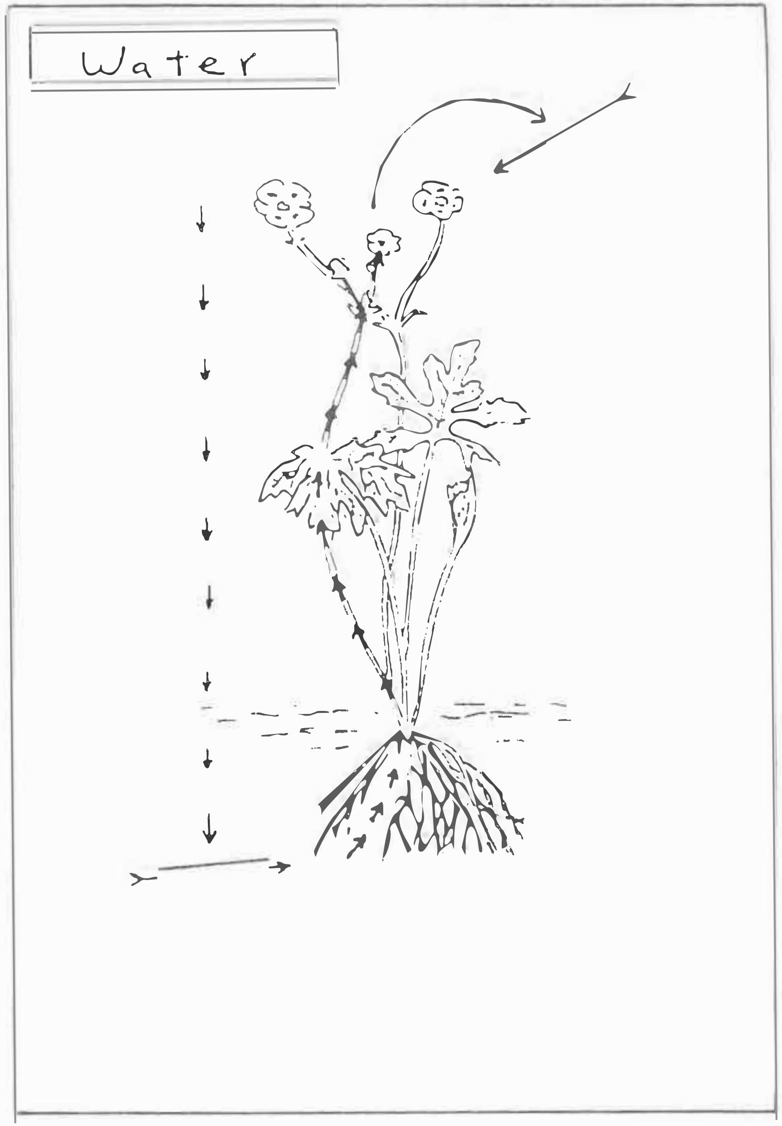


Figure 7 : Using the record sheet. (Figures 7 to 19 are shown half actual size.)



Stimulus items D (Figure 8) and E (Figure 9) were printed sheets.

Stimulus items F (Figure 10) and G (Figure 11) were two booklets designed for use with children of age 5-7 years (Anon, 1980a) and age 7-9 years (Anon, 1980b).

Stimulus items A and B were examples of the interview-about-instances (Osborne and Gilbert, 1980a), and stimulus items D and E were a form of the interview-about-events (Osborne and Cosgrove, 1983). Stimulus item C was an innovation which gave pupils the chance to nominate the environmental factors which they considered to be important to plants and to describe their movement. This item generated more useful data than any other.

3.2.2 The Interview Sample

Twenty-eight pupils (14 boys and 14 girls), ranging in age from 8 to 17 years, were interviewed. Ten pupils were younger than secondary school age, i.e. a boy and a girl of each age from 8 to 12 years inclusive. Quotations from these pupils are identified by a number giving the pupil's age and a letter, B or G, for 'boy' or 'girl', thus '11B' is the 11-year-old boy. The 18 secondary school pupils comprised two 13-year-olds and four 14, 15, 16 and 17-year-olds, again with equal numbers of boys and girls at each age level. A subscript was used to distinguish quotations from the two pupils of the same age and sex, thus '$16G_2$' refers to one of the two 16-year-old girls. Except for pupil 13G, all the secondary school pupils had been taught about photosynthesis (referred to an 'post-teach'), as opposed to the younger pupils who had not met the topic in the classroom (referred to as 'pre-teach').

Figure 8 : Stimulus item D, 'Boy/Tree/Sun'.

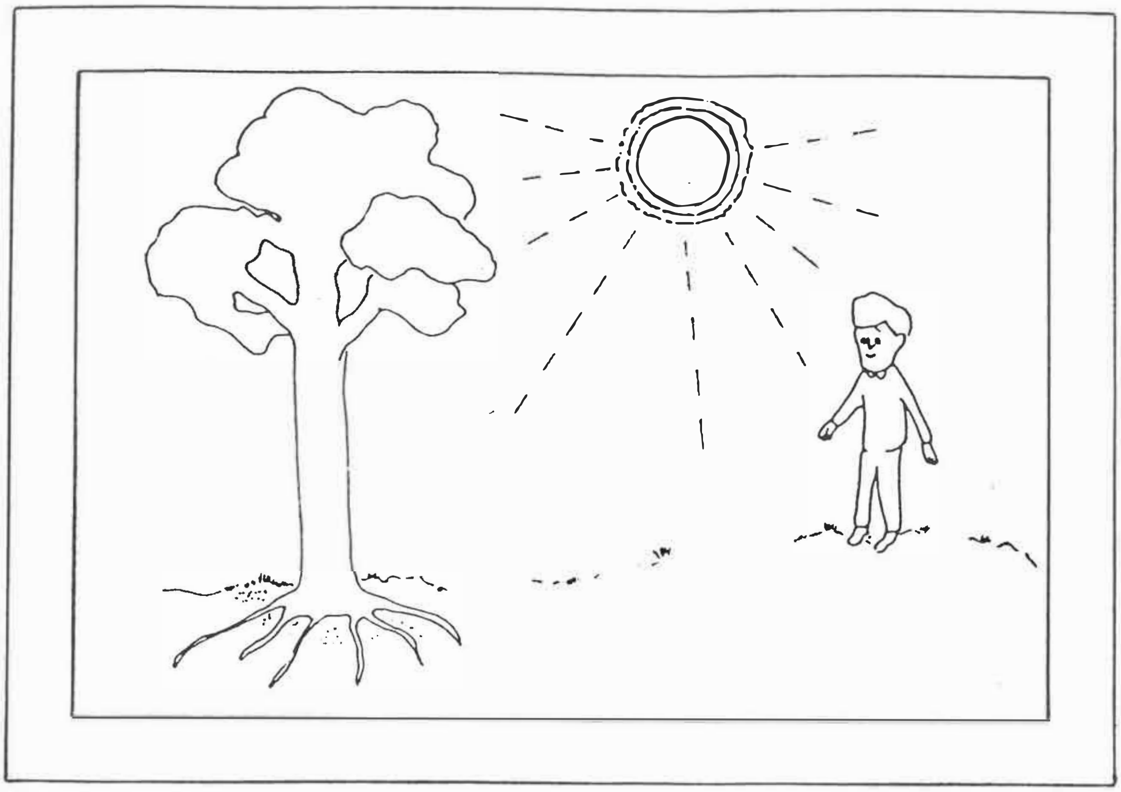


Figure 9 : Stimulus item E, 'Growing Plant'.

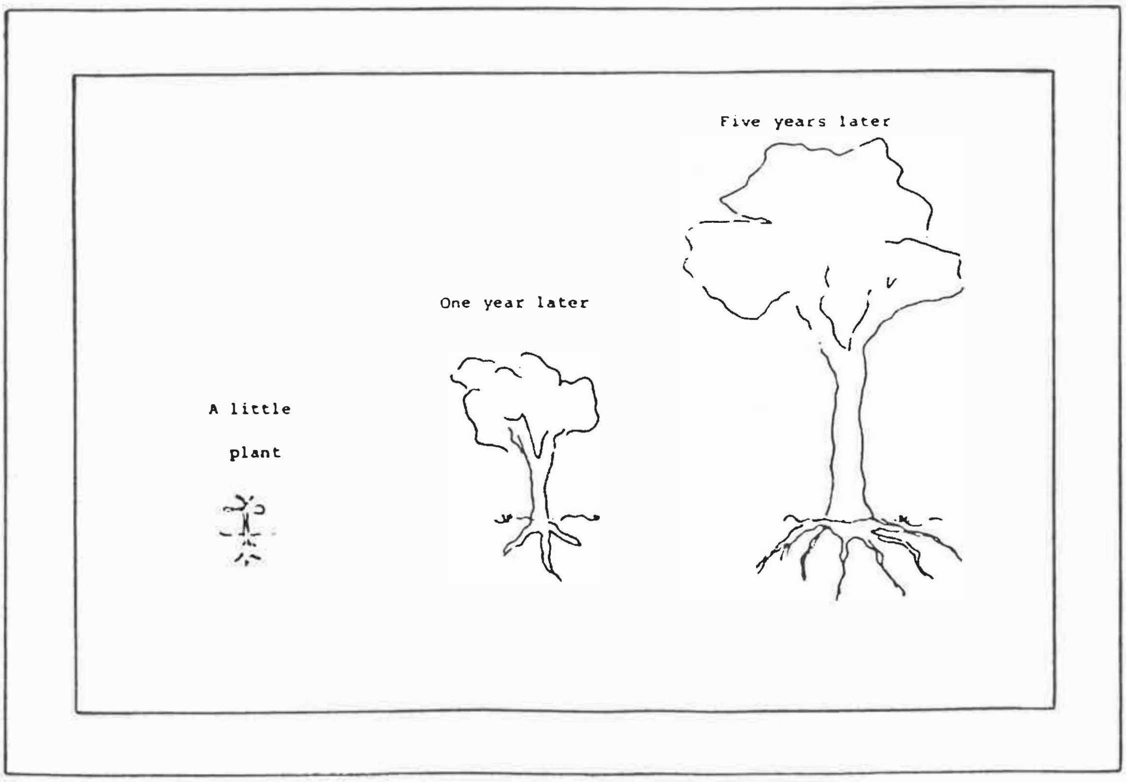


Figure 10 : Stimulus item F, 'Small Plants'.

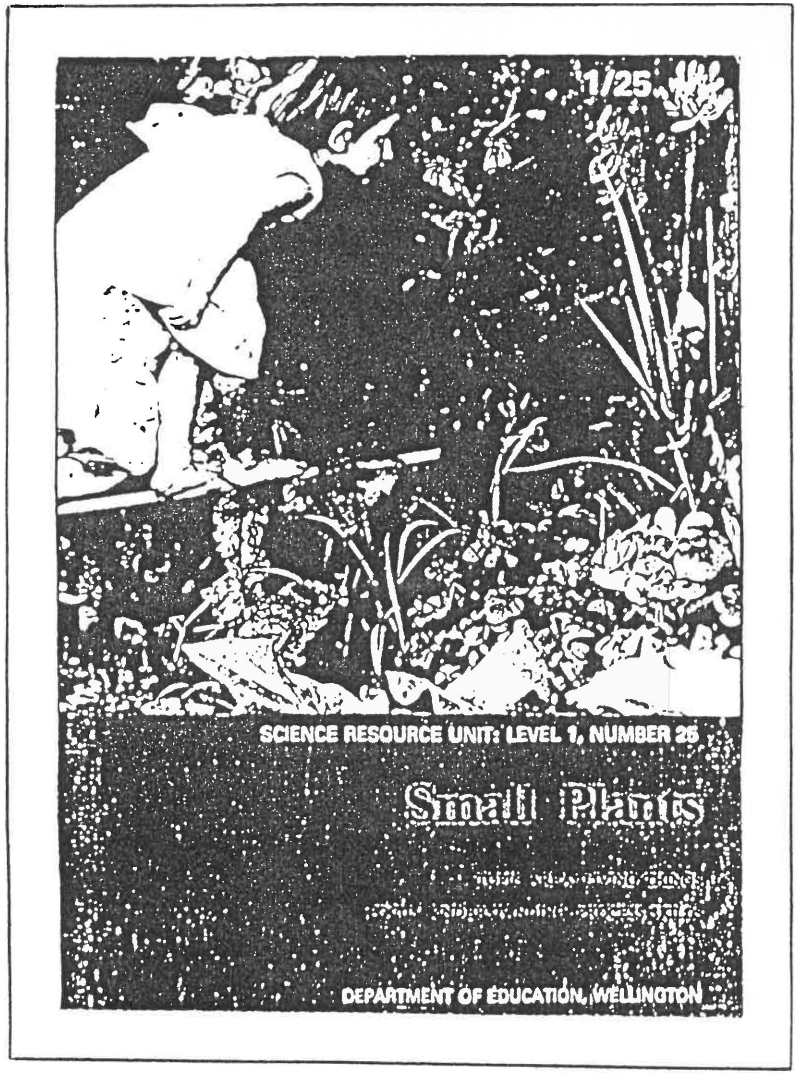
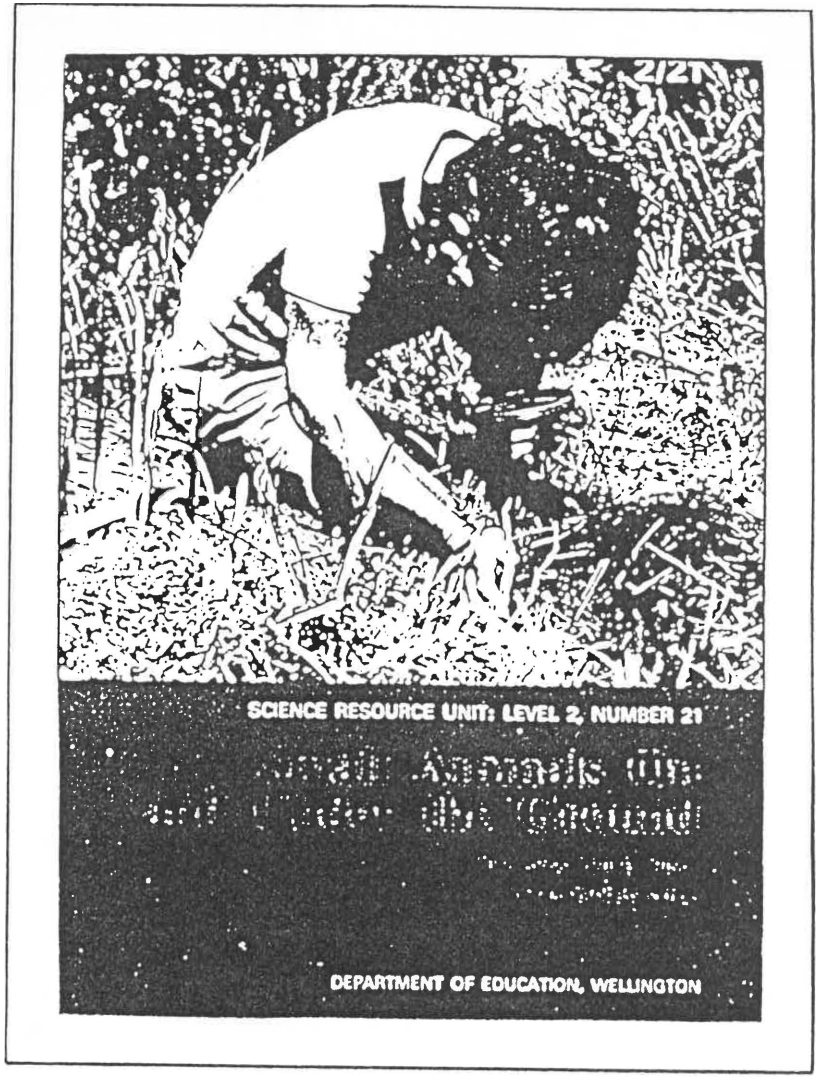


Figure 11 : Stimulus item G, 'Small Animals'.



Teachers described 26 pupils as being of average ability, but two pupils (10B and $15B_2$) were considered to be above average. A variety of school and home environments was deliberately chosen: nineteen pupils came from co-educational schools, four from boys' schools, and five from girls' schools. Fifteen pupils were from urban environments and 13 from rural areas.

3.2.3 The Interview Procedure

The interviews were of 35-55 minutes duration and were conducted as suggested by Bell and Osborne (1981). Sixteen interviews were conducted in private homes and twelve at the pupil's school. The audio-tape produced during each interview was transcribed during the following fortnight. Initial analysis of the tapes was carried out by the researcher. Dr R.J. Osborne also read many of the transcripts and his independent categorisations of pupils' views were compared with those of the researcher and taken into account.

3.3 PHASE II, QUANTITATIVE RESEARCH - THE SURVEYS

3.3.1 The Pencil-And-Paper Survey Instruments

The eight survey instruments (Figures 12-19) were devised as an outcome of the interviews. For example, Science Survey 8 (Figure 19) arose from pupils' responses to stimulus item C (Figure 5) in the interview.

Figure 12 : Science Survey 1 (below).

Figure 13 : Science Survey 2 (at right).

Science Survey 1

Name : ....

Age : Years ..... Months ....

In the space below, write an answer to the question in the BOX. You can continue on the back of this sheet if you need to.

BOX [What is photosynthesis ?]

Science Survey 2

Name : ....

Age : Years ..... Months ....

These questions are asking you to think about whether it may be possible, in the future, to have :

Test-tube Photosynthesis

ie to have the photosynthesis reaction occurring in a test-tube, rather than in a leaf.

Think about it carefully and read the three questions through first, before you start to answer.

Question One

Choose which of these two statements you like best and put a TICK in the box at the end :

Statement A - I think that test-tube photosynthesis may be possible in the future. ☐

Statement B - I think that test-tube photosynthesis will probably never be possible. ☐

Question Two

Try and consider how scientists might actually go about attempting to achieve test-tube photosynthesis in the laboratory. What problems do you think they might meet, and would have to solve, in their experiments ?

Write your answer in the space below.

Question Three

Give your opinion on the sentence below by putting a TICK in one of the boxes.

"I think that scientists should be trying to achieve test-tube photosynthesis."

☐ I agree ☐ I disagree ☐ I have no strong opinion

In the space below, give the reasons for your choice.

Figure 14 : Science Survey 3.

Science Survey 3 | Name : ....

Age : Years ..... Months ......

Question One

In the table below are the names of some substances.

In the right hand column write words like : orange, grey, colourless etc. to describe the colour of each substance.

Name of Substance	Colour of Substance
Carbon dioxide	
Chlorophyll	
Iodine solution	
Bromothymol blue	
Starch	
Water	
Oxygen	

Question Two

As Mary was leaving the room, she noticed a small bottle of a red liquid on the teacher's desk. The bottle was labelled "Phenol Red".

"What's that for, Miss ?" Mary asked her teacher.

"You can add phenol red to another liquid if you want to find out if the other liquid is an acid or an alkali," replied Miss Stevens. "The phenol red turns yellow with an acid, but it stays red with an alkali."

I know," said Mary suddenly. "The phenol red must be an *******"

"Correct !" said Miss Stevens. "Let's try it."

TICK the box below which shows the missing word which Mary used.

☐ acid ☐ oxidiser ☐ indicator ☐ alkali ☐ atom

Question Three

Which one of these is the best way of showing what happens when photosynthesis occurs ? TICK the box beside your choice.

☐ Starch + Water $\xrightarrow[\text{Sunlight}]{\text{Chlorophyll}}$ Food

☐ Starch + Oxygen $\xrightarrow[\text{Sunlight}]{\text{Chlorophyll}}$ Carbon dioxide + Water

☐ Carbon dioxide + Water $\xrightarrow[\text{Sunlight}]{\text{Chlorophyll}}$ Starch + Oxygen

☐ Food $\xrightarrow[\text{Sunlight}]{\text{Chlorophyll}}$ Growth + Energy

☐ Carbon dioxide + Water $\xrightarrow{\text{Chlorophyll}}$ Starch + Oxygen + Sunlight

Question Four

Here are three sentences written by science students.

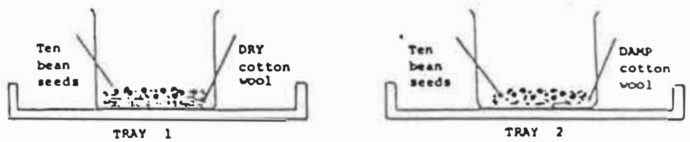
Is each sentence true or false ? Put a TICK in one of the boxes on the right.

In the space underneath, write your reason for choosing the "true" or the "false" box.

	Students' sentences	I think the sentence is .....
(i)	"Starch can be used to test whether or not iodine is present in a leaf."	True ☐ False ☐
	My reason :	
(ii)	"Iodine can be used to test whether or not chlorophyll is present in a leaf."	True ☐ False ☐
	My reason :	
(iii)	"Starch will dissolve in methylated spirits, but chlorophyll will not dissolve in methylated spirits."	True ☐ False ☐
	My reason :	

Question Five

Katrina was finding out whether bean seeds without water can begin to germinate (ie sprout). She set up her apparatus in a warm place on two trays, like this :



Which of the statements below is true ? TICK the box beside your choice.

☐ Tray 1 is the theory, and tray 2 is the experiment.

☐ Tray 1 is the experiment, and tray 2 is the result.

☐ Tray 1 is the experiment, and tray 2 is the control.

☐ Tray 1 is the method, and tray 2 is the result.

Figure 15 : Science Survey 4.

Science Survey 4

Name : ....

Age : Years .... Months ....

Question One

Is each of the things in the list below usually a liquid, a gas, or a solid ?

If you think that the answer is one of these, put a TICK in the correct column.

If you think it is none of these, put a TICK in the right hand column.

List	Liquid	Gas	Solid	None of these
Carbon dioxide				
Starch				
Energy				
Water				
Oxygen				
Sugar				
Sunlight				
Heat				

Question Two

Which of these is a true statement about chemical reactions and car engines ?

TICK the box next to your choice :

☐ A chemical reaction occurs in the engine, but no-one could ever know what the reaction is.

☐ The waste gases coming out of the engine's exhaust pipe after the chemical reaction are hidden in the petrol right from the start.

☐ A chemical reaction in the engine changes the petrol and air into waste gases.

☐ A chemical reaction occurs in the engine. A simple way to show it is :

Waste gases + Air ⟶ Petrol

☐ Chemical reactions can't occur in a car engine.

Question Three

Jane and Sally left a green plant in a dark cupboard for 48 hours. An iodine test on a leaf then showed that no starch was present. Next, Jane and Sally left the plant in the sunlight for 48 hours. Then they tested another leaf from the plant with iodine, and they found that starch was now present.

TICK the box beside the true statement about how the starch was formed :

☐ The starch was there all the time but the sunlight made it show up when the leaf was tested the second time.

☐ The starch could not have been formed by a chemical reaction.

☐ Tiny bits of starch, too small to see, were there from the start and the iodine made them all join up.

☐ A chemical reaction occurred and the equation was :

Starch + Oxygen ⟶ Carbon dioxide + Water

☐ The plant must have used some substances (we don't know what they are from this experiment) and turned them into starch.

Question Four

Think about the meaning of the word "test" in this sentence :

"Because starch turns blue-black when iodine is added to it, iodine can be used as a test for starch."

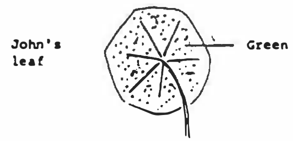
Which of the words below has the closest meaning to "test" as used in the sentence ? TICK the box beside your choice.

☐ examination ☐ match ☐ trial

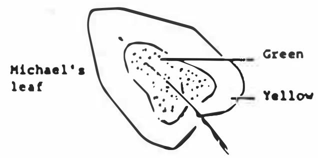
☐ indicator ☐ control ☐ experiment

Question Five

John and Michael were wanting to find out if plants need chlorophyll (the green pigment) to make starch. "Let's use leaves from this tree," said John. "They should work well because they are green all over."



"I think it would be better to use these ivy leaves," replied Michael." They are partly yellow and partly green, and we would have a control for our experiment."



Think about the way in which Michael has used the word "control". Which of the words below has the closest meaning to "control" in the way that Michael used it ? TICK the box beside your choice.

☐ authority ☐ regulator ☐ comparison ☐ power

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Figure 16 : Science Survey 5 (below).

Figure 17 : Science Survey 6 (at right).

Science Survey 5

Name : ....

Age : Years ..... Months ....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX **Plants And Their Food**

Science Survey 6

Name : ....

Age : Years ..... Months .....

Question One

Where does photosynthesis occur ? Write your answer in the box below :

For each of these examples, TICK either the "Yes" box or the "No" box.

Example	Can photosynthesis occur in the example ?	
A person	Yes ☐	No ☐
A cow	Yes ☐	No ☐
An oak tree	Yes ☐	No ☐
A fire	Yes ☐	No ☐
A wheat plant	Yes ☐	No ☐
A whale	Yes ☐	No ☐
A car	Yes ☐	No ☐
A mushroom	Yes ☐	No ☐
An earthworm	Yes ☐	No ☐
A brown seaweed	Yes ☐	No ☐

Question Two

Why are some things, and not others, described as "food" ? Write your answer in the box below :

For each of these examples, TICK either the "Yes" box or the "No" box.

Example	Is it food ?	
Petrol	Yes ☐	No ☐
Sugar	Yes ☐	No ☐
Asprins	Yes ☐	No ☐
Water	Yes ☐	No ☐
Air	Yes ☐	No ☐
Grass	Yes ☐	No ☐
Salt	Yes ☐	No ☐
Rubber	Yes ☐	No ☐
Pepper	Yes ☐	No ☐
Starch	Yes ☐	No ☐
Wood	Yes ☐	No ☐
Vitamin C pills	Yes ☐	No ☐

Figure 18 : Science Survey 7.

Science Survey 7

Name : ....

Age : Years ....Months .....

Question One

Here are some sentences written by science students.

Is each sentence true or false ? Put a TICK in one of the boxes on the right.

In the space underneath, write your reason for choosing the "true" or the "false" box.

	Students' sentences	I think the sentence is ....
(i)	"Photosynthesis is the name for the way plants use energy to make chlorophyll."	True ☐ False ☐
	My reason :	
(ii)	"During photosynthesis, energy is stored up in food."	True ☐ False ☐
	My reason :	
(iii)	"Green plants get their food from the soil."	True ☐ False ☐
	My reason :	
(iv)	"Green plants can change sunlight into energy."	True ☐ False ☐
	My reason :	
(v)	"When photosynthesis occurs, green plants use heat from the sun."	True ☐ False ☐
	My reason :	

Question Two

Where does a green plant get its energy from ?

Show your answer by TICKING one or more of the boxes :

☐ Soil ☐ Sun ☐ Mineral salts ☐ Carbon dioxide ☐ Water

Question Three

Here are some common substances. Which of them has a lot of stored energy ?

Show your answer by TICKING one or more of the boxes :

☐ Oxygen ☐ Sugar ☐ Water ☐ Salt

☐ Starch ☐ Wood ☐ Carbon dioxide

Question Four

Here are some sentences about sunlight, and a green leaf on a growing plant in the middle of the day.

Which sentences are true ? Show your answer by TICKING one or more of the boxes.

☐ The sunlight which reaches the leaf is travelling at a very high speed.

☐ There is sunlight all around the leaf but the sunlight is not moving.

☐ The leaf is making its own sunlight.

☐ No sunlight is coming away from the leaf.

☐ There is less sunlight leaving the leaf than is reaching it.

Question Five

This question is about human beings. Put a TICK in the box or boxes below to show where our energy comes from :

☐ Our movement.

☐ The air we breathe.

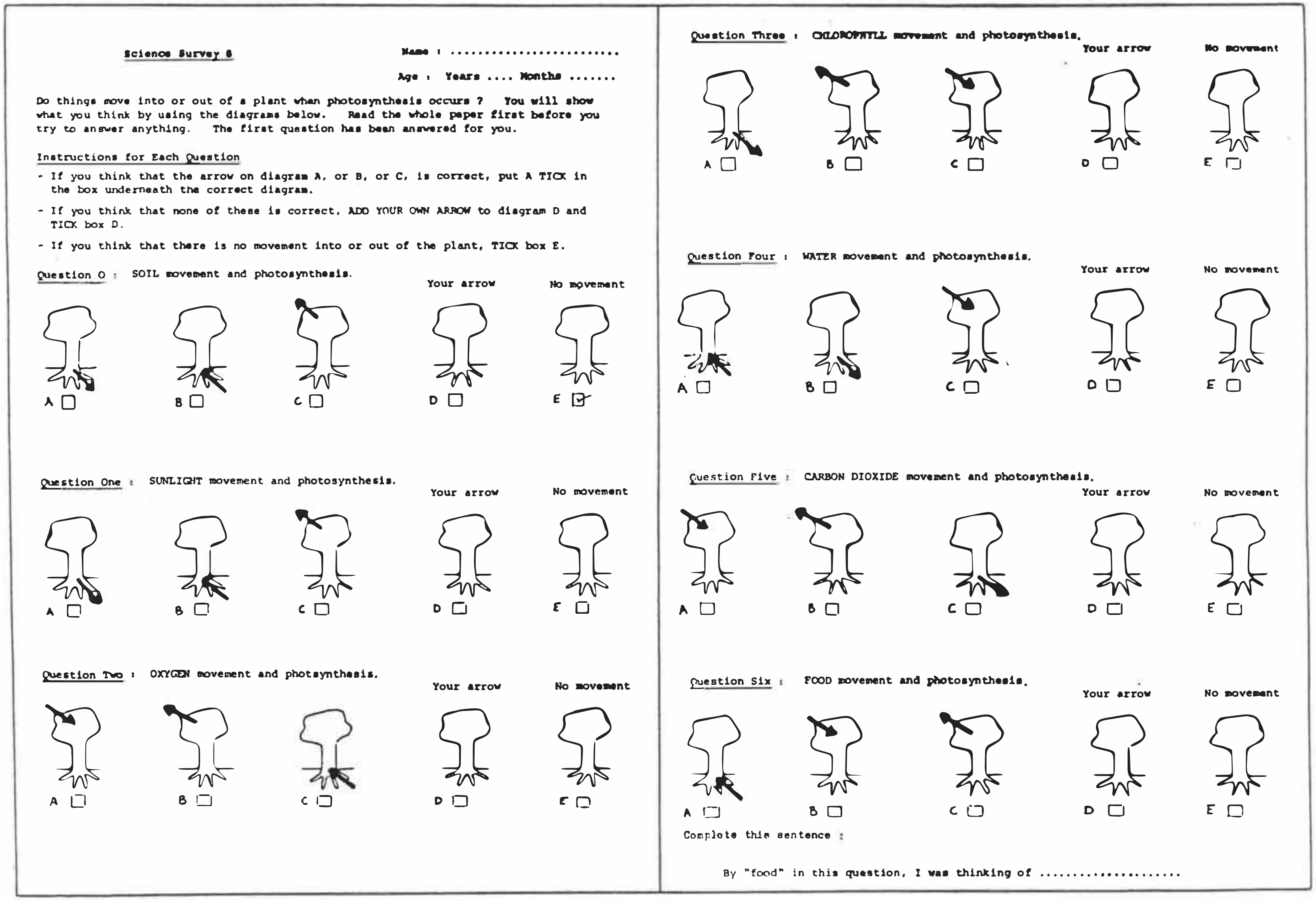
☐ The food we eat.

☐ The water we drink.

☐ Our rest and sleep.

☐ The sunlight reaching our bodies.

Figure 19 : Science Survey 8.



Science Survey 8

Name : ....

Age : Years .... Months ....

Do things move into or out of a plant when photosynthesis occurs ? You will show what you think by using the diagrams below. Read the whole paper first before you try to answer anything. The first question has been answered for you.

Instructions for Each Question

- If you think that the arrow on diagram A, or B, or C, is correct, put A TICK in the box underneath the correct diagram.
- If you think that none of these is correct, ADD YOUR OWN ARROW to diagram D and TICK box D.
- If you think that there is no movement into or out of the plant, TICK box E.

Question 0 : SOIL movement and photosynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☑

Question One : SUNLIGHT movement and photosynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☐

Question Two : OXYGEN movement and photsynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☐

Question Three : CHLOROPHYLL movement and photosynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☐

Question Four : WATER movement and photosynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☐

Question Five : CARBON DIOXIDE movement and photosynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☐

Question Six : FOOD movement and photosynthesis.

Your arrow | No movement

A ☐ B ☐ C ☐ D ☐ E ☐

Complete this sentence :

By "food" in this question, I was thinking of ....

3.3.2 The Pencil-And-Paper Survey Sample

Students of age 10 to 18+ years[3], from primary, intermediate and secondary schools and from one university, in the northern half of the North Island of New Zealand, were surveyed.

The school students were from both rural and city environments, about equal numbers of boys and girls were sampled, and the ethnic origins of the students reflected approximately the New Zealand population at large. The primary and intermediate students were all from state co-educational schools. The secondary students were drawn from state co-educational and state single-sex schools. No students from remedial or accelerate groups were included in the survey.

The primary and intermediate school students had been exposed to little or no school instruction about photosynthesis. The third, fourth and fifth form students (13, 14 and 15 years of age) in the secondary schools were all studying science, and those in forms six and seven (16 and 17 years of age) were all current biology students. Those at form three and six level had all been exposed to extensive teaching about photosynthesis prior to survey, but the students in form four had received no further instruction since the previous year. The fifth and seventh formers had experienced only a little revision of the topic during that year.

Tertiary students from a first year university biology class were also surveyed after a series of lectures in cell biology which included photosynthesis. The entire class was surveyed but only data from those students who had previously studied biology to form seven level (60% of the class) were used. Thirty seven percent of these students were female, 10% were Maori, and 10% were overseas students.

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3 The ages quoted here, and subsequently, are those of the majority of students at a given level of schooling.

Table 1 shows that nearly 6,000 surveys were completed. Primary and intermediate students were given only Science Survey 5 because this survey did not mention photosynthesis by name.

3.3.3 The Survey Procedure

The surveys were given to primary and intermediate students in their own classrooms and by their usual teachers. The secondary and tertiary students were surveyed under the supervision of either the researcher or their usual science or biology teacher, in laboratories or classrooms where science or biology was usually taught. The tertiary students were surveyed by the researcher at the start of a laboratory session. In all cases students worked individually and were given as much time as they needed to complete the survey.

Table 1 : The numbers of completed surveys at each student level.

Student Level	Age (Years)	Survey Instrument 1	2	3	4	5	6	7	8
Standard 4*	10					159			
Form 1**	11					179			
Form 2	12					186			
Form 3***	13	101		156	143	269	156	156	158
Form 4	14	99	28	150	150	152	150	150	150
Form 5	15	97		148	148	148	148	148	148
Form 6	16	103	57	117	117	137	117	117	117
Form 7	17	55		94	94	99	94	94	94
Tertiary	18+	51		101	99	96	102	97	101

* The standard 4 students were from three co-educational state primary schools (one rural and two urban).

** The form 1 and 2 students were from two co-educational state intermediate schools (one rural and one urban).

*** The form 3 to 7 students were from seven state secondary schools (one rural and six urban). The latter included one boys' school and one girls' school.

CHAPTER 4 THE FINDINGS OF PHASES I & II - THE BIOCHEMICAL THEME

My investigations lead me to show how water and air contribute more to the formation of the dry matter of plants growing in a fertile soil than does the humus matter they absorb, in aqueous solution through their roots ....

(Nicholas de Saussure, 1804, quoted by Nash, 1964, p.425)

4.1 INTRODUCTION

This chapter documents children's views about plant materials in the following sequence: plants and water; plants, carbon dioxide, and oxygen; leaves and chlorophyll; plant products (wood, sugar, and starch). Each section comprises a resumé of the scientists' view (including earlier scientists' views where relevant to children's views), the research findings concerning children's views, and a summary and discussion. This format is followed in chapter 5 (which deals with the ecological energetic theme) and chapter 6 (which deals with the trophic theme).

4.2 PLANTS AND WATER

4.2.1 The Scientists' View

4.2.1.1 The functions of water in plants[4]

Water is essential to plants for a number of reasons. It is the major constituent of protoplasm (the living part of plant cells) sometimes comprising up to 95% of the total weight. Water takes part

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4 The present study also produced data which suggests that some fundamental differences may exist between the ways in which scientists and children think about water movement through plants. These views are reported in Barker (1985b).

in a number of important chemical reactions in plant cells, e.g. photosynthesis (section 4.2.1.2). It is the material in which many other substances are dissolved and in which they undergo chemical reactions. Water confers turgidity, i.e. water keeps plant cells (and hence the whole plant) rigid. Osmotic uptake of water can cause cell enlargement. Surface films of water allow minerals and gases to dissolve and enter the plant.

4.2.1.2 Water and photosynthesis

Water has long been suspected of contributing to plant growth as well as performing other functions. Aristotle, for example, believed that "all organic bodies are formed mainly from soil and water" and that these are "changed into plant substances through contact with air and fire, i.e. heat" (Lieth, 1978). However, in about 1600 van Helmont, supported by Robert Boyle, produced impressive quantitative data which appeared to confirm the view that water alone is converted into plant materials by a process of transmutation (Webster, 1966). It was not until 1804 that Nicholas de Saussure, in Geneva, demonstrated that carbon dioxide and water co-react in a process, later called photosynthesis, which forms organic matter (such as sugar, starch, and cellulose) as well as oxygen gas.

4.2.2 Children's Views

4.2.2.1 The interview questions[5]

This section reports on children's responses to two questions, which were discussed in conjunction with stimulus item C, 'Plant' (page 28):

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5 The survey questions mainly revealed children's views about water movement in plants (Barker 1985b).

5. Here's another picture. Can you tell me about it?
6. Let's use the picture to talk about anything that goes into or comes out of a plant. We can write the names of things on these blank cards here, and we can use these arrows to show where things go. Can you think of something which a plant needs? ....Well, write it on the card and show me where it goes with the arrows.

A typical conversation, with David, the 12-year-old boy, follows.

(Figure 7 was made during this conversation):

I: *Thanks, David. What's something else a plant needs?*
12B: *Water.*
I: *O.K. ...* (8 second break while David writes 'water' on the card and moves a red arrow onto the stimulus item).
12B: *Well the water comes down from here ... onto the soil and then you leave a lot on all the soil so all the good things get in it ... and lots of water and things come up here ... into the roots ... and then it comes up here into the leaves and um from the leaves the flowers grow and some water goes with the flowers*
I: *Goes up to the flowers.*
12B: *Um ... well, um, a bit of it does and the rain gives it a bit too. Yeah, it goes up into the flowers.*

4.2.2.2 The functions of water in plants

All but two of the pupils (9G and 12G) nominated water and gave at least one function for water in plants. Three pupils (10B, $15B_2$, $17B_1$) gave as many as three functions. The responses are described below under eight categories, in decreasing order of frequency. Typical responses are quoted initially:

(a) Water is plant food. (13 responses; 7 pre-teach, 6 post-teach)

It goes right up into the plant. It feeds all the plant. (9B)

Well the leaves sort of need it for food like we need it for food. (12B)

The plant needs to eat something so it drinks water. Water is one of its main foods. ($15G_2$)

The pupils who considered water to be a food for plants (apart from its involvement in photosynthesis, see below) were from a wide age range. As well as the three pupils quoted above, these were 10B, 10G, 11B, 11G, 13G, $14B_2$, $14G_1$, $14G_2$, $16B_1$, and $16G_1$. The question of water as plant food is explored further in chapter 6.

(b) Water is needed for plant growth. (9 responses; 6 pre-teach, 3 post-teach)

Well it (i.e. a plant) *would need air to keep it healthy sort of and water to help it grow and sun and fertilizer when it's little maybe.* (11G)

Well the plant needs water all the time so the flowers shoot up and the leaves get nice and big. ($15G_2$)

Six instances came from pre-teach pupils (8B,9B, 10B, 11B, 11G, 13G). The other three were from post-teach pupils who had not considered water to be a photosynthetic reactant ($14G_2$, $15G_2$, $16B_1$).

(c) Water maintains turgor (rigidity) or prevents dehydration. (5 responses; 2 pre-teach, 3 post-teach)

(Water is used) for the stems, for the fluid in the stems, in the plant to keep rigid and things like that. ($17G_1$, and similarly from $16G_2$)

You can tell when the leaf is dying. When it's got no water it just sort of shrivels up and grows down. (13G, and similarly from 12B and $14B_2$)

(d) Water is a reactant in photosynthesis. (5 post-teach responses)

$14B_1$: (moving an arrow and discussing water) *Into the leaves ... um ... er ...*
I: *What happens in the leaves?*
$14B_1$: *Um ... it's photo photosynthesis. Joins with the carbon dioxide coming in and makes its food.*
I: *Where does ... what is the food?*
$14B_1$: *The food is sugar ... sugary substances.*
I: *Where does the water go in the end?*
$14B_1$: *Um ... er, out through the leaves.*
I: *Does it all go? Can you move the arrows?*
$14B_1$: *Some of it comes out.*
I: *Where does the rest go?*
$14B_1$: *The rest is in the food.*

Of the 17 post-teach pupils, the only ones to volunteer water as a reactant in photosynthesis at this stage of the interview were $14B_1$, $15B_1$, $16B_2$, and $17B_1$. One further pupil mentioned water after the term 'photosynthesis' had been introduced (question 28):

I: *Can you tell me what the word 'photosynthesis' means?*
$15B_2$: *It means the plant's way of using the um water and carbon dioxide and sun's energy to make a form of food for itself.*

Only one of these five pupils explored the role of water further:

It (i.e. a plant) *uses water to build up its own organic molecules I mean the hydrogen in the water can end up in glucose and things.* ($17B_1$)

(e) Water is necessary, in general terms only. (5 responses; 2 pre-teach, 3 post-teach)

I: *O.K. Goes right up to the leaves, does it?*
13B: *Yeah.*
I: *What happens then?*
13B: *I suppose it probably gets used up, like the food.*
I: *Used up? Do you know how that happens?*
13B: *... No I don't know.*

(Pupils 11B and $15G_1$ also talked of 'using up.')

Well it uses it to survive. ($15B_2$)

When they get old and start running out of water they die. ($15G_2$)

(f) <u>Water cools the plant.</u> (4 post-teach responses)

They mainly uses it as a cooling system for the leaves in the sunlight so they don't burn. ($16B_2$, and $14B_1$, $17B_1$, $17G_2$ similarly)

(g) Water transports material into and around the plant. (3 responses; 2 pre-teach, 1 post-teach)

It wets the soil and makes the soil easier to slide up the plant. (8G)

Well the water comes down into the soil and then you have a lot on all the soil so all the good things get in it and lots of water and things come up here into the roots. (12B)

Well it (i.e. water) *gets nutrients and food from the soil around it and it goes up through its stems and it goes up to the leaves that grow and it goes up to the flowers that grow as well cos it needs these things to grow cos it can't grow without moisture and nutrients and that.* ($14G_2$)

(h) <u>Idiosyncratic responses.</u> (2 pre-teach responses)

I: *What happens after it's got to the leaf?*
9B: *Well it sort of ... makes it go green.*

Water stays there (i.e. in the flowers) *or changes into nectar and all the other supplies that the flower needs.* (10B)

In conclusion, it was noted that five pupils (11B, $14B_1$, $15B_2$, $16B_2$, $17G_2$) used language associated with sweat production, a mammalian characteristic, to describe water relations in plants. Whether they were thinking of the osmoregulatory (i.e. salt and water regulating), excretory, or cooling function of sweat (and hence water) in plants was not always clear:

I: *You talked about the <u>excess</u> (water)?*
$15B_2$: *Well I should imagine that the plant uses some of it ... uses some of the water up completely.*
I: *What for?*
$15B_2$: *Well it uses it to survive like ... well the more I think about it the less sure I am* (laughs) *I was going to say: we take in a lot of water but we don't let much of it out, but we <u>do</u> from ways we don't think of like perspiring so I would say 'yes', it uses none of it. It all eventually comes off. I changed my mind on that one!*

I suppose it would get rid of it in the end by sweating. A kind of sweating. (11B)

I'd say it's used for the same sort of thing that people need it for. To send out on a hot day. Although that sort of thing implies that plants have got senses. I can't see that. I don't know. ($17G_2$)

4.2.3 Summary And Discussion

The interviews suggest that children frequently associate water with plant feeding and growth, in very general terms, even at a young age. However, children (and even senior students) frequently do not hold the view that water and carbon dioxide co-react in a carbohydrate-producing process. Children, it seems, view plant 'drinking' essentially as an isolated activity and their views appear to have more in common with van Helmont's theory of direct transmutation rather than the contemporary scientists' view of chemical synthesis involving water and carbon dioxide.

Children's thinking about plants and water is frequently human-centred. As well as noting that the pupils frequently used metaphors like 'drinking' and 'sucking' to describe interactions between plants and water, this study (including Barker, 1985b) has revealed cases where pupils drew analogies between plants and humans. Explaining the plant water transport system in terms of 'a sort of bloodstream', and transpiration as 'a kind of sweating' were common.

4.3 PLANTS, CARBON DIOXIDE, AND OXYGEN

4.3.1 The Scientists' View

The view that plants absorb 'fixed air' (carbon dioxide) and release 'dephlogisticated air' (oxygen) emerged gradually from the work of Priestley, Ingen-Housz, and Senebier in the late 18th century. Ingen-Housz realised that "this operation begins only after the sun has prepared the plants to begin anew their beneficial operation upon the air, and thus upon the animal creation", that it is "not performed by the whole plant but only by the leaves and green stalks that support them", and that "it ceases entirely at sunset" (quoted by Nash, 1964, p.370-371). In 1796 Ingen-Housz proclaimed that this process of gaseous exchange was not an isolated plant activity but was part of a larger integrated process within the plant. Arnon (1982) describes Ingen-Housz's position as a belief that "the curious behaviour of plants in light was not an act of providential philanthropy towards the animal world, but a process that provided nourishment for plants."

In 1804 Nicholas de Saussure suggested that water was also involved and he established the basis of the modern view, i.e. that carbon dioxide and water co-react in a process, later called photosynthesis, which forms organic matter (such as sugar, starch, and cellulose) as well as oxygen gas. De Saussure was wrong on one point, namely his notion that "in no case do plants decompose water directly, assimilating its hydrogen and eliminating its oxygen in a gaseous state. They emit oxygen gas only by the direct decomposition of carbonic acid gas" (De Saussure, quoted by Nash, 1964, p.430). Modern-day experiments with isotopes of oxygen have shown that the oxygen gas comes from the water and not the carbon dioxide.

4.3.2. Children's Views

4.3.2.1 The interview and survey questions

Section 4.3.2 considers pupils' responses to three interview questions. (Stimulus item C, 'Plants' was used with questions 5 and 6):

5. Here's another picture. Can you tell me about it?
6. Let's use the picture to talk about anything that goes into or comes out of a plant. We can write the names of things on these blank cards here, and we can use these arrows to show where things go. Can you think of something which a plant needs? ... Well, write it on the the card and show me where it goes with the arrows.
22. A kid once told me that the world will run out of air in the end because of all the animals breathing the air in. Do you believe that?

Two survey items (pages 54, 55) also contributed data to this section.[6]

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[6] Survey results showing that students usually hold the scientists' view of the colour and physical state of carbon dioxide and oxygen are described in Barker (1985c).

Pupils' views about the movement of gases into and out of plants (section 4.3.2.2) and the influence of their undertanding about animal breathing (section 4.3.2.3) are discussed. Pupils' ideas about the functions of plant gaseous exchange (section 4.3.2.4) and some alternative conceptual constructions made by post-teach pupils about plant gaseous exchange follow (section 4.3.2.5).

4.3.2.2 Plants and the movement of gases

All 28 of the pupils who were interviewed volunteered air or one or more of its constituents when answering question 6. (Their views about water vapour were discussed in section 4.2.2). Table 2 summarises the pre-teach pupils' responses in terms of named gases entering or leaving a plant, and the entry or exit points. Table 3 summarises the post-teach pupils' responses similarly. Older pupils were more likely to correctly identify carbon dioxide and oxygen and to restrict the occurrence of gaseous change to the leaves.

Two survey items (Figures 20, 21) investigated students' responses about movement of carbon dioxide and oxygen during photosynthesis. More than 60% of the third formers (who had recently studied photosynthesis) gave the scientists' response, but among form four students (who had received no further instruction since the previous year) these responses dropped to 45% for carbon dioxide movement and 33% for oxygen movement. The older students, who had been exposed to further instruction, were increasingly likely to express the scientists' views.

Figure 22 shows how students responded jointly to these two items. Only 19% of fourth formers gave the scientists' view, and 58% of students at this level gave 'other responses' in which they indicated that uptake or release of at least one of the gases was not

Table 2 : A summary of the pre-teach interviewees' responses about plants and gases.

Pupil Code	Gas Absorbed		Gas Released	
	Name	Entry point(s)	Name	Exit point(s)
8B	Air	Roots, low stem	- "A different sort of gas"	Flowers
8G	- "Hydrogen or something"	Roots	Oxygen	Leaves
9B	Carbon dioxide	Roots, stem, leaves, flowers	Air	Roots, stem, leaves, flowers
9G	- "The stuff we breathe out"	Leaves	- "The stuff we breathe in"	Leaves
10B	Carbon dioxide	Leaves	Air (oxygen)	Leaves
10G	Air(oxygen)	Roots	Air(oxygen)	Leaves, flowers
11B	Carbon dioxide	Leaves, stem, flowers	Oxygen	Leaves, stem, flowers
11G	Carbon dioxide	Leaves, stem, flowers	Oxygen	Leaves, stem, flowers
12B	Air	Leaves, stem, flowers	-	-
12G	Carbon dioxide	Leaves	Air	Leaves
13G	-	-	Oxygen	Leaves

Table 3 : A summary of the post-teach interviewees' responses about plants and gases.

Pupil Code	Gas Absorbed		Gas Released	
	Name	Entry point(s)	Name	Exit point(s)
13B	-	-	Air	Leaves, stem, flowers
$14B_1$	CO_2*	Leaves	Oxygen*	Leaves
$14B_2$	Carbon dioxide*	Lower stem	Oxygen	Leaves
$14G_1$	CO_2	Leaves	Oxygen	Leaves
$14G_2$	-	-	Oxygen	Leaves
$15B_1$	Carbon dioxide*	Leaves	Oxygen*	Leaves
$15B_2$	CO_2*	Leaves	Oxygen*	Leaves
$15G_1$	Carbon dioxide	Leaves,stem, flowers	Oxygen	Leaves, stem, flowers
$15G_2$	Oxygen*	Leaves, stem, flowers	Carbon dioxide*	Leaves, stem, flowers
$16B_1$	Carbon dioxide	Leaves, stem, flowers	Oxygen	Leaves, stem, flowers
$16B_2$	Carbon dioxide	Leaves, stem, flowers	Oxygen	Leaves, stem, flowers
$16G_1$	Carbon dioxide*	Leaves	Oxygen*	Leaves
$16G_2$	CO_2*	Leaves	Oxygen*	Leaves
$17B_1$	CO_2*	Leaves	Oxygen*	Leaves
$17B_2$	CO_2*	Leaves	Oxygen*	Leaves
$17G_1$	CO_2*	Leaves	Oxygen*	Leaves
$17G_2$	CO_2 Nitrogen	Leaves Leaves	Oxygen	Leaves

* In these cases the gas was identified as a photosynthetic reactant or product.

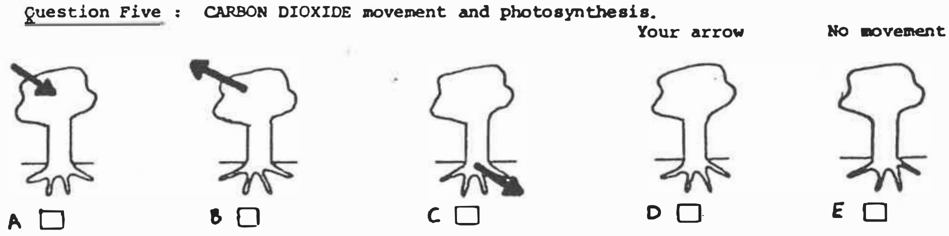
Figure 20 : Students' responses about carbon dioxide movement and photosynthesis.

Do things move into or out of a plant when photosynthesis occurs ? You will show what you think by using the diagrams below. Read the whole paper first before you try to answer anything. The first question has been answered for you.

Instructions for Each Question

- **If you think that the arrow on diagram A, or B, or C, is correct, put A TICK in the box underneath the correct diagram.**
- **If you think that none of these is correct, ADD YOUR OWN ARROW to diagram D and TICK box D.**
- **If you think that there is no movement into or out of the plant, TICK box E.**

Question Five : CARBON DIOXIDE movement and photosynthesis.



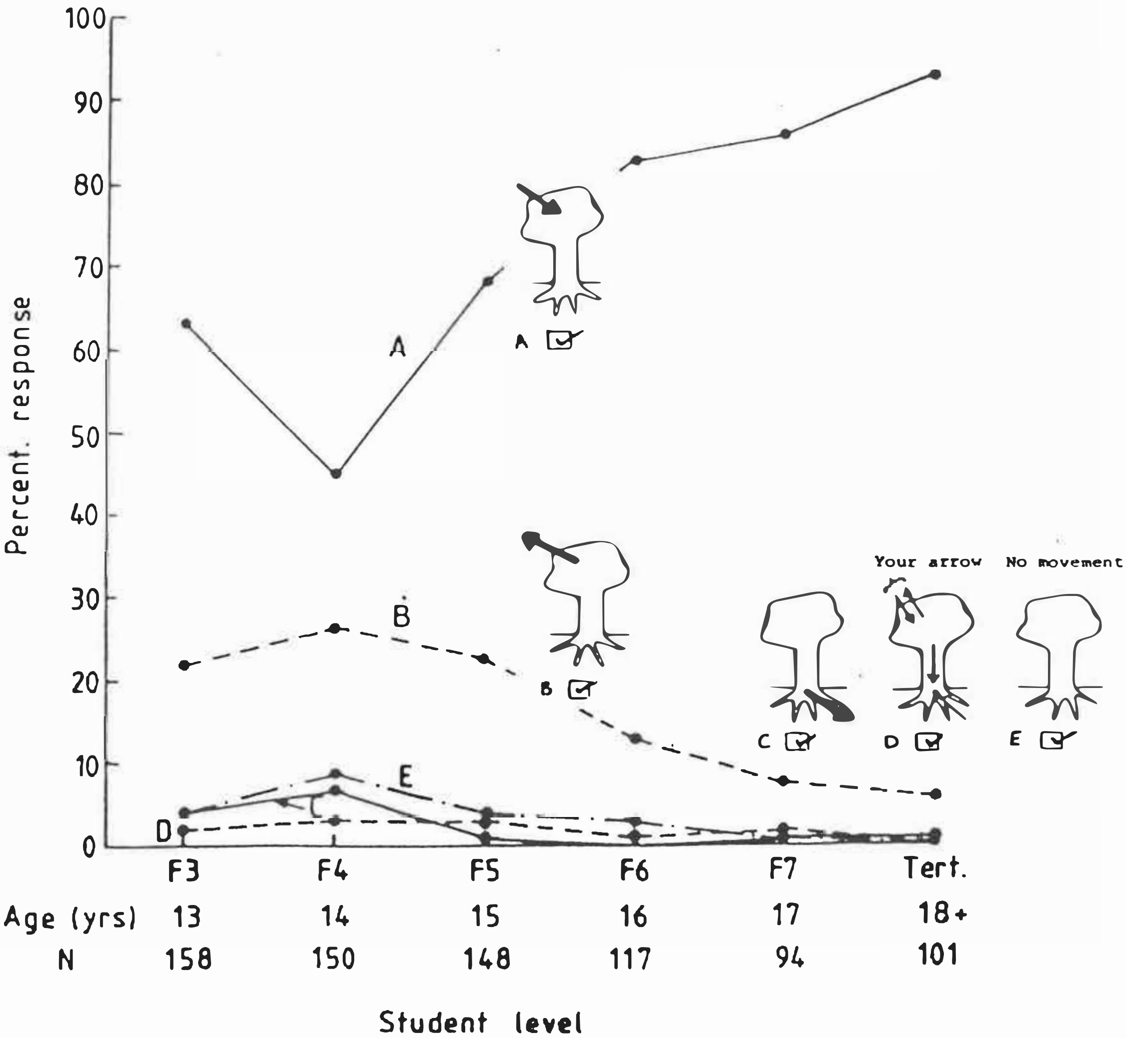


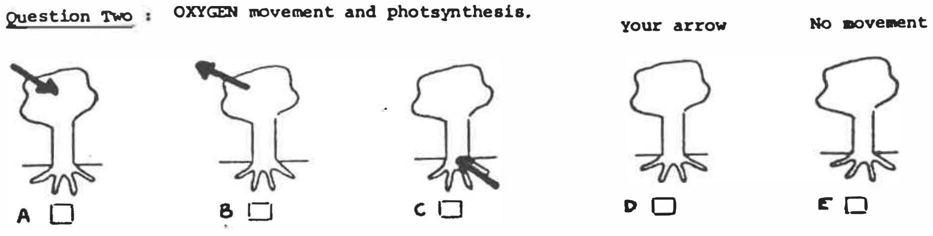
Figure 21 : Students' responses about oxygen movement and photosynthesis.

Do things move into or out of a plant when photosynthesis occurs ? You will show what you think by using the diagrams below. Read the whole paper first before you try to answer anything. The first question has been answered for you.

Instructions for Each Question

- **If you think that the arrow on diagram A, or B, or C, is correct, put A TICK in the box underneath the correct diagram.**
- **If you think that none of these is correct, ADD YOUR OWN ARROW to diagram D and TICK box D.**
- **If you think that there is no movement into or out of the plant, TICK box E.**

Question Two : OXYGEN movement and photsynthesis.



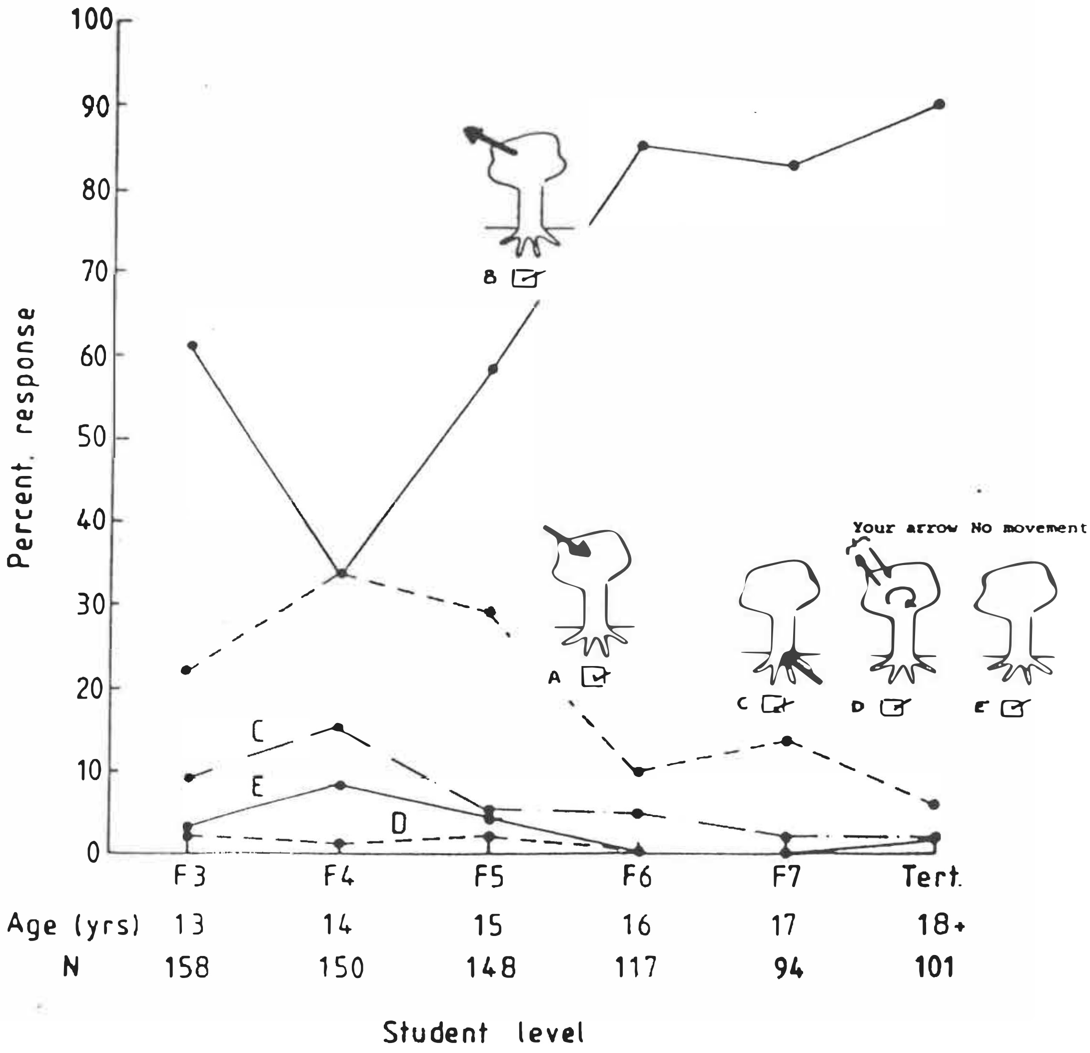
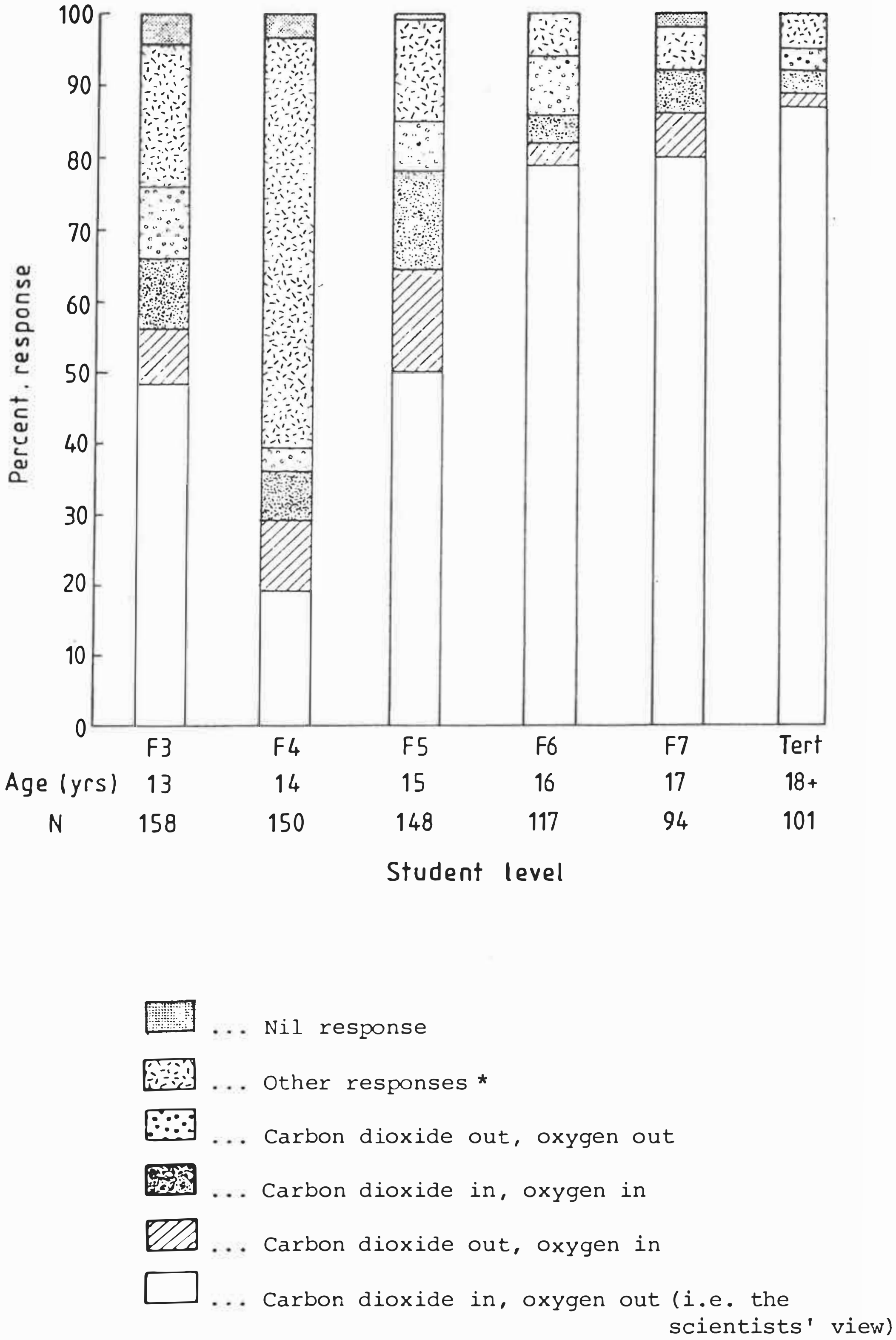


Figure 22 : Students' responses about movement of carbon dioxide and oxygen into and out of leaves during photosynthesis.



* Includes suggestions that one or both of these gases move in through the roots, do not move, etc.

localised in the leaves. That 'carbon dioxide out, oxygen in' is not the major alternative to the scientists' view suggests that a direct confusion between photosynthesis and respiration is not the major source of the alternative views at this level.

4.3.2.3 The 'plant breathing/animal breathing' model

Pupils even from a young age often nominated carbon dioxide and oxygen as gases which plants respectively absorb and release; they connected these two processes closely (often discussing them jointly); and they frequently justified this by contrasting the situation with human breathing:

We breathe in the oxygen and we breathe out the carbon dioxide and the plants take in carbon dioxide and sort of breathe out oxygen so if there were plenty of plants kept on the world we wouldn't run out of oxygen. (11G)

Plant gaseous exchange was viewed as the reciprocal of human breathing by the youngest pupil interviewed:

Cos if, um, if the animals breathe it in they have to breathe it out and then the trees breathe it in. All the plants get it and they br...., they get, um, make it back into air. (8B)

This was strongly evident in seven of the eleven pre-teach pupils.

Teaching about photosynthesis (Table 3) may modify this view but a concept of plant gaseous exchange as an isolated plant activity, related to human breathing, was held by five post-teach pupils ($14G_1$, $15G_1$, $16B_1$, $16B_2$, $17G_2$):

Well the carbon dioxide goes in through the leaves and then oxygen comes out of it and the oxygen we take and the plant takes in carbon dioxide and then it just goes all the way through the plant". ($14G_1$)

These five pupils, when asked (question 28) "Do you know what photosynthesis means?" did not mention these gases. They focussed on 'making carbohydrates' ($14G_1$, $15G_1$), or 'trapping energy' ($16B_2$) or had no concept of photosynthesis ($16B_1$, $17G_2$).

Six pupils of all ages (9B, 9G, 11G, $14B_2$, $16B_1$, $16B_2$) referred to this isolated process of carbon dioxide absorption and oxygen release as 'plant breathing':

It's something what they (i.e. plants) *breathe. They sort of breathe in and they push out and they take out and they breathe in the stuff. I'm not sure what it is - carbon dioxide, I think.* (9B)

Younger pupils, especially, held a human-centred form of the model. Although all 28 pupils rejected the proposition that "the world will run out of air in the end because of all the animals breathing the air in" (interview question 22), all but one (11B) of the pre-teach pupils subsequently discussed global gas balance in terms of plants and 'us'.[7] Only five of the 17 post-teach pupils spoke of gas relations between plants and 'animals'.

4.3.2.4 The functions of plant gaseous exchange

All 28 pupils who were interviewed nominated a function for plant gaseous exchange and two pupils ($15B_2$, $16G_2$) gave two functions. The responses are described below under four categories:

(a) Plants provide air and/or oxygen for humans and (other) animals. (16 responses; 9 pre-teach, 7 post-teach)

I: *Why does the plant take in carbon dioxide and give out oxygen?*
$17G_2$: *It's very convenient. I don't know why. Certainly we wouldn't be here now if they didn't.*
I: *Is it convenient to the plant?*
$17G_2$: *Well it must be. They obviously need it. They wouldn't take it in otherwise.*

This process was seen as being useful to the plant, although no benefit could be nominated. Plants were viewed as air-freshening devices in which gases are 'changed', 'turned into' (other things), or 'made again'. For example, in response to question 22:

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7 Stead (1980c) suggests that children often classify animals and humans in separate groups.

Well that couldn't happen because we are breathing it (i.e. air) *in but at the same time it's being made again. It's being ... plants sort of ...* (12G)

(b) Carbon dioxide and oxygen are reactant and product in photosynthesis. (8 post-teach responses)

$14B_1$: *The carbon dioxide comes from the air, ah ... into the leaves for photosynthesis and it goes both into making the sugar ... and oxygen goes out after the carbon dioxide's made so it really stops in the leaves.*
I: *I see. What's the oxygen got to do with the carbon dioxide?*
$14B_1$: *It's formed after the carbon dioxide's changed into the molec ... how can I ... made into sugar. The ... and it goes out through the leaves.*
I: *Is it formed from the carbon dioxide?.*
$14B_1$: *Um, no I don't think so.*

(c) Plants need carbon dioxide for general survival. (4 post-teach responses)

I: *Why does the plant take in carbon dioxide?*
$14G_1$: *To live and keep it sort of going.*

Yeah, the carbon's used and parts of the oxygen s used throughout the plant and then it will give off the excess. ($17G_1$ and $16B_1$, $16B_2$ similarly)

(d) Plants need gas for food (2 pre-teach responses)

I: *What happens to the air when it gets inside the plant?*
12B: *Well, it goes into little veins and, um, sort of makes the food and sends it up to the flowers and some to the stalks.*
I: *It 'makes the food'. Can you tell me about that?*
12B: *Well it doesn't make food. It helps make the food. Um...um...*
I: *What is the food?*
12B: *um ... well ... aw, I don't really know.*
I: *Does it help make the food or is it the food?*
12B: *Well it is sort of mostly the food except it needs the water and a bit of goodness from the ground to help make it too.*

I: *W've got the carbon dioxide coming in. What happens?*
10B: *I suppose it changes to oxygen and then goes off again.*
I: *I wonder why the plant takes in the carbon dioxide?*
10B: *Because of its food. It uses the carbon part.*
I: *Do you know what sort of food?*
10B: *I suppose sap.*

Neither of these pupils held any concept of photosynthesis.

4.3.2.5 Photosynthesis and gases - some alternative constructions.

This section documents three learning outcomes which may have occurred as students attempted to reconcile classroom instruction about photosynthesis with their existing ideas about plants and gases. In each case, students appear to be able to accommodate only some aspects of photosynthesis.

(a) Confusion of photosynthesis and respiration. (6 responses; 2 pre-teach, 4 post-teach)

No, because they say that trees breathe in at night or something or other ... they say that if you have a plant in your room probably you've a lot of air cos the plants give it. I dunno ... I've heard that but ... (laughs) (9G)

They (i.e. trees) *breathe in carbon dioxide during the day and breathe out oxygen, but during the night it breathes just as animals and people.* (11B)

These two pre-teach pupils have hinted that the 'plant breathing/animal breathing' model was not a complete explanation, and that time of day was also a factor. Similar, often very muddled statements were found among the post-teach pupils when they were justifying their view that the world will not run out of air:

No because we get an internal supply of oxygen from plants every night. ($14G_2$)

The tree takes in oxygen when it's light and gives off carbon dioxide when it's dark. ($15G_2$)

Three older pupils had apparently been very confused by the increasing biochemical complexity explored in further teaching:

I: *Do you know what 'photosynthesis' means?*
$15G_2$: *It's the plant taking in food and giving off different kinds of things giving us carbon dioxide ... It's about the plant taking in carbons and water and oxygen and giving us carbon dioxide.*

I: *What's the point of the sun reacting with the chlorophyll?*
$17B_2$: *Ah well that's how it starts off. Reacts with the chlorophyll producing green leaves starting a chain reaction, you know. The carbon dioxide comes in and reacts with the ATP, produces oxygen, and ATP comes off that and so forth.*

When 'sugar' had been introduced as a possible example of food, the third pupil said:

It's (i.e. sugar) *broken down into its different ...* (quietly) *by sunlight ...YEAH! By the process of photosynthesis they can make use of what they need in it* (quietly again) *I can't remember. Aw, you've got carbon and hydrogen and oxygen. C six H twelve O six. Something like that and you get .... With the use of the sun's energy it would break down to carbon dioxide and water and hydrogen or oxygen. I'm not sure. Can't remember those.* ($17G_1$)

In answer to question 6, the same pupil mentioned carbon dioxide in relation to transpiration:

$17G_1$: *Well, it* (i.e. carbon dioxide) *comes in from the atmosphere into the plant through the leaves and it's used in photosynthesis transpiration and respiration so it all goes in through the leaves.*
I: *It's used in all of those processes?*
$17G_1$: *Well it's called transpiration I think in plants.*

(b) The oxygen comes directly from the carbon dioxide. (5 responses; 1 pre-teach, 4 post-teach)

I: *Anything else a plant needs?*
$15B_2$: *Carbon dioxide it absorbs it, from what I understand, through the leaves. I would say there in the leaves it's combined with the water, the nutrients and so on coming up the plant and the oxygen's given off.*
I: *Where does the carbon dioxide go?*
$15B_2$: *Well the oxygen's given off which gets rid of the O two so we are left with the carbon and the carbon is used by the plant as food.*

A similar view of the direct 'splitting' of carbon dioxide in photosynthesis was found in four post-teach pupils ($14B_2$, $15B_2$, $16G_2$, $17G_1$) all of whom generally held the scientists' view that gaseous exchange is an integrated part of photosynthesis. Only one pupil,

$17B_1$, stated that the oxygen is, in fact, derived from the other reactant, water. Pre-teach pupil 10B viewed 'the carbon part' of carbon dioxide as food (see page 59).

(c) Photosynthesis is plant breathing. (1 post-teach response)

I: *Do you know what 'photosynthesis' means?*
$16G_1$: *It means the plant breathing in carbon dioxide and letting out oxygen so we can live.*
I: *Has the making of starch got anything to do with the photosynthesis or feeding or is it different?*
$16G_1$: *No. The photosynthesis is the making of oxygen.*

4.3.3 Summary And Discussion

4.3.3.1 The pre-teach 'plant breathing/animal breathing' model

From as early as eight years of age some pupils view plant gaseous exchange as a process isolated from other plant activities. They contend that we breathe in a gas, oxygen, and we breathe out another gas, carbon dioxide, that plants do the reverse and that this situation is essential for our continued survival.

4.3.3.2 The influence of classroom teaching

Successful teaching results in integration of the pre-teach notion of 'plant breathing' into a coherent view of photosynthesis. However, some pupils retain this notion unmodified and others merely apply the name 'photosynthesis' to it. Teaching about respiration is a source of confusion. An unmodified view was still apparent after four years of secondary schooling:

I: *Why does a plant do this? Why does it take in carbon dioxide and give out oxygen?*
$16B_2$: *Um, because plants do basically the same as we do only they are the opposite gases.*

Driver *et al*. (1983) noted that very few of the English 15-year-olds whom they surveyed connected plant gaseous exchange with the process of plant growth. These authors suggested that some pupils fail to relate the intake of carbon dioxide to the increased weight of a tree because they consider gases to be weightless.

Confusion was noted by Simpson and Arnold (1982b), who studied the development of Scottish pupils' knowledge of photosynthesis, respiration, breathing, and digestion. They concluded that "the newly encountered information (at secondary school) on the use of air by plants led most pupils to conclude that plants used the air in the opposite way to animals." The present study supports their finding that pupils become confused when attempting to reconcile photosynthesis with other topics, but suggests that a notion of 'plant breathing' may be a pre-teach phenomenon.

In conclusion, the present study has identified three cross-age trends among 8 to 17-year-olds:

(a) Towards correct identification of gases

Older pupils were more likely to identify carbon dioxide and oxygen correctly by name. Wandersee (1983), working with American pupils, reported that the view that oxygen moves out of a plant during photosynthesis was held by 51% of 5th graders (10-year-olds), 75% of 8th graders (13-year-olds), 83% of 11th graders (16-year-olds), and 87% of collegians (18 years and older). Data relating to movement of carbon dioxide into a plant during photosynthesis were, respectively, 62%, 74%, 84% and 85%. However, Driver *et al*. (1983) surveyed English 15-year-olds and found that only 36% of pupils advanced the idea that trees give out oxygen, and only 25% stated that trees take in carbon dioxide.

(b) Towards a focus on leaves

Older pupils usually restricted the occurrance of gaseous exchange to the leaves. However Simpson and Arnold (1982b) found that "almost 50% (of O-level biology students) believed that the gas necessary for photosynthesis was absorbed through the roots and stems of the plants."

(c) Away from human-centred views

Older pupils were more likely to discuss global gas balance in terms of 'animals' rather than 'us'.

4.3.3.3 Children's views and earlier scientific views

The following children's views about plants and gases are similar to earlier scientific views which have since been rejected or are now regarded as incomplete (section 4.3.1):

Gaseous exchange in plants occurs in isolation from other plant processes.

Gaseous exchange in plants serves to balance animal gaseous exchange.

Gaseous exchange in plants is a non-localised plant activity.

Carbon dioxide serves as food or nourishment for plants.

The oxygen gas comes directly from the carbon dioxide.

The implications of this are discussed further in section 7.4.

4.4 LEAVES AND CHLOROPHYLL

4.4.1 The Scientists' View

4.4.1.1 The functions of leaves

The present-day view that leaves are associated with photosynthesis[8] , which was established in the early 19th century, superseded many earlier explanations. For Aristotle, "the parts of plants in spite of their extreme simplicity are 'organs': e.g. the leaf serves to shelter the fruit, while the roots of plants are analogous to the mouth of animals, both serving for the absorption of food" (De Anima II, 1, 412 b 3; Aristotle, in Hutchins, 1952, p.642).

In the seventeenth century Marcello Malpighi suggested that leaves digest sap and eliminate moisture from it (Nash, 1964, p.336; Singer, 1960, p.364) and Nehemiah Grew concluded that the assimilation of nutrients or the excretion of waste gases or vapours through the stomata was important in the vital economy of plants (Nash, 1964, p.335). Bonnet suggested that the fact that stomata are usually found on the lower surface of leaves indicated that leaves facilitate absorption of aqueous and other vapours rising from the ground (Nash, 1964, p.372).

In 1727 Stephen Hales expressed the view that leaves perform "the same office that the lungs of animals do plants very probably drawing through their leaves some part of the nourishment from the air" (Hales, 1727, p.185-186). The anatomical analogy with animals was still being elaborated seventy years later, by Erasmus Darwin who, discussing how the fluid within a plant is exposed to the influence of air, stated that "this is done by the leaves of plants or the petals of flowers, those in the air resembling lungs and those in water resembling gills" (Darwin, 1800, p.6).

8 Transpiration, another important function of leaves, is discussed in Barker (1985b).

In 1779 Ingen-Housz demonstrated that it was the leaves and green stalks only (not the flowers, fruit, and roots) which have the power to "change bad into good air" and that "this wonderful operation is (due to) the influence of the light of the sun upon the plant" (Ingen-Housz, quoted by Nash, 1964, p.370). In 1804 Nicholas de Saussure established that when sunlight falls on the green parts of a plant carbon dioxide and water co-react in a process, later called photosynthesis, which forms organic matter (such as sugar, starch and cellulose) as well as oxygen gas.

4.4.1.2 The function of chlorophyll

In 1817 Pelletier and Caventou isolated chlorophyll, which Engelmann in 1880 found to absorb the blue and red regions of the visible light spectrum (Hall and Rao, 1981). In the 1940s the interaction between light and chlorophyll was further elucidated. Chlorophyll is a substance which possesses electrons capable of absorbing red and blue light, for example from the sun.* The eventual result is that the synthesis of new chemical compounds, sugar, starch, and wood is facilitated. These new compounds, when combusted, can release energy.

4.4.2 Children's Views

4.4.2.1 The interview and survey questions

The interview data in this section comprises pupils' responses to six questions. Two were designed to elucidate views about leaves and chlorophyll:

17. Why does a plant have leaves?
18. What is the most common colour for leaves? Why do you think this is so?

The structure of chlorophyll is such that the energy difference between the ground state and the excited state of some of its electrons can be provided by the absorption of red and blue light.

and four others (occurring earlier in the interview) sought pupils' views about plants and the sun. (These explanations often involved leaves and chlorophyll):

7. Here's another picture (i.e. stimulus item D, 'Boy/Tree/Sun', page 31). What's happening in this picture?
8. What happens to a boy when he stands outside in the sunshine?
9. And the tree? What happens to a tree standing outside in the sunshine?
10. Do the boy and the tree both need the sunshine? What do they need sunshine for?

The three survey instruments which contribute data to this section are reproduced on pages 74, 76 and 79.

4.4.2.2 Why does a plant have leaves?

Although some pupils had difficulty formulating an answer, all found this a challenging question. They appeared to assume that leaves are adaptive and must have a purpose:

(a) <u>Leaves are centres for nutrition</u> (13 responses; 1 pre-teach, 12 post-teach)

I: *Why does a plant have leaves?*
11B: *To process the minerals the water and the air, its food.*
I: *Can you explain 'process'?*
IIB: *Change it into what the plant will use and get rid of the waste through sweat.*
I: *What does it change it into?*
IIB: *I don't know.*

The 12 post-teach pupils all used the term photosynthesis in this regard but their understandings of this process varied widely (see chapter 8).

(b) Other scientifically acceptable functions (30 responses; 8 pre-teach, 22 post-teach)

Although all the pre-teach pupils had mentioned leaves earlier in the interview in connection with uptake and loss of water (see section 4.2.2), or gaseous exchange (section 4.3.2), or absorption of solar radiation (section 5.2), they had usually not considered these activities as being confined to leaves. When asked later why plants have leaves (i.e. question 17), five of the pupils reiterated some of these functions, often without a great deal of conviction, and then supplemented them with non-scientific functions (see below). The post-teach pupils all produced at least one scientifically acceptable function.

(c) Non-scientific functions (14 responses; 12 pre-teach, 2 post-teach)

It's like we need arms and that and they need leaves. (10G, and 8B similarly)

To shield some flowers when they are all withered from the sun. (8G, and 10G, 13G similarly)

That's probably where it all stores some of its water cos if it runs out of water and if it had water in the leaves it would be able to use the water in the leaves. (9B, and 12B similarly)

They might be part of the moving of a plant - you know how the plant moves around. It might be part of the ... something to do with the leaves. Might be the leaves move first then the branches. (11G)

The two post-teach pupils expressed non-scientific views in addition to scientifically acceptable ones:

.... *to make it* (i.e. the plant) *look pretty.* ($14G_1$)

Helps shelter them from the rain. In that way they don't get so much damage. ($14B_2$)

This range of propositions, especially those involving analogies with humans, often appeared to be arrived at by a process of on-the-spot invention.[9] Pupils' answers were characterised by a long initial pause, sudden exclamations like *I know!*, and statements like *I've never really thought about that before.*

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9 This is considered further in section 12.2.1

4.4.2.3 Knowledge about chlorophyll and its role

All 28 pupils interviewed nominated 'green' as the most common colour for leaves. No pre-teach and only seven post-teach pupils volunteered the name 'chlorophyll' or could supply it when asked directly "Can you tell me the name of the green stuff in leaves?" Pupils' explanations about the colour of leaves (question 18) were grouped as follows:

(a) The scientists' view (3 post-teach responses)

Only two pupils ($17B_1$, $17B_2$) could specify a reasonably accurate function for chlorophyll and relate it successfully to photosynthesis:

I: *Well, what happens when the light hits the leaf?*
$17B_1$: *Well, the rest of the light, the non-green part, gets absorbed by the leaf.*
I: *O.K. Can you tell me what happens there?*
$17B_1$: *Well it* (i.e. sunlight) *gets absorbed by a chloroplast. There's a magnesium atom I think in the middle of the chlorophyll and it increases the energy of an electron roaring around and it goes through a series of cycles and the energy of the electron is removed and locked up in the form of bonds in other molecules. That's how plants go about synthesizing organic molecules.*

A third pupil gave a reasonably accurate version of the function of chlorophyll without mentioning it by name:

I: *O.K. So you have told me that we've got sunlight changing into energy, say in this leaf ... How does that happen?*
$16B_2$: *Well we've been told that, um, the leaves are green so they can pick up the sunlight and that's the main place they get the photosynthesis because they have photosynthesis cells in the leaf.*

This pupil's later explanation of photosynthesis suggested that he did not relate the 'picking up' of sunlight to the production of organic material:

I: *Can you tell me what 'photosynthesis' means?*
$16B_2$: *It means taking sunlight into substances that they need. That's basically all I can remember about it.*
I: *But you don't know what the substances are?*
$16B_2$: *No other than ah...no no ...*

The two pupils who adequately described the function of chlorophyll ($17B_1$, $17B_2$) were the only ones who could give a reasonable explanation as to why plant leaves look green:

I: *All right. Can you tell me about those (sun's) rays? What are they?*
$17B_2$: *Certain colours that we learn you know are in the rays, are what reacts with the chlorophyll. I can't remember what colour it is. Red and blue I think it is or something but these colours are what cause the chlorophyll to react and the green orange and yellow are reflected by the chlorophyll and that causes its colour.*

(b) Chlorophyll as absorbed material (1 post-teach response)

One pupil considered that chlorophyll is a highly mobile colourless material which originates from the sun, moves around inside plants, and keeps them alive:

I: *Can you think of anything a plant needs?*
$16B_1$: *Chlorophyll. It comes in through the leaves ... from the air.*
I: *O.K. Just the leaves?*
$16B_1$: *Um yeah I think so.*
I: *O.K. Where does it come from?*
$16B_1$: *The sun.*
I: *What does it look like?*
$16B_1$: *Aw you can't see it ... When it gets into the leaves it turns them into green.*
I: *It comes into the leaves?*
$16B_1$: *Yeah. It goes all through the plant apart from the roots. Down the stems. Up the other ones.*
I: *O.K. Up the stems? Where does it go then?*
$16B_1$: *Mm. Just stays there I suppose.*
I: *In the stems and the leaves?*
$16B_1$: *Yeah. Everywhere.*
I: *What does it need the chlorophyll for?*
$16B_1$: *To keep alive.*

Later in the interview, pupil $16B_1$ suggested how he might have constructed these views about chlorophyll (page 77).

(c) Chlorophyll as a photosynthetic product (2 post-teach responses)

Two pupils suggested that chlorophyll is a substance produced in photosynthesis by the action of light on a plant. In one case this was revealed when the stimulus item had prompted a discussion about the action of light on leaves:

I: *O.K. What happens to the light in the leaves, Jill?*
$16G_1$: *You have to have light to make chlorophyll and you have to have chlorophyll in photosynthesis.*
I: *Where does the chlorophyll come from?*
$16G_1$: *It's made.*
I: *Where?*
$16G_1$: *I don't know. In the leaves or the stalks.*

The other pupil also volunteered that sunlight makes chlorophyll:

I: *To make chlorophyll?*
$16G_2$: *Well to make its food.*
I: *What is the food you are thinking of?*
$16G_2$: *Starch.*
I: *You said making chlorophyll. Does it do that as well?*
$16G_2$: *Yeah. It makes chlorophyll in the leaves.*

While not specifically discussing photosynthesis or chlorophyll, three other pupils commented in a way which suggests that some children think in general terms of the sun as promoting healthy growth and that this is manifest by the production of new green plant material:

I: *Why are leaves green?*
$17G_2$: *Probably whatever they get out of the sun um just has that effect, turns them green. I mean they could be any colour really.*

Pupil 9G (who had previously described green as a 'new sort of colour') responded similarly:

I: *What happens to the tree standing outside in the sun?*
9G: *Grows a little bit and gets a bit greener.*

The third instance arose during a discussion about plant growth. The pupil was commenting about why she thought a tree, visible from the interview room through a window, was growing:

Yip it's growing cos I can see little bits of roots coming out from the side of the tree, little green sort of sprigs of leaves and they are growing and there's a number of really really nice new green looking leaves. ($14G_1$)

(d) Other non-scientific functions (9 responses; 3 pre-teach, 6 post-teach)

Four pupils (8G, 12B, $16G_2$) voiced aesthetic considerations, e.g. that green is a 'nice colour' (8G) and green 'looks good' (12B). Another three post-teach pupils ($14B_2$, $15B_1$, $17G_1$) related the green colour to chlorophyll and photosynthesis but could not cite a specific function for chlorophyll:

I: *O.K. Can you tell me why plant leaves are green?*
$17G_1$: *Because they contain chlorophyll which is a pigment which is green.*
I: *Right. What's the chlorophyll needed for? Do you recall that?*
$17G_1$: *It's needed in photosynthesis to um ... chemically it's needed in the process of photosynthesis.*
I: *Can you tell me more about that?*
$17G_1$: *No not really. You've got your chlorophyll and your chloroplasts and they are used in um the making of food, well the main form of ... I don't know.*

The two final pupils in this group (11G, $15G_2$) were the only ones to volunteer a specific biological adaptation, but not for the plant itself:

I: *Do you know why most leaves are green?*
11G: *Well there must be a reason for it. Might be a means of camouflage or something maybe.*

(e) No response (13 responses; 8 pre-teach, 5 post-teach)

These pupils were at a complete loss to give any explanation why leaves are usually green. Pupil 11G's assumption that 'there must be a reason' reflects the attitude of all the interviewees. Just as when they were confronted with the question "Why do plants have leaves?", the pupils also found that the green colour of leaves was a surprising and challenging issue. Again, they often appeared to resort to on-the-spot invention as a strategy but on this occasion it generally proved less fruitful than earlier.

Three pencil-and-paper survey items also provided information about students' knowledge of chlorophyll and its role. An item in which secondary school students were asked for the colour of chlorophyll (Figure 23) showed that third and fourth formers were more likely to give non-scientific responses than when they were asked the same question about four other materials involved in photosynthesis. Forty-four percent of third formers (all post-teach) described chlorophyll as 'green' (or 'greenish-yellow' or 'greenish-blue'). This dropped to 32% among fourth formers (none of whom had received further classroom instruction since the previous year). Continued instruction at higher levels correlated with an increase in scientists' responses. Among the alternative colours (Figure 24) 'colourless' was the most frequent at all levels.

The second item surveyed students' responses about possible movement of chlorophyll and photosynthesis (Figure 25). Forty-four percent of third formers and 31% of fourth formers gave the scientists' response, i.e. option E, 'no movement'. Option C (i.e. movement into the upper part of the plant) was chosen by 25%, 28%, and 22% of students at form three, four, and five levels respectively. This suggests that a view that chlorophyll originates from outside the plant may be quite wide-spread. One fourth former's responses showed very explicitly that she or he was thinking of chlorophyll as originating from the sun:

Figure 23 : Correct student responses for the colour of five materials involved in photosynthesis.

In the table below are the names of some substances.

In the right hand column write words like : orange, grey, colourless etc. to describe the colour of each substance.

Name of Substance	Colour of Substance
Carbon dioxide	
Chlorophyll	
Iodine solution	
Bromothymol blue	
Starch	
Water	
Oxygen	

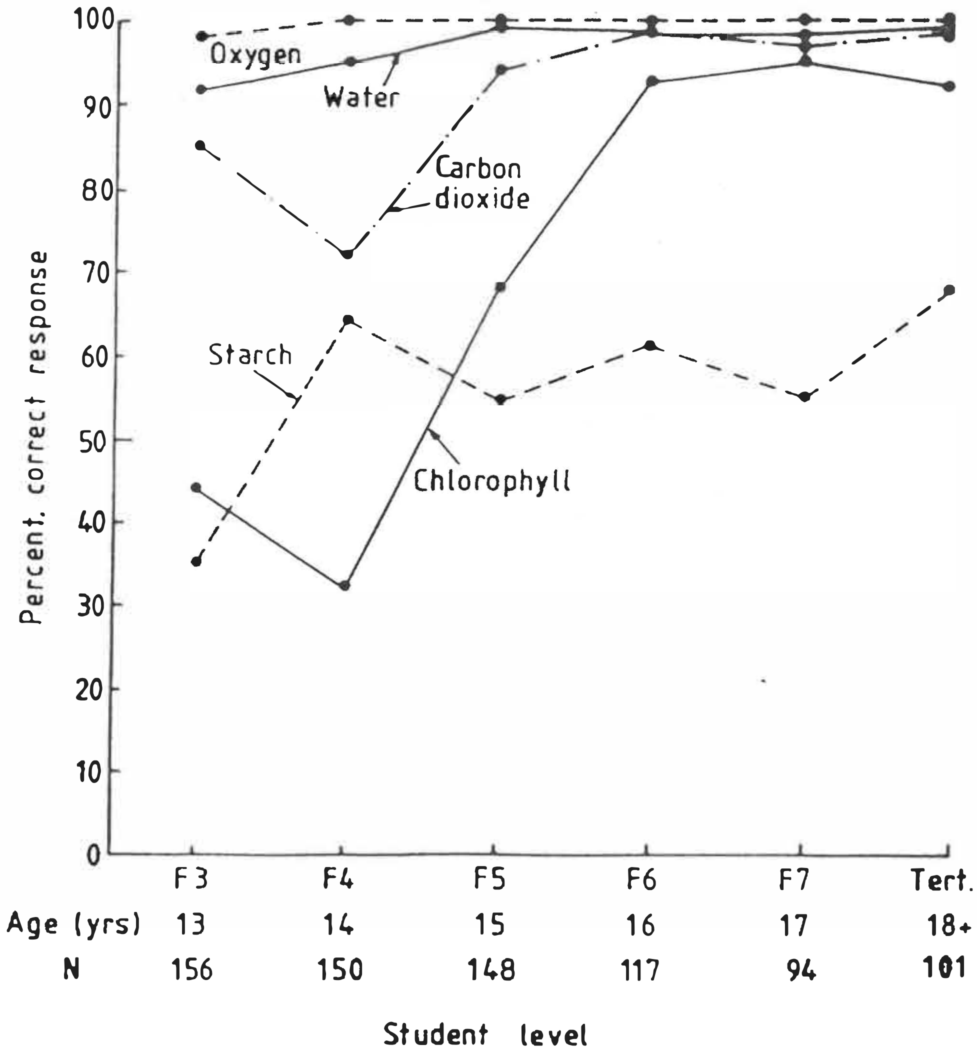
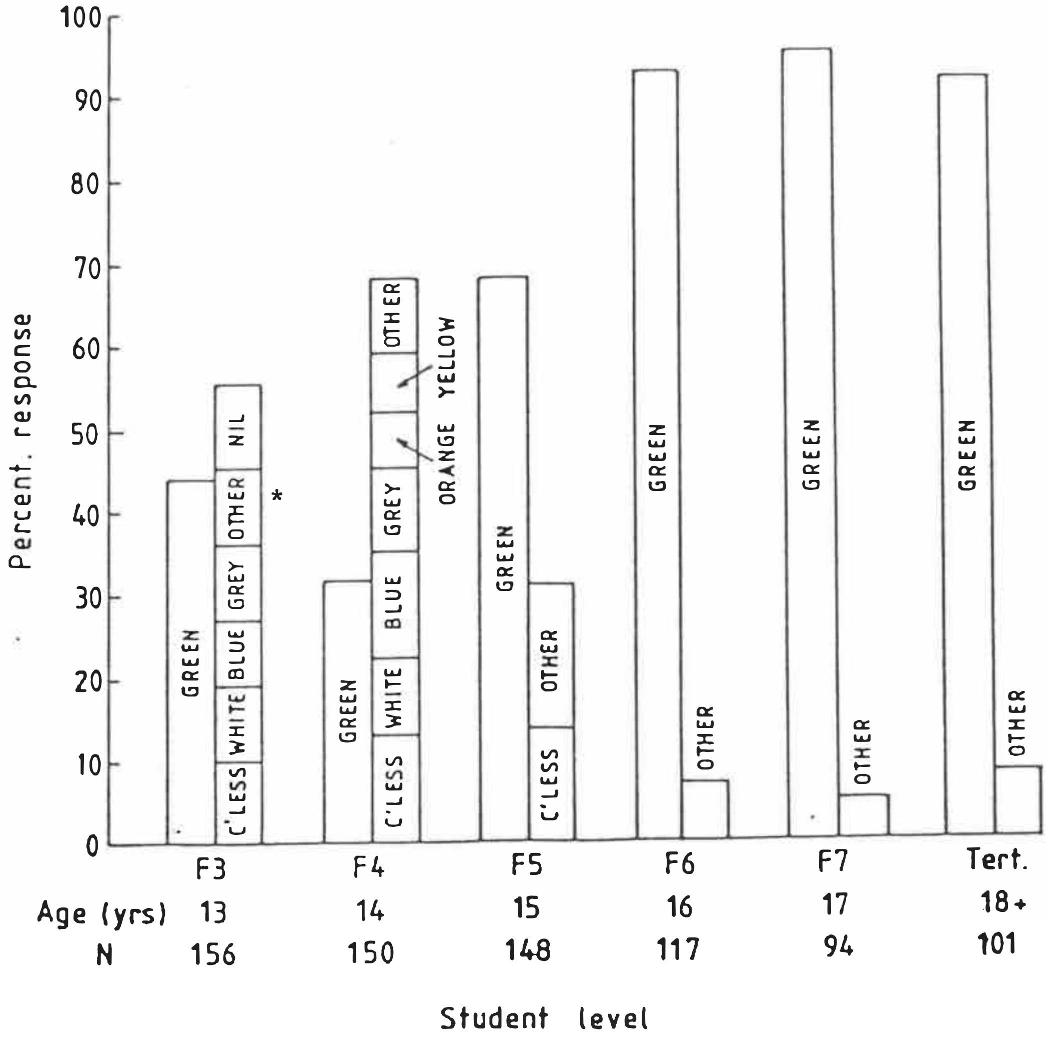


Figure 24 : Students' responses about the colour of chlorophyll.

In the table below are the names of some substances.

In the right hand column write words like : orange, grey, colourless etc. to describe the colour of each substance.

Name of Substance	Colour of Substance
Carbon dioxide	
Chlorophyll	
Iodine solution	
Bromothymol blue	
Starch	
Water	
Oxygen	



* Colours nominated by less than 5% of students at each level are grouped as 'other'.

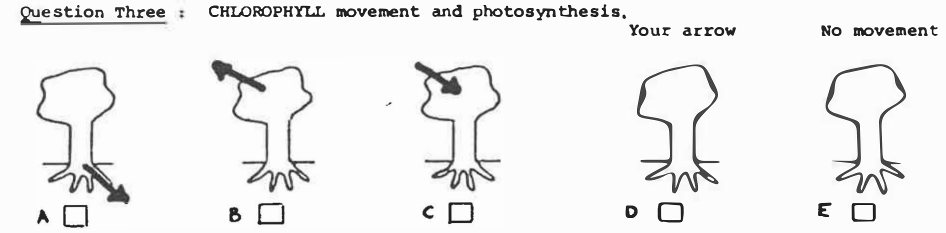
Figure 25 : Students' responses about chlorophyll movement and photosynthesis.

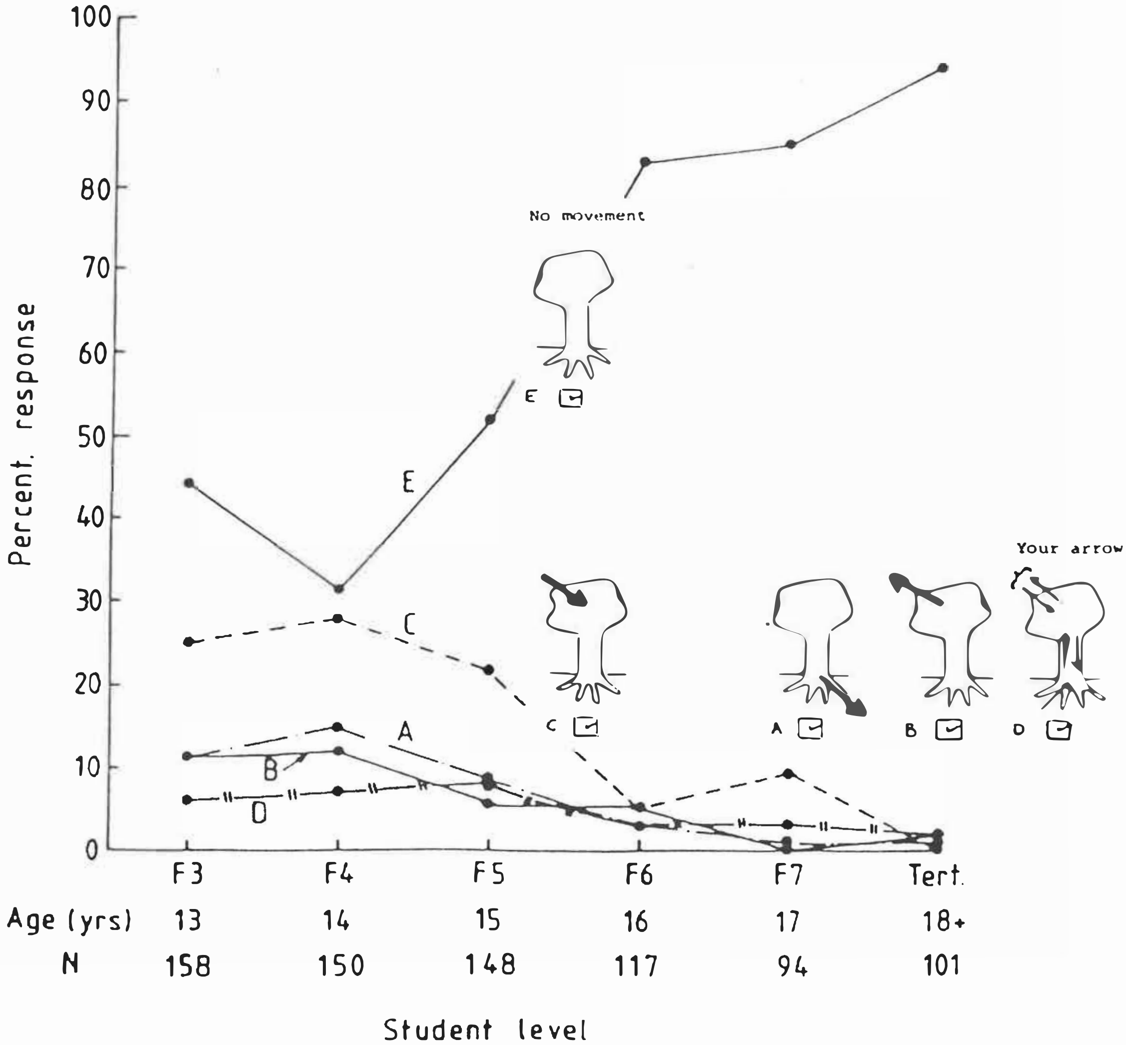
Do things move into or out of a plant when photosynthesis occurs ? You will show what you think by using the diagrams below. Read the whole paper first before you try to answer anything. The first question has been answered for you.

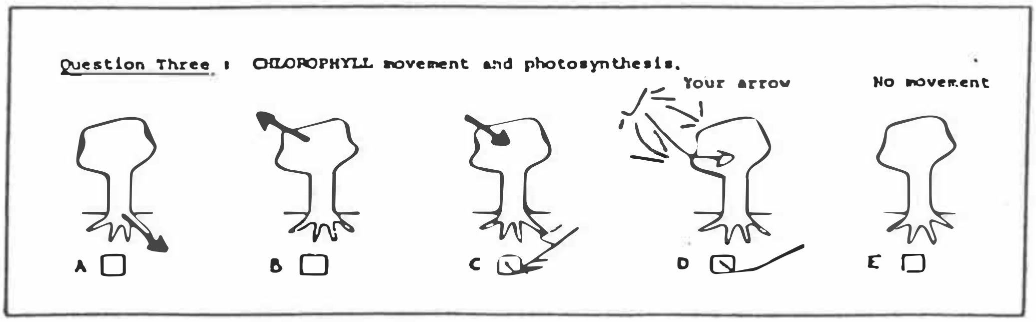
Instructions for Each Question

- If you think that the arrow on diagram A, or B, or C, is correct, put A TICK in the box underneath the correct diagram.
- If you think that none of these is correct, ADD YOUR OWN ARROW to diagram D and TICK box D.
- If you think that there is no movement into or out of the plant, TICK box E.

Question Three : CHLOROPHYLL movement and photosynthesis.







The third survey item is discussed in section 4.4.2.5.

4.4.2.4 Constructing knowledge about chlorophyll

The interview data has revealed two alternatives to the scientists' view about the role of chlorophyll. The pupils justified their views with empirical evidence. A common backyard experience was used in support of the 'chlorophyll as absorbed material' view (page 70) by the pupil who considered that chlorophyll comes from the sun:

I: *What happens at night-time?*
$16B_1$: *Doesn't get any more chlorophyll.*
I: *But it can survive?*
$16B_1$: *Yeah, on the stuff it stored during the day.*
I: *And this happens in a small plant and a big old plant?*
$16B_1$: *Yeah.*
I: *What happens to it if it doesn't have* ***any*** *chlorophyll?*
$16B_1$: *Aw it dies.*
I: *Straight away?*
$16B_1$: *Not straight away, no.*
I: *How could you make this happen?*
$16B_1$: *Not giving it chlorophyll. Um ... under a box. It doesn't get any sunlight or anything.*
I: *But what would you see?*
$16B_1$: *Gradually wilting. It would die off.*
I: *Does it stay green though?*
$16B_1$: *No. Turns brown. Brittle.*

The 'chlorophyll as photosynthetic product' view (page 70) was supported by 'an experiment last year' ($16G_1$). Presumably she was combining two well-known experiments involving positive starch tests to indicate that photosynthesis has occurred:[10]

I: *Mm. And what did that experiment tell you?*
$16G_1$: *That you need light to make chlorophyll and the oxygen.*
I: *Where does the chlorophyll come from?*
$16G_1$: *It's made.*
I: *Where?*
$16G_1$: *I don't know. In the leaves or the stalks.*
I: *And if the plant's not getting light for a while what happens?*
$16G_1$: *It would die.*
I: *What happens about the chlorophyll?*
$16G_1$: *The chlorophyll would disappear and the plant can't do photosynthesis.*

4.4.2.5 Chlorophyll, energy, and photosynthesis

A third item surveyed whether students considered that a sentence about the relationship between chlorophyll and energy in photosynthesis was true or false, and invited them to give a reason for their choice (Figure 26). In the scientists' view the sentence is false. Students who gave the scientists' response were considered to have given an acceptable reason if they either gave an adequate explanation of photosynthesis in terms of production of food, sugar, starch, or wood or energy transfer, or if they wrote an adequate statement about the role of chlorophyll. The results show that about 50% or more of students up to form five level considered that the sentence in which photosynthesis is equated with 'making chlorophyll'was acceptable.

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10 In one experiment black paper excludes light from part of a green leaf (giving a negative starch test in that area) and in the other only the green areas of a variegated leaf give a positive starch test.

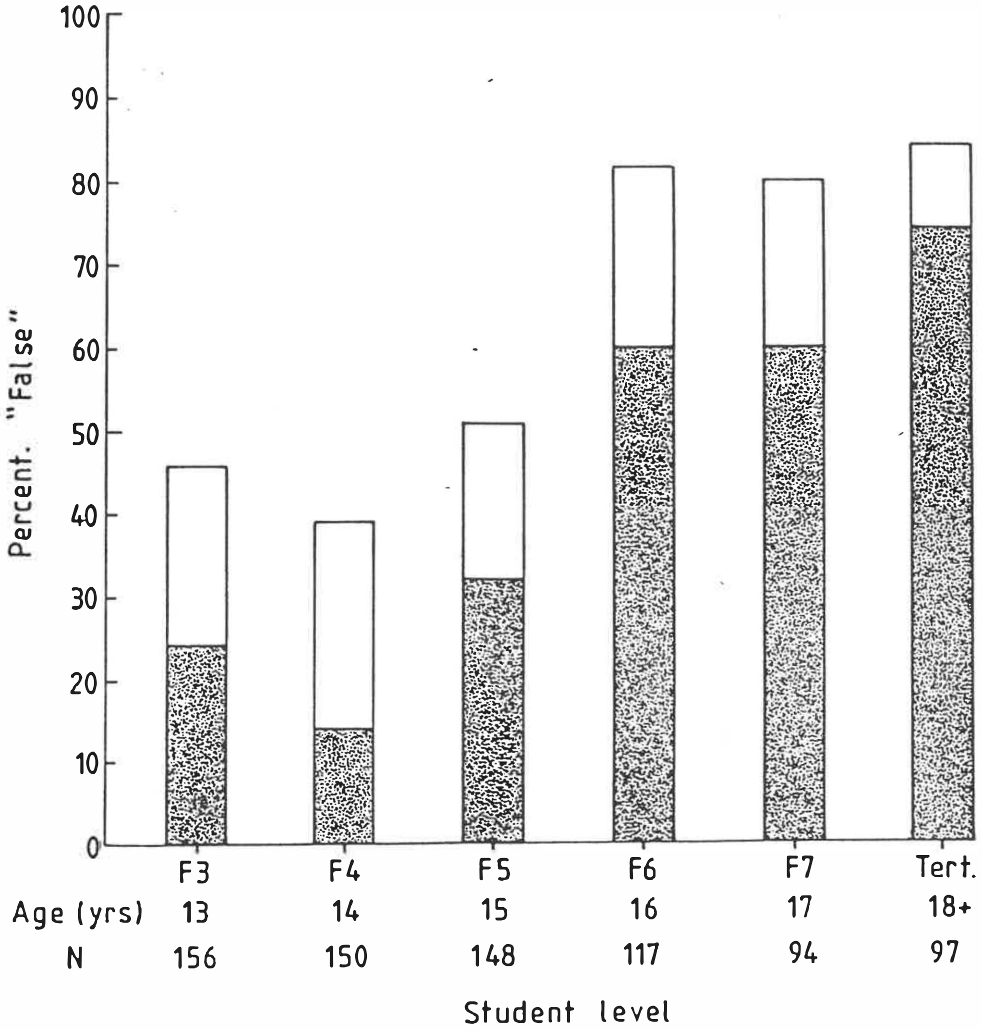
Figure 26 : Students' "True"/"False" responses to a sentence about photosynthesis, energy and chlorophyll.

Here are some sentences written by science students.

Is each sentence true or false ? Put a TICK in one of the boxes on the right.

In the space underneath, write your reason for choosing the "true" or "false" box.

Students' sentences	I think the sentence is ....
"Photosynthesis is the name for the way plants use energy to make chlorophyll."	True ☐ False ☐
My reason :	



KEY: ... indicates students who wrote scientifically acceptable reasons.

4.4.3 Summary And Discussion

4.4.3.1 The functions of leaves

Before classroom instruction about photosynthesis, children usually do not associate leaves with feeding or nutrition. Instead, children consider that a number of functions (e.g. absorbing radiation, absorbing or losing water) are common to leaves and other parts of a plant. When asked to give a specific function for leaves they give a wide variety of responses, often apparently using on-the-spot inventions.

Just as a variety of theories have been proposed at different times in history to explain the functions of leaves (page 65) so also did the interviews in the present study reveal a diversity of suggestions (page 67). The alternative explanations which both groups offer sometimes appear similar, e.g. that leaves mainly serve to protect other plant parts, get rid of waste, or store water.

Wandersee (1983), working with American students from 5th grade (10 years old) through to collegians (18+ years old), found that in addition to the view that leaves make food, students also considered that leaves shade the tender shoots from the sun, that they catch rain and dew for the plant, and that they capture warmth from the sun. (Similar views were found in the present study.) From the responses to a multichoice item which contained these four views Wandersee reported that "it is noteworthy that nearly one-half (45%) of the fifth graders tested did not believe that the main job of a leaf is to make food. Almost one-third (32%) of the eighth grade students were also unaware of that. Consider the college students: approximately one-fifth still held contrary notions."

4.4.3.2 Knowledge about chlorophyll

Children know very little about chlorophyll. Only seven pupils (all post-teach) of the 28 who were interviewed volunteered the name 'chlorophyll' for the green stuff in leaves. Pencil-and-paper surveys revealed that only 44% of third formers (recently taught about photosynthesis) and 32% of fourth formers (who had experienced no further instruction since the previous year) gave 'green' as the colour for chlorophyll. 'Colourless' was the most frequent alternative.

Wandersee (1983) suggests that chlorophyll is not well known to American students. He asked students to collegian level to describe how the colour change in deciduous tree leaves affects the leaves' main job. He found that "only 24% of the students across all classes mentioned chlorophyll by name." Wandersee also reports that students were inclined to use 'chlorine' or 'chloroform' or 'chloraseptic' where 'chlorophyll' would be expected.

4.4.3.3 The role of chlorophyll

The role of chlorophyll in absorbing sunlight is seldom appreciated by pupils. Three of the 28 interviewees (all older secondary school pupils) were able to give a reasonable account of the role of chlorophyll, and three others held that chlorophyll was needed in photosynthesis but could not say why. Interview and survey data suggested that some pupils (especially at junior secondary school) consider that chlorophyll is a colourless substance which originates from the sun and is absorbed by the plant, and others believe that chlorophyll is produced during photosynthesis. None of the remaining 19 pupils interviewed related the green colour of leaves (or chlorophyll) to plant feeding (or photosynthesis). Thirteen pupils gave no explanation as to why leaves are green.

Bell and Brook (1984) report on the responses of English 15-year-olds to a written item in which students were asked to predict the effect of spraying the countryside with a chemical which destroys chlorophyll. Only 35% of the students gave a response which the researchers considered was acceptable. Among the scientifically unacceptable functions ascribed to chlorophyll were: attracting light, protection, and for use as a food substance or for storage, or as a life-giving substance.

4.5 PLANT PRODUCTS - WOOD, SUGAR, AND STARCH

4.5.1 The Scientists' View

4.5.1.1 The origin of plant organic matter

Liquid water constitutes a large part of the fresh weight of most plants. When this water has been removed, the remaining dry weight comprises organic matter (produced by photosynthesis) and a small quantity of minerals. Vaughan *et al.* (1982) report that water constitutes 80% of the fresh weight of lucerne, 80% of pasture, 50% of Pinus radiata, and 14% of maize grain. When this is removed, the resulting dry weights (Table 4) are dominated by carbohydrates, usually cellulose and hemicellulose.

Bloomfield (1977) states that carbohydrates make up about 75% of the organic matter in plants at large and that over 50% of the total organic matter in the living world (i.e. both plants and animals) is cellulose. Wood is composed of 50-60% cellulose, the remainder being roughly equal amounts of hemicelluloses and lignin (Lapedes, 1977, p.651).

Table 4: The percentage composition of the dry weight of four plants (Vaughan *et al.*, 1982).

Compounds	Plants			
	Lucerne	Pasture	Pinus radiata	Maize (grain)
Sugars	9	14	-	3
Starch	-	1	-	70
Cellulose and hemicellulose	27	29	69	12
Complex carbohydrates e.g. lignin	13	4	28	2
Total carbohydrate	49	48	97	87
Total fat	-	-	-	-
Total protein	26	25	-	8
Total minerals (i.e. ash)	10	13	2	1
Total other	15	14	1	4
Grand Total, Dry Weight	100	100	100	100

4.5.1.2 The carbohydrates in plants

Glucose, a simple sugar, is a well-known early organic product of photosynthesis. Molecules of glucose are used by the plant as an energy source, but they can also be linked together to form two important long chain molecules, starch and cellulose.

Starch molecules are highly branched structures composed of about 300 glucose units. Because starch can be broken down readily to glucose it is used largely as an energy store. Starch usually appears temporarily in mature leaves which, by performing photosynthesis during the hours of sunlight, produce carbohydrate faster than they can export it. This was first demonstrated by Sachs in 1864 who took green leaves which had previously been in the dark for some hours, exposed them to sunlight, and found that when tested with iodine vapour they turned dark violet due to the formation of a starch-iodine complex. In the hours of darkness most of the starch is converted to another sugar, sucrose (a two-unit carbohydrate, see Richardson, 1968) which is moved out of the leaves (Fogg, 1963, p.194). In some plants the sucrose is transported to the roots, stem, or seeds where it is converted to starch in significant amounts, e.g. corn, tapioca, potato, sago, wheat, and rice.

Alternatively, glucose made available from sucrose after transport may be converted into cellulose. This large unbranched chain molecule is composed of several thousand glucose units. Cellulose is not usually degraded back to glucose and its strength and durability make it useful as a structural material within the plant. Wood is a combination of celluloses, hemicelluloses, and other complex carbohydrates like lignin.

4.5.1.3 Growth and differentiation

The production of new organic material in both plants and animals can give rise to growth. Growth, in the scientists' view, is characterised by "an increase in volume or mass resulting from cell multiplication and cell expansion" (Purves and Orians, 1983). This is distinct from differentiation, which is the committing of cells to specific structures and functions. The production of new cells with cellulose cell walls, much of which is characterised as wood in older plants, is the main source of plant growth.

4.5.2 Children's Views

4.5.2.1 The interview and survey questions

Three of the six interview questions were asked about stimulus item E, 'Growing Plant' (page 31):

11. Let's think about this picture now. What does it tell us?
12. How did the plant increase in size over the five years?

13. Where does the stuff that the tree is made of come from?

The fourth question, late in the interview, deliberately introduced the concept of photosynthesis and provided an opportunity to relate this process to wood, sugar, and starch:

28. Do you know what 'photosynthesis' means?

Two other questions, earlier in the interview, probed pupils' concepts of wood, sugar, and starch (but in a general trophic context only) by employing stimulus item A, 'Foods' (page 27) in which pupils decided whether 12 progressively revealed examples were food or not:

1. I'm interested to find out your ideas about food. Let's look at some things and see whether they are food or not ... Is (sugar) a food? ... What tells you that? ... Could it be a food? O.K. Let's put (sugar) in the (food/not food) pile.
2. Can you tell me why all these ones are food, and all these ones aren't food?

4.5.2.2 Plant growth - children's meanings

All 28 pupils interviewed expressed ideas about plant growth when presented with the stimulus item 'Growing Plant'. None described the process in terms of cellular multiplication or expansion (i.e. the scientists' view). Three meanings for plant growth were noted:

(a) Growth as enlargement (28 responses; 11 pre-teach, 17 post-teach)

I: *How do you know it's growing?*
$14B_1$: *Well it started off very small and it's getting large.*

Again:

I: *Is growing the same as getting bigger or is it different?*
$17B_1$: *Aw well it's putting on more mass. Getting more massive.*

(b) Growth as development (4 responses; 2 pre-teach, 2 post-teach)

These pupils (10B, 11G, $14G_1$, $15B_2$) also considered that a plant was growing if it showed signs of change:

Yip (i.e. it is growing) *cos I can just see little bits of roots coming out from the side of the tree, little green sort of sprigs of leaves and they are growing and there's a number of really really nice new green looking leaves.* ($14G_1$, commenting on a tree outside the interview room, visible through a window.)

(c) Growth as existing, being alive (4 responses; 2 pre-teach, 2 post-teach)

These pupils (11G, 12G, $14B_2$, $15B_2$) talked of growing in a way which is relevant to plants but not animals, that is, although the location of a thistle may be conveyed by the phrase 'growing under a hedge' one would not talk of a cat 'growing by the fireside'):

Well it has to be growing. Either that or it's dying. ($15B_2$)

Well it's alive and everything that's alive I think is growing. (12G)

That pupils readily switch from one of these views of plant growth to another, or even use them jointly, was clear:

I: *How do you know a tree is growing?*
$15B_2$: *Well you can't measure it but as long as it's living and, well, as far as I can see as long as it's not dying it's growing and you can tell if it's dying but you can't necessarily tell if it's growing except over a long period of time. Especially with the new foliage you can tell if it's growing.*

Again:

I: *What do you mean by 'grow' in that sense? - 'The sun helps the plant to grow'.*
$14B_2$: *Existing ... and growing and growing.*
I: *What does 'growing and growing' mean?*
$14B_2$: *Aw well they grow where it exists and they grow when it grows.*
I: *What does the 'grow' mean?*
$14B_2$: (laughs) *It gets bigger!*

4.5.2.3 What plants are made of - children's explanations.

This section reports on the conversations which followed from interview questions 11, 12, and 13 and the stimulus item 'Growing

Plant'. These questions focussed on the nature and origin of plant materials.

When invited to identify 'the stuff that the tree is made of' all but one of the 28 pupils volunteered 'wood', usually in conjunction with other responses of a morphological type:

Aw, wood, leaves, green leaves, aw it doesn't have to be green, roots, branches. (13G)

Biochemical terminology was also volunteered by only two of the 28 pupils, ($15B_2$, $15G_2$):

Wood and more loosely than that organic material. ($15B_2$)

One other pupil talked initially in biochemical terms only, but she readily concurred with a suggestion about wood from the interviewer:

$17G_1$: *Um chemical compounds which have been used in such a way to create its leaves and its trunks and its twigs and things like that.*
I: *Right. I I would have said it's made mainly of wood, but*

$17G_1$: *Wood yeah well wood* <u>*is*</u> *a compound. I was thinking of getting right into the middle of it sort of.*

Neither sugar, starch, nor cellulose were mentioned by any of the 28 pupils in response to these three interview questions.

4.5.2.4 The origins of plant growth children's explanations.

This section reports on interview responses to the questions:

12. How did the plant increase in size over the five years?

13. Where does the stuff that the tree is made of come from?

Because all but one of the pupils had already introduced 'wood' into the discussion (see section 4.5.2.3), this substance featured largely in the ensuing dialogue.

Most of the conversations with pupils of all ages followed a consistent pattern. The pupil would propose a theory or explanation about plant growth, further discussion would lead the pupil to conclude that the theory was inadequate, an alternative theory would be proposed, challenged, replaced, and so on until the pupil often finally arrived at a position like that of the oldest girl interviewed:

I: *Just about the wood. Where does the wood come from in a tree?*
$17G_2$: ... (10 seconds) ...*No! Haven't an idea. Not a one.*

Each pupil advanced a selection from the theories given below, usually in the following order:

(a) Growth as a tautology (13 responses; 5 pre-teach, 8 post-teach)

Nine pupils of all ages offered preliminary explanations of this type. For example, in response to question 12: "How did the plant (in the stimulus item 'Growing Plant') increase in size over the five years?" two responses were:

Um (laughs) *from the little tree! From ... from the little tree.* (laughs) ($15G_1$)

Well it gets thicker in the trunk and it gets taller because the, um, stems shoot out so much. ($15B_1$)

Interview question 13, i.e. "Where does the stuff that the tree is made of come from?" produced responses of the same type:

It produces it itself. ($17G_1$)

It's just there. There's no sort of um ... it's sort of just there. It's just ... it's there. ($14G_1$)

A further four pupils focussed on annual rings as a way of explaining where the stuff comes from that a tree is made of:

Well the tree builds it (i.e. wood) *up as it grows like with the rings you get. The wood's organic in itself and it's part of the growing* *process but I wouldn't be prepared to be more specific than that. I can't really tell where it comes from, I mean how it gets there.* ($15B_2$)

(b) Growth happens because the plant absorbs materials (15 responses; 4 pre-teach, 11 post-teach)

These pupils, of all ages, readily perceived that, as a complete explanation, this was inadequate:

I: *How did this plant increase in size over the five years?*
$15B_2$: *Well the nutrients helped it grow and it could take in more nutrients and more water and put that towards the growth.*
I: *What would you say the tree's made of?*
$15B_2$: *Wood and more loosely than that organic material again.*
I: *It* (i.e. wood) *doesn't look much like the stuff that comes in through the roots does it?*
$15B_2$: *No no.*

Section (e) below shows how seven pupils developed this line of thinking. Others either supplemented it with, or abandoned it in favour of:

(c) The seed is responsible for growth (5 pre-teach responses)

Those who advanced this idea (9B, 9G, 10G, 11B, 11G) rapidly shifted their ground:

I: *Where does the stuff come from that the tree is made of?*
11G: *Out of the ground maybe. Aw, it would be in the seed or from when it was planted and it just sort of sprouts.*
I: *But it's a tiny seed and that's a big tree isn't it?*
11G: *Yeah well all the food it gets would help to grow the leaves and the branches and all that.*

(d) Plant growth is like human growth (4 responses; 1 pre-teach, 3 post-teach)

These pupils proposed explanations of this type, or at least couched the problem in human terms:

(The plant grows) *this wood, this material, just like we don't look like the food that comes into us despite the fact that they say you are what you eat.* ($15B_2$, and 12B similarly)

It grows like we grow skin. I mean I dunno where skin comes from. ($17G_1$, and $14B_2$ similarly)

(e) Growth results from changes wrought by the plant on absorbed material (4 responses; 2 pre-teach, 2 post-teach)

Three pupils pursued this idea as follows:

Might mix something up, make something, make something together, turns into that stuff. (points to 'Growing Plant') (8B)

When the plant uses them yeah uses them somehow and they turn solid somehow. ($16B_1$)

Um chemical compounds that have been used in such a way to create its leaves and its trunk and its twigs and things like that. ($17G_1$)

The other pupil suggested that humans can facilitate this:

I: *But the wood doesn't look much like the fertilizer and the water does it?*
11G: *No well it would probably be grinded up small by a machine or something and then put in the fertiliser.*

Four further pupils specifically identified the change process in plants, i.e.

(f) Growth is an outcome of photosynthesis (4 post-teach responses)

One pupil had immediate recourse to this explanation:

Well the wood itself would be a photosynthetic product. ($17B_1$)

Two others ($15B_1$, $16G_2$) employed it at an early stage to explain growth and they also identified photosynthesis as being responsible for producing wood although they were less confident about the latter point:

I: *Can you think where the wood comes from in a big tree?*
$16G_2$: *From the starch and the food that the tree makes in photosynthesis.*

I: *How does it get the wood?*
$16G_2$: *From water carbon dioxide and sunlight.*

The fourth pupil ($14B_1$) used photosynthesis to explain growth but not the origin of wood.

4.5.2.5 Wood, sugar, starch, and photosynthesis

Early in the interviews the 28 pupils were not directed towards the concept of photosynthesis. No pre-teach and only three post-teach pupils volunteered this concept to explain the origin of wood. Interview question 28, "Do you know what photosynthesis means?", was designed to elucidate which organic products pupils do associate with photosynthesis.

The 11 pre-teach pupils were at a loss to explain the meaning of the term 'photosynthesis'. Only 8 of the 17 post-teach pupils volunteered one or more specific organic products in their explanations. These were:

Pupils	Sugar	Starch	Wood
$14B_1$	S	-	-
$14G_1$	-	St	-
$15B_1$	-	-	W
$15B_2$	-	St	-
$15G_1$	-	St	-
$16G_2$	S	St	W
$17B_1$	S	St	W
$17B_2$	S	St	-
$17G_1$	S	St	-

This suggests that students' understanding of photosynthesis is centred on the production of organic materials which organisms use for energy release, i.e. sugar and starch, rather than on structural material, i.e. wood. No pupil mentioned cellulose by name.

4.5.2.6 Familiarity with sugar and starch

Sugar and starch are the plant products which feature most frequently in pupils' descriptions of photosynthesis. This section reports on interview and survey responses about sugar and starch.

In interview questions 1 and 2 (in conjunction with stimulus item A, 'Foods', page 27) pupils were invited to classify sugar and starch, along with ten other examples, as 'Food' or 'Not Food'. This exercise and its significance is reported more fully elsewhere (Barker, 1985e). For the 11 pre-teach pupils this was the only part of the interview where sugar and starch were discussed, i.e. these materials did not arise in the later conversations about plants.

Sugar was clearly a familiar substance. All but three of the 28 interviewees (8G, 12G, $14G_1$) classified sugar as food, on the grounds of its edibility (younger pupils) and that it provides energy (older pupils). The younger pupils, especially, discussed sugar mainly in the context of the breakfast table.

Starch proved to be a much less familiar substance, particularly to the younger pupils. Three of the pre-teach and 16 of the post-teach pupils classified starch as food. Five pre-teach pupils could volunteer no information about starch at all, and three associated it only with clothes and washing. The responses of four of the post-teach pupils suggested that they too were largely unaware of starch in their daily lives:

I: *Have you got any around (home) here?*
$15G_1$: *Um no I don't think so.*

Again:

Um ... you find it in   in ... I've never seen starch! ($16B_2$)

Two post-teach pupils ($14G_2$, $16G_2$) made scientifically incorrect statements about the relationships between sugar and starch:

I: *Can you tell me a little bit about starch? What it looks like? What colour it is?*
$14G_2$: *Well it's usually a sugary, not a sugary, but a fattening kind of food. It's quite sweet.*

Two other pupils made mutually contradictory statements:

It's (i.e. starch) *made up of sugars*, but later: *It's* (i.e. sugar) *broken down into starch.* ($15G_2$)

It's (i.e. sugar) *a starch*, but later: *It's* (i.e. starch) *the basis for sugar.* ($17B_2$)

Students' knowledge of the colour and physical state of sugar and starch were surveyed. A pilot survey of 53 third formers (13-year-olds) showed, as expected, that they knew the colour of sugar. When students were asked the colour of starch (Figure 23, page 74) no more than 67% of students at any level described starch as white. 'Colourless' and 'brown' were frequent alternatives (Figure 27). (Some students may have considered that white materials can be described as colourless because they lack colour. Even so, the combined total for 'white' and 'colourless' was 49% at form three level and never rose above 81%.)

A second survey item (Figure 28) investigated students' responses about the physical state of sugar and starch. Students were much more likely to give an incorrect response for starch, the most frequent alternative being to describe starch as a liquid.

4.5.2.7 Starch and classroom experiences

There were hints that four post-teach pupils may have drawn unintended conclusions from classroom experiences involving chemical testing for starch. When discussing starch as a possible food, one pupil related starch and oxygen in an unexpected way:

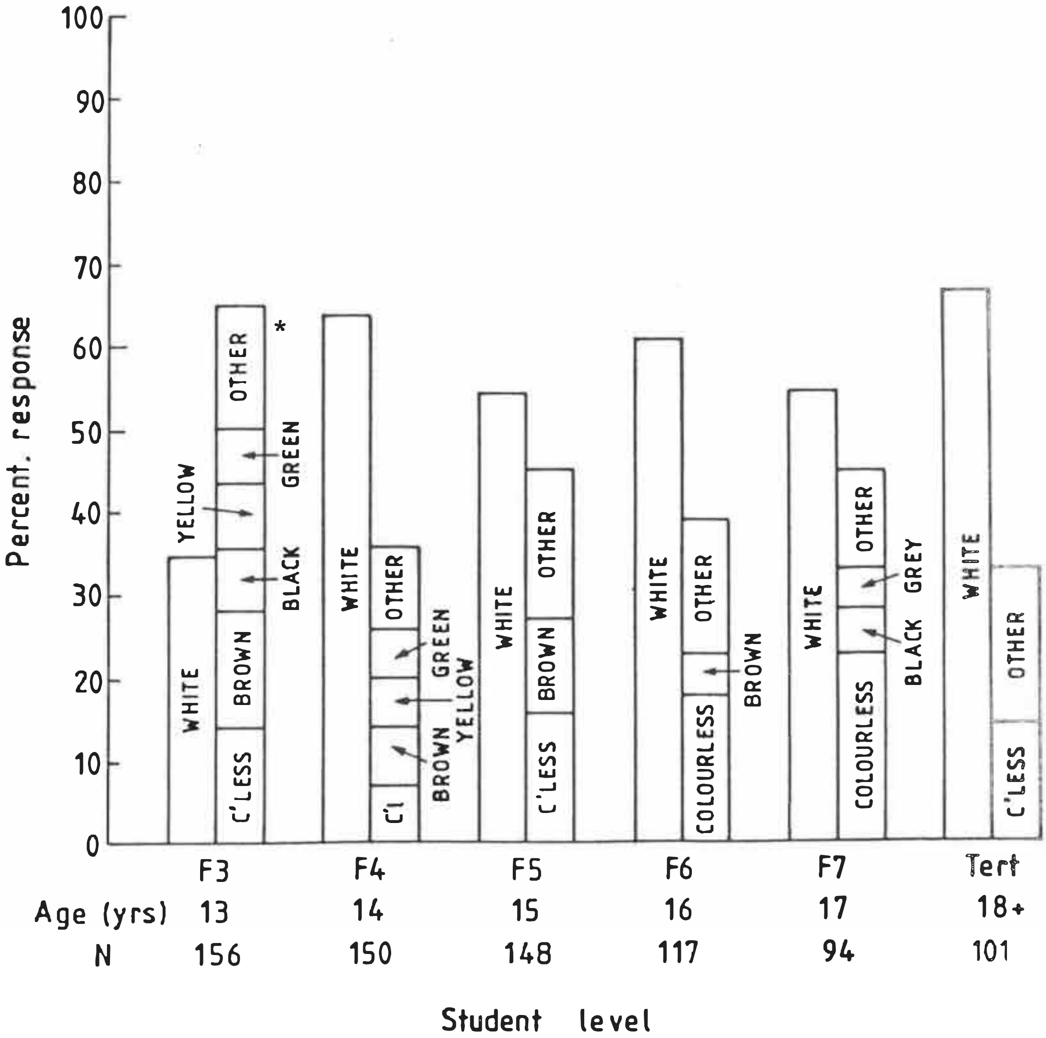
I: *Where did you hear about starch?*
$14B_1$: *We used it for telling whether um ... there's oxygen in the leaves of a tree.*

Figure 27 : Students' responses about the colour of starch.

In the table below are the names of some substances.

In the right hand column write words like : orange, grey, colourless etc. to describe the colour of each substance.

Name of Substance	Colour of Substance
Carbon dioxide	
Chlorophyll	
Iodine solution	
Bromothymol blue	
Starch	
Water	
Oxygen	

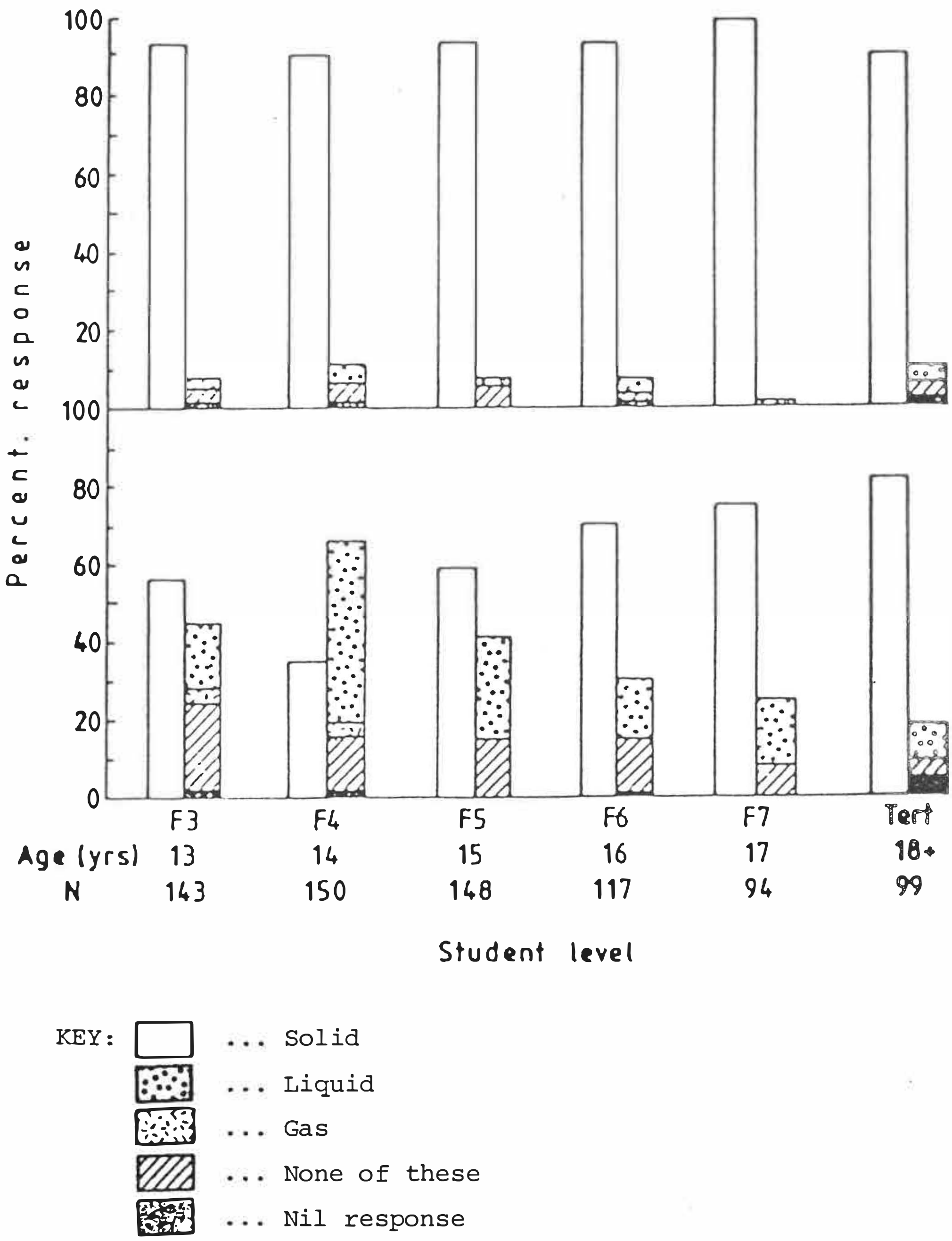


* Colours nominated by less than 5% of students at each level are grouped as "other".

Figure 28 : Students' responses about the physical state of sugar (upper graph) and starch (lower graph).

Is each of the things in the list below usually a liquid, a gas, or a solid ?
If you think that the answer is one of these, put a TICK in the correct column.
If you think it is none of these, put a TICK in the right hand column.

List	Liquid	Gas	Solid	None of these
Carbon dioxide				
Starch				
Energy				
Water				
Oxygen				
Sugar				
Sunlight				
Heat				



I: *This was at school?*
$14B_1$: *Yes, for our science.*

The second pupil appeared to be having difficulty divorcing the mechanics of the iodine test (refer page 83) from the properties of starch itself:

I: *Can you tell me what it* (i.e. starch) *looks like?*
$17B_2$: *Mm ... good question. It's white, isn't it? I'm just trying to think of that iodine test. You know where you bring out starch with iodine but I can't really...*
I: *Can you remember about the test?*
$17B_2$: *Yes. I'm not s... Putting iodine into, um, that brings out the starch ...*
I: *What did you see in the test? Do you remember?*
$17B_2$: *It's purple or something, aw, I can't remember if the starch was purple or if it was white but ah it was a certain colour that brought out the starch.*

Another pupil also initially attributed the colour which iodine solution often assumes to starch:

I: *Do you know what colour it* (i.e. starch) *is?*
$15B_1$: *Sort of red I think. No, it's the green colouring in the leaves.*

Confusing starch and chlorophyll may have caused an unintended outcome from practical work:

$16G_1$: *Well we did an experiment last year where we had a bit of black paper and put it over a leaf and then we went back a few days later and the only part that had chlorophyll was the shape that had been cut out of the black paper.*
I: *Mm. And what did that experiment tell you?*
$16G_1$: *That you need light to make chlorophyll and the oxygen.*
I: *Where does the chlorophyll come from?*
$16G_1$: *It's made.*
I: *Where?*
$16G_1$: *I don't know. In the leaves on the stalks.*
I: *And if the plant's not getting light for a while what happens?*
$16G_1$: *It would die..*
I: *What happens about the chlorophyll?*
$16G_1$: *The chlorophyll disappears and the plant can't do photosynthesis.*

4.5.3 Summary And Discussion

4.5.3.1 Children's descriptions of growth

Pupils of all ages most frequently talk of plant growth in terms of enlargement of morphological structures like wood, leaves, roots, and branches. They very infrequently talk of plant growth in biochemical terms, i.e. production of cellulose, starch, or organic material.

The origins of plant growth are difficult for pupils to explain and the comment of Driver *et al.* (1983) could well apply to many of these pupils, certainly at the start of the interview: "Growth of the tree was simply not a problem to be explained - it just happened. This suggests that for many pupils the everyday experience of the growth of plants is accepted at its face value rather than being interpreted in terms of where the additional matter comes from." Usually, by what appeared to be a process of on-the-spot invention, pupils in the present study attempted (without a great deal of conviction) to explain growth in terms of the seed, annual rings, or material absorbed from the ground. Sometimes they argued by analogy with humans. Only three pupils related what they knew about photosynthesis to the question of plant growth and the origin of wood.

4.5.3.2 Photosynthesis and organic products

Pupils sometimes miss the point that photosynthesis produces organic products, and only very infrequently do they appreciate that wood, and hence plant growth, are outcomes of photosynthesis. Only 9 of the 17 post-teach pupils who were interviewed associated photosynthesis with the formation of a specific organic product, only three of them named wood as the product, and none mentioned cellulose by name.

The results of a pencil-and-paper survey in which students were invited to respond to the question "What is photosynthesis?" are reported in full in chapter 8. In summary, this survey showed that the formation of an organic product was nominated by only 19% of third formers, 11% of fourth formers, 45% of fifth formers, 60% of sixth formers, 72% of seventh formers, and 67% of tertiary biology students.

Wandersee (1983) suggests that carbohydrates, as a group, are often not thought of as products of photosynthesis. Given a choice between carbohydrates, proteins and fats as the possible products, the percentages of American pupils who opted for carbohydrates were: 5th graders (10-year-olds) - 37%, 8th graders (13-year-olds) - 39%, 11th graders (16-year-olds) - 41%, collegians (18-year-olds) - 51%.

4.5.3.3 Knowledge about sugar and starch

Having cited oxygen, pupils nearly always quote sugar or starch as the other product of photosynthesis. Starch is usually not considered by students to be a familiar substance.

Younger children have little knowledge of starch (page 92) and the older post-teach pupils are often unclear about the relationship between starch and sugar (page 92). Post-teach students often did not nominate 'white' or even 'colourless' as the colour for starch (page 93) and frequently classified starch as a liquid (page 93). Confusion about classroom experiments involving starch (page 93) leads to the suggestion that starch is brown (the usual colour of iodine solution) or blue and/or black (the colour of the starch-iodine complex).

Dow, Auld and Wilson (1978), Simpson and Arnold (1982a), and Stavy and Stachel (1984) have reported that learners have more difficulty correctly classifying finely-powdered solids (like starch) than they do other materials. That powders can be poured appears to be a powerful argument to learners for classifying them as liquids. On the other hand, considering that students in the present study could correctly classify sugar, the confusion may be due to lack of direct experience of starch, or to students' experiences of house-hold 'liquid starch'.

4.6 SUMMARY - PLANTS AND MATERIALS

Below is a summary of the findings of chapter 4. Some effects of classroom experiences about photosynthesis on children's views, as documented fully in chapter 8, have been included below, as have some data from chapter 6 concerning children's ideas about fertilizers, minerals and nutrients.

The summary compares scientists' views with children's science views (i.e. "those views of the natural world and the meanings for scientific words held by children before formal science teaching"; Gilbert, Osborne and Fensham, 1982) and students' science views. The latter term describes the views students hold after teaching (Zylbersztajn, 1983). The table documents alternative student's science views, i.e. views held by students other than the scientists' view.

In some cases in the summary, knowledge appears to be shared (e.g. that plants absorb carbon dioxide and release oxygen), sometimes there is partial concurrence (e.g. the link between water uptake and mass increase), and in other cases the views are mutually exclusive (e.g. the relationship between carbon dioxide and mass increase), or find no point of correspondence (e.g. the green colour of leaves).

In chapter 7 the more general characteristics of the two viewpoints will be discussed.

Scientists' Views	Children's S_{ch}) and Students' (S_{st}) Science Alternative Views
Water	
As well as being necessary for a variety of other functions, water co-reacts with carbon dioxide in a process (photosynthesis) which forms organic matter (cellulose, sugar, starch) as well as oxygen gas. This results in plant growth.	S_{ch}: Water is plant food. Plants drink water. Water is needed for growth.
Carbon Dioxide and Oxygen	
Carbon dioxide and water are co-reactants in photosynthesis. Oxygen is a product in the process which also forms organic matter (cellulose, sugar, starch).	S_{ch}: Carbon dioxide is more closely related to oxygen than to water. We (i.e. humans) breathe in a gas and breathe out another gas, plants do the reverse, and this situation is essential for our continued survival.
Plant gaseous exchange and the formation of organic products are two aspects of one chemical process, i.e. photosynthesis.	S_{ch}: 'Plant breathing' occurs in isolation from other plant processes.
Photosynthesis occurs only in the green parts of a plant, i.e. those containing chlorophyll.	S_{ch}: 'Plant breathing' occurs in the flowers, stem, etc. as well as in the leaves.
Photosynthesis occurs only in the presence of light. Plant respiration occurs at all times.	S_{st}: Photosynthesis is 'plant breathing'. Photosynthesis and respiration are easy to confuse.
Leaves and Chlorophyll	
Leaves are concerned with nutrition, i.e. they produce organic material during the process of photosynthesis.	S_{ch}: Leaves have nothing to do with plant feeding. Leaves are for absorbing water and sunshine, to look beautiful, etc.
Chlorophyll can absorb red and blue light which provides the chemical energy stored in the organic products of photosynthesis.	S_{ch}: Chlorophyll is not a well-known substance. It has nothing to do with plant nutrition. S_{st}: Chlorophyll comes from the sun. Chlorophyll is produced by photosynthesis.

Sugar, Starch, Growth and Wood

Glucose sugar is an early organic product of photosynthesis. It is often stored in the form of starch. Both are important in plant respiration.	S_{ch}: Sugar (sucrose) is well known, but starch (its colour, state, nutritive function) is not well known.
Plant growth is characterised by an increase in volume or mass resulting from cell multiplication and cell expansion. Differentiation, the committing of cells to specific structures and functions, is not growth.	S_{ch}: Visible enlargement is an indication of growth. The appearance of new shoots and leaves is evidence of growth. Continued existence (as opposed to dying) is sometimes a kind of growing.
Plant growth results largely from the formation of cellulose (the major component of wood), a structural product of photosynthesis.	S_{ch}: Plant growth and where wood comes from are difficult to explain. S_{st}: Photosynthesis has nothing to do with wood and growth.
Almost all organic matter on earth originates, directly or indirectly, from photosynthesis	S_{st}: Photosynthesis does not form any specific named product.

Fertilizers, Minerals, Nutrients

Although a variety of minerals is essential for continued plant growth (e.g. nitrogen, sulphur, phosphorus) they constitute only about 5% of the weight of most plants (apart from the water). Most of the dry weight of a plant is carbohydrate (comprised of carbon, hydrogen, and oxygen) formed as a photosynthetic product.	S_{ch}: Fertilizers (maxi-crop, compost, manure) are food for plants. S_{st}: Minerals and nutrients are food for plants. Absorption of fertilizers, minerals, or nutrients is a possible explanation for where wood comes from.

CHAPTER 5 : THE FINDINGS OF PHASES 1 & 11

- THE ECOLOGICAL ENERGETIC THEME

The plant world constitutes a reservoir in which the fleeting sun rays are fixed and ingeniously stored for future use, a providential measure to which the very existence of the human race is inescapably bound.

(Julius Robert Mayer, 1845, quoted by Arnon, 1982, p.25)

5.1 PLANTS AND ENERGY - THE SCIENTISTS' VIEW

The relationship between plants and the sun has long been commented on. Aristotle considered that heat from the sun was important in transforming water and earth into plant matter: "All these (i.e. plants, fungi, truffles and the like) naturally grow in warm places, because the heat warms up the moisture in the recesses of the earth, and the sun holds the heat there, hence occurs evaporation, and hence the change into a plant" (On Plants, II, iv, 825b 19; Aristotle, translated Hett, 1936, p.207). The importance of the influence of heat on plant processes continued to be stressed until 1779 when Ingen-Housz demonstrated that "light, and not the heat, of the sun was responsible for the effect of plants in the purification of air" (Krikorian, 1975, p.40). By 1804 Nicholas de Saussure had established that when sunlight falls on the green parts of a plant, carbon dioxide and water co-react in a process, later called photosynthesis, which forms organic matter (such as sugar, starch and cellulose) as well as oxygen gas.

Energy was introduced into descriptions of plant processes in 1845 when J.R. Mayer "pointed out that solar energy is involved in plant metabolism and that part of this energy is fixed or stored in plant substances" (Nash, 1964, p.432). Photosynthesis is now often described as a process in which "by the input of the sun's energy the energy-poor compounds, CO_2 and H_2O, are converted into energy-rich compounds, carbohydrates and O_2" (Hall and Rao, 1981). In biological systems, where the energy-releasing processes are oxidations (comparable with combustion), water and carbon dioxide are frequently thought of as 'energy-poor' since they cannot be oxidised further.[11] The part which chlorophyll is now known to play in the absorption of red and blue light which accompanies the synthesis of carbohydrates has already been discussed in section 4.4.1.2.

The scientists' concept of energy is especially complex and can result in considerable difficulties for teachers and learners. This problem will be discussed in section 5.3.1.

5.2 PLANTS AND ENERGY - CHILDREN'S VIEWS

5.2.1 The Interview And Survey Questions

The interview data in this chapter comprises pupils' responses to the following seven questions:

7. Here's another picture. What's happening in this picture?
8. What happens to a boy when he stands outside in the sunshine?
9. And the tree? What happens to a tree standing outside in the sunshine?
10. Do the boy and the tree both need the sunshine? What do they need sunshine for?
15. Do you know what happens to the sunlight when it reaches a plant?
20. Could you say in a sentence or two what the word 'energy' means to you?
21. Let's go back to this picture. Is there any energy in this picture?

Stimulus item D, 'Boy/Tree/Sun' (page 31) was used in conjunction with all of the questions except numbers 15 and 20.

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11 The term 'energy-poor' requires precise definition of the reaction concerned and could cause confusion when water reacts vigorously and exothermically with a metal such as sodium.

The five survey items which contributed data to this chapter are reproduced on pages 108, 109, 112, 118 and 120.

5.2.2. Where Plants Get Their Energy From

All those interviewed (except for pupils 8B and 9B) considered that plants can have or need energy. The following is a typical interview extract:

I: *Where does it* (i.e. a plant) *get its energy from, Rachel?*
$15G_2$: *It came from the air and the sun and the ground.*
I: *It gets its energy from the ground?*
$15G_2$: *The soil. The nutrients out of the soil.*
I: *And it gets energy out of the air?*
$15G_2$: *Aw, well part of the photosynthesis is probably giving it energy, um, to make its food and stuff like that.*
I: *The energy comes from the photosynthesis?*
$15G_2$: *Um, no, it would mostly come from out of the ground, I'd say.*
I: *Does it come from the sun?*
$15G_2$: *Yeah, there's light energy and heat energy coming from the sun.*

Twenty-six pupils thought that plants obtained their energy from the sun, and additional sources of energy were proposed by 15 pupils (7 pre-teach and 8 post-teach). The sources of energy for plants are described below under five categories in decreasing order of frequency.

(a) Plants get their energy from the sun. (26 responses; 9 pre-teach, 17 post-teach)

I: *Can you say in a sentence or two what the word 'energy' means to you? Energy. What's that?*
8G: *It makes plants grow.*
I: *What sort of energy is that?*
8G: *Aw ... the sun's energy. The sun comes down and gives it energy.*

This pupil is one of 13 who used generic terms only to describe the radiation. Seven of these spoke only of 'the sun' (8G, 9G, 10B, 10G, $15B_2$, $16G_2$, $17G_2$), one talked only of 'sunshine' (13G), and the remaining five used the term 'sun's rays (12B, $14G_2$, $14B_2$, $15G_1$, $17B_2$):

I: *What's happening in this picture?*
12B: *Well the tree's getting the sun's rays and it's hitting all the leaves and giving it sort of strength and a bit of energy.*

One of these five pupils identified the sun's rays as heat:

I: *Is there any energy in this picture?*
$14B_2$: *The sun's a form of energy.*
I: *Can you tell me about that?*
$14B_2$: *Not really. It gives us all energy so it's a form of energy.*
I: *Gives us energy? Humans?*
$14B_2$: *Mm. I don't know. Only gives the tree energy.*
I: *What is it that comes from the sun to the tree?*
$14B_2$: *The sun's rays. The heat.*

In contrast to the 13 pupils who used generic terms, the other 13 pupils employed more specific terms. Six of these spoke (as would a scientist) only in terms of 'sunlight' ($14B_1$, $15B_1$, $16B_1$, $16G_1$, $17B_1$, $17G_1$) as a plant's source of energy, two talked of solar heat (11G, 12G), and the remaining five either began talking about 'sunlight' but later introduced 'heat' into the conversation ($14G_1$, $16B_2$) or stated that plants obtain their energy from sunlight and heat (11B, 13B, $15G_2$). The following four responses typify each group of pupils:

I: *Can you tell me where the tree gets its energy from?*
$17B_1$: *Well the tree gets its energy from the fact that it absorbs sunlight and then manufactures what it needs.*

I: *Does the tree get any heat (from the sun)?*
12G: *Yes, it would be getting heat 'cos the sun's giving out a lot of heat and the tree can't block it off.*
I: *What happens to the heat when it hits the plant?*
12G: *It gives it energy sort of, I think ... it's one of the ways which helps the plant to grow.*

I: *Is there any energy in that picture?* (the stimulus item)
$16B_2$: *Yes.*
I: *Can you tell me about that?*
$16B_2$: *It's the sunlight energy which ... just helps the plants to grow and stay in the right balance. Mainly heat energy in sunlight.*

I: *Can you tell me something else which a plant needs?*
13B: *Sunlight.*
I: *What happens to the sunlight when it hits the leaves?*
13B: *It gets energy from the sun through the leaves.*

I: *Can you tell me more about that getting energy?*
13B: *Mm ... I suppose ... heat, um, yeah, I suppose heat would do it. Gets heat from the sunlight.*
I: *Are they both energy?*
13B: *Yeah, I think they would be, to the plant.*

Only one pupil clearly assigned separate roles to heat and light in the way that a scientist would:

I: *What is the sunshine made up of?*
$16G_2$: *Light and heat from the sun.*
I: *Does the plant need both of those?*
$16G_2$: *Yes. It has to have the light for photosynthesis and it has to have heat as well to live otherwise it would freeze.*

Minor confusion about infra-red radiation (commonly called 'heat') was voiced as an afterthought by a pupil who had just given a detailed account of sunlight as an energy source for photosynthesis:

It absorbs the visible light (then, quietly) *Does a plant use infra-red for photosynthesis? It might for all I know. I know that plants radiate the green but is infra-red energetic enough to knock off an electron?* ($17B_1$)

More substantial difficulties were revealed when the effect of complete darkness on a plant was deliberately introduced in six interviews. Three pupils suggested that sunlight was indispensable and in its absence *it wouldn't grow*, ($14G_2$, and $14B_1$, $15B_1$ similarly). However, the responses of the other three pupils were more qualified:

They would be a bit weaker, I suppose. They would still survive. (10G)

It wouldn't grow very much and it wouldn't be very healthy. (11B and 8G similarly)

The sixth pupil voiced his uncertainly about the relative importance of heat and sunlight:

I don't think it's (i.e. sunlight) *as important as the other ones. I think p'raps instead of sunlight I should have said warmth. I don't know because you can grow many plants in a hot cupboard say with no sunlight but I don't think the plants would thrive as well without the sunlight really.* ($15B_2$)

Two survey items sought pupils' views about plants, sunlight and heat. The proposition which was put to the students: 'When photosynthesis occurs, green plants use heat from the sun' is false from the scientists' viewpoint. (Although an appropriate temperature is necessary for all cellular reactions, the photosynthesis reaction is initiated by light.) Twenty-three percent of third formers considered that this statement was false (Figure 29), rising to 82% at tertiary level. Acceptable scientific reasons such as "they don't, they use sunlight" were given by 5% of third formers and 60% of tertiary students. A selection of reasons given by third formers is shown below. (Only reason 8 was considered acceptable):

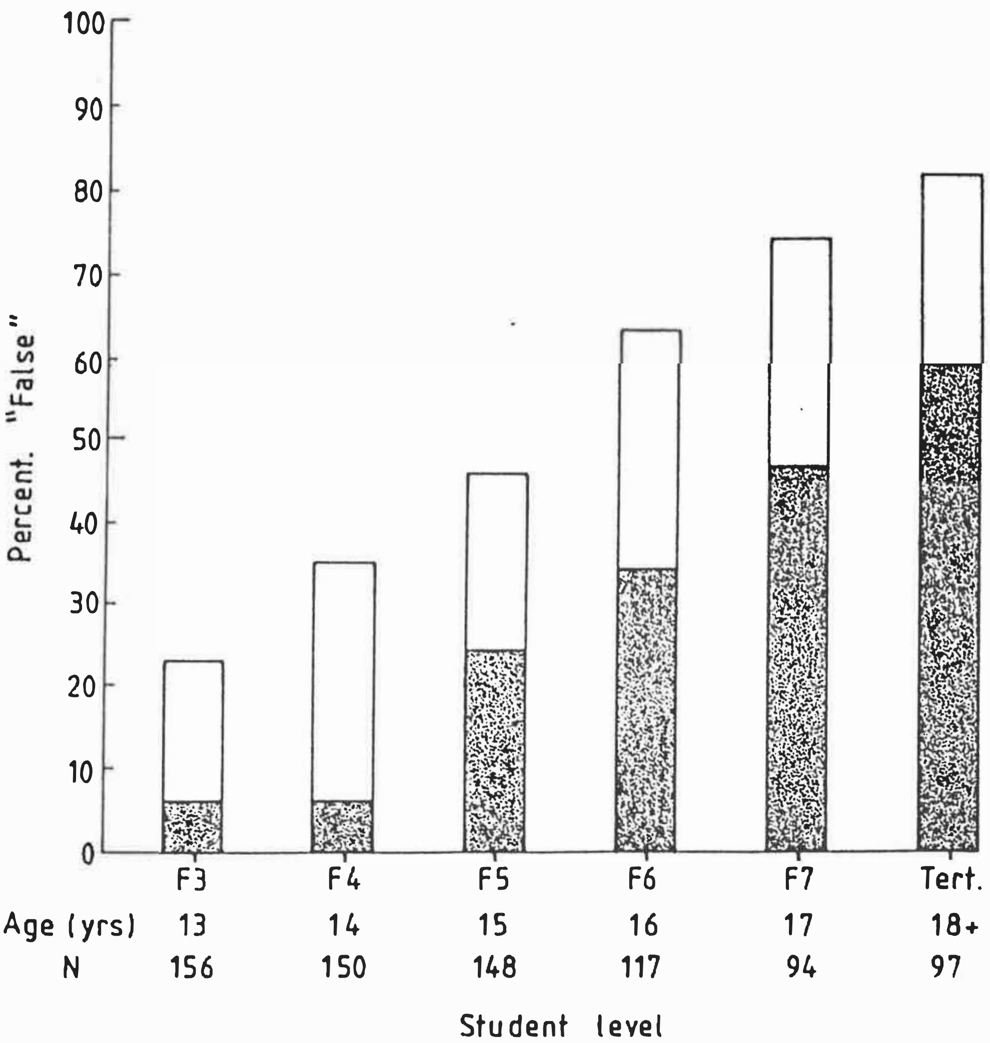
Reasons Given By Students Who Considered The Statement Was ...		
TRUE	1.	Plants use heat and light from the sun.
	2.	They can do it with the sun's heat because they need the energy.
	3.	They use the heat from the sun to make energy.
	4.	The plant uses the heat with the rays from the sun.
	5.	They use sunlight for energy to make photosynthesis occur.
	6.	Plants need sun during the photosynthesis process.
	7.	Because they don't grow at night.
FALSE	8.	It uses the light and not the heat.
	9.	Because plants use the sun for energy.
	10.	Because photosynthesis is to make food, not heat.
	11.	They use heat.
	12.	They use ultraviolet rays.
	13.	Because they make there (sic) own light.
	14.	They use it at night.
	15.	They use the rays from the sun.

The second survey item, a multichoice question about the interaction of sunlight and a green leaf (Figure 30) revealed that students at senior secondary level were still giving a significant percentage of non-scientific responses. Students' views about sunlight and green leaves are discussed further in section 4.4.2.3.

Figure 29 : Students' "True"/"False" responses to a sentence about photosynthesis, green plants and heat.

Here are some sentences written by science students.
Is each sentence true or false ? Put a TICK in one of the boxes on the right.
In the space underneath, write your reason for choosing the "true" or the "false" box.

Students' sentences	I think the sentence is ....
"When photosynthesis occurs, green plants use heat from the sun."	True ☐ False ☐
My reason :	



KEY: ▒ ... indicates students who wrote scientifically acceptable reasons.

Figure 30 : Students' responses to a multichoice item about sunlight and a green leaf.

Here are some sentences about sunlight, and a green leaf on a growing plant in the middle of the day.

Which sentences are true ? Show your answer by TICKING one or more of the boxes.

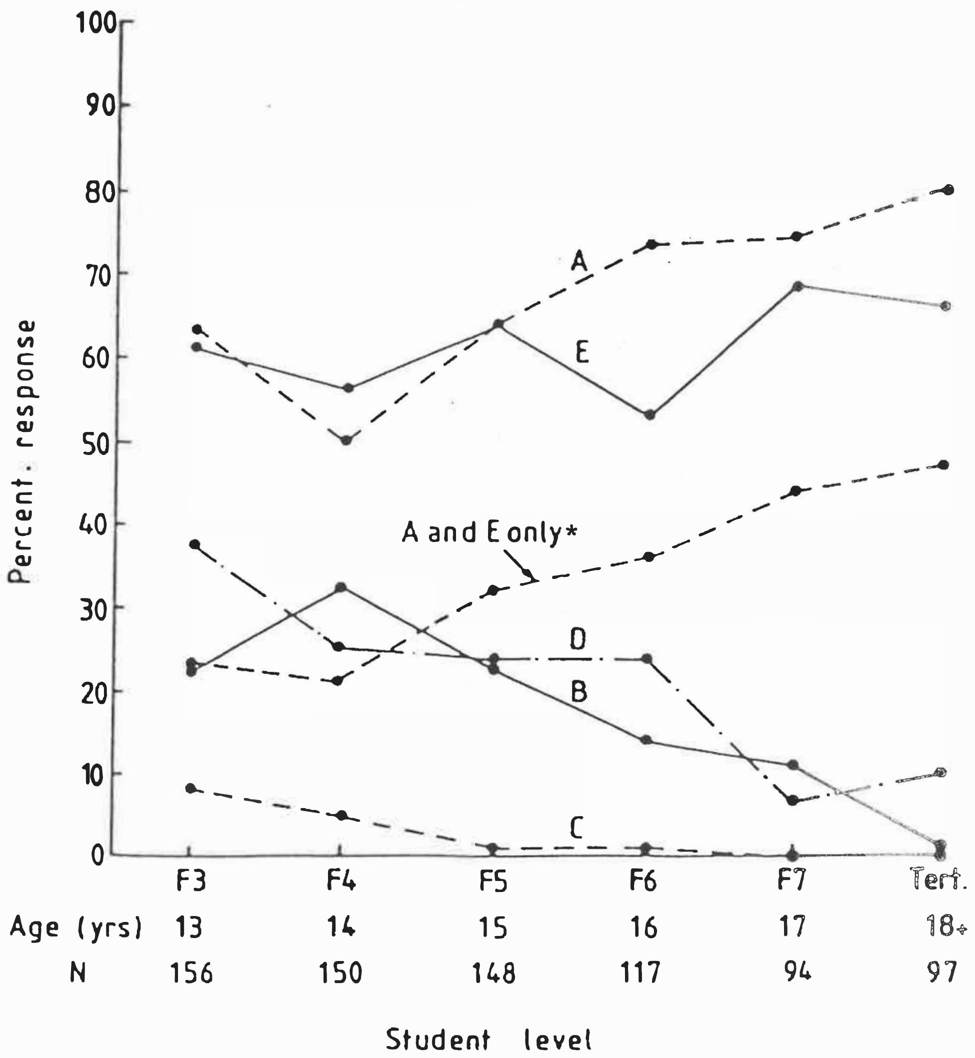
☐ The sunlight which reaches the leaf is travelling at a very high speed.

☐ There is sunlight all around the leaf but the sunlight is not moving.

☐ The leaf is making its own sunlight.

☐ No sunlight is coming away from the leaf.

☐ There is less sunlight leaving the leaf than is reaching it.



* Indicates students who gave the scientists' response, i.e. selected sentences A and E <u>only.</u>

(b) Plants get their energy from the soil. (14 responses; 7 pre-teach, 7 post-teach)

Four pupils named the soil itself:

I: *Where does the tree get its energy from?*
10G: *Soil, the water, the sun.*
I: *Mm. Does the plant get more energy from the sun or more from the soil?*
10G: *I think it gets more from the soil because, you know, the soil is more food and um ... dunno.*

Particular materials in the soil were also nominated. These were minerals (including phosphates and nitrates) - 5 responses; vitamins - 2 responses; protein - 1 response; starch - 1 response; nutrients - 1 response. Both pupils who cited vitamins (8G, 12G) mentioned them in conjunction with minerals:

I: *You talked about vitamins. Does a tree get vitamins from the soil?*
12G: *Yeah, I think so. Vitamins and minerals from the soil.*
I: *Are vitamins and minerals the same as each other?*
12G: *No. The vitamins are sort of, um ... I'm not sure really how they are different. I just think they are.*
I: *What are vitamins for?*
12G: *They are to give energy. There's energy in vitamins.*

(c) Plants get their energy from water. (5 responses; 3 pre-teach, 2 post-teach)

I: *Where's the tree getting the energy from?*
$15B_2$: *From the sun, from the water by the roots, from the nutrients, and the carbon dioxide.*

(d) Plants get their energy from air. (4 responses; 1 pre-teach, 3 post-teach)

Two pupils ($15G_2$, $17G_2$) named air as a source of energy for plants and two others (10B, $15B_2$) specified carbon dioxide.

(e) Plants get their energy from the wind. (1 pre-teach response)

I: *Where does the tree get its energy from?*

11G: *The sun and maybe when it's windy, um, it might have some energy when it just moved its branches or something.*

The findings of a further survey item (Figure 31) summarise this section. Although it showed that students usually recognise the sun as a source of energy for plants, it also revealed that many students consider that there are multiple sources of energy for plants. The responses of students who indicated that plants obtain their energy only from the sun did not reach 50% until form seven, i.e. 17-year-olds.[12]

5.2.3 Why Plants Need Energy

As has been noted (page 104) only two pupils (8B, 9B) expressed doubts as to whether plants could have, or need, energy. Apart from two pupils (10G, 11G), all the remaining 26 pupils expressed at least one and sometimes as many as three reasons why plants need energy:

(a) <u>Plants need energy for photosynthesis.</u> (11 post-teach responses)

Nine pupils (all post-teach) stated that energy was necessary for producing sugar (glucose) and/or starch (seven pupils) or food (two pupils) in the process of photosynthesis. Four of these pupils ($15G_1$, $15B_2$, $17G_1$, $17B_2$) stated that energy was needed for the process but only in very general terms:

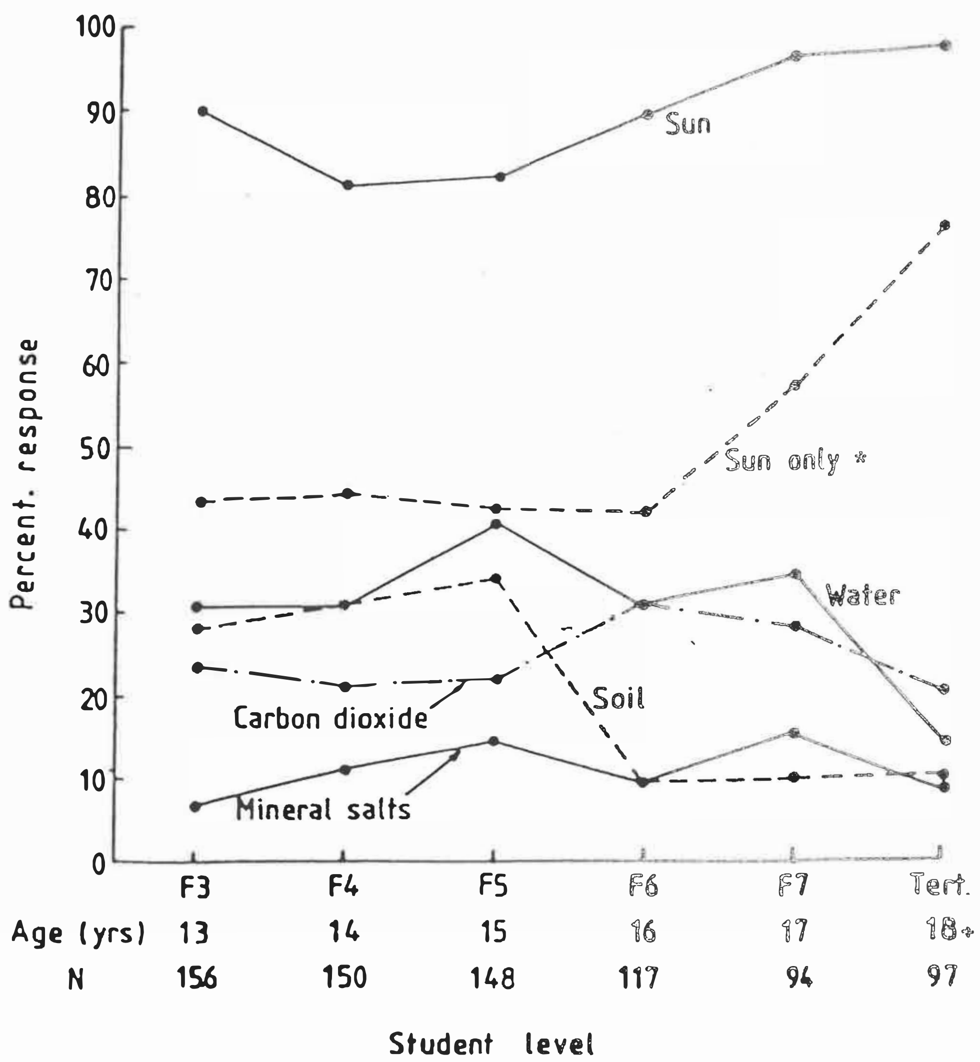
12 By way of comparison, a similar item (Barker, 1985d) which questioned where our (i.e. human beings') energy comes from was administered to the same group of students. While most students considered that we obtain our energy from food, additional sources of energy were again cited. The percentage of students who indicated that we obtain our energy from food only did not reach 50% until form seven.

Figure 31 : Students' responses about where a green plant gets its energy from.

Where does a green plant get its energy from ?

Show your answer by TICKING one or more of the boxes :

☐ Soil ☐ Sun ☐ Mineral salts ☐ Carbon dioxide ☐ Water



* Indicates students who gave the scientists' response, i.e. selected 'sun' only.

I: *What happens when the sun s rays strike the leaves and the flower?*
$15G_1$: *Um, the plant draws in the energy that it gets from it on the sun and makes food out of it.*
I: *Makes food out of the sun's rays?*
$15G_1$: *Yes.*
I: *Can you tell me any more about the making food?*
$15G_1$: *Um ... aw ... no. I dunno.*

The other five pupils ($14B_1$, $14B_2$, $15B_1$, $16G_2$, $17B_1$) indicated that energy becomes stored in the products:

I: *You said the energy approaches the leaf. Where does it go then?*
$14B_1$: *Um, into the leaves.*
I: *O.K. What happens to the sunlight in the end?*
$14B_1$: *It gets turned into energy and, er, and the plant uses the energy from sunlight to make the photosynthesis ... for the photosynthesis.*
I: *Where does the energy go?*
$14B_1$: *Um, into the sugar.*

Only one of these five pupils went close to highlighting the energy difference between photosynthetic reactants and products. Having previously described how the sun's energy becomes *locked up in the form of bonds in ... organic molecules* he was then asked:

I: *That's* (i.e. the sun) *the only place where it* (i.e. a tree) *gets its energy from?*
$17B_1$: *... As far as I know. I mean, it has to absorb molecules and water but when it needs energy the energy input in the tree is in the form of sunlight.*

Two other post-teach pupils ($16B_2$, $17G_2$) related energy and photosynthesis, but they described photosynthesis in non-material terms:

I: *Can you tell me what that word* (i.e. photosynthesis) *means to you?*
$17G_2$: *Mm. Without actually knowing exactly what it does I would say that it changes one form of energy to another like it changes whatever it gets out of the air or the sun or whatever, I forget which, into a form of energy that it can use, so I guess that's what I'd call it. Something that can change energy from one form to another.*

One pre-teach pupil (12B) considered that plants need energy for a "food-making process" but he did not associate this with photosynthesis.

(b) Plants need energy for growth. (9 responses; 4 pre-teach, 5 post-teach)

Nine pupils stated that plants need energy for growth or growing. Six of them suggested that the energy was needed to cause the growing process to occur and some suggested that its involvement was short-lived:

I: *Where did the energy go?*
11B: *Into making itself grow.*
I: *Where is the energy now?*
11B: *... mm ... well, it would be getting some all the time and it would be growing all the time so the energy would be coming and going pretty fast.*

I: *Do you know what happens to the energy (from the sun)?*
12G: *I think it helps it. One of the ways which helps a plant to grow.*
I: *Where does the energy go in the end after the growing?*
12G: *It's just used up in the tree growing.*

Only one pupil expressed a contrary view, i.e. that the energy is not readily dissipated, but like pupil $15G_1$ (page 113) her answer suggested that the energy is converted into matter:

I: *Where does the energy (from the sun) go in the end?*
$14G_2$: *It gets used in the plant to help it grow. It's not, you know ... but it does stay in the plant.*
I: *I see. Where does the energy go in the end?*
$14G_2$: *It's turned into atoms and that makes the plant grow.*

(c) Plants need energy to maintain life. (6 responses; 2 pre-teach, 4 post-teach)

Five pupils (10B, 13B, $15G_1$, $16B_1$, $16B_2$) stated that plants need energy to live or to stay alive:

I: *Is there any energy in the plant?* (i.e. in the stimulus item)
$16B_2$: (laughs) *By rights there should be but I don't know.*

I: *Why do you think there should be energy in the plant?*
$16B_2$: *Because if they had no energy they would just go PHUT!! Just wouldn't be able to live.*

Only one of these five pupils was more specific. He was apparently thinking of a translocation function:

Without energy the sap wouldn't run upwards. (10B)

Similarly, the final pupil in this group stated that a plant needs energy to *move atoms around.* ($14G_1$)

5.2.4 Using Energy And Storing Energy

Views about energy being used to sustain certain plant processes (photosynthesis, growth, maintenance of life) were widespread. However only 5 of the 17 post-teach pupils suggested that energy becomes stored in what they considered to be photosynthetic products, i.e. sugar and starch.

In eight of the interviews with post-teach pupils, opinions about the energy content of wood were sought by the interviewer or volunteered by pupils. One of these eight pupils, thinking about combustability, reasoned that there was energy stored in wood:

I: *Is there any energy stored in wood?*
$17G_2$: *Yes.*
I: *How do you know that?*
$17G_2$: *... Energy in wood ... well it gives out heat and it gives out light. Those are forms of energy so there must be energy in it to change to those things.*

Four of the remaining seven pupils ($14G_1$, $14G_2$, $16B_2$, $16G_1$) stated that there would only be energy present in wood in a living plant:

I: *Would you say there was any energy in wood?*
$16G_1$: *While it's still living. While it's in the tree there must be some energy going through it but when it's been chopped down there isn't any energy in it.*
I: *Can you tell me about the energy going through it when it's living?*
$16G_1$: *It's the energy passing up through the roots and up to the leaves so they can do all their jobs.*

The other three pupils ($13G$, $15B_1$, $16G_2$) did not think that energy could be stored in wood:

I: *Is there any energy in wood?*
13G: (laughs) *No, I don't think so.*
I: *So is there much energy in a plant at all?*
13G: *No, except for the sun. That's the only energy.*
I: *And the sun? What happens to the sun?*
13G: *The sun shines down on the tree.*
I: *And what happens then?*
13G: *The tree grows.*

Ten pupils (11B, 12B, 12G, 13B, 13G, $14G_1$, $14G_2$, $15G_1$, $16G_1$, $16B_2$) may have had an alternative model for plants and energy. According to this model, the sun (and perhaps the ground) energises a plant directly and the energy circulates rapidly through the plant, facilitating vital processes. The youngest (11B) described energy as *coming and going pretty fast* in a plant. Pupil 12B described the action of the sun on a plant as follows:

12B: *Um well it goes on and the sun isn't ... it's sort of a bit like ice, um, it can't really stay there very long 'cos its energy would sort of run out and all its energy goes into the leaves and then it sort of melts away and goes away.*
I: *I see. And that would happen how soon after the sun's rays had hit the plant?*
12B: *Aw about ... half an hour because they get more all the time.*

Pupil $14G_1$ considered that the energising process occurred more rapidly than did pupil 12B and she also described the fate of the energy:

$14G_1$: *The energy goes sort of through the leaves and down the stalk and right down into the roots and then the roots circulate it around and then it goes back up again.*
I: *How did you find out about that?*
$14G_1$: *We did it in science last year but I've forgotten quite a bit of it though.*
I: *Yeah. This idea of energy moving around the plant ...*
$14G_1$: *Yeah, it goes all the way around the plant and then it sort of wears out and by the time it wears out there is always more to come through again.*
I: *I see. Does this take quite a long time or how do you see it?*
$14G_1$: *Not very long. Probably takes a minute two or three minutes to go right around and then it's dead.*

Two survey items also suggested that children and scientists may differ in their views about plants and energy storage. Students' views about the proposition that 'during photosynthesis, energy is stored up in food' were explored (Figure 32). In the view of many school text-books the proposition is true (see chapter 6). A selection of the reasons advanced by third form students is given below (including the acceptable response, i.e. reason 1).

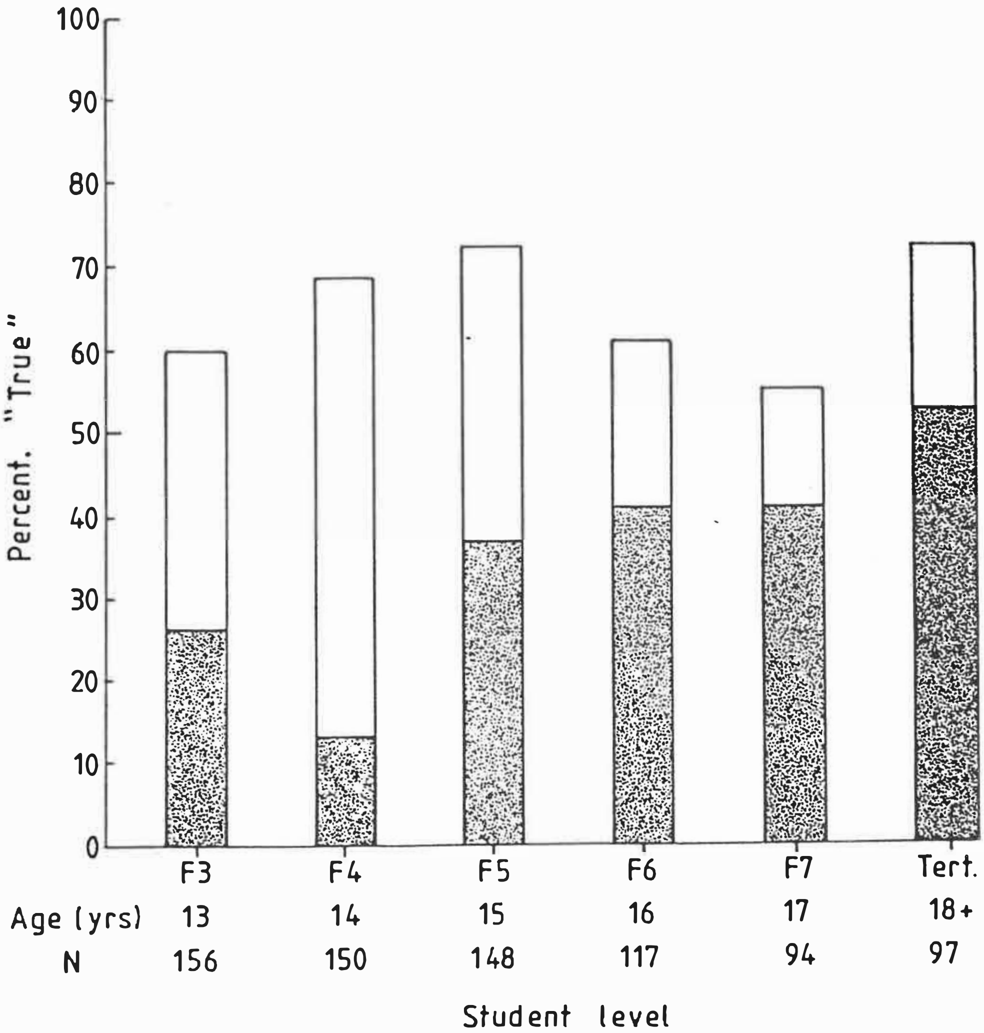
Reasons Given By Students Who Considered The Statement Was ...		
TRUE	1.	Because energy is stored up in the form of sugar which is the plant's food.
	2.	Because plants make their own food by sunlight.
	3.	Food is energy.
	4.	Yes because there was energy in the food already.
	5.	The plant uses photosynthesis to bring food up from the soil which it stores in the leaves.
	6.	Food is made up of most of the minerals the plant absorbs.
FALSE	7.	Because they get their energy from the sunlight.
	8.	Because it gets energy all the time.
	9.	The energy circulates around the plant.
	10.	It cannot store energy in food because energy goes in and out.
	11.	What's the use in storing the energy up?
	12.	It is making energy from sunlight so this is false.
	13.	Because it has to go straight to the plant all the time instead of being stored.
	14.	During photosynthesis the plant is making the food, not storing the energy in food.
	15.	Photosynthesis is not used for producing food.
	16.	During photosynthesis energy is produced as food.
	17.	Because the food is in the soil and that's where plants get their food from.

The form three students often suggested that plants used solar energy directly and did not need to store energy (reasons 7 - 13 above). Students' notions about making or producing food or the identity of food (reasons 4-6 and 14-17) which differed from the teacher's view were also found. The views that children have about plants and food are explored further in chapter 6. Non-scientific statements about the nature of energy were evident (reasons 2 and 3).

Figure 32 : Students' "True"/"False" responses to a sentence about photosynthesis, energy and food.

Here are some sentences written by science students.
Is each sentence true or false ? Put a TICK in one of the boxes on the right.
In the space underneath, write your reason for choosing the "true" or the "false" box.

Students' sentences	I think the sentence is ....
"During photosynthesis, energy is stored up in food."	True ☐ False ☐
My reason :	



KEY: ... indicates students who wrote scientifically acceptable reasons.

The second survey item (Figure 33) explored students' views about the substances usually associated with photosynthesis and their stored energy. The percentages of students who gave the scientists' response (selecting wood, sugar and starch only) showed that growth in awareness of energy-rich and energy-poor as concepts was gradual. A consistently lower percentage of students selected wood rather than sugar or starch. In classroom discussion after survey, students who had responded positively for wood used their understanding of combustion to effectively persuade others to their point of view.

5.3 TOWARDS TEACHING ABOUT PLANTS AND ENERGY

5.3.1 Biologists' And Children's Views About Energy

According to Wood-Robinson (1985), the biologists' viewpoint on energy (as evidenced in the teaching of photosynthesis, respiration, animal nutrition, and the interdependence of living organisms) places little reliance on a definition of energy as 'the capacity to do work' or on a rigorous thermodynamic approach. Biology teachers more frequently consider the heats of combustion of organic materials and take a more literal everyday view of the nature of energy conservation.

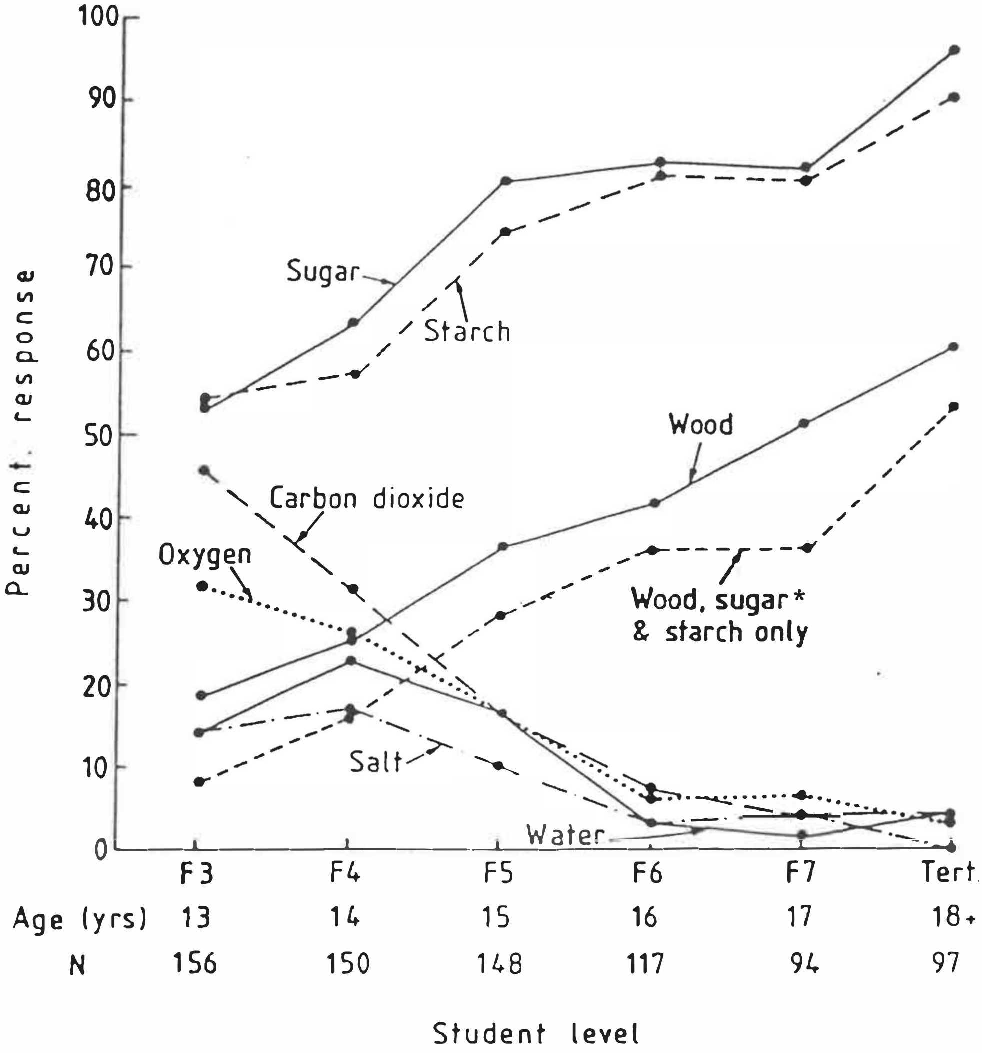
Teaching and learning about energy at large has received considerable attention (Welch, 1985), including studies which have investigated children's views (Gilbert and Watts, 1983). This section discusses three such studies (Stead, 1980b; Solomon, 1982; Watts, 1983a) which serve as the background to a summary of the present findings (section 5.3.2).

Figure 33 : Students' responses about common substances and stored energy.

Here are some common substances. Which of them has a lot of stored energy ?
Show your answer by TICKING one or more of the boxes :

☐ Oxygen ☐ Sugar ☐ Water ☐ Salt

☐ Starch ☐ Wood ☐ Carbon dioxide



* Indicates students who gave the scientists' response, i.e. selected "wood", "sugar", and "starch" only.

Stead (1980b) interviewed 52 pupils (11 to 16-year-olds) and found that younger children frequently related the word 'energy' to living things which need or use energy to be active, i.e. they associated energy with movement, fitness and strength. By contrast, inanimate objects (especially non-moving ones) were seen as not needing or using energy. Stead considered that early emphasis in school on food chains and community organisation could reinforce this view of energy. She found that older children also associated energy with fuels. However, in some cases this meant that fuels were seen to be energy rather than a source of energy. Barker (1985d) confirmed this tendency towards reification with regard to the non-material components of photosynthesis. Students were asked to indicate whether energy and sunlight (and a number of photosynthetic materials) were usually a liquid, a gas, a solid, or none of these. Non-scientific responses (i.e. responses other than 'none of these') for energy and sunlight were given by 27% and 22% of third formers respectively. These values dropped steadily with older students. 'Gas' was by far the most common non-scientific response at all levels. Some of these students later offered verbal justifications along the lines that "natural gas is energy, isn't it?"

Solomon (1982) documented students' difficulties when they are extending their concept of energy as 'energeticness' to fuels: "The subject of photosynthesis and the storage of energy in foods occurs early in most integrated science courses. Although pupils are ready enough to see a connection between eating and energy, they find it harder to imagine how active 'energeticness' could be stored in quiescent food or fuel."

Watts (1983a), as a result of interviews with forty 14 to 16-year-olds, described seven alternative frameworks which the pupils used for energy. Each framework was used more than once in each interview, and by more than one pupil. According to Gilbert and Pope (1982), the four of these seven frameworks which were most commonly utilised by pupils were:

- depository: energy is a causal agent, stored within certain objects.
- obvious activity: energy is often viewed as movement itself.
- fluid transfer: energy as a flowing, fluid substance.
- human centred: inanimate objects do not have energy.

5.3.2 Summary And Discussion

While nearly all students in the present study consider that plants obtain energy from the sun, many also believe that plants obtain energy from the soil and its contents (e.g. minerals), water, air and wind. Solomon (1983) noted that the proposition that 'all energy comes from the sun' (even nuclear energy) is almost universally held by children: "It seemed like a litany, or a relic of the young child's view which colours the sun so brilliantly and huge in their painting." Stead (1980b) also found that some students believe that plants obtain energy from the soil and from water as well as the sun.

Some pupils have alternative views about the form of solar energy supply to plants. Young children often use generic terms to describe radiation, and the more specific terms 'heat' and 'light' are sometimes used interchangeably by pupils at all levels. Solar heat is often considered to be utilised by plants in photosynthesis. Some students consider that the sunlight around a plant is non-mobile and that it is absorbed by the plant in its entirety. The tendency of students to use the terms 'light' and 'heat' interchangeably has also been noted in a general context by Lemke (1982), and with regard to the effects on a plant in particular (Watts, 1983b).

Students' responses to a survey item (page 109) about plants and sunlight are consistent with what is known of children's views about light in general terms (Happs, 1983; Gilbert and Watts, 1983). The responses also confirm the comment of Stead and Osborne (1980) that "with regard to the transmission of light, some students did not see light as travelling at all." However, of particular relevance to the understanding of photosynthesis is the finding from the same survey that nearly 40% of third formers considered that no sunlight was coming away from the leaf. This view became less frequent with older students. The finding is consistent with that of section 4.4.2.3 which suggested that the two interviewees "who adequately described the function of chlorophyll were the only ones who gave a reasonable explanation as to why plants look green." Smith and Anderson (1983) also noted that the difficulties which children have in explaining why objects appear coloured has a bearing on their understanding of the part sunlight plays in photosynthesis.

Many students consider that energy which a plant receives from the sun is used immediately and directly to sustain vital processes in plants. This through-flow occurs rapidly and plants are often not considered by students to contain stored energy. This is considered further in section 12.3.1.

5.4 SUMMARY - PLANTS AND ENERGY

Below is a summary of the findings of chapter 5 expressed in terms of scientists' views, children's science views, and students' science alternative views (as defined on page 99).

As was found in chapter 4, the extent of agreement varies widely, ranging from issues on which common ground is evident (e.g. the importance of the sun as an energy source) through to issues where the views are mutually exclusive (e.g. the question of possible energy storage in plants). In chapter 7 the more general characteristics of the two viewpoints will be discussed.

Scientists' Views	Children's (S_{ch})[13] and Students' (S_{st})[14] Science Alternative Views
Plants utilise light as their only external energy source.	S_{ch}: Plants obtain energy from the sun. The soil and its contents (e.g. minerals), water, air and wind are sometimes also cited as energy sources. S_{st}: Even at tertiary level some students still consider that plants have multiple sources of energy.
Apart from red and blue light,other radiation from the sun,including infra-red (often labelled heat) and much of the green light, is either re-radiated or dissipated by convection or conduction.	S_{ch}: The terms 'heat' and 'light' can often be used interchangeably. S_{st}: Plants can use solar heat as an energy source for processes like photosynthesis.
By the input of light the energy-poor compounds carbon dioxide and water are converted into energy-rich compounds, carbohydrates, and oxygen. As photosynthesis proceeds, energy can be described as stored in these plant substances.	S_{ch}: The energy which a plant receives from the sun is used immediately and directly to sustain vital plant processes. This through-flow of energy occurs rapidly and plants are often not considered to contain stored energy.

13 Views held by children before formal science teaching.

14 Non-scientific views held by students after science teaching.

CHAPTER 6 THE FINDINGS OF PHASES I & II - THE TROPHIC THEME

The roots of plants are analogous to the mouths of animals, both serving for the absorption of food.

(Aristotle, De Anima)

6.1 PLANTS AND FOOD

6.1.1 The Scientists' View

There is no commonly-accepted scientific definition of 'food' (Barker, 1985e) and scientists usually do not use the term in connection with photosynthesis. However, the notion of food has been important in many earlier explanations about plants.

Aristotle believed that the key to the understanding of plants was to be found in the study of animals (Krikorian, 1975) and in the view of scholars in his time "the absorption of food is part of the principle of the plant's nature, and this is a characteristic common to animal and plant" (On Plants, I, 1, 816b13; Aristotle, translated Hett, 1936, p.151). It followed that "the roots of plants are analogous to the mouths of animals, both serving for the absorption of food" (De Anima, II, 1, 412b3; Aristotle, in Hutchins, 1952, p.642). The general notion was that the soil acted for plants somewhat like the stomach in animals, where materials were predigested and supplied to the organism (Krikorian, 1975) and "consequently food is being supplied continuously to the feeder, until it reaches its season of decay: and both plants and animals must employ food of the same kind as the elements of which each of them is composed" (On Plants, I, 1, 816b20; Aristotle, translated Hett, 1936, p.151).

The Aristotelian view, that the materials of which a plant is composed are contained in that form in the earth, was opposed in the seventeenth century by van Helmont and Robert Boyle who argued that plants are capable of transmutation, i.e. direct transformation of water. Boyle believed that a plant grown in pure water "would appear to have been materially but[15] water with what exotic quality so ever it may afterwards, when transmuted, be endowed" (Boyle, 1772, p.69). His proof was that by distillation of a plant so grown, a true oil could be obtained which would not mix with water (Harré, 1964, p.83).

However, the Aristotelian view persisted. By the mid 18th century Jethro Tull, the English agriculturist, still equated roots with guts (Tull, 1751, p.7) and thought of plant nutrition as follows (p.14): "The chief Art of an Husbandman is to feed Plants to the best Advantage; but how shall he do that, unless he knows what is their food? ... 'Tis agreed, that all the following Materials contribute, in some manner, to the Increase of Plants; but 'tis disputed which of them is that very Increase or Food, 1. Nitre 2. Water 3. Air 4. Fire[16] 5. Earth." Tull's argument for selecting earth was supported by Erasmus Darwin (1800) who held that "vegetables are in reality an inferior order of animals" (p.3) but that "vegetables are immoveably fixed to the soil from whence they draw their aliment ready prepared" (p.5).

In the 17th century another tradition, the precursor to the present scientific view of photosynthesis, arose. This proposed that leaves rather than roots are the centres of plant nutrition and it focussed on air as the likely source of plant nutriment. By the early 19th century the process of drawing analogies between plants and animals and attempting to identify which absorbed materials constitute

---

15 i.e. only

16 Possibly Tull was thinking of the sun.

food for plants was no longer considered to be fruitful (Delaporte, 1982).

Today, scientists equate the process of photosynthesis with plant nutrition and their explanations are expressed almost entirely in biochemical and energetic terms, e.g. Hall and Rao (1981), Arnon (1982). The term 'food' is employed, in an imprecise way, only in a wider ecological context. Feeding is implicit in the term 'autotroph' (auto, Gk, self; trophos, Gk, nourishment) which is used to describe green plants, but the definition of this term is from a biochemical and energetic perspective, i.e. autotrophs are organisms which can use carbon dioxide from the physical environment and require an external energy source (Anderson, 1980).

6.1.2 Teachers' Views

A survey of 127 teachers investigated their views about four propositions involving plants and food. They were asked if they would encourage or discourage a pupil who was heard to volunteer one of the following four propositions:

1. "Plants make their own food in their leaves."
2. "A plant's food is starch" (or "sugar" or "carbohydrate").
3. "Plants take in their food from the soil" (or "the air").
4. "A plant's food is water" (or "minerals", or "sunlight", or "oxygen", or "carbon dioxide").

The 42 primary teachers responded in the context of a standard four (10-year-old) pupil and the 85 secondary teachers in the context of a form three (13-year-old) pupil. Pre-service and in-service teachers at both levels were surveyed.

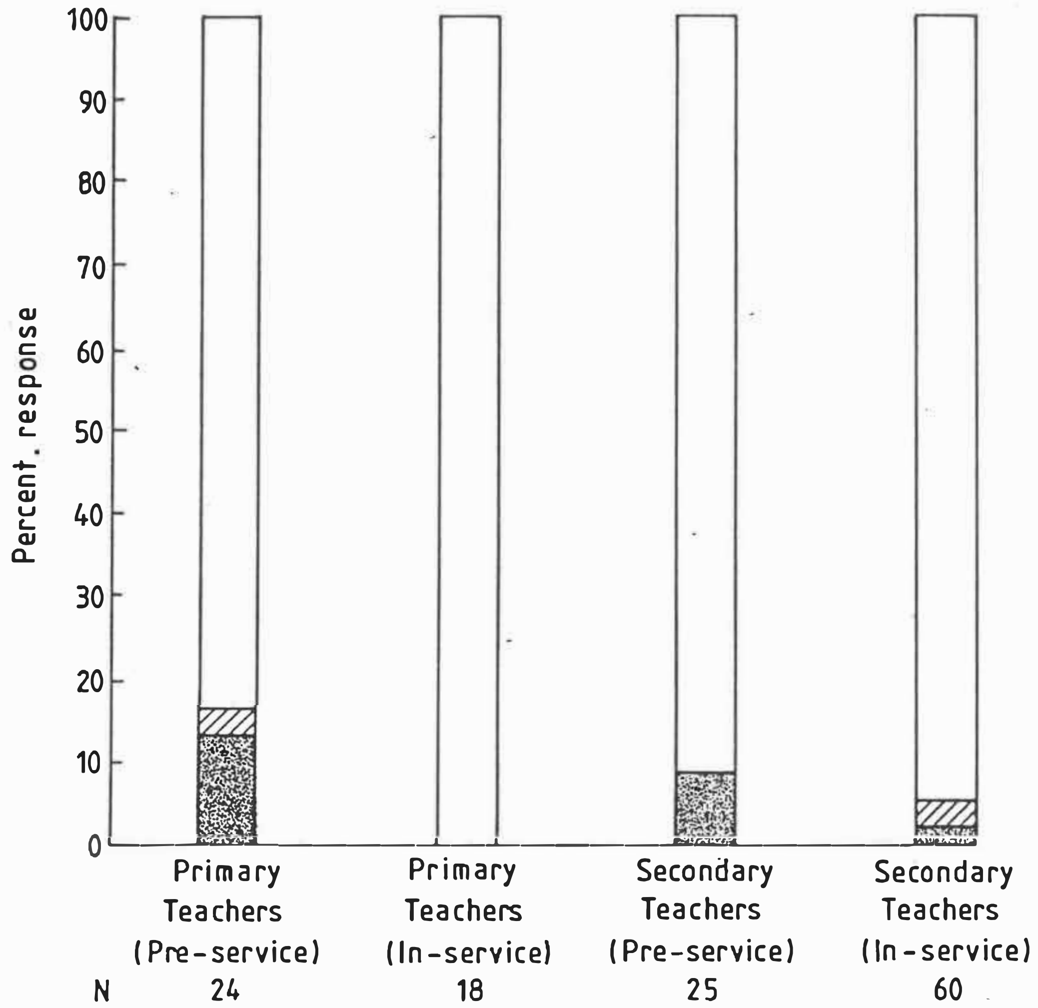
Teachers indicated whether each proposition was to be encouraged or discouraged by writing a tick or a cross on an informal survey sheet. They wrote a question mark if only a qualified response was possible or if only part of the proposition was to be encouraged. They were also asked for their comments. The survey was conducted in as relaxed a manner as possible either on a one-to-one conversational basis (17 of the 60 secondary in-service teachers), or in small groups but with individual responses during in-service courses (the remaining 43 secondary in-service teachers and the 18 primary in-service teachers), or during the course of the normal Teachers' College time-table (the 25 secondary and 24 primary pre-service teachers).

The teachers generally considered that the proposition that "Plants make their own food in their leaves" (Figure 34) and "A plant's food is starch" (or "sugar" or "carbohydrate") (Figure 35) were to be encouraged in their students but they were more divided about whether the materials which plants absorb can also be considered as food. Although a clear majority of secondary teachers considered that the propositions that "Plants take in their food from the soil" (or "the air") (Figure 36) and "A plant's food is water" (or "minerals", or "sunlight", or "oxygen", or "carbon dioxide") (Figure 37) were to be discouraged, the primary teachers were about equally divided. It would appear that by the time children reach form three, teachers are encouraging them to regard photosynthetic <u>products</u> as food and discouraging them from considering <u>absorbed</u> materials as food.

6.1.3 Views Expressed In Text Books

Ten texts in current use in New Zealand form three to five science and biology classes (i.e. 13 to 15-year-olds) were examined with regard to their treatment of the concept of food. The books had been published over the period 1978-83, five in New Zealand, three in

Figure 34 : Teachers' responses to the proposition "Plants make their own food in their leaves".



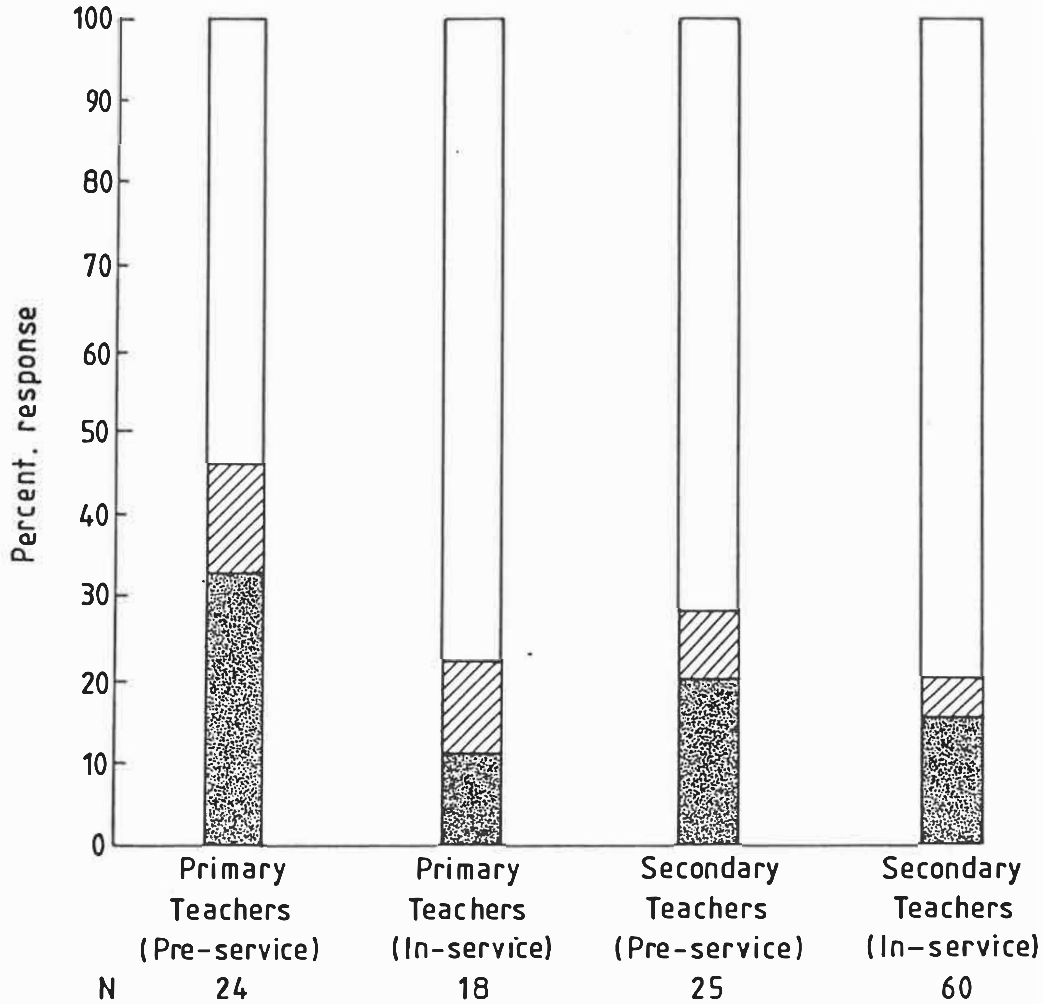
KEY:

... indicates teachers who thought that the proposition should be encouraged.

... indicates nil teacher response; a qualified response, e.g. "needs some modification"; or indicated that only part of the proposition should be encouraged.

... indicates teachers who thought that the proposition should be discouraged.

Figure 35 : Teachers' responses to the proposition "A plant's food is starch" (or "sugar" or "carbohydrate").



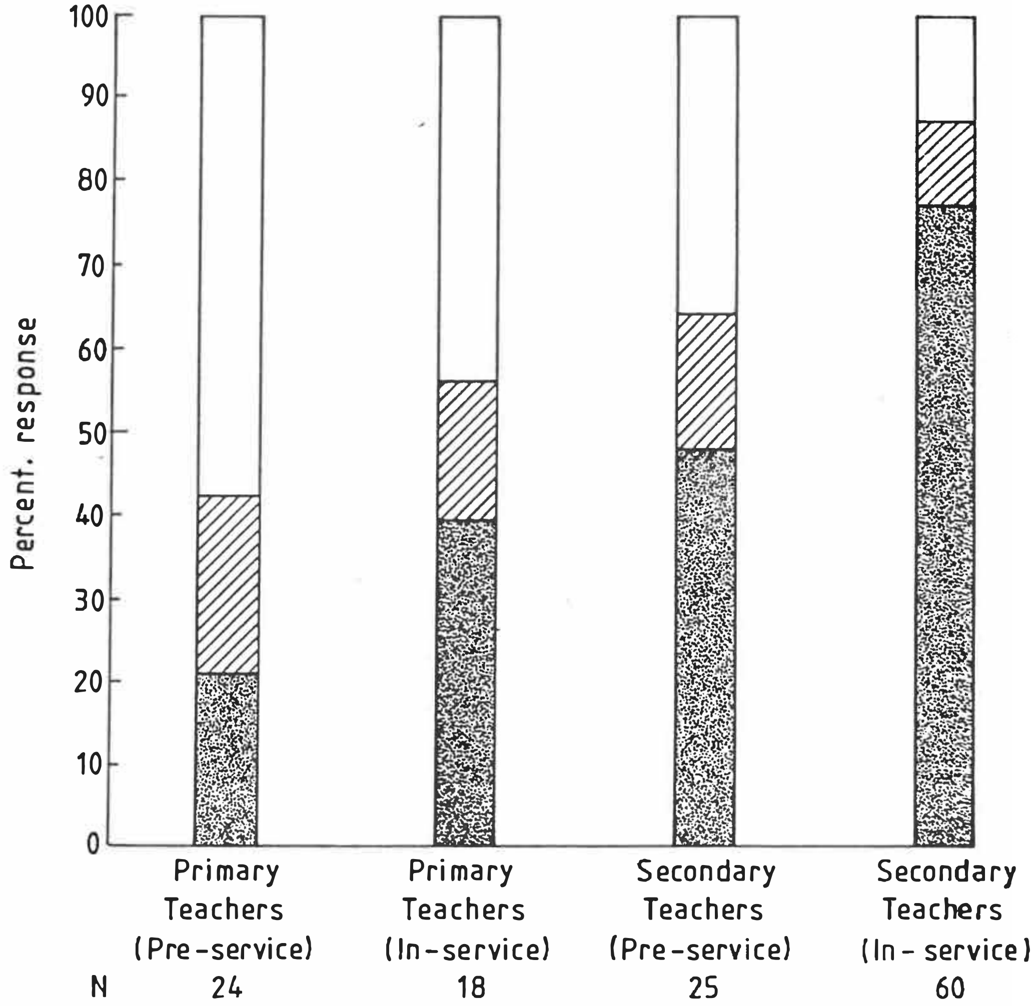
KEY:

... indicates teachers who thought that the proposition should be encouraged.

... indicates nil teacher response; a qualified response, e.g. "needs some modification"; or indicated that only part of the proposition should be encouraged.

... indicates teachers who thought that the proposition should be discouraged.

Figure 36 : Teachers' responses to the proposition "Plants take in their food from the soil" (or "the air").



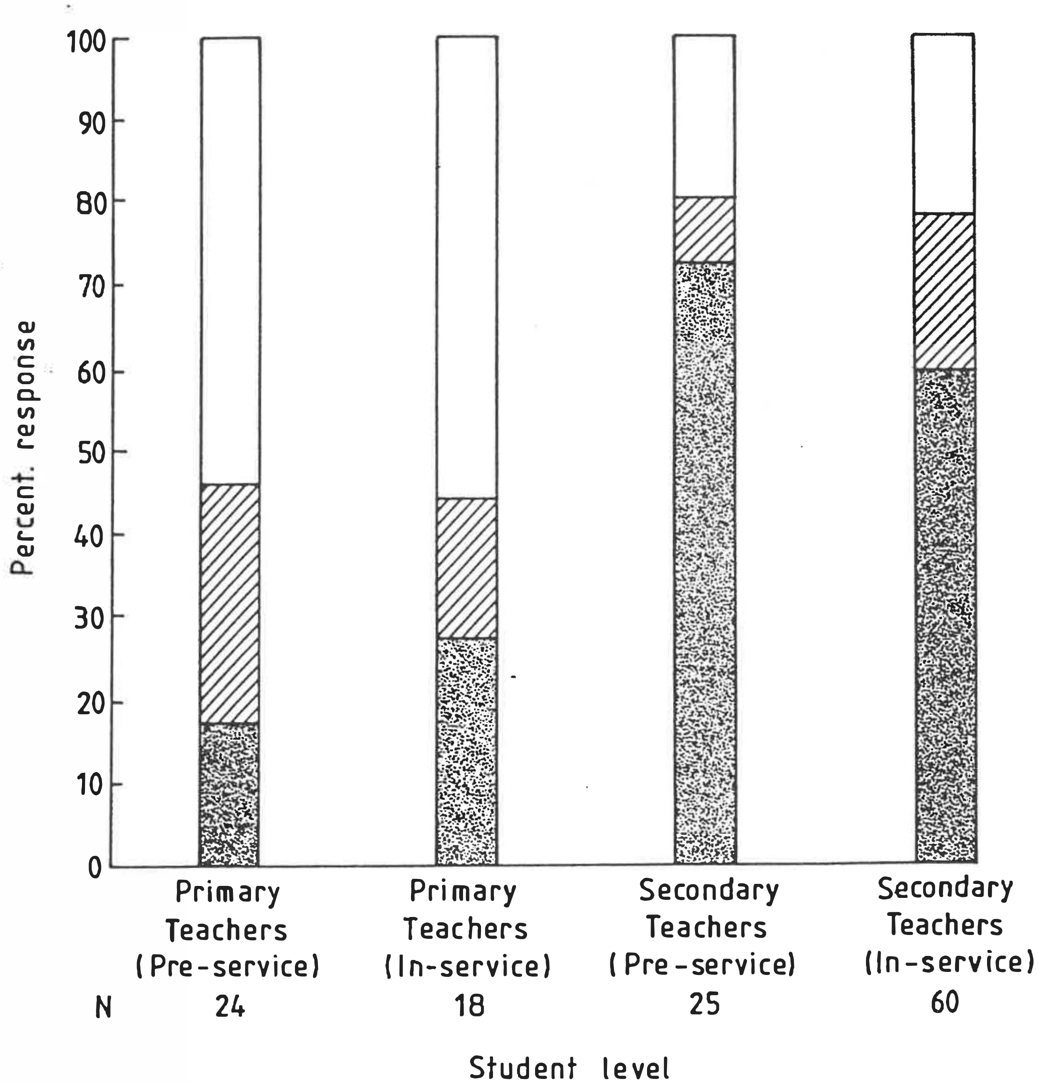
KEY:

... indicates teachers who thought that the proposition should be encouraged.

... indicates nil teacher response; a qualified response, e.g. "needs some modification"; or indicated that only part of the proposition should be encouraged.

... indicates teachers who thought that the proposition should be discouraged.

Figure 37 : Teachers' responses to the proposition "A plant's food is water" (or "minerals", or "sunlight", or "oxygen", or "carbon dioxide").



KEY: ... indicates teachers who thought that the proposition should be encouraged.

... indicates nil teacher response; a qualified response, e.g. "needs some modification"; or indicated that only part of the proposition should be encouraged.

... indicates teachers who thought that the proposition should be discouraged.

the United Kingdom, and two in Australia. Details of the ten texts and relevant quotations are found in Appendix A.

Nine of these texts discussed food in the context of photosynthesis and all made similar statements about the materials produced in the process, i.e. they described photosynthesis as a food making/building/producing/manufacturing process, and they all identified the food as glucose (sugar) and/or starch. Five of the texts described these as energy-rich materials.

The ten texts were less clear about the status of the absorbed materials. Although none described these materials as food in the photosynthesis context, only one actually stated that they were "not food". However, this text and two others in another context (animal nutrition) listed water as a class of food. One of these three texts contained the further contradiction that "no plants ever really 'engulf' their food" and yet "the food of plants is inorganic".

6.2 CHILDREN'S VIEWS ABOUT THE IDENTITY OF PLANT FOOD

6.2.1 The Interview And Survey Questions

Interview questions established which of the examples in stimulus item B (page 27) pupils considered as plants and how each example gets its food. This section reports on pupils' responses to the latter point only for those examples which they considered to be plants. The questions were:

3. Now let's look at these. Can you tell me which ones are the animals? Which ones are the plants? What tells you that? What about the rest? Which ones are the green plants? [17]
4. Let's think about food again. Does (an oak tree) need food? How does (an oak tree) get its food?

The survey item which contributed data to the present chapter is reproduced on page 139.

17 Pupils' views about 'green plants' are reported in chapter 8.

6.2.2 Interview Data

The pupils all identified the oak tree, the wheat, and the mushroom as plants and considered that feeding in the oak tree and the wheat were similar. They were less certain about the mushroom. Four pupils ($15G_2$, $16G_2$, $17G_1$, $17B_1$) stated that feeding in the mushroom differed from that in the other two examples but were unable to say precisely how. The following report is confined to pupils' responses about feeding in the oak tree and the wheat. The pupils were divided into three groups depending on whether they identified food as absorbed or produced material:

(a) Food is the material which plants absorb. (18 pupils; 11 pre-teach, 7 post-teach)

All the pre-teach pupils and 7 post-teach pupils (13B, $14G_2$, $15G_2$, $16G_1$, $16B_1$, $16B_2$, $17G_2$) identified only absorbed materials as food for plants. Some considered that this food comes exclusively from the soil:

I: *What about the oak tree: Does it need food?*
$16B_1$: *Yeah comes from the soil mainly ... all from the soil ... food ... yeah, food all comes from the soil.*

The others believed that the parts of a plant above the ground can also absorb food:

I: *Does an oak tree need food?*
10B: *Yes. Carbon monox... dioxide through the leaves and food out of the soil.*

Pupils considered that the following materials could be classed as food for plants:

1. Water (15 responses)

It (i.e. the oak tree) *needs, um, it needs water. It needs lots of water and it drinks, that's all. It gets it sucks up water out of the earth and it makes it grow.* (8B)

2. The soil itself (3 responses) **or** materials in the soil (11 responses)

These latter included fertilizers:

Well it needs some sort of food else it wouldn't live. Some sort of ... something from the earth. Water and ... I don't know what it is they give it blood something or whatever you call it. (9B)

and minerals and nutrients:

Yeah and the oak tree needs water and soil and all the nutrients that come out of the soil so it does need food. ($15G_2$)

One pupil described starch as food which plants absorb from the ground:

I: *Does an oak tree need food?*
$16B_2$: *Yes. It gets it from the soil where the roots are.*
I: *What is an oak tree's food?*
$16B_2$: *Um, just the starches and carbohydrates and things which are in the ground when the ground was made ... whenever that was, and it brings the, um ... as much of that out of the ground where the roots are at the moment and then at the same time they are strongly making the roots stronger so they keep on living.*
I: *O.K. What's it do with the carbohydrate that it gets from the soil? The starch.*
$16B_2$: *Um, it makes it into the it helps grow the new leaves and things.*

Pupils often appeared to be thinking about absorption from the soil in human terms:

Just like we've got mouths they sort of suck up through their roots and we put it in our mouths. ($14G_2$)

3. Air or its constituents (7 responses)

I: *What are the things that are food for the oak tree?*
12B: *Um, air. Little particles in the air*

4. Sun, or sun's rays, or heat (5 responses)

10G: *(Water) makes it grow bigger. Same with the sun.*
I: *Would you say the sun is its food?*
10G: *Well it makes it grow. Yes, I would say it is.*

(b) Food is the material which plants produce. (4 post-teach pupils)

Four pupils ($14B_1$, $15B_2$, $17G_1$, $17B_1$) identified photosynthetic products, i.e. sugar or starch, as food for plants:

I: *Does an oak tree need food?*
$14B_1$: *Yes, it makes it own.*
I: *Can you explain that?*
$14B_1$: *Ah ... photosynthesis which is carbon dioxide and ... takes in carbon dioxide through the leaves and through a process called photosynthesis it makes, um, sugar which it stores in its stem and trunk.*

These four pupils did not consider that the absorbed substances were also food:

These things (i.e. water, minerals) *aren't actually food, but the way it chemically makes it up it can use it ... it can create it into something it can use.* ($17G_1$)

(c) Both the absorbed and produced materials are plant food. (6 post-teach pupils)

These pupils responded to the stimulus item in the same way as those in group (a) above. However, later in the interview when they either introduced the notion of photosynthesis themselves or were finally asked directly about it, they also identified photosynthetic products as food, either by stating simply that plants make food ($14B_2$, $15B_1$) or nominating sugar and/or starch as food ($14G_1$, $15G_1$, $16G_2$, $17B_2$):

I: *Does an oak tree need food?*
$16G_2$: *Yeah an oak tree needs food in the form of air, water and sun ... so it can make starch molecules.*

but later

I: *Can you tell me what the word photosynthesis means to you?*
$16G_2$: *It means the plant's way of using the um water and carbon dioxide and sun's energy to make a form of food for itself.*
I: *What is the form of food?*
$16G_2$: *Sugar and starches.*

A final quotation is typical of the egocentric nature of pupils' thinking about plants and food:

I: *Does an oak tree need food?*
$17B_2$: *Yeah, it does, I guess, just like I need food to be talking here, to be walking around. It needs food to be doing what it's supposed to be doing.*

6.2.3 Survey Data

Analysis of responses to the pencil-and-paper survey item, in which students were invited to write a paragraph about "Plants And Their Food", was based on the clear dichotomy of views between teachers and text-books, on one hand, and children who had not been taught about photosynthesis, on the other. The present study has suggested that teachers and text-books promote the view that plants produce food, while children prior to teaching regard absorbed materials as plant food. Survey data was therefore analysed according to students' commitment to four propositions:

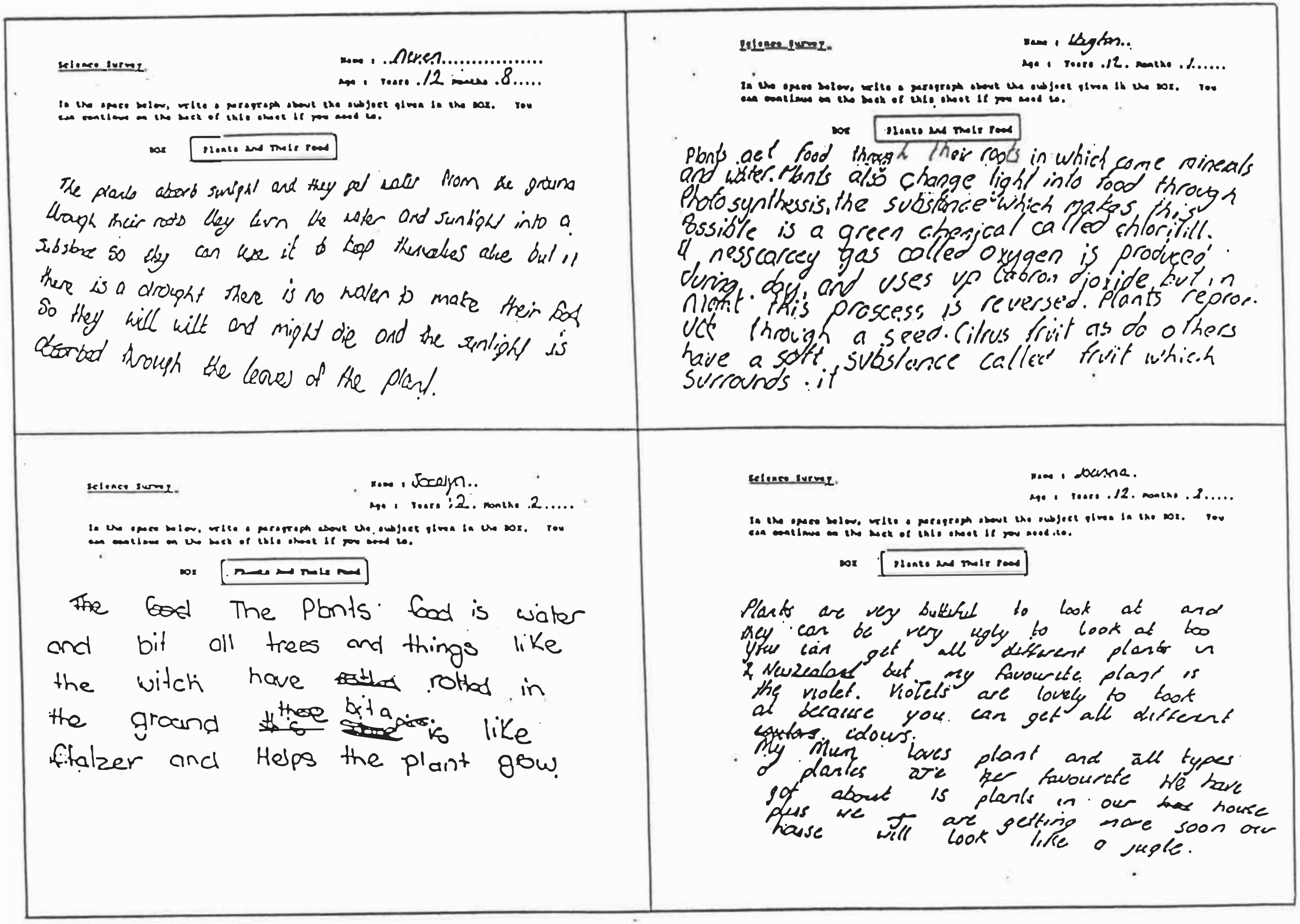
Children's Science Propositions	Plants take in their food from the soil and/or the air.	S_{ch1}
	A plant's food is minerals or water and/or sunlight or oxygen or carbon dioxide.	S_{ch2}
Teacher's Science Propositions	Plants make their own food in their leaves.	S_{T1}
	A plant's food is starch or sugar or carbohydrate.	S_{T2}

The combination of propositions advanced by a student resulted in him or her being placed in one of four groupings. If a student advanced proposition S_{T1} or proposition S_{T2}, or both, the student was classified as S_T. Similarly, a student who advanced one or both children's science propositions was classified as S_{ch}. A third grouping, S_{chT}, comprised students who subscribed to at least one of the teacher's science propositions and at least one of the children's science propositions. A fourth grouping, S_o, comprised students who advanced none of the four propositions. Figure 38 shows four examples of student responses to the survey item and the way these responses were classified.

Nearly 1500 responses were classified into these four groupings. The students in standard four and forms one and two had received little or no school instruction about photosynthesis. The third, fourth and fifth formers were all studying science, and the sixth and seventh form and tertiary students were all studying biology. The third formers had all completed a unit of work on photosynthesis and were surveyed 4 weeks after the teaching and again 20 weeks later. The fourth form students had received no further instruction about photosynthesis since the previous year.

The results (Figure 39) suggested that the view of plant food as absorbed material, i.e. S_{ch}, was dominant among students prior to secondary school and then became a powerful, enduring alternative to the teacher's view of plant food as produced material, i.e. S_T. Initial teaching about photosynthesis resulted in a short-lived appearance of the teacher's science view, which steadily re-emerged over the subsequent four years. The percentages of students who were classified as S_T on the grounds that they actually named sugar, starch or carbohydrate as plant food (i.e. subscribed to proposition S_{T2}), as

Figure 38 : Four responses to the survey item "Plants And Their Food" (half actual size). The classifications S_T etc. are explained in the text.



S_T

Science Survey. Name : ..Owen..... Age : Years .12. Months .8.....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX: Plants And Their Food

The plants absorb sunlight and they get water from the ground through their roots they turn the water and sunlight into a substance so they can use it to keep themselves alive but if there is a drought there is no water to make their food so they will wilt and might die and the sunlight is absorbed through the leaves of the plant.

S_{chT}

Science Survey. Name : Leighton.. Age : Years .12. Months .1.....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX: Plants And Their Food

Plants get food through their roots in which come minerals and water. Plants also change light into food through Photosynthessis. the substance which makes this possible is a green chemical called chloritill. A nesscarcey gas called oxygen is produced during day and uses up carbon dioxide but in night this proscess is reversed. Plants reproduce through a seed. Citrus fruit as do others have a soft substance called fruit which surrounds it

S_{ch}

Science Survey. Name : Jocelyn.. Age : Years .12. Months .2.....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX: Plants And Their Food

The ~~food~~ The Plants food is water and bit all trees and things like the witch have ~~rotted~~ rotted in the ground ~~the s~~ ~~three~~ bit a ~~stop~~ is like fitalzer and Helps the plant grow.

S_o

Science Survey. Name : Joanna. Age : Years .12. Months .2.....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX: Plants And Their Food

Plants are very butiful to look at and they can be very ugly to look at too You can get all different plants in New Zealand but my favourite plant is the violet. Violets are lovely to look at because you can get all different ~~colors~~ colours. My Mum loves plant and all types of plantes are her favourite We have got about 15 plants in our ~~hou~~ house plus we are getting more soon our house will look like a jugle.

Figure 39 : Four groups of students classified according to their views about plants and their food.

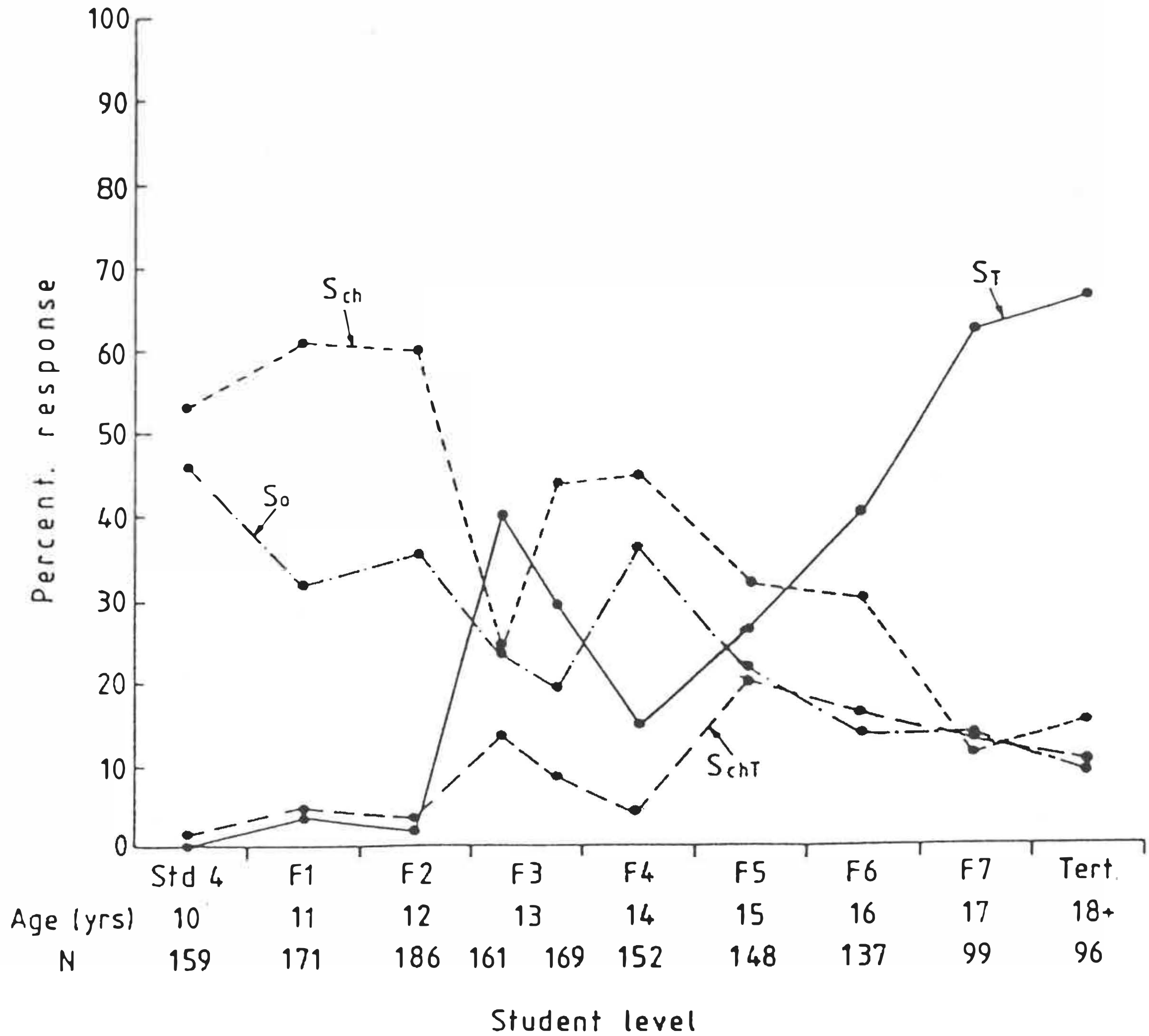
Science Survey 5

Name : ....

Age : Years ..... Months ....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX | Plants And Their Food |



opposed to stating only that plants make food (proposition S_{T1}) were: form three - 41% (and 37% twenty weeks later); form four - 43%; form five - 61%; form six - 80%; form seven - 85%; tertiary - 71%.

The secondary school years (forms three to seven) saw the amalgam view, i.e. S_{chT}, peaking at 20% in form five. The percentage of students who expressed neither view (i.e. were classified as S_0) gradually declined. Students in this grouping either focussed mainly on materials but did not label them as food for plants (about 35% of the S_0 group), or discussed plant care by humans (25%), non-trophic activities of plants (20%), eating or destruction or plants by pests (10%), or gave minimal or unclassifiable responses (10%).

The materials which students identified as plant food when they advanced propositions S_{ch2} and S_{T2} were grouped into eight categories:

1. SUN - including sunshine, sun s energy and (sun) light.
2. AIR - including gases and named gases, e.g. oxygen, carbon dioxide.
3. CARBOHYDRATES - including sugar, glucose, and starch.
4. INSECTS - including flies, bugs, bees etc.
5. WATER - including rain and moisture.
6. EARTH - including dirt and soil.
7. MINERALS and NUTRIENTS - including phosphate, nitrate, and vitamins.
8. FERTILIZER - including bulk fertilizers in powdered form (blood and bone, super) commercially prepared garden fertilizers (maxi-crop, potting mix, food spikes), and domestic fertilizers (compost, manure, egg-shells, etc.)

The results (Figure 40) suggested that, from a young age, students associate plant food with the soil rather than with the parts of the plant above the ground. Some absorbed materials became relatively less frequently identified as food, i.e. sun, air, water, earth, and fertilizers, while carbohydrates increased (presumably as the result of classroom teaching). Minerals and nutrients emerged as the major competitor to carbohydrates even at tertiary level. The activities of

Figure 40 : Eight categories of plant food nominated by students.

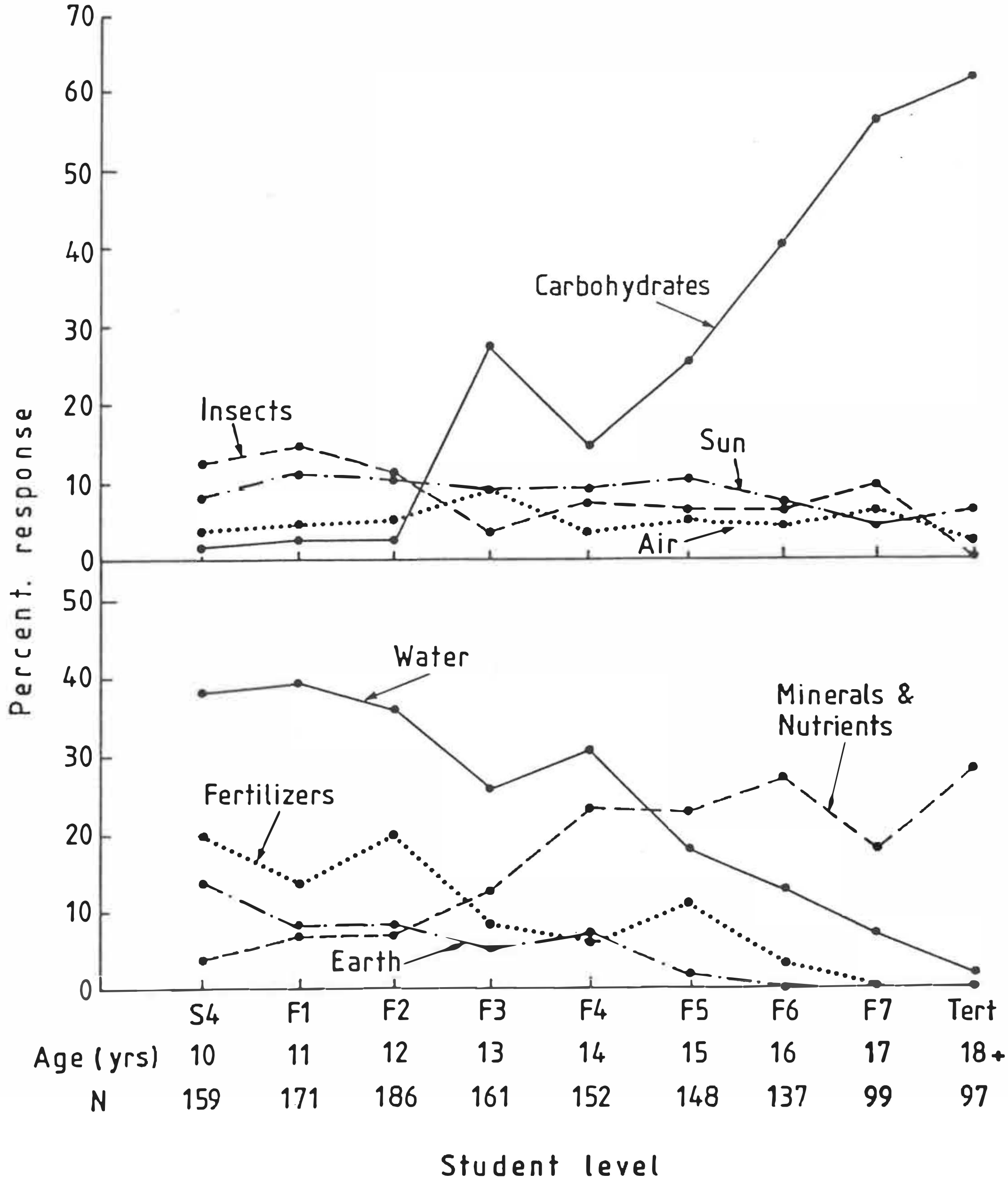
Science Survey 5

Name : ....

Age : Years ..... Months ....

In the space below, write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

BOX | Plants And Their Food



The categories are grouped into those associated with the above ground parts of a plant (upper), and those associated with the ground itself (lower).

insectivorous plants are apparently well-known and memorable to students despite the extreme rarity of this form of plant nutrition.

Two other pencil-and-paper surveys (a multi-choice item and a true/false item) were also used to investigate whether students consider absorbed or produced material to be plant food, and to determine which materials students identify as plant food. The results (Barker, 1985f, Appendix) from all three surveys are similar on both points.

6.3 SUMMARY AND DISCUSSION

Although teachers and text-books usually consider food in the context of photosynthesis to be the materials which plants produce (e.g. carbohydrates), children who have not been taught about photosynthesis think about materials which plants absorb as being food (e.g. water, carbon dioxide, fertilizers, minerals and nutrients). The interview and survey data suggest that a powerful and enduring children's science model (Figure 41, S_{ch}) exists in competition with the teacher's science view (Figure 41, S_T). Other studies report similiar findings. Stead (1980d), who interviewed New Zealand children to ascertain their concept of 'plant' noted that the unacceptable criterial attribute that plants get their food from the ground was advanced by some children. Larger scale studies by Simpson and Arnold (1982b) with children in Scotland, by Wandersee (1983) and Smith and Anderson (1983) with American students, and by Bell and Brook (1984) with English students all report that this alternative view is widespread.

The alternative view has much in common with earlier, now discarded, historical views which identified plant food as absorbed materials by analogy with animal nutrition. Children who write:

Figure 41 : Eight models concerning the identity of plant food.

	MODELS OF STUDENTS' VIEWS ABOUT PLANTS AND FOOD	STUDENT GROUPINGS
1	[Materials Absorbed → Materials Produced] Materials Produced = FOOD	The Teachers' Science View S_T
2	[Materials Absorbed] [Materials Produced] Materials Absorbed = FOOD; Materials Produced = FOOD	The Amalgam View S_{ChT}
3	[Materials Absorbed → Materials Produced] Materials Absorbed = FOOD; Materials Produced = FOOD	
4	[Materials Absorbed] Materials Absorbed = FOOD	The Children's Science View S_{Ch}
5	[Materials Absorbed → Materials Produced] Materials Absorbed = FOOD	
6	[Materials Absorbed]	Neither View Expressed S_o
7	[Materials Absorbed → Materials Produced]	
8	[ ]	

Models 1, 3, 5 and 7 all involve a chemical change process, i.e. photosynthesis.

Models 3, 5 and 7 appear to be relatively rare.

Model 8 relates to pupils who volunteered non-trophic information only.

Plants are a type of animal which get their food from the ground
or
Their roots act a bit like their mouth. They suck water from the dirt
or
I think plants are little people. Water to them is like drinking orange juice.

appear to be echoing the dominant view of plant nutrition from Aristotle to Erasmus Darwin. This has also been noted by Wandersee (1984) in his exploration of American students' ideas about plants and food. When children were asked for their views about 'food' in general (Barker, 1985e), edibility by humans was the dominant criterion which they used. In the context of plant nutrition it seems that 'edibility' very readily becomes 'absorbability'. This is discussed further in section 7.4.

6.4 SUMMARY - PLANTS AND FOOD

Below is a summary of the findings of chapter 6 comparing scientists' views with children's science and students' science alternative views. Findings from Barker (1985e) concerning views about 'food' in a wider context are also included. In contrast to the earlier summaries (sections 4.6 and 5.4), there is no overlap between children's and present-day scientists' views about food because scientists have no formal definition of food. The views about plant food expressed by children and by school science texts appear to be mutually exclusive. In chapter 7 the more general characteristics of scientists' and children's views will be discussed.

Scientists' Views	Children's (S_{ch}) and Students' (S_{st}) Science Alternative Views
Food technologists, health scientists, etc. define 'food' in different ways. Biologists generally have no precise definition for this term. (School science texts, however, do define food but in various ways, although they usually class the energy-rich chemicals carbohydrates, fats and proteins as food.)	S_{ch}: Material is food if it is edible or palatable (i.e. is non-toxic, tastes nice). How widely this criterion is applied can vary, i.e. notions about the size of the set of eaters, how often eating occurs, whether metaphorical as well as literal eating is included, are personal and idiosyncratic.
Biologists do not define 'food' in the context of photosynthesis and it features very little in their accounts of process. (School science texts, however, consider that food in the context of photosynthesis is the materials which plants produce, e.g. the carbohydrates, sugar and starch. Teaching generally reflects this view.)	S_{ch}: Materials which plants absorb are food, e.g. water, fertilizers (like maxi-crop, compost, manure), gases. S_{st}: Minerals and nutrients are plant food.

CHAPTER 7 : PLANT ACTIVITIES

- SCIENTISTS', TEACHER'S, AND CHILDREN'S MODELS

With the help of physical theories we try to find our way through the maze of observed facts, to order and understand the world of our sense impressions. We want the observed facts to follow logically from our concept of reality. Without the belief that it is possible to grasp the reality with our theoretical constructions, without the belief in the inner harmony of our world, there could be no science.

(Einstein and Infeld, 1961, p.296)

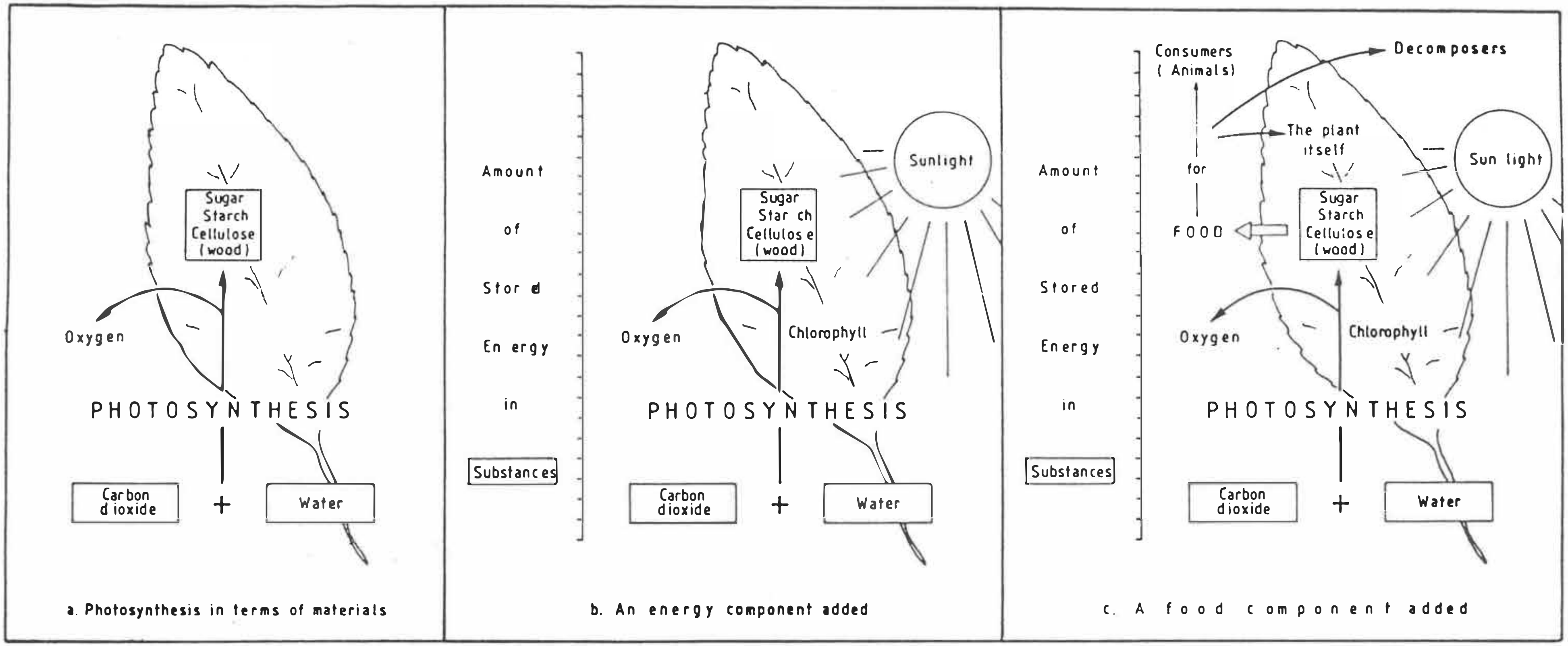
7.1 INTRODUCTION

In this chapter the teacher's science view of photosynthesis will be reiterated briefly. Then aspects of the children's science view of plant nutrition, as described under separate headings in chapters 4, 5 and 6, will be drawn together and viewed as a whole. Some general features of this children's science view will be discussed and contrasted with the teacher's science view of photosynthesis. This anticipates chapter 8, which documents some of the learning outcomes when these two views meet in the classroom. The present chapter concludes with a comment about some apparent similarities between the children's science view of plant nutrition and earlier, now discarded, scientific views.

7.2 THE TEACHER'S SCIENCE VIEW

An essential feature of the teacher's science view of photosynthesis (Figure 42) is that it is a single unified theory,

Figure 42a, b, c : The cumulative teacher's science view of photosynthesis.



couched in precise terminology, which can be expressed in non-personal objective language. In their green leaves, so the theory goes, plants convert materials, carbon dioxide and water, into carbohydrates like sugar, starch and cellulose, and form oxygen gas at the same time (Figure 42a). The carbohydrates are energy-rich materials because energy from sunlight is stored in them as they are produced. The starting materials, carbon dioxide and water, have little energy in them which living things can use (Figure 42b).

The present study has also shown that teachers (section 6.1.2), and the text-books (section 6.1.3) and syllabi (section 1.3) which they use, consider that a trophic theme is an integral part of the concept of photosynthesis. Thus the teacher's science view maintains, in addition, that the energy-rich carbohydrate is food because it can provide energy for the plant itself or for the animals, bacteria and fungi which make up the food chains which start with a green plant (Figure 42c).

7.3 THE CHILDREN'S SCIENCE VIEW

The children's science view differs significantly from the teacher's science view. It demonstrates three of the features which Osborne, Bell and Gilbert (1983) claim are hall-marks of children's alternative views in general:

7.3.1 Particular Explanations

Children are interested in particular explanations for specific events in their familiar world.

Like scientists, children also have views about plants and materials, energy, and food. They have ideas about plant drinking, plant breathing, and plant growth (Figure 43a), about how plants get energy (Figure 43b), and about plant feeding (Figure 43c), but a child holds these component ideas <u>in isolation</u> from each other.

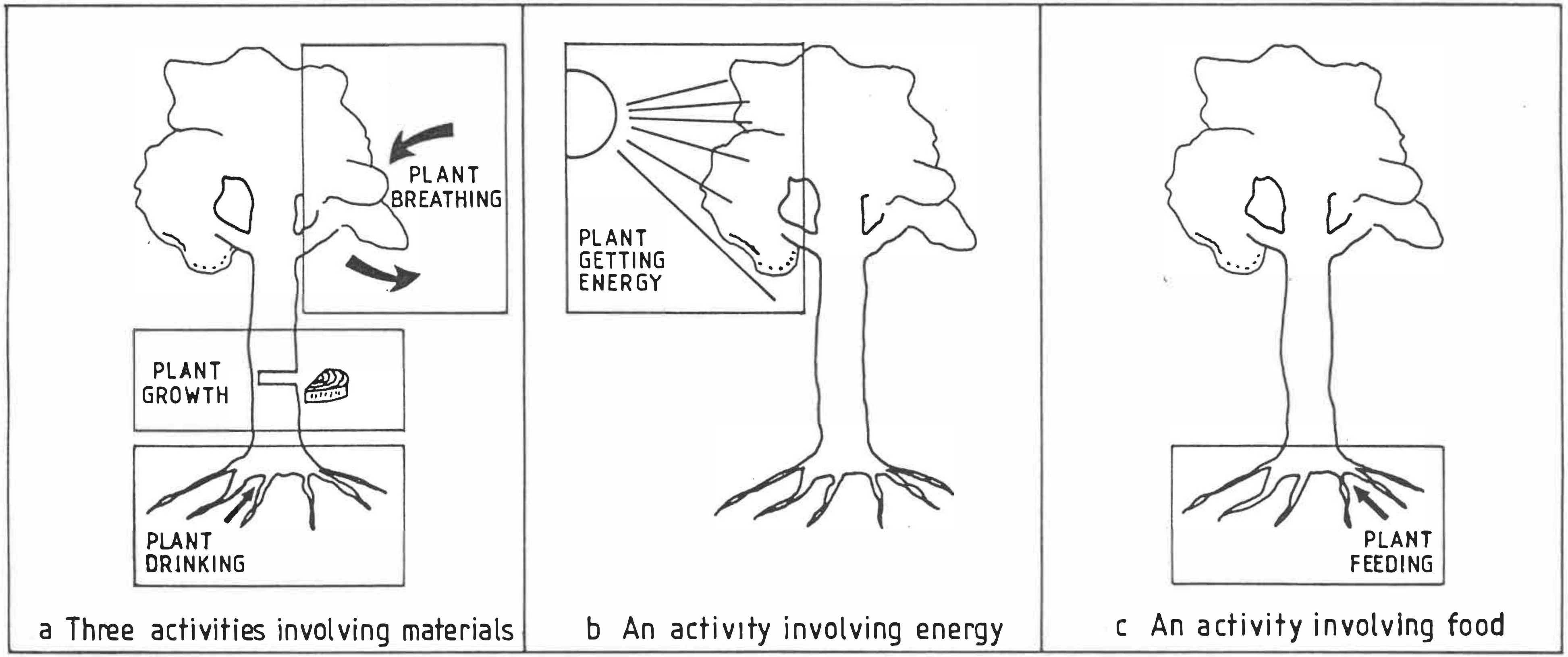
In their situation-specificity and their lability, these components are reminiscent of what Claxton (1985a) has termed, 'mini-theories', i.e. they are knowledge modules whose primary characteristic of interest is their 'boundary', specifying the domain of experience to which they are currently applied. For example, these components, which operate only within the context of plant activities, are characterised by cross-age (section 4.3.3.2) and stimulus-triggered (section 6.2.2c) lability. Like mini-theories, these components are often characterised by absence of overlap, e.g. the 'plant drinking' and 'plant breathing' components, and by the demonstration that some events appear to lie within the boundaries of none of the mini-theories and hence defy explanation, e.g. the material aspect of plant growth (section 4.5.2.4). In Claxton's view, learning occurs when the extent and 'fuzziness' of the boundaries of mini-theories are subject to modification. In section 10.4.1 the modification of children's views about plant activities will be considered from this viewpoint.

7.3.2 Precision Of Language

Children are less concerned than their teachers with the need for precision of language.

While children's explanations about plants are expressed in everyday, often generic, language (e.g. sun, air, wood, green leaves, dirt, growing, feeding), teacher's explanations are couched in more precise, often chemical, language (e.g. sunlight, carbon dioxide, cellulose, chlorophyll, and so on). Even when teachers are apparently

Figure 43a, b, c : The children's science view - five separate plant activities.



a Three activities involving materials

b An activity involving energy

c An activity involving food

using everyday language (e.g. food-making, energy, green plants) they may be using it more precisely.

This comparison between children and teachers (or scientists) in terms of the language they use when they are talking about plant activities appears to exemplify Holt's (1967) statement about learning styles in general: "A trained scientist wants to cut all irrelevant data out of his experiment. He is asking nature a question and he wants to cut down the noise, the static, the random information, to a minimum, so that he can hear the answer. But a child doesn't work that way. He is used to getting his answers *out* of the noise. He has, after all, grown up in a strange world where everything is noise, where he can understand and make sense of a tiny part of what he experiences". This view of science activities as a process of 'reducing the noise' has also been discussed by Simpson and Arnold (1984).

7.3.3 Egocentricity

Children's views are frequently self-centred or human-centred.

Piaget (1929, 1930) suggested that an initial state of egocentrism in young children (a precausal phase) gives way to the objectivity of young adults. Replication studies indicate that precausal thinking can persist into early adolescence (Driver and Easley, 1978). This egocentrism has frequently been shown to manifest itself when children express themselves in the form of metaphors and analogies (Ortony, 1979; Lackoff and Johnson, 1980; Sutton 1980b). In this section the terms 'analogy' and 'metaphor' will be used in the sense of Sutton (1978). In his view, an analogy is an extended simile in which an attempt is made to trace multiple points of comparison. However, it is acknowledged explicitly that one is making `just a comparison and there is no suggestion that the analogy is the reality. A metaphor is less explicit and more mentally teasing. It always forces the hearer to search among his associated ideas for possible connections. What sometimes starts as an interaction in thought (a `live' metaphor) may drift towards substitution in the `dead' one, and the metaphor becomes the only possible way of describing things - literal, `true' and obvious.

The present study has revealed many instances of egocentricity in children's thinking about plant activities. Trees have leaves, we were told, because they `look pretty' (section 4.4.2.2) and leaves are green because green is a `nice colour' (section 4.4.2.3). Children's views about plant gaseous exchange were often based on the proposition that "they do basically the same as we do only they are the opposite gases" (section 4.3.3.1), while their view that heat is more effective than light as an agent in photosynthesis (section 5.3.2.2) could well derive from sensations which they experience themselves. Some children likened water movement in plants to blood circulation (section 4.2.3.2) and others used analogies with humans to try to explain the origin of wood (section 4.5.2.4) and the functions of leaves (section 4.3.3.1). Human activities were frequently attributed (apparently in a metaphorical way) to plants, which were described as `drinking' or `sucking' water. Plants `sweat' water (section 4.2.3.2) and `eat' food (section 6.3.2). Children considered material in general to be food, not by virtue of its intrinsic chemistry, but in relation to their potential action on it, i.e. its edibility (Barker, 1985e).

The literal way in which children talked of `plant food' (presumably reinforced by, or derived from, media advertisements) answers Sutton's description of a dead metaphor. At this point the metaphor has evolved into a model, in a process which occurs widely in the history of science itself (Black, 1962; Schon, 1963). In the present instance, however, children's intuitive use of metaphor has lead them to a position which is contrary to the teacher's science view of photosynthesis. Whilst children assert that plant food is material which plants absorb, the teacher holds a very different mental model, i.e. one in which plant food is material produced by the plant (section 6.3.1). The significance of this finding in terms of the modification of children's views of plant nutrition is discussed in section 10.3.3.

7.4 CHILDREN'S VIEWS AND SCIENTISTS' VIEWS - THE HISTORICAL PERSPECTIVE

At four points in the present study it has been noted that children's intuitive ideas show various degrees of similarity with earlier, now discarded, scientific views. Children's theories about the part which water plays in growth (section 4.2.3.1) and how sap circulates within a plant (section 4.2.3.2), their views about the place of gaseous exchange in relation to other plant processes (section 4.3.3.3), their theories about the functions of leaves (section 4.4.3.1) and, finally, their tendency to think of plant food as absorbed material (section 6.3.2) all appear to be echoes of earlier scientific beliefs.

This possible relationship, which Piaget (1972) described as "a parallelism between the progress made in the logical and rational organisation of knowledge and the corresponding formative logical processes" has been noted in other areas of biology. Deadman and Kelly (1978) and Brumby (1979) report that children's intuitive interpretation of evolution is essentially Lamarckian, while Tamir *et al.* (1981) have shown that some children express views akin to spontaneous generation when they are discussing the continuity of life. In other areas of science the same phenomenon has been noted. Some children appear to hold an elementary caloric theory (Erickson, 1979) and McCloskey (1983) claims that in exposing their intuitive ideas in the area of mechanics his subjects "recapitulated the medieval impetus theory". Solomon (1983) considers that children's views about energy as the "source of life" contain an element of vitalism typical of thinking prior to Helmholtz.

Science educators have responded to this parallelism either by discussing the extent of overlap between the views (Gilbert and Watts, 1983) or by considering the implications for classroom conceptual change (Nussbaum, 1983). Wandersee (1984) analysed the responses made by American students (10 to 18-year-olds) to nine written tasks about photosynthesis. He has concluded that "although the misconceptions of the past can be found in the conceptual frameworks of today's students it seems obvious ... that students do not merely recapitulate the history of science in learning the photosynthesis concept".

Why do children's views about plant nutrition appear similar to earlier now discarded views? The present study has shown that metaphorical comparisons and the drawing of analogies between plants and humans are powerful processes in the development of children's views (section 7.3.3). But egocentricity has apparently always been a factor in the way in which people have viewed the natural world. For example, Thomas (1983) claims that "it is impossible to disentangle what people of the past thought about plants and animals from what they thought about themselves". More specifically, there is considerable evidence that metaphor and analogy were perceived as powerful tools by early plant physiologists. Delaporte (1982) claimed that the process of drawing analogies between plants and animals dominated the subject from antiquity to the beginning of the nineteenth century[18] "In physiology, epistemological priority belonged to the animal kingdom. Plant physiology in fact followed in the wake of animal physiology and modelled its objects on those of its predecessor. Plant physiology was slow to develop because the apparent simplicity of the plant made it impossible to say what role was played by each of its parts. By contrast ... it was possible to decipher the structure of animals by comparing their internal organs, which are easily visible, to mechanical devices"[19] The application by Stephen Hales of techniques for measuring blood pressure to refute the notion of sap circulation (Harré, 1981) was one example of real progress, but as late as 1800 Erasmus Darwin was still postulating that plants possess a pulmonary system in which leaves and flowers in the air resemble lungs, and leaves in the water resemble gills (Darwin, 1800). It was not, in fact, until the early nineteenth century that the unproductive process of analogy-making broke down in the face of physicochemical explanations of vegetation derived from Lavoisier's system of chemical elements (Morton, 1981).

To sum up, it would appear that the views of both children and earlier scientists about plant nutrition have processes of metaphor-making and analogy at their source, and in both cases this egocentricity is, or has been, an impediment to the understanding of photosynthesis.

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18 See also section 6.1

19 Miller (1978) elaborates the importance of technological advances in providing conjectural models for explaining the human body.

CHAPTER 8 : PHOTOSYNTHESIS - LEARNING OUTCOMES

He said, 'One day perhaps I'll be able to explain - not explain, because it's difficult for me, isn't it, to put into words - but to make you see. Words are not what make you see'. 'I was taught they were', Waldo answered in hot words. 'I dunno', Arthur said. 'I forget what I was taught. I only remember what I've learnt'.

(Patrick White, 1966, The Solid Mandala p.58)

8.1 PHOTOSYNTHESIS - THE TEACHER'S SCIENCE VIEW

This study has adopted the definition of Hall and Rao as a statement of the scientists' view of photosynthesis: "By the input of the sun's energy the energy-poor compounds, CO_2 and H_2O, are converted to the energy-rich compounds, carbohydrate and O_2" (section 1.2). The teacher's science view (section 6.1.2), in addition to these biochemical and ecological energetic themes, also includes a trophic theme, in which the energy-rich compounds (carbohydrates) produced by plants are identified as food. From this three-fold point of view, photosynthesis is a process which produces carbohydrate, stores energy, and makes food. Children, on the other hand, while possessing no clear single alternative view to photosynthesis, do possess their own children's science views of plant nutrition (chapter 7). The present chapter documents the conceptual restructuring which occurs when these children's science views are confronted by classroom instruction about photosynthesis. The format of this chapter is similar to that of chapters 4, 5 and 6.

8.2 PHOTOSYNTHESIS - PUPILS' UNDERSTANDINGS

8.2.1 The Interview And Survey Questions.

The interview data in this chapter comprises pupils' responses to the following four questions:

3. Now let's look at these. Can you tell me which ones are the animals? Which ones are the plants? What tells you that? What about the rest? Which ones are the green plants?

19. Could you say that any of these can make their own food?

28. Do you know what 'photosynthesis' means?

29. Have any of these pictures got anything to do with photosynthesis?

Questions 3, 19 and 29 were discussed in conjunction with stimulus item B, 'Examples' (page 27). The question "Do you know what 'photosynthesis' means?" was placed near the end of the interview to ensure that it did not act as a cue when pupils were asked other more open-ended questions about plant activities. This ordering therefore revealed whether pupils who had been taught about photosynthesis introduced the concept themselves when they were responding to other questions. Questions 3, 19 and 29 were used to compare whether or not pupils selected the same examples as being green plants (question 3), able to make their own food (question 19), and capable of performing photosynthesis (question 29). These three questions were separated by a large number of others, on a variety of topics, to prevent any implied association between them.

The two survey questions which contributed data to this section are reproduced on pages 162 and 171. The surveys were administered 12 weeks or more after teaching.

8.2.2 What Is Photosynthesis?

None of the 11 pre-teach pupils mentioned photosynthesis during the interview, and when finally asked about the process (question 28) none could explain the meaning of the term. All 17 post-teach pupils said that they had heard of photosynthesis, and 10 of them (all aged between 14 and 17 years) employed their concept of photosynthesis during the course of the interview before being finally asked directly about it:

(a) Teacher's science responses about photosynthesis (11 post-teach pupils)

Eleven of the 17 post-teach pupils gave explanations of photosynthesis exclusively in terms of one or more of the three teacher's science views, i.e. that photosynthesis is how plants produce carbohydrate, store energy, and make food. Two of these 11 pupils focussed only on one of these views when they were asked "Do you know what 'photosynthesis' means?" Pupil $17G_2$ talked only of energy storage:

It changes whatever it gets ... out of the sun or whatever ... into a form of energy which it can store up and use ... something that can change energy from one form to another inside the plant or on the leaves, on the stem and on the trunks. Like the energy comes from the outside and then it's photosynthesized to whatever form of energy the plant needs.

Pupil $15G_1$ spoke only of food-making:

Um, oh... no! I used to know. (laughs) *I think it's, um, something to do with food and a part of the plant and how it makes its food.*

A further seven of these 11 pupils drew on two of the teacher's science views. Four of the seven ($14G_1$, $15B_2$, $17G_1$, $17B_2$) talked in terms of producing carbohydrate and making food:

It's a process that plants go through to make starch ... starch is a food for plants really. They make it and then animals, some little animals like ants will crawl along them and gnaw their way through it and eat it. ($14G_1$)

One pupil spoke of photosynthesis in terms of producing carbohydrate and storing energy:

It's the way the energy ... is locked up in the form of bonds in other molecules. That's how plants go about synthesizing organic molecules like amino acids and glucose ... It's more complicated than that but that's basically what happens. ($17B_1$)

Two pupils ($14B_2$, $15B_1$) utilised views about storing energy and making food:

Well it uses sunlight to make it grow for this process and it needs the sunlight so it can make its food... the plant uses the sun as an energy and it helps it to keep the system going.
I: *Can you tell me about the energy? Where does the energy come from?*
$15B_1$: *The sun.*
I: *And where does the energy go to?*
$15B_1$: *Into the process, you know, the energy is used in making the food.*
So where does the energy end up?
In the food.

The final two pupils ($14B_1$, $16G_2$) mentioned all three components (carbohydrate, energy and food):

$14B_1$: *Photosynthesis ... Water joins with the carbon dioxide coming in through the leaves and makes its food.*
I: *What is the food?*
$14B_1$: *The food is sugar ... sugary substances ... It can't make the process without sunlight. It's needed ...*
I: *What happens to the sunlight in the end?*
$14B_1$: *It gets turned into energy and, er, and the plant uses the energy from sunlight to make the photosynthesis ... for the photosynthesis.*
I: *Where does the energy go?*
$14B_1$: *Um, into the sugar.*

Two of these 11 pupils ($14B_1$, $15G_1$), in discussing the relationship between energy and food, seemed to suggest that the two are interconvertable:

The plant draws in the energy that it gets from the sun ... and makes food out of it. ($15G_1$)

(b) Other responses about photosynthesis (6 post-teach pupils)

Because the term photosynthesis was so unfamiliar to the pre-teach pupils who were interviewed, it would be inappropriate to describe the views of the remaining six post-teach pupils as children's science views in the sense of Osborne, Bell and Gilbert (1983). Five of the six post-teach pupils who did not advance one or more of the teacher's science views applied the label 'photosynthesis' to a small component of the process. Three of these pupils (13B, $16B_1$, $16B_2$) identified photosynthesis as the absorption of sunlight:

It means taking sunlight into substances that they need. That's all I can remember about it. ($16B_2$)

The two others ($15G_2$, $16G_1$) equated photosynthesis with forms of gaseous exchange:

It means the plant breathing in carbon dioxide and letting out oxygen so we can live ... It takes in water and light and carbon dioxide and it puts out oxygen They all work together so that they can change the carbon dioxide to oxygen and let it out for us to breathe. ($16G_1$)

The final pupil in this group apparently recalled only that photosynthesis is related to certain laboratory procedures:

Doesn't it mean when animals and that need ... it's testing if animals and plants need oxygen and light and things that they need to survive. It's to find out what, um, animals need to survive. What plants need to survive. ($14G_2$)

Responses to a survey item in which students were required to write a paragraph about "What is photosynthesis?" (Figure 44) were classified according to whether reference was made to one or more of the three teacher's science views. Students who expressed more than

Figure 44 : Students' descriptions of photosynthesis in terms of three teacher's science views.

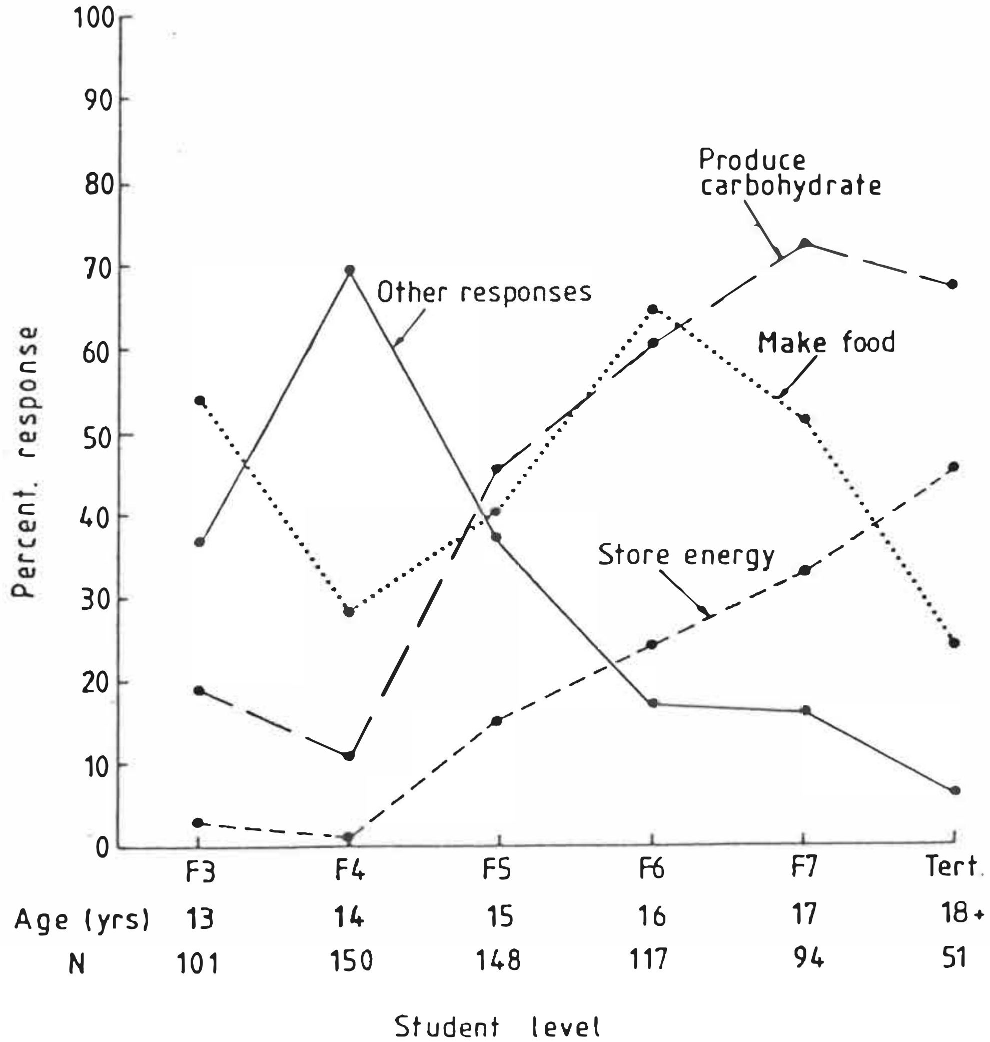
Science Survey 1

Name : ....

Age : Years ..... Months ....

In the space below, write an answer to the question in the BOX. You can continue on the back of this sheet if you need to.

BOX | What is photosynthesis ? |



one view contributed to more than one trace. The responses of students who advanced views about photosynthesis other than teacher's science views are also discussed below.

(a) Teacher's science responses about photosynthesis

Some students wrote only in terms of one of the teacher's science views, e.g. about producing carbohydrate:

Photosynthesis is the process plants use to make sugar from the sun and minerals from the soil. Plants take carbon dioxide from the air and minerals from the soil and make carbohydrate and release the oxygen not needed back into the air. (form five girl)

or about storing energy:

Photosynthesis is a process which converts light energy into chemical energy. This process is used by plants and takes place in the chloroplasts. (form six girl)

or about making food:

Photosynthesis is the way plants make their food. The sun is needed for this process to take place. (form five boy)

Other students used two of these views in their paragraph, or even all three views:

* *Photosynthesis is the process where food is made for the plants.*
  - *The first product of photosynthesis is the production of a molecule of glucose.*
  - *Light is important for photosynthesis to occur.*
  - *Chlorophyll is needed for photosynthesis.*
  - *The sugar made during photosynthesis is converted to starch.*
  - *CO_2 is needed for photosynthesis + O_2 is liberated during photosynthesis.*
  - *Photosynthesis takes in energy and builds high energy compounds.*
  - *The opposite to photosynthesis is respiration.* (form five girl)

The results (Figure 44) showed that after exposure to teaching in form three, students most frequently responded that photosynthesis is how plants make food. This was the only teacher's science view expressed by 42% of third formers. A further 12% held this view in conjunction with one of the other two teacher's science views. With no further teaching in form four, all three teacher's science views declined. The teacher's science views that photosynthesis is how plants produce carbohydrate or store energy steadily increased with older students, but the food-making view peaked at form six and then declined.

The percentages of students who held more than one teacher's science view were:

	F3	F4	F5	F6	F7	Tert.
Two teacher's science views (%)	12	9	25	42	47	37
Three teacher's science views (%)	0	0	6	12	13	2

The percentages of students who wrote statements which suggested that energy (or sunlight) and food (or carbohydrate) are interconvertable are given below, i.e. they wrote statements like "Plants can convert the sun's energy into starch" or "Photosynthesis is changing sunlight into simple sugars":

F3	F4	F5	F6	F7	Tert.
9	5	12	18	12	4

These percentages would have been much greater if statements like "Plants take light and water and carbon dioxide and change them into glucose and sugar" had been included.

(b) Other responses about photosynthesis

The students who advanced none of the teacher's science views responded in three ways. Some students apparently identified the label 'photosynthesis' with views which other sections of the present study have suggested are held by children prior to teaching about photosynthesis, e.g. the notion of plant breathing (section 4.3.3.1):

It is the process in which plants breathe. It is the O_2 that goes in and the CO_2 that is released. (form five girl)

or the idea of plants absorbing energy but with no notion of storage (section 5.3.2.3):

Photosynthesis is when the sun shines on the plants leaves and it gives it energy. (form four girl)

or the view that plants get food from the ground and/or the air (section 6.3.1):

Photosynthesis is how plants get their food and moisture from the ground and from the air the food for the plant is carried up either the Phloem or the xylem to the veins and is carried to all parts of the plant... (form five boy)

A second type of response focussed on a view about chlorophyll as a product of photosynthesis. Students apparently constructed this view during teaching (section 4.4.3.3):

Photosynthesis is the name of the process by which plants make chlorophyll which is the green pigmentation in the leaves. The plants get light energy (which is necessary to make chlorophyll) from the sun. If they could not and were left in the dark somewhere their leaves would turn yellow instead of green and they would most likely die in the end. A plant also has to live off water but the main substance needed to make chlorophyll is light energy. (form five boy)

A third type of response was classed as miscellaneous:

Photosynthesis is something to do with plants. Studying different sorts or species of plants. (form five girl)

Figure 44 shows the percentages of students who gave other responses. The composition of this group was as follows:

Other Responses	Percentages of Students					
Photosynthesis is how plants	F3	F4	F5	F6	F7	Tert.
.....breathe.	4	4	8	3	3	0
.....absorb energy.	1	12	7	4	0	0
.....get food from the ground.	5	19	5	0	0	0
.....make chlorophyll.	0	2	1	2	0	0
Miscellaneous responses	27	31	15	8	6	3

8.2.3 Where Does Photosynthesis Occur?

This section reports on pupils' responses to the three interview questions about the 10 examples in the stimulus item. In the teacher's science view the oak tree and wheat plant are the correct answers to all three questions:

(a) Which ones are the green plants?

The pre-teach pupils' responses (Table 5) were all based on a simple literal interpretation of the question. The oak tree was therefore always classed as a green plant:

Well most trees are green. Some of them are reddy colours and that but most of them are green. (13G)

The mushroom was never classed as a green plant:

No. You see brown mushrooms or something. I haven't seen any green mushrooms yet. (9G)

However, the pre-teach pupils had difficulty with wheat and they argued either way:

The wheat before it's ripe (is a green plant). It's green when it's just growing and just before harvesting it's a nice golden colour. (11G)

Some post-teach pupils continued to apply only this literal interpretation to the question, although others used their knowledge of chlorophyll and taxonomy:

Table 5 : The numbers of interviewees who answered "yes" when asked three questions about ten examples.

Examples	11 Pre-teach pupils			17 Post-teach Pupils		
	Is it a green plant?	Does it make its own food?	Does it perform photo-synthesis?	Is it a green plant?	Does it make its own food?	Does it perform photo-synthesis?
A person	0	9		0	2	1
A cow	0	5		0	3	1
An oak tree	11*	5*		17*	7*	17*
A fire	0	2		0	1	0
A wheat plant	4*	3*		13*	8*	15*
A whale	0	1		0	1	1
A car	0	0		0	1	0
A mushroom	0	2		0	3	5
An earthworm	0	0		0	1	1
A spider	0	0		0	1	1

* These responses constitute the teacher's science view.

Because they (i.e. oak and wheat) *need chlorophyll. Yeah, but as far as I know the mushroom doesn't.* ($16B_1$)

Mushroom's a fungi. That's different from green plants ($15B_1$).

Four pupils indicated that they held the teacher's science view that the sets of green plants and photosynthesizers are equivalent, and that the term 'green plant' is not to be taken literally. For example, one of these pupils justified his selection of wheat, along with the oak tree, as a green plant as follows:

$15B_1$: *... because although the wheat is often brown in coloration it's different because they are the trees or plants which in my opinion conduct photosynthesis.*
I: *You said wheat's brown. What makes a green plant?*
$15B_1$: *Well, it comes back to what I said. Something that does photosynthesis.*

(b) Can any of these make their own food?

The pre-teach pupils' responses (Table 5) ranged from a rejection of all the examples as food-makers (10G) to acceptance of as many as seven (10B). The person was usually accepted on the grounds that *They get a cook-book out or something or a recipe and they look up something and they make it* (8B) and also *if they are using seeds to grow vegetables* (11B) or *getting milk out of the cow and they could churn it* (13G). Production of milk qualified the cow as a food-maker for four pupils and another argued that *the cow pat falls to the ground, causes more grass to grow, and it eats the grass* (10B). The oak tree was justified as a food-maker by reasons like *a tree can grow some peaches and all those things ... different breeds of trees* (12B). This example produced the only pre-teach response which was similar to the teacher's science view, i.e.

It can (make food) when it gets its minerals and other things it needs. It processes them in its leaves I suppose it modifies the food if you want ... modifies the food a little bit that it gets. (11B)

The fire was considered to be a food-maker on the grounds that *you throw a match away and it can make its own food of wood* (12B). Recycling of materials was advanced in relation to wheat and mushroom:

Some of the wheat might drop down and go rotten and then the wheat that's growing might be able to take it up again. (11G)

The whale was justified on the grounds that:

It makes blubber. It feeds itself on the blubber ... and makes it warm and healthy. (10B)

The post-teach pupils generally accepted fewer examples as food-makers. One pupil, however, described all of the examples except fire and car as food-makers on the grounds that:

Anything can make its own food provided it has an input. Like we can make our own food in the form of fat as long as we have an input of other food. ($15B_2$)

However, three others (13B, $14G_1$, $17G_2$) rejected all 10 examples. The reasoning of one of these pupils is in contrast with the previous view:

It (i.e. person) *gets it from its environment like it eats cows, it eats wheat, mushrooms too, but it can't sort of make its own food inside itself. It's got to have something ... all the things it needs have to be put in it from outside.* ($17G_2$)

Only four pupils ($14B_1$, $16G_2$, $17G_1$, $17B_1$) associated the question about food-making with their concept of photosynthesis, and selected oak and wheat accordingly:

I: *Can you tell me why you picked out those two?* (i.e. oak and wheat as food-makers)
$16G_2$: *Because they are plants and they photosynthesize.*

(c) Has it anything to do with photosynthesis?

The pre-teach pupils were not asked this question because they had not heard of photosynthesis. Only post-teach pupils' views about which examples actually perform photosynthesis are reported here (Table 5).

The 17 post-teach pupils generally had similar views to the scientist about where photosynthesis occurs. The five pupils who responded positively to mushroom, and the two who responded negatively to wheat, all showed some uncertainty:

Aw, it wouldn't happen in the mushroom there ... hang on ... it's a plant. Yeah! In the mushroom. (13B)

Um, no, it (i.e. wheat) *might not. I was thinking of most green plants go through photosynthesis. I don't know about wheat since wheat's brown.* ($17B_2$)

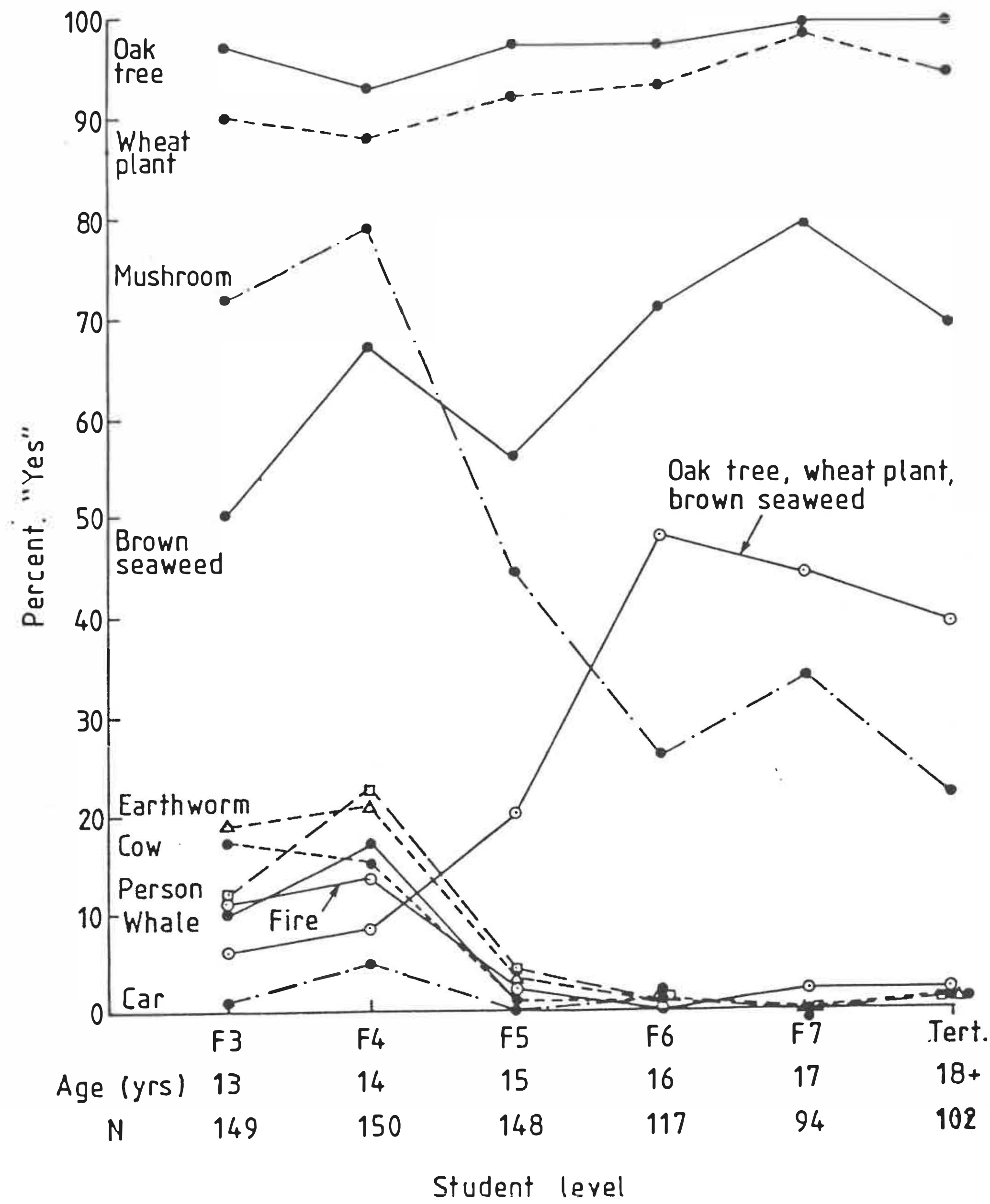
In summary, the 17 post-teach pupils generally correctly correlated the sets of green plants and photosynthesizers, although wheat (because it was not thought of as usually being literally green) and mushroom (because it was considered to be a plant) sometimes produced non-scientific responses. On the other hand, there was much less post-teach correlation between the set of food-makers and the set of photosynthesizers. The wide variety of ways in which pre-teach pupils think about food-making is relevant here. Only four post-teach pupils ($14B_1$, $16G_2$, $17G_1$, $17B_1$) selected oak and wheat only in answer to all three questions. These four pupils had all advanced either two or three of the teacher's science views of photosynthesis.

A survey item (Figure 45) asked students whether or not photosynthesis can occur in 10 examples. In the scientists' view, only the oak tree, the wheat plant, and the brown seaweed can perform photosynthesis. While students generally gave the scientists' response with regard to oak tree and wheat plant, affirmative responses for brown seaweed never rose above 80%. On the other hand, mushroom was widely regarded as a photosynthesizer.

Figure 45 : Students' responses about where photosynthesis occurs.

For each of these examples, TICK either the "Yes" box or the "No" box.

Example	Can photosynthesis occur in the example ?	
A person	Yes ☐	No ☐
A cow	Yes ☐	No ☐
An oak tree	Yes ☐	No ☐
A fire	Yes ☐	No ☐
A wheat plant	Yes ☐	No ☐
A whale	Yes ☐	No ☐
A car	Yes ☐	No ☐
A mushroom	Yes ☐	No ☐
An earthworm	Yes ☐	No ☐
A brown seaweed	Yes ☐	No ☐



8.3 SUMMARY AND DISCUSSION

Five points about the cognitive restructuring which occurs in children who are exposed to teaching about photosynthesis have emerged:

(a) The appearance of the three teacher's science views

Interviews and surveys suggested that students may accept one or more of three teacher's science views about photosynthesis, i.e. that it is a process in which plants produce carbohydrate, store energy, and make food. The last of these three views was the major learning outcome at form three level. A survey showed that 54% of these students described photosynthesis in terms of food-making, 19% in terms of producing carbohydrate, and 3% in terms of storing energy.

(b) Other student constructions

Where students did not give any of the three teacher's science views, they nevertheless indicated that they considered that photosynthesis is a process which occurs in plants. However, they sometimes misapplied the label 'photosynthesis' to some smaller-scale process, often one which is commonly advanced prior to teaching, e.g. they stated that photosynthesis is "how plants get food from the ground."

(c) Photosynthesizers and food-makers

Interviews suggested that pupils can readily justify their selection of a variety of animals (and even inanimate objects) as well as plants as food-makers. There was little correlation between the set of examples which the post-teach pupils selected as food-makers and the set of photosynthesizers which they selected later in the interview.

(d) Photosynthesizers and green plants

There was a closer correlation between the set of examples which post-teach interviewees considered to be green plants and the examples which they selected as photosynthesizers. However, a survey suggested that students only gradually begin to associate the occurrence of photosynthesis exclusively with green (i.e. chlorophyll-containing) plants. For example, 72% of third formers believed that a mushroom can perform photosynthesis. On the other hand, only 50% of third formers considered that photosynthesis can occur in a brown seaweed, i.e. a plant where the chlorophyll is hidden by another pigment.

(e) Photosynthesis and energy/matter conservation

Statements which appeared to suggest that energy (or sunlight) and food (or carbohydrate) are interconvertable were made by two pupils during interview and at least 12% of the students who were surveyed.

PART 2:

THE MODIFICATION OF CHILDREN'S VIEWS OF PLANT NUTRITION

CHAPTER 9 : MODIFYING CHILDREN'S VIEWS

- A SURVEY OF THE LITERATURE

I am reminded of the story of the man who, when asked how to get to Little Boglington, answered: `If I was you, I wouldn't start from here'.

(Margaret Donaldson, 1978, p.106)

9.1 INTRODUCTION

Part 1 of this study contained, in chapters 4-7, a description of children's intuitive knowledge about plant nutrition. This knowledge was presumably acquired haphazardly over a considerable period of time. Chapter 8 documented some outcomes when this knowledge is confronted by formal school instruction about photosynthesis. Part 2 considers this classroom interaction further and explores possible new directions for the teaching and learning of photosynthesis. The view of Strike and Posner (1984) that the task of learning is "primarily one of relating what one has encountered (regardless of its source) to one's current ideas" seems an appropriate starting point, both because we are considering the classroom as a place where this encounter occurs, and also because the focus on `current ideas' is consistent with the constructivist tradition (section 2.1) in which this study was undertaken.

Section 9.2 surveys research into classroom modification of children's views generally, and section 9.3 describes research carried out when photosynthesis was being taught.

9.2 CHANGE IN CONCEPTUAL UNDERSTANDING

A large amount of research describes the factors which promote and inhibit changes in the understanding of concepts, and comprehensive reviews are available (Gilbert and Watts, 1983; Driver and Erickson, 1983; Bell, 1984; Osborne and Freyberg, 1985).

West and Pines (1984) suggest that an image proposed by Vygotsky may be helpful in categorising approaches to change in conceptual understanding. This image is of an upward-growing vine (intuitive knowledge) meeting a downward-growing vine (formal school instruction). According to West and Pines (1984), three factors may be involved in the classroom:

(a) Conceptual change. This is the outcome if, to use Vygotsky's image, a major clash involving both structures in their entirety occurs. The resolution of such a conflict can be painful and difficult to accomplish. This situation was addressed by much early work in this field. For example, Erickson (1979) and Nussbaum and Novick (1981) stressed the importance of `anomaly manoeuvres' and `creating conceptual conflict' respectively.

(b) Conceptual resolution. This is the outcome if, to use the image, smaller scale clashes between individual branches occur. For example, differences in meaning between real-world and curriculum usage of terms will need attention. Conceptual resolution has been proposed by more recent studies as a means of promoting conceptual understanding. In the scheme of Hewson and Hewson (1984) integration and differentiation of students' prior non-irreconcilable ideas amount to a conceptual resolution strategy. (These workers use the term `exchange' strategies in cases of major clash.) In Claxton's (1985a) terminology, cognitive mini-theories undergo processes of subsumption, integration, derivation, and so on in situations which correspond both to conceptual change and conceptual resolution, depending on the size of the discrepancy. The distinction between a revolutionary and an evolutionary view of learning (Sutton and West, 1982) also corresponds broadly to these two categories respectively. In their view, researchers with a revolutionary view see children's prior knowledge as a potential barrier to subsequent learning, while those with an evolutionary view see prior knowledge as the interpretative framework for subsuming subsequent knowledge. The revolutionary view of conceptual change is consistent with a catastrophe theory model, while the evolutionary view rests comfortably with a smooth-change model (Gilbert and Watts, 1983). These two models derive in large measure from the work of Kuhn (1970) and Toulmin (1972) respectively.

(c) Conceptual development. This is the outcome if, to use the image, a gradual expansion and increased intertwining of the downward-growing vine is needed. This involves teachers and curriculum developers in integrating and differentiating the various components of the school knowledge which is to be presented to the learner. Analysis of the requisite skills and cognitive demands of the syllabus was a major aspect of the developmental psychology and behaviourist traditions (section 2.1). However, analysis of this type in the context of the constructivist tradition, aimed at achieving secure multiple points of contact between the two bodies of knowledge, is a recent development. (The work of West, Fensham and Garrard, 1984, is an example of this approach.)

9.3 PHOTOSYNTHESIS AND ACTION RESEARCH

Section 2.3 detailed the considerable amount now known about children's existing ideas in biology (excluding plant nutrition, which was described in section 2.4). However, only one of the studies in section 2.3 (Stead, 1980c) has been followed up by what Osborne, Freyberg and Tasker (1979) call action research[20] with the aim of achieving change in conceptual understanding. Of the studies which have investigated children's existing ideas about plant nutrition (section 2.4), those of Roth, Smith and Anderson (1983) and Bell and Brook (1984) have given rise to action research.

Smith and Anderson (1983), capitalising on their earlier work with Roth, produced a revised version of the Science Curriculum Improvement Study (SCIS) Communities unit, which they trialled with 10-year-olds in Michigan. The new unit addressed student preconceptions about plant food, light and growth and endeavoured to move students toward the view that plants use light energy to make food. Although learning did not improve in this study, a modification of this work resulted in greater success (Roth, 1985b). Specially prepared reading material (Roth, 1985a) explained to students that food is material which gives things energy, that plants in sunlight produce food, and that absorbed material is not plant food. Roth (1985b) used daily interviews to trace the thinking of 18 students, seven of whom read the prepared text and the other eleven read two standard texts. She reported that the seven students nearly all attained the four goal concepts, but little success was achieved with the other students.

The work of Bell and Brook (1984) gave rise to the preparation of a lesson sequence for use in English schools (Anon, 1985). This sequence, which is clearly constructivistic in its outlook, emphasised that photosynthesis is a process which makes energy foods (identified as glucose and starch). To date, no formal evaluation of this material has been published.

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20 Exploring with teachers possible ways of overcoming the identified difficulties and problems in teaching and learning science.

Two other action research studies in this area have been published. Smith and Lott (1983) used SCIS material (devised in 1962) which anticipated the student preconception that plants take in their food from the soil. They confronted students with the discrepancy of plants dying in the dark despite the presence of rich soil. However, the students failed to appreciate that light is indispensable in plant food-making. Instead, they simply added light to their list of examples of plant food.

Test and Heward (1980), whose interest was in the area of audio-visual aids rather than in conceptual understanding, taught photosynthesis to seven male students (all juvenile offenders) aged between 13 and 18 years. Test and Heward used a teaching strategy in which each student had an overhead projector at his disposal. They reported that this was effective in stimulating high rates of student response and it enabled students to see and discuss the responses of others. The use of transparencies and overlays by each student enabled them to experience a concrete dimension to each concept.

9.4 CONCLUSIONS

This chapter has suggested that for any school science topic a comprehensive attempt to effect change in conceptual understanding must consider both the nature of the matching process between school knowledge and the learner's existing knowledge (conceptual change and conceptual resolution), and also the components of the topic being presented to the learner (conceptual development). Where the topic was photosynthesis, research has confined itself to classrooms where the trophic theme was dominant. These issues were taken into account in the development of a photosynthesis action research programme (chapter 10).

CHAPTER 10 : PHOTOSYNTHESIS

- TOWARDS ACTION RESEARCH

> *Hardly do we guess aright at the things that are upon earth, and with labour do we find the things that are before us... And this observation do we find sufficiently verified in vegetable nature, whose abundant productions, tho' they are most visible and obvious to us, yet are we much in the dark about the nature of them...*
>
> (Stephen Hales, 1727, p. 181)

10.1 INTRODUCTION

This chapter documents the process by which a new strategy for teaching photosynthesis was devised. To use Vygotsky's image (section 9.2), the strategy is a classroom technique for coping with the situation where a downward-growing vine, the scientists' view of photosynthesis confronts an upward-growing vine, children's intuitive ideas about plant nutrition. The scientists' view is briefly revisited (section 10.2) and considered in terms of epistemological priorities. This corresponds to a process of conceptual development. Three existing strategies for understanding photosynthesis are then reviewed and evaluated (section 10.3). One of these strategies has been the focus of all the existing action research described in section 9.3. As an outcome of the findings of the present study concerning children's intuitive ideas, section 10.4 advances a teaching strategy which applies the generative learning model of Osborne and Wittrock (1985). Sections 10.3 and 10.4 therefore focus on the issues of conceptual change and conceptual resolution in the topic of photosynthesis and relate them to conceptual development. Section 10.5 describes some specific issues related to the devising of a teaching package entitled "Where Does The Wood Come From?"

10.2 PHOTOSYNTHESIS - SCIENTISTS' EPISTEMOLOGY

Following the first scientific formulation of the photosynthetic process (in terms of plant materials) by de Saussure in 1804, the concept of energy was implicated by J.R. Mayer in 1845 (section 5.1). These biochemical and ecological energetic themes are the key aspects of the scientists' concept today (section 1.2). Identification of the reactants and products, prior to a consideration of their energetics, remains an appropriate epistemology. Also, current research[21] is revealing the difficulties that teachers have in explaining the concept of energy, and a consequent need for further conceptual development.[22] This suggests a classroom teaching strategy which would address the biochemical theme, then the ecological energetic theme and, finally, the trophic theme (Figure 46).

10.3 UNDERSTANDING PHOTOSYNTHESIS - THREE STRATEGIES EVALUATED

Three existing strategies (guided discovery, element analysis, and trophic) are summarised in Figure 47.

10.3.1 The Guided Discovery Strategy

Practical work in photosynthesis in secondary schools is dominated by a strategy which takes advantage of the fact that the

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21 The Learning In Science Energy Project, LISP(E), centred at the Science Education Research Unit, University of Waikato, Hamilton, N.Z.

22 Dr M.D. Carr (pers. comm.)

Figure 46 : Photosynthesis - a possible cumulative teaching/learning framework.

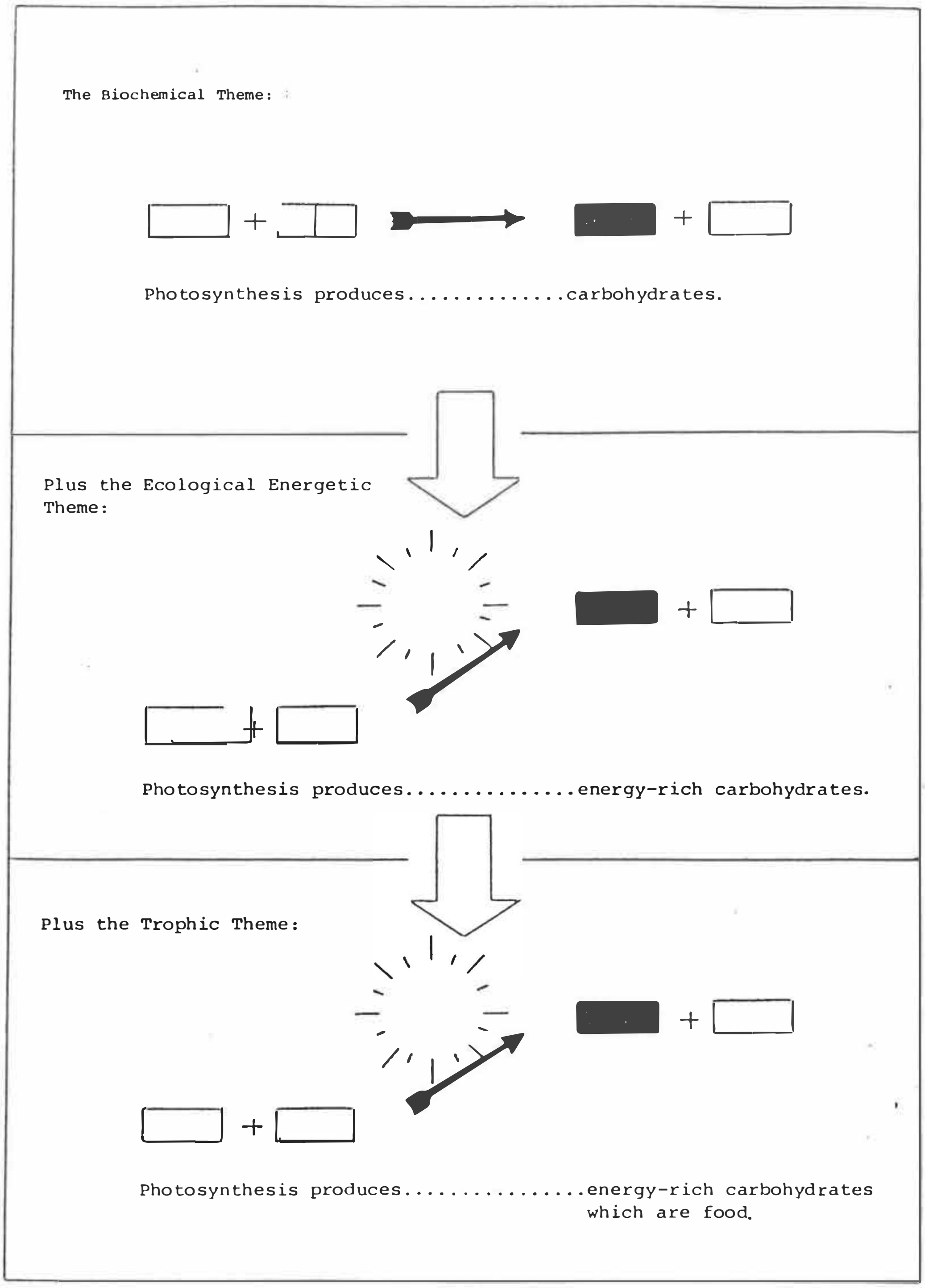


Figure 47 : Four strategies for understanding photosynthesis.

STRATEGY	GUIDED DISCOVERY	ELEMENT ANALYSIS	TROPHIC CONFLICT	GENERATIVE
USERS	All secondary school science teachers	Biochemists	Some science education researchers	-
MODELS	S_T Making sugar, starch Induction, Transmission. S_T Expt./Controls, Chemical tests. S_{Ch} Wood, water, gases, minerals	S_T Making wood, sugar, starch Deduction, Transmission. S_T Chemical elements S_{Ch} Wood, water, gases, minerals	S_T Making food Exchange Exchange S_T Energy S_{Ch} Absorbing food	S_T Making wood Generating links, constructing meaning S_{Ch} Wood, water, gases, minerals
CRITERION 1 Does it reflect the scientists' view?	No	Yes	No	Yes
CRITERION 2 Does it take account of students' prior knowledge?	No	No	Yes	Yes

synthesis of starch in leaves can be demonstrated by a chemical test with iodine. This chemical behaviour is contrasted with that in experiments in which necessary conditions or materials are missing (control experiments). The starch-iodine technique was first used by Sachs in 1864 (section 4.5.1.2). Of the 48 practical exercises found in the 10 school texts which have been explored in the present study (Appendix A), 47 involve some form of chemical testing. In 33 instances, the starch-iodine test is used; but the presence of glucose is also demonstrated using Benedict's solution, the presence of carbon dioxide with bromo-thymol blue, and the presence of oxygen with alkaline pyrogallol or a glowing splint. Forty-two of the 48 practical exercises involve the use of control experiments, the remaining six mostly serving to introduce the chemical testing technique itself. The way these exercises are integrated with other material in the texts suggests that Claxton's (1984) description of guided discovery applies: "It usually involves leading people to a predetermined concept by providing them with a series of planned experiences. The teacher's role is not to communicate the understanding in words (tuition), nor simply to ask people to act in ways that will generate valuable and digestible feedback (instruction), but to orchestrate the learners' experience for them, and nudge their comprehension in the 'right' direction".

A considerable body of research suggests, however, that there are significant problems involved with the classroom use of guided discovery learning, controlled experiments, and chemical testing, both generally and in the area of photosynthesis. Guided discovery learning has been a popular topic of debate for some time (Hermann, 1969; Solomon, 1980; Zylbersztajn and Gilbert, 1981; Rowell and Dawson, 1983; Osborne, 1984b). The comment of Strike and Posner

(1984) sums up a very common viewpoint when they describe the notion that students never really learn something unless they find it out for themselves, as being 'manifestly untrue'. Again, research into students' understandings of experiments and controls (Kamm, 1971; Lawson, Blake and Nordland, 1974; Ryman, 1976; Driver, 1978, 1983a; Tamir, 1978) suggests that, at least at junior secondary school level, learners have considerable difficulty with the abstract nature of the concept of a control and that any understanding is context-specific. Little work appears to have been done on pupils' understanding of chemical tests, but Shayer and Adey (1981) considered that for students at the early formal stage of understanding (which includes most junior secondary school students) "the principle of most chemical tests would not be understood".

Three studies (Ausubel, 1968; Barnes, Britton and Rosen, 1969; Delamont, 1976) have made passing reference to classroom practical exercises in photosynthesis. Ausubel (1968, p. 529) singles out photosynthesis as an example of the misapplication of the guided discovery approach: "It is unnecessary and educationally wasteful to wait for such concepts to evolve spontaneously from direct experience. Further, many abstract concepts (for instance, 'photosynthesis', 'ionisation') can only be acquired verbally since they are not susceptible to direct experience". More specifically, Barnes, Britton and Rosen (1969), observing a lesson on chlorophyll extraction, noted that the teacher asked 'pseudo-questions' and failed to open up discussion which would have exposed the students' perception of events, despite very clear indications that misconceptions existed. Finally, Delamont (1976) quotes a student commenting on the very common experiment designed to show that starch forms only in those parts of a leaf which are exposed to sunlight and not in areas covered by aluminium foil: *...I don't see how that will prove it - it could be all sorts of other things we don't know anything about ... Well, you* (her teacher) *said if there was starch in the bare patches it would mean that there was ... it was because of the light, but it could be the chemicals in the foil, or something we know nothing about.*

Bell (1985) documents fully two series of lessons involving these practical exercises. She reports numerous instances of student confusion, of searches for the 'right' answer, and of unintended conclusions. In desperation, the teachers resorted to a 'teaching is telling' technique in an attempt to salvage the situation. The present study has shown that students often possess little prior knowledge about starch (section 4.5.3.3), and that they sometimes construe practical situations about chlorophyll (section 4.4.2.4) and starch (section 4.5.2.7) in unanticipated ways.

To summarise: By focussing on starch, which in the scientists' view is a relatively minor product of photosynthesis compared with soluble sugars and cellulose (section 4.5.1.1), the guided discovery strategy highlights a material about which learners possess little prior knowledge. Instead, their children's science understandings about plant materials are not addressed. This strategy is further confounded by the requirement for a considerable amount of prerequisite teacher's science knowledge about experimental controls and chemical testing (Figure 47).

10.3.2 The Element Analysis Strategy

An historically decisive step in the understanding of photosynthesis was de Saussure's application of the new chemical system of Lavoisier to plant physiology in 1804. De Saussure, "using quantitative measurements of weight, showed that the bulk of the dry matter of plants was composed of carbon, hydrogen, oxygen, carbonic gas, and water, and that a part of the oxygen was given off into the atmosphere. He also determined the quantities and kinds of substances that entered into the organisation of the plant. The botanists learned from the chemists" (Delaporte, 1982). Thus although the essential qualitative aspects of photosynthesis were known by about 1782 as an outcome of thousands of experiments conducted by Priestley, Ingen-Housz and Senebier, it was de Saussure who "finished the fundamental experimental work and supplied a convincing theoretical interpretation of the whole" (Nash, 1964). The new theory, which proved to be the historical prerequisite for the understanding of photosynthesis, is described by Morton (1981) as follows: "There was now a clear language in which the descriptive observations of chemistry could be expressed the language of chemically defined elements and compounds, applicable to their interactions everywhere, whether in living or non-living systems. The general law on which the new chemistry was built - the conservation of matter, expressed in the chemical equation gave meaning and emphasis to the use of quantitative methods in investigations of the metabolism of living organisms."

Could an approach to photosynthesis based on chemical analysis of water, soil, air, and plant material be a fruitful classroom strategy at junior secondary school level? Research in chemical education suggests that students at this level have considerable difficulty in understanding the particulate nature of matter. Students often prefer to operate on a "descriptive and functional" level (Johnstone, 1982) and give "primary type responses" (Simpson and Arnold, 1982a) rather than thinking or talking about matter from an atomic viewpoint. The tendency to classify powders as liquids because they can be poured suggests that some students have alternative classifications even at the macroscopic level, while Schollum (1984) has shown that students may construct alternative diagramatic representations of particles. Students are, in fact, confused by the word 'particle' and often do not understand the words 'atom' or 'molecule' in the scientific sense (Happs, 1980). The comprehensive studies of Dow, Auld and Wilson (1978) and Brook, Briggs and Bell (1983) support many of the above findings. Students also have difficulty with the concept of chemical change. They have problems with the notion of reactants and products (Schollum, 1981, 1982), in representing changes in equation form (Russell, 1984), in interpreting given equations (Weninger, 1982; Schollum, 1983), and with the whole area of stoichiometry (Fensham, 1983).

To summarise: Whilst the element analysis strategy undoubtedly reflects the scientists' view of photosynthesis, it ignores children's existing macroscopic views about plant nutrition. Instead, it has as its prerequisite a theory-laden body of teacher's science which students apparently have considerable difficulty accepting (Figure 47). As Layton (1973) puts it: "In terms of a general education involving science the very steps which have increased the power of science as a mode of intellectual inquiry have generated formidable problems associated with its teaching and learning".

10.3.3 The Trophic Conflict Strategy

Researchers who have proposed a strategy for action research and photosynthesis (Smith and Lott, 1983; Roth, 1985a; Anon, 1985) have all adopted an approach which aims to have students relinquish their existing ideas about plant food as absorbed material and to accept the view that the food is produced within the plant.

Photosynthesis is thus described as a food-making process. In addition, Roth (1985a) assumes that students will accept that food is material which supplies energy to living things. Further, Anon (1985) identifies the food which plants produce as sugar and starch.

There appear to be four major difficulties with this strategy:

(a) The definition of food

Scientists have no agreed definition of food (Barker, 1985e), neither is the notion of food an important theme in their accounts of photosynthesis (section 6.1.1). School texts differ widely in their definitions of food. Energy-rich materials (carbohydrates, fats, protein) are always classed as food but the definition is often extended (in decreasing order of frequency) to minerals and vitamins, water, and roughage (Barker, 1985e). Children possess a concept of food which is variable and context-dependent. Exactly who or what is capable of eating food, how frequently it is eaten, whether we are to consider materials in isolation or in combination with other materials, and whether we are talking about food literally or metaphorically, are some of the issues which younger students grapple with when they are deciding what constitutes food. For older students, the provision of energy emerges (at the expense of edibility and palatability) as a criterion for deciding whether something is food (Barker, 1985e). However, younger students apparently construe energy storage in food in various unanticipated ways (Solomon, 1982). It is clear that neither teachers nor students are justified in assuming that they are using the word 'food' in the same way when they talk together.

(b) The meaning of 'food-making'

The proposition that 'plants make their own food' is the major, and often the only, learning outcome when junior secondary school students are exposed to current teaching about photosynthesis (section 8.2.2). This proposition often constitutes for students a piece of dogma, unrelated to other understandings. On the other hand, students can apply the term `food-maker' sensibly to human beings, cows, and so on (section 8.2.3).

(c) Food, plants and animals

It could be argued that a classroom approach to photosynthesis via the trophic theme could capitalise on students' personal interest in eating and food chains. However, children are all too ready to draw analogies between plants and animals (section 7.3.3) and an early association between the concepts of food and eating in a teaching sequence could merely reinforce the intuitive notion that for plants, edibility becomes absorbability. The key point is that understanding photosynthesis as a mode of nutrition different from animal nutrition requires a concept of food distinct from the concept of eating. Historically, analogy-making long obscured understanding of photosynthesis (section 7.4), yet the study of Roth, Smith and Anderson (1983) confirms that today's students still argue by this analogy. These workers considered that since pupils "did not think beyond what they could see", they did not focus on internal plant processes such as food-making. It may be that children do think beyond what they can see, but that they use an unproductive analogy to reinforce their intuitive views about plant food as absorbed material.

(d) Conceptual change and insecure egos

Conceptual change, as defined by West and Pines (section 9.2), strikes at the core of one's beliefs. Non-rational factors are therefore important in determining continuation of learning (Novak, 1981; West and Pines, 1983; Watts and Bentley, 1984). As Claxton (1984) puts it: "When people feel threatened they stop learning".

The trophic strategy may risk much in exchange for a view of photosynthesis which is not central to that of the scientist.

To summarise: Whilst the trophic conflict strategy does address children's existing ideas about plants and food, it leaves other aspects of children's knowledge about plants undisturbed and it has as its end point only a peripheral aspect of the scientists' view of photosynthesis (Figure 47).

10.4 UNDERSTANDING PHOTOSYNTHESIS - A NEW STRATEGY

10.4.1 Children's Science Meets Scientists' Science

None of the three strategies reviewed so far adequately reflects the scientists' view of photosynthesis and also takes account of children's prior understandings about plant nutrition. This section focusses again on both of these views.

Children's views about plant nutrition comprise a number of isolated explanations for specific events (section 7.3.1). When confronted with the concept of photosynthesis in classrooms, students often identify the new concept with one of their isolated understandings (section 8.2.2) or reject it outright as superfluous to their existing understandings which they find still adequate (Figure 48). Conversely, an understanding of photosynthesis will be acquired if it is perceived by learners as an umbrella-like principle which encompasses all their existing relevant views (Figure 49). Integration, as understood by Hewson and Hewson (section 9.2) must therefore be a dominant aspect of any attempt to achieve change in conceptual understanding in this subject. If, as in Claxton's (1985a) terminology, the existing views are `mini-theories' (section 7.3.1) then what is needed is for these to coalesce to form a single `maxi-

Figure 48 : A common student perception of classroom instruction about photosynthesis in relation to prior knowledge.

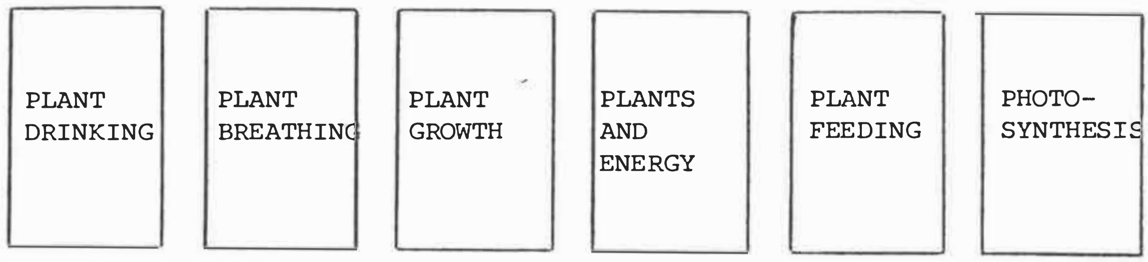
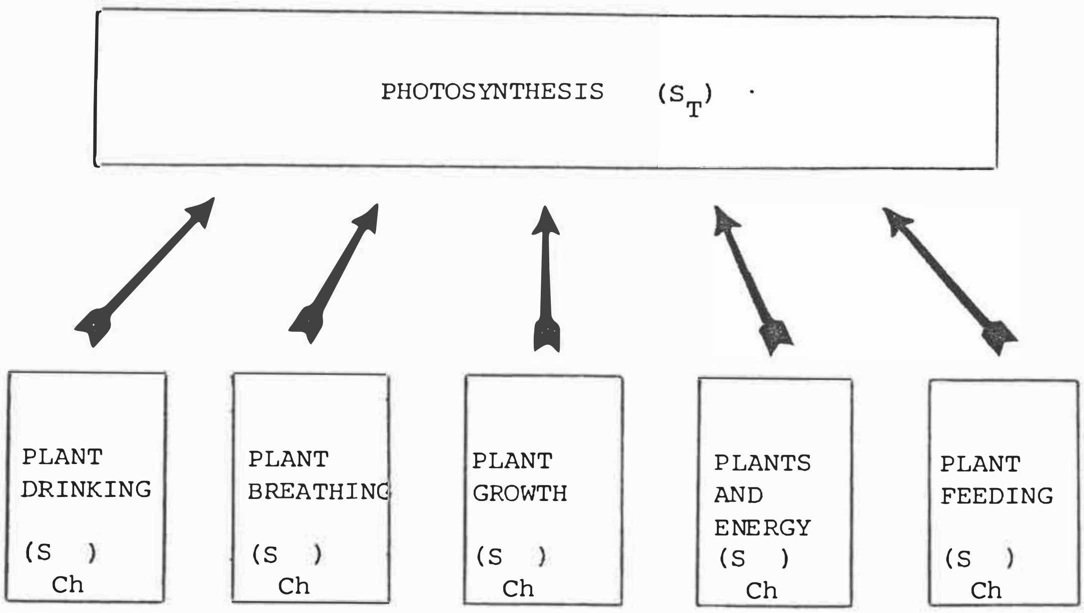


Figure 49 : The researcher's perception of classroom instruction about photosynthesis and the intended outcome.



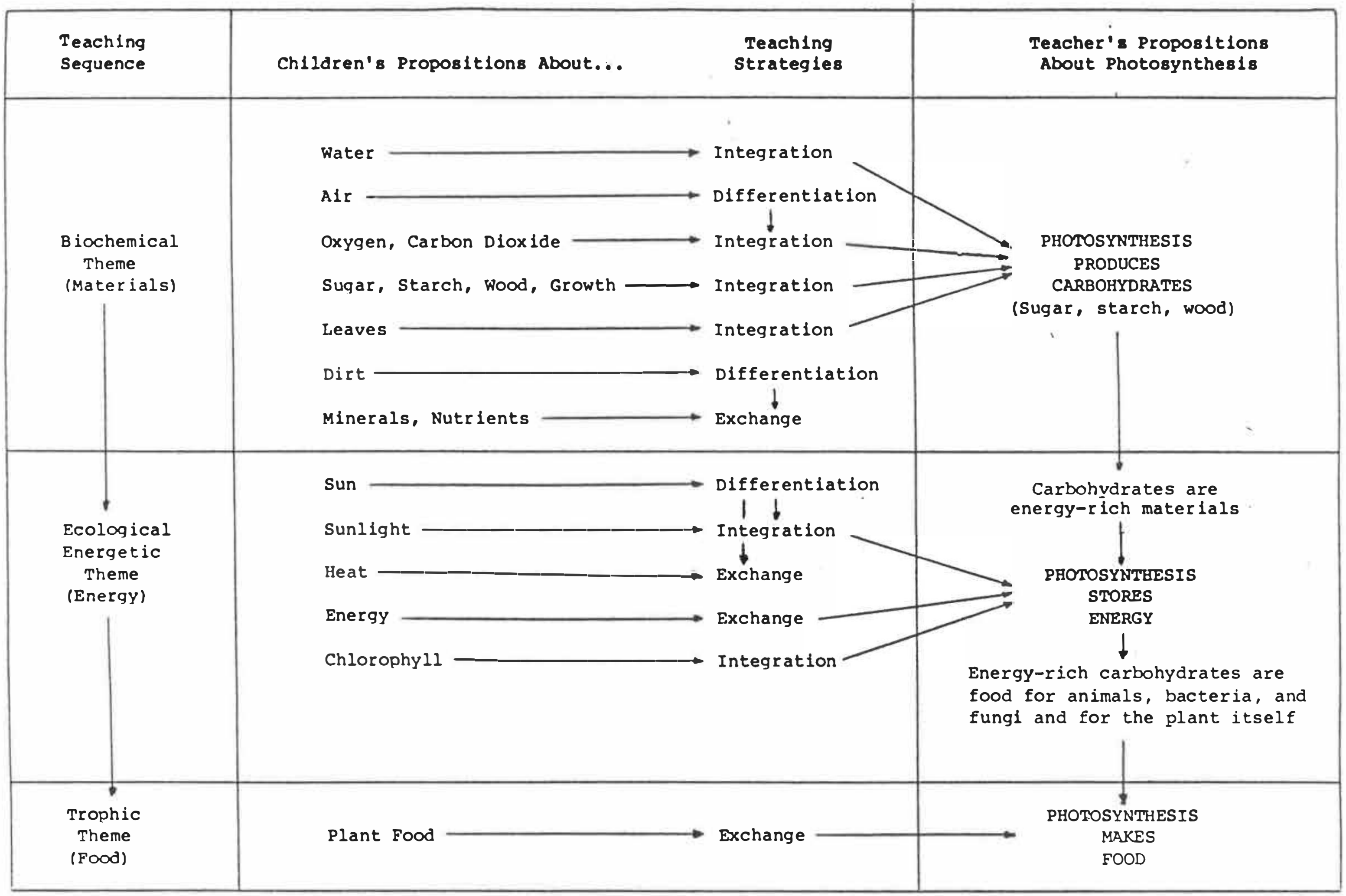
mini-theory'. Because children's language is often imprecise (section 7.3.2), some prior differentiation (Hewson and Hewson, 1984) of children's generic terms like 'dirt', 'air' and 'sunshine' will also be necessary. Where teachers' and children's views are irreconcilable, cognitive exchange (Hewson and Hewson, 1984) will be required. One possibility (involving major cognitive restructuring) is that the original term (e.g. 'food') will be retained but with a new meaning in the context of photosynthesis. Another possibility is that the term may play little part in the new conception (e.g. 'heat' or 'minerals').

Figure 50 shows diagrammatically the restructuring of the teacher's propositions (developed from Figure 46), i.e. West and Pines' (1984) process of conceptual development. It also shows the restructuring of children's propositions, required in anticipation of conceptual change and conceptual resolution. In the next section a strategy for classroom implementation of the framework in Figure 50 will be proposed.

10.4.2 The Rationale For A Generative Learning Strategy

Very few of the studies of children's intuitive ideas have been followed up by action research (section 9.3). There is also a lack of studies which suggest ways of implementing any constructivistic model of learning in the classroom. Smith and Anderson (1983), as an outcome of a study based on the work of Posner *et al.* (1982), suggested that instructional materials should provide explicit information about children's prior understandings, without overloading the teacher's information-processing capacity, and that materials should also promote a conceptual change view of teaching within the teacher. The work of Tasker and Osborne (1983) gave

Figure 50 : Photosynthesis - a framework for the interaction of children's and teacher's propositions.



rise to a series of checklists for evaluating classroom science activities (Osborne and Freyberg, 1985).

The generative learning model of Osborne and Wittrock (1985) is an instance where the classroom implications of a model of learning have been considered in detail (Figure 51). The model postulates that learning is an outcome of an interaction between one's existing ideas and the sense information which one actively selects and attends to. Learning involves generating links between these two and hence actively constructing meaning. The model has clear implications for the classroom because learners' existing ideas affect classroom interaction, and because teachers contrive situations which provide sensory input.

No previous study has devised a teaching strategy along the lines suggested by Osborne and Wittrock. This was seen to present two interesting research possibilities. It provided an opportunity to:

(i) document specific learning outcomes about the concept of photosynthesis resulting from the new strategy

and (ii) explore the practical issues encountered when applying the generative learning model to a specific syllabus content area.

The production of a teaching package was therefore undertaken (section 10.5.1). Practical issues are described in section 10.5.2. The student learning outcomes are documented in section 11.2.

Figure 51 : The generative learning model (Osborne and Wittrock, 1985).

(i) *the learner's existing ideas influence what use is made of the senses and in this way the brain can be said to actively select sensory input.* For example a pupil may be asked to look for animals in a forest. His or her meaning for the word animal will influence *where* the pupil will look. If birds are not considered animals — and for many children they are not (Bell 1981) — then it is less likely pupils will look skywards.

(ii) *the learners' existing ideas will influence what sensory input is attended to and what is ignored.* For example, much of what we hear is considered irrelevant to our immediate interests and focus of attention. Such sounds are heard but ignored; whether they be from the birds outside the classroom window or the noises from the class in the adjacent room.

(iii) *the input selected or attended to by the learner, of itself, has no inherent meaning.* For example, a teacher states that 'There is a force on a ball rolling down a hill'. To the teacher this statement has a certain meaning but this meaning cannot be conveyed directly to the learners; only the *sounds* are conveyed to the learners' brains.

(iv) *the learner generates links between the input selected and attended to and parts of memory store.* A learner unfamiliar with physics is unlikely to generate links to a uniform slope, or to the idea of gravity acting on the ball, when he or she hears that 'There is a force on a ball rolling down a hill'. He or she might link the sensory input to a specific experience of a ball rolling and bouncing down a grass hillock, for example. Unfortunately such links generated may be quite inappropriate if the learner is to construct a meaning similar to the teacher's meaning.

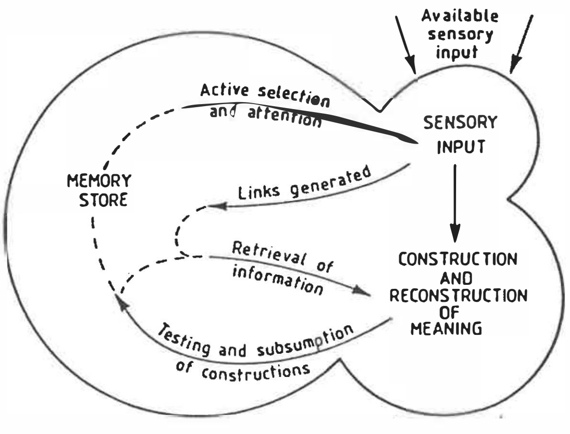
(v) *the learner uses the links generated and the sensory input to actively construct meaning.* For example, from the sensory input heard from the teacher, and the specific experience in memory to which links have been generated, a meaning can be constructed for 'There is a force on a ball rolling down a hill'. Our non-physics learner may think of the force as the jolting of the ball against the rough hillside or a force within the ball by virtue of its speed (see Gilbert, Watts and Osborne 1982). Neither construction is likely to be similar to the teacher's meaning.

(vi) *the learner may test the constructed meaning against other aspects of memory store and against meanings constructed as a result of other sensory input.* Testing constructed meanings involves generating links to other aspects of memory store. Does the newly constructed meaning relate well to other related ideas that can be constructed from memory store. Is the newly constructed idea compatible with prior constructions? As an example, let us assume the next sentence stated by the teacher was 'The greater the slope of the hill the greater the force'. Our non-physics student might construct a meaning from this which tests out well against his or her earlier construction. With a greater slope, a steeper hill, the jolting of the ball will be greater and/or the speed the ball acquires will certainly be greater. However, if the next sensory input was a visual stimulus from the blackboard '$F = mg\sin\theta$' our non-physics student might (possibly?) suspect that his or her constructed meaning for the earlier statements was different in some unaccountable way from the teacher's ideas. Alternatively, and possibly more likely, he or she may simply feel unable to construct anything meaningful from the blackboard statement but remain relatively happy with his or her construction from the first statements.

(vii) *the learner may subsume constructions into memory store.* If the constructed meaning makes sense in terms of its evaluation with other aspects of memory store then it may be incorporated into memory, influencing and possibly altering the memory-store itself in the process. The greater the number of links generated to other aspects of memory store, and the greater the number of these links that reaffirm a useful constructed meaning has been made, the more likely the idea will be remembered and make sense to the learner.

(viii) *the need to generate links and to actively construct, test out and subsume meanings requires individuals to accept a major responsibility for their own learning.* All the activities involved in learning with understanding require intellectual effort on the part of the learner. Learners and teachers have distinctive responsibilities in science education. No learner can read a book, listen to a talk, see a demonstration or a film, and learn with understanding without actively taking responsibility for that learning (Wittrock and Lumsdaine 1977). When students accept that they, rather than their teachers, their parents, other people, or other factors, are primarily responsible for constructing the meanings that represent their success or failure in school, their learning is likely to increase. Teachers, parents, and other people have a distinctive responsibility for facilitating learning by teaching. But good teaching is not sufficient to attain good learning, which requires active intellectual effort by the learner.

Figure 1: Schematic representation of the generative learning model



THE ACTIVE CONSTRUCTION OF MEANING

10.5 COMPILING THE TEACHING PACKAGE

10.5.1 Design Features Of The Package[23]

Action research in the present study is confined to the biochemical theme, i.e. in assisting learners to acquire a preliminary understanding of the material changes in photosynthesis.

The teaching package was shaped according to the eight postulates of the generative learning model and their implications for the classroom (Osborne and Wittrock, 1985). It was divided into three distinct teaching phases (focus, challenge, and application) according to the teaching sequence of Cosgrove, Osborne and Tasker (n.d.). Cosgrove and Osborne (1985) considered this sequence to be a teaching model for generative learning. Some of the eight postulates were therefore highlighted in each of the phases, e.g. postulates (i) and (ii), which deal with the way learners select and attend to stimuli, were seen as being central to the focus phase.

The teaching package has no hidden agenda, inaccessible to teacher or pupils. The overall structure of the package is disclosed to the teacher (page 259) and to the learners (page 262) at an early stage. That the package is based on the generative learning model is made explicit to the teacher (page 257). It is explained to pupils that their becoming aware of their own ideas in their learning will be a key feature (page 262). The focus phase activities are therefore not in the guided discovery tradition, but the discovery by students of their own ideas anticipates the crucial step in the challenge phase (pages 293 and 294) in which a Self-Teach Booklet assists the students to construct the scientists' view.

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23 The teaching package is found in Appendix B.

One feature of the package, the use of 'paper memories', goes beyond the suggestions of Osborne and Wittrock. Rowell and Dawson (1984) argued that if a teacher can describe an alternative (i.e.scientists') explanation by linking it to ideas already held by students, then "each individual, having constructed both theories, has no greater need to enhance, maintain or defend one rather than the other". The teaching package requires that students carry their responses to surveys in the focus phase through to the application phase where their earlier responses can be evaluated against their newly constructed scientists' view.

10.5.2 Applying The Generative Learning Model - An Assessment

This section documents some practical issues encountered when using the generative learning model to compile the teaching package about photosynthesis. The model provided fruitful suggestions about three key issues which always arise in instructional design:

(a) Formulating cognitive objectives

Photosynthesis results, directly or indirectly, in the formation of nearly all the organic material on earth (section 1.2). The teaching package needed to convey this more successfully than previous strategies (section 10.3). The learner's reliance on existing knowledge in memory store for the generation of new concepts (postulate iv) suggested a realistic cognitive objective. Junior secondary school pupils are unfamiliar with the terms 'carbohydrate' and 'organic material', and the specific product starch (section 4.5.3.3). Wood (the cellulose of which is the major photosynthetic product) is familiar to children (section 4.5.2.3) even although its origins are difficult for children to explain (section 4.5.2.4). Providing students with an answer to the specific question, "Where does the wood come from?" or more generally, "Where does the stuff in a plant come from?" (page 259) was therefore chosen as a realistic objective for the teaching package. This provided an instance of what Osborne (1984b) considered to be a general objective of all science learning, namely, making better sense of the natural, physical, and technological world in which students live. In Claxton's (1985b) terms, the teaching package aims to "dissolve science into common sense".

(b) Devising practical experiences for students

Postulates (i) and (ii), which state that what pupils select and attend to is influenced by their own existing ideas, provided a valuable criterion in the design of classroom experiences. The mechanics of chemical testing and the concept of experimental controls are design features which can distract teachers and learners from focussing on the key cognitive objective, namely, the origin of plant materials (section 10.3.1). Consequently, the four investigations in the focus phase highlighted the question of plant material and its origin and the four surveys drew students' attention to their own useful ideas.

(c) Facilitating meaningful longer-term learning

Teachers frequently assert that a teaching package must be relevant to a student's world and that its effects should be enduring. A mechanism for achieving these ends was found in Osborne and Wittrock's commentary on postulate (viii) where it states that "the greater the number of links generated to other aspects of memory store ... the more likely the idea will be remembered and make sense to the learner". This provided the rationale for devising nine checkpoint items which related the new construction to a variety of prior experiences (page 314).

In three further respects, however, the generative model proved difficult to implement:

(a) Matching the generative learning model to the three phase teaching sequence

In general, the model appears to be linear and can hence be related to the teaching sequence. Postulates (i) and (ii) relate to the focus phase, postulates (iv) and (v) to the challenge phase, and postulates (vi) and (vii) to the application phase. Postulate (viii), however, which stresses that individuals should accept a major responsibility for their own learning appears more general and equally applicable to all three phases.

(b) Distinguishing between selection and attention

In practice, it would appear to be difficult to separate these processes or to place them in sequence since each can generate the other. Some authorities (for example Norman, 1969; Hilgard, Atkinson and Atkinson, 1979) refer to 'selective attention', while the more general term 'focussing' (Barnes, 1976) may better convey the essential point that teachers and students may perceive different aspects of a situation as being the most relevant feature.

(c) Implementing postulate (iii)

Postulate (iii) that "the input selected and attended to by the learner, of itself, has no inherent meaning" appears to relate to the orientation of the whole model rather than implying specific classroom outcomes. To state that meanings are personal, idiosyncratic constructions within the learner's brain is consistent with the constructivist tradition, but there are everyday and philosophical justifications for using the term 'meaning' in various other ways (Parkinson, 1968). The use of the terms 'public knowledge' and 'private understandings' (Sutton, 1981; West, Fensham and Garrard, 1984) may be equally appropriate in this context.

CHAPTER 11 : PHASE III, ACTION RESEARCH

- METHODOLOGY AND FINDINGS

> *When a child interprets what we say to him his interpretation is influenced by at least three things (and the ways in which these interact with each other) - his knowledge of the language, his assessment of what we intend (as indicated by our non-linguistic behaviour), and the manner in which he would represent the physical situation to himself if we were not there at all.*
>
> (Margaret Donaldson, 1978, p.69)

11.1 METHODOLOGY OF THE ACTION RESEARCH

11.1.1 The Design Of The Action Research

Action research, i.e. exploring with teachers possible ways of overcoming the identified difficulties and problems in teaching and learning science (Osborne, Freyberg and Tasker, 1979) is typically collaborative, participatory and self-evaluative, and generally does not involve the classical comparison of learning outcomes from rival teaching strategies under controlled conditions (Cohen and Manion, 1980). Interest in children's intuitive ideas (section 2.1) and a change in focus from teacher behaviour towards pupil understanding (Driver, 1983b) have resulted in an increasing refinement in the techniques of classroom observation (Tasker and Osborne, 1983). The latter is now an almost inevitable aspect of action research (Cohen and Manion, 1980).

Some features of the present study favoured an action research approach. Teachers had helped to collect data for phases I and II and had attended in-service courses where results were discussed and the need for a different teaching strategy considered. To allow for the possibility that the findings could be generalised, a class of middle ability band students from a medium-sized co-educational state secondary school was chosen. Their teacher had voluntarily identified with phases I and II and in the opinion of his peers and the researcher had reached a high level of competence. It was also hoped that this choice of class and teacher would give credence to the research findings in the eyes of other interested teachers. An action research programme (Figures 52, 53, 54) was designed to evaluate the teaching package. The programme sought answers to 20 research questions and used five types of research strategies:

(i) Observations of teacher/class interactions. (A tape recorder was permanently stationed near the front of the room.)

(ii) Observations of students. (A hand-held tape recorder documented researcher/student and student/student conversation.)

(iii) Out-of-class interviews with individual students.

(iv) An out-of-class interview with the teacher.

(v) Analysis of students' written responses in the investigations, surveys, checkpoints, etc.

11.1.2 The School, The Students, The Teacher

The co-educational state secondary school in which the strategy was trialled was founded in 1972, has a staff of 55 (including 11 science teachers and one technician) and a student roll of 1120 third to seventh formers.

The class of 28 fourth formers (14-year-olds) comprised 18 girls and 10 boys and was one of seven equivalent middle ability classes. (The school also has two accelerate and one remedial form four classes.) Twenty-three students were of European ethnic origin, four Maori, and one Indian. None had been taught about photosynthesis

Figure 52 : The action research programme (focus phase).

The FOCUS Phase				
Postulates of the Generative Learning Model (Osborne And Wittrock, 1985, p.64-66)	Implications For The Classroom (Osborne And Wittrock, 1985, p.70-76)	Features Of Instructional Package: "Where Does The Wood Come From?" (Appendix B)	Research Questions	Research Strategies
(i) The learner's existing ideas influence what use is made of the senses and in this way the brain can be said to actively select sensory input.	Pupils need the opportunity to select sensory input for themselves, at least initially. (p.71)	As an outcome of the stimulus question "What do plants need to grow?", students have a free choice from four investigations (p.260)	1. Were students curious about the four investigations and eager to embark on the investigation of their choice?	Observation of teacher -class negotiations.
(ii) The learner's existing ideas will influence what sensory input is attended to and what is ignored.	A teacher needs to influence the learner's voluntary control over attention. (p.71) Teachers can influence the learners' control over attention by ensuring that (i) written material has carefully worded headings, sub-headings and focus questions, (ii) substantive and key objectives clarify the intent of a lesson, and (iii) instructions encourage pupils to attend to the key purpose and important design features of an experiment. (p.71)	The investigations direct pupils' thinking about what plants need to grow (sun, seeds, soil, minerals, water, air) towards the key question "Where does the stuff in a plant come from?" Pupils are invited to form theories of their own (p. 260) Finally, the teacher directs pupils towards a specific form of the key question, i.e. "Where does the wood in a tree come from?" (p. 260)	2. Did the teacher's purpose (i.e. focussing on the key question "Where does the stuff in a plant come from?") become the students' purpose? 3. Did the students readily form their own theories in response to the key question? 4. Did the students' theories involve the important design features of the investigations (sun, seeds, soil, minerals, water, gases?	Observation of students. Interview A, question (ii). Teacher interview. Observation of teacher -class discussion. Observation of students. Interview A, question (iii). Analysis of "What do plants need to grow?" (p.263) Analysis of investigation responses.
(iii) The input selected or attended to by the learner, of itself, has no inherent meaning. (viii) The need to generate links and to actively construct ... meanings requires individuals to accept a major responsibility for their own learning.	Pupils (need to be) encouraged or find it profitable ... to attempt to generate multiple links between sensory input and existing knowledge. (p.70) Learners (need) to become aware that meaning is something that they construct. (p.72)	The four surveys and the discussions which follow are designed to help learners clarify and value their present views about plants, air, water etc (p. 260) The focus phase concludes with the teacher suggesting that pupils could construct the scientists' answer from their own views (p. 260)	5. Did the anticipated prior knowledge exist in the students' memories? 6. Was this knowledge exposed by class discussion? 7. Were students motivated to seek the scientists' view?	Analysis of Surveys 1,3,4. Interview A, question (i). Observation of teacher -class discussion. Observation of teacher -class discussion. Interview A, question (iv).

Figure 53 : The action research programme (challenge phase).

The CHALLENGE Phase				
Postulates Of The Generative Learning Model (Osborne And Wittrock, 1985, p.64-66)	Implications For The Classroom (Osborne And Wittrock, 1985, p.70-76)	Features Of Instructional Package: "Where Does The Wood Come From?" (Appendix B)	Research Questions	Research Strategies
(iv) The learner generates links between the input selected and attended to and parts of memory store.	Teachers can remind pupils of the important and relevant aspects of the previous lesson(s). (p. 72) Teachers can relate the scientific principle to pupils prior experiences both in and beyond the classroom. (p. 72) The teacher can repeat the explanation in written as well as oral form. (p. 72)	The student's self-teach booklet (plus OHP's) initiates an account of the scientists' response to the question at the end of the focus phase, i.e. "Where does the wood come from?" in terms of pupils' prior knowledge of plant drinking, breathing, feeding, etc. (p.290) The scientists' view is presented in both written (student's self-teach booklet) and oral (OHP's) format.	8. Did the pupils relate the activities in the challenge phase to the focus phase, or did they see them as isolated episodes?	Interview C, question (iii). Teacher interview.
			9. Which format (self-teach booklet or teacher's description) did students find most helpful?	Interview C, question (ii).
(v) The learner uses the links generated and the sensory input to actively construct meaning.	The learner represents his or her tentative constructions on paper as verbal summaries, pictures, tables, diagrams. (p.73)	The student completes the self-check item "What is photosynthesis?" (p. 313) and discusses responses in groups.	10. Did learning (construction) occur?	Interview B, question (iii). Interview C, question (i).
			11. Did alternative constructions occur?	Analysis of surveys 1, 4, and the self-check item (p.313) responses.
(viii) The need to generate links and to actively construct ... meanings requires individuals to accept a major responsibility for their own learning.	Learners need to be aware that meaning is something that they construct (p.71)	An individualised student booklet to be utilised at home, at the start of the challenge phase, precedes teacher involvement.	12. What purpose did students ascribe to the self-teach booklet?	Interview B, question (ii).
			13. Did students use the self-teach booklet individually to construct the teacher's science response?	Interview B, question (i).

Figure 54 : The action research programme (application phase).

The APPLICATION Phase				
Postulates Of The Generative Learning Model (Osborne And Wittrock, 1985, p 64-66)	Implications For The Classroom (Osborne And Wittrock, 1985, p.70-76)	Features Of Instructional Package: "Where Does The Wood Come From?" (Appendix B)	Research Questions	Research Strategies
(vi) The learner may test the constructed meaning against other aspects of memory store and against meanings constructed as a result of sensory input.	Teachers need to make available a range of models, experiences, demonstrations, worked examples and analogies to enable pupils to test out their constructions. Pupils may also need to be encouraged to ask questions, identify and pursue what appear to them to be inconsistencies in what they see or hear and to undertake the routine problems found in science text-books. (p.73)	The nine checkpoints all present new sense data, involving aspects of photosynthesis. Six checkpoints also invite pupils to contrast their new constructions with their original views by using the surveys from the focus phase as "paper memories" (p.314) Another checkpoint reappraises one of the four investigations in the light of the new construction. (p.322)	14. Did the students relate the activities in the application phase to the previous phases, or did they see them as isolated episodes?	Interview D, question (i).
			15. Could students distinguish between their original and new constructions?	Analysis of Checkpoint 1.
			16. Did students actively appraise their new constructions while they were doing the checkpoint activities?	Observation of students engaged on Checkpoint 1 responses.
(vii) The learner may subsume constructions into memory store.	Instruction needs to encourage learners to generate firm links between constructed meanings and a variety of appropriate aspects of knowledge structures in memory ... historical, philosophical, technological, mathematical, experimental and everyday. (p.75)	The checkpoints to knowledge structures in the following areas: historical (p.317) everyday (p.320) experimental (p.327) and other areas of science knowledge (p.330)	17. Did the students already possess the relevant knowledge assumed in the checkpoints and apply it to their new constructions?	Analysis of Survey 2, Checkpoints 8 and 9 responses.
			18. For how long did the new construction remain subsumed in memory store?	Analysis of Survey 4 and self-check item responses 12 weeks after teaching.
(viii) The need to generate links and to actively construct ... meanings requires individuals to accept a major responsibility for their own learning.	A teacher needs to provide opportunities for pupils to consider, contemplate, and expand their views of the world .. (and to) better understand their own views. .. Success (is) dependent on the pupils' own actions ... and is a consequence of their own effort. (p.75)	Six of the checkpoints can be carried out by individuals, maybe at home (e.g. p.315) Pupils' own prior knowledge is specifically addressed in six of the checkpoints (e.g. p.325)	19. Did students perceive the importance of their own prior knowledge as a novel feature of the unit as a whole?	Interview D, question (ii).
			20. Did students appear threatened by the possibility of individual knowledge restructuring, or did they relish the experience?	Interview D, question (iii).

or respiration (or, in fact, any animal or plant physiology) at the school. In their teacher's view *there might be one or two students ... who show any particular promise in science. The rest of them are pretty ordinary In terms of their concentration span some are pretty limited.*

The teacher, Mr R., had been teaching science, and biology to form seven level, for seven years since graduating with a masters degree with honours in biology. He had established a quiet authority in the classroom and the atmosphere throughout the research was positive and congenial. Mr R. was well-disposed towards the postulates of the generative learning model and his classroom procedures almost exactly reflected the expectations of the teaching package.

11.1.3 The Lessons, The Interviews

The 12 lessons (Figure 55) took place in an attractive, well equipped laboratory either during period three (11.20 am - 12.20 pm) or period five (2.20 pm - 3.20 pm). As prescribed in the package, the focus phase (the four investigations and four surveys) took two weeks, i.e. eight periods, the challenge phase (the Self-Teach Booklet) took one period, and the application phase (the nine checkpoints) took one week, i.e. three periods. The researcher was present for all lessons except those on March 11th (non-package work) and March 24th (Mr R. was absent). Investigation 1 ('Mini-mowing', detailed on page 264) was set up in an adjacent horticulture courtyard. The selection of checkpoints 1,4,8 and 9 was made jointly by the teacher and the researcher.

Three interviews designated A, B and C (Figure 56), each with the same five students, were designed to monitor conceptual change

Figure 55 : The lesson sequence and the interviews.

Date	Day	Period	Classroom Activities	Individual Out-Of-Class Interviews
Feb.26	Wed.	3	Task sheet (p.263); Setting up Investigations (p.264)	
28	Fri.	3	Survey 1 (p.281); Discussion of Investigations	
Mar. 4	Tue.	5	Discussion of Survey 1; Survey 3	
5	Wed.	3	Investigation 1 harvest; Discussion of Survey 3; Survey 2	
7	Fri.	3	Investigation 1 dry weights; Discussion of Surveys 2 and 4	
11	Tue.	3	(Other work, on periodic table)	
12	Wed.	5	Harvest Investigations 1-4	
13	Thu.	3	Complete investigations; Issue Self-Teach Booklet (p.290)	A Same — After lesson
18	Tue.	3	Challenge transparencies (p.302); Checkpoint 1 (p.315)	B five — Before lesson C pupils — After lesson
20	Thu.	3	Self-Check Item (p.313) Checkpoint 4 (p.322)	
23	Sun.	-		Teacher interview
24	Mon.	3	Survey 1*; (Other work, video)	D Five other pupils, during lesson time
26	Wed.	3	Survey 4*; Checkpoint 8; Checkpoint 9; Class discussion with researcher	

* These activities were inserted to meet the school's requirements for assessment, and to provide research data.

around the crucial challenge lesson. Interview D, near the end of the application phase, probed five other students' perceptions of the package as a whole. These took place in a resource room next to the classroom and lasted about 10 minutes. The teacher was interviewed in his own home on Sunday March 23rd. This less-structured interview took 35 minutes.

Figure 56 : The action research student interview questions.

Interview	Interview questions	Relevant Research Question
A	(i) Can you tell me about what you wrote here? (i.e. Survey 1 questions 3,10,15, Survey 3, Survey 4) (ii) What did you think was the point of doing the investigation? (iii) Did your group come up with an idea about where the (dry) weight increase came from? (iv) Have you thought about where the wood in a tree comes from? Would it be interesting to know?	5 2 3 7
B	(i) Did you read the self-teach booklet? (ii) What did you think was the point of reading the self-teach booklet? (iii) What was the self-teach booklet about?	13 12 10,11
C	(i) What do you remember about today's science lesson? (ii) Did you learn more from the lesson or the self-teach booklet? (iii) Do you think the lesson had anything to do with the last two week's work in science?	10,11 9 8
D	(i) Do you think these checkpoints have anything to do with the self-teach booklet? Or with the surveys and investigations? (ii) Did the unit seem like what you usually do in science or was it different? (iii) Did you change your ideas about plants during the unit? Was it hard to change your ideas?	14 19 20

11.2 FINDINGS OF THE ACTION RESEARCH

11.2.1 The Four Investigations - Students' Empirical Results

The students divided into six groups of four or five students each. Two groups worked on 'Sand, Seeds, Sprouts', two on 'Water Plants', and one each on 'Mini-mowing' and 'Super Air'. The procedures and the results (which were generally as predicted in the Teacher's Notes, page 277) are summarised below. (The discrepant results, all outcomes of procedural mistakes, then follow.):

1. 'Mini-mowing' (page 264). Grass in two adjacent squares of lawn (one of which would be covered by shade mesh) was trimmed down to bowling green level. After 7 and 14 days the fresh and dry weights of new grass from the squares were determined. The students obtained a greater dry weight from the shady square (6.65g) than the sunny square (5.43g) at the first harvest. This was reversed (2.38g and 11.07g respectively) at the second harvest.
2. 'Sand, Seeds, Sprouts' (page 267). Ten weighed dwarf bean seeds were germinated for 14 days in a sand-mineral mix and the fresh and dry weights of the seedlings were determined. One group found that all eight seeds which germinated increased in fresh weight (272% mean increase) and dry weight (21% mean increase). Eight of the other group's seeds also germinated, with a mean fresh weight increase of 422%.
3. 'Water Plants' (page 270). Ten Tradescantia cuttings were grown in water (to which a mineral pellet had been added) for 14 days and the increases in fresh weight were determined. Increases in dry weight could also be found. Both groups obtained fresh weight increases in all 10 cuttings, with mean increases of 66% and 72%. (Although final dry weights were determined, Mr R. did not suggest

that the students use the graph on page 273 to estimate initial dry weights because the other groups had already completed writing up their investigations.)

4. 'Super Air' (page 274). Students floated 15 duckweed leaves in each of eight jars under a strong lamp, blew twice daily into four of the jars for 14 days, and recorded increases in plant growth. In fact, only two pairs of jars received the anticipated treatment. After 14 days the numbers of duckweed leaves in all four of these jars remained the same but there was massive algal growth in the two jars being blown into.

Three groups made procedural mistakes. The second group working on 'Sand, Seeds, Sprouts' (see above) recorded only three dry weights, became confused about the numbering of their dry weight samples, and used the other group's results. One group working on 'Water Plants' forgot to add the mineral pellet to one flask, and this plant happened to have the lowest final fresh weight. Students interpreted this in various ways (see below) but, in fact, the percentage fresh weight increase for this plant was above the mean. The 'Super Air' group set up the mercury vapour lamp too near one end of the two rows of jars and after two days the high temperatures had killed the duckweed in two of the four pairs of jars.

11.2.2 Findings From The Research Questions

<u>Question 1. Were students curious about the</u> four <u>investigations and eager to embark on the investigation of their</u> choice?

After Mr R. had introduced the four investigations and demonstrated the equipment, the students expressed individual preferences by show of hands. These were: 'Mini-mowing' - 6 students;

`Sand, Seeds, Sprouts' - 9 students; `Water Plants' - nil; `Super Air' - 10 students. Comments between students suggested that the prospect of working outside (`Mini-mowing') or operating the electronic digital balance (`Sand, Seeds, Sprouts') or the mercury vapour lamp (`Super Air') was attractive. Familiarity with germination experiments accounted for the popularity of `Sand, Seeds, Sprouts' relative to `Water Plants', where the outcome was less predictable. Negotiations, chaired by Mr R., resulted in 17 students achieving their first choice. In summary, the students were attracted to the investigations for a variety of reasons, were generally allocated their first preference, and were eager to start.

Question 2. Did the teacher's purpose (i.e. focussing on the key question "Where does the stuff in a plant come from?") become the students' purpose?

The groups varied widely in their perception of the purpose. Students working on `Water Plants' and `Sand, Seeds, Sprouts' appeared to focus early on the weight increase:

Paul: *Yeah, they'll (the seeds) grow. They'll sprout. The plants will grow, get bigger.*
I: *How will you know?*
Paul: *By looking at it and weighing it. The weighing will tell us its bigger in mass.*

The `Mini-mowing' students initially constructed their own purpose:

Um well we are trying to find out if ... well the little piece we cut out we put the shade over ... if the shade mesh over it helps it grow or if it grows better without shade mesh. (Wendy)

When contradictory results were apparent they modified this position:

Well we didn't know which really cos the two times we did it they were both different. One was more one time and the other the other. (Wendy)

In summary, by the end of the two weeks, Mr R. appeared to have focussed the attention of the students in these three groups onto the weight increase and its origins. However, at least two students working on 'Super Air', in which no weighings were made, apparently never accepted the teacher's purpose. Mr R. commented on a design feature which undoubtedly contributed to this:

Maybe the important thing about these two (i.e. 'Sand, Seeds, Sprouts' and 'Water Plants') *is that they weighed the stuff before they started. The other ones they didn't, see, so that got them onto the weighing and the weight increase idea.*

Question 3, Did the students readily form their own theories in response to the key question?

This section comments on student theorising during group work and class discussion. There was little spontaneous theorising about the origin of plant materials during group work, i.e. instances like the following, where Sharlene and Areta ('Mini-mowing') were watching Mark working on 'Super Air', were rare:

Sharlene: *They* (i.e. the duckweed plants) *won't grow cos they don't need light.*
Areta: *Yeah. Don't need light.*
Mark: *Nah ... I reckon they would grow cos you breathe out carbon dioxide and they need carbon dioxide to grow.*
(Sharlene and Areta look doubtful, then giggle)
Mark: *Yeah. They'll get bigger. More duckweed plants.*

The considerable time spent in reporting progress in the investigations to the whole class was more fruitful in exposing alternative theories. Andrew and Neil ('Super Air') had worked closely together but they now disagreed:

Andrew: *Well I don't really see ... nothing really happened.*
Neil: *Yes it did!*
Andrew: *Two of them got algae in them. And those ones got too hot and it died and that's it really.*
Neil: *No. The ones that we ...*
Mr R.: *Two of them got algae. Which ones were they?*
Neil: *The two that we were blowing in.*

Later, an interview revealed that Neil's theorising had lead him to a conclusion central to photosynthesis:

I think they need carbon dioxide to feed off cos there's a lot more algae in those ones we blew in ...

However, Andrew's theory was very different:

Andrew: *Yeah the one ... they don't like it too hot. The ones up the back, they died. And the ones at the front were just at the right temperature. So that's all. Probably the temperature.*
I: *So you didn't think the breathing was important?*
Andrew: *Aw not really as I didn't really notice much change when we were breathing on them and at the end and so I don't really see it done much.*
I: *And all that green slimey stuff?*
Andrew: *Aw I think of that as a sort of disease.*

Members of the 'Water Plants' group formed rival theories to explain the apparent relative lack of growth in the one flask without minerals. Mary and Lindsay suggested that this proved *the more minerals, the more growth.* However, in Sarah's view the result supported the reverse conclusion: *Minerals can't have caused it cos a mineral (pellet) only weights 0.05 and we got much more growth than that.*

Interview responses at the end of the focus phase showed that some students never formed precise theories:

... The plant? It came from ... it ... I dunno really. (Rebecca)

Aw it just grew from the air and the water and a bit of mineral. I'm not sure really. (Sandra)

In summary, students were more likely to form their own theories in class discussion than during group work but some students apparently never formed precise theories of their own.

Question 4. Did the students' theories involve the important design features of the investigations (sun, seeds, soil, minerals, water, gases)?

Students' written responses to the question "What do plants need to grow?" (page 263) at the start of the focus phase were nearly all anticipated by the investigations. The numbers of these responses, when grouped, were:

AIR (including carbon dioxide, oxygen, gases)	36
SUN (including sunlight, warmth, sunshine)	26
WATER (including moisture, rain)	26
EARTH (including soil)	15
MINERALS, NUTRIENTS	12
FERTILIZER (including food)	8
OTHER ORGANISMS (i.e. pollution, people, love, other plants)	4
OTHER (i.e. nitrogen, shade, shelter)	3
STARCH	1

At the end of the focus phase the investigations posed the question "What do you think the stuff that makes up the dry weight is?" The seven students who responded wrote "water, gases, soil", "wood", "cellulose", "natural plant material", and "stem, leaves, roots". Eleven of the 14 students who answered the further question "Where do you think this stuff comes from?" employed design features, e.g. "It comes from the seed and the sun and the oxygen help it to grow". The other three gave answers like "the plant made it".

In summary, students' theories throughout the focus phase nearly all involved design features of the investigations.

<u>Question 5. Did the anticipated prior knowledge exist in the students' memories?</u>

In Survey 1, page 281, (N = 26), multichoice question 10, fifteen students chose option D ("The plants we grow all need water, soil and air") as the best statement about growing plants. In question 15, sixteen students chose option A ("All plants can change carbon dioxide into oxygen") as the best statement about plants and carbon dioxide.

In Survey 3, page 286, (N = 25) students wrote a paragraph about "Plants And Water". The 30 responses giving reasons why plants need water comprised: "to grow" (13), "to survive" (6), "to live" (4), "to stop drying out" (12), "to produce sugar" (1), nil response (4).

In Survey 4, page 286, (N = 21) students wrote a paragraph about "Plants And The Gases In The Air". Their responses were of five types:

1.	Carbon dioxide produces plant material (the scientists' view)	2
2.	Photosynthesis is the name given to "plant breathing" in the "plant breathing/animal breathing" model (p.57)	3
3.	The "plant breathing/animal breathing" model	12
4.	Mentioned "plant breathing" only	2
5.	Nil response	2

In summary, the students did possess much of the anticipated knowledge, e.g. that soil is essential for growth and that the requirements of water and carbon dioxide are unrelated to each other and to specific growth products.

<u>Question 6. Was this knowledge exposed by class discussion?</u>

Completion of Surveys 1 and 3 were followed by fruitful, wide-ranging classroom discussions chaired by Mr R. These lasted for 12 and 14 minutes respectively. Topics touched on included cacti, 'air plants', annual rings, hydroponics and marine algae. Conversation about Survey 4 (four minutes) was more desultory, as if there was little to discuss. The "plant breathing/animal breathing" model seemed to be accepted as common knowledge and was not challenged by the two students whose responses had described the production of plant material.

Question 7. Were students motivated to seek the scientists' view?

Although it was difficult to gauge the general level of enthusiasm, the five interviewed students all professed interest in knowing where wood comes from. Satisfying curiosity was the main reason:

Yip! It's something you don't know and you would be better off knowing. W've got this far with all these water plants and stuff so we might as well find out where it all comes from. (Rebecca)

Yeah, yeah, cos there's wood all around us. (Sandra)

Aw yeah. Just to get it behind you. Just to know. (Andrew)

Yes cos I've never really thought about it before ... and it would be handy to know. (Neil)

Yes (laughs) *because like the way I thought where wood comes from ... I could be wrong and I could be right and they could have a different thing and half my question and half their question and everyone else's questions could all lead together and make one good answer.* (Wendy)

Question 8. Did the students relate the activities in the challenge phase to the focus phase or did they see them as isolated episodes?

A wide difference of opinion was expressed in the interviews. Two students had difficulty relating wood (the subject of the Self-Teach Booklet) to the growth products of the investigations:

No, no ... well it's hard to say. Growing those water plants well wood's growing, isn't it? Where the growing comes from sort of. (Sandra)

Not really. They were just little plants (in the investigation). Wood's wood. So ... no, I'd say. (Rebecca)

However for Neil (who already held much of the scientists' view) the booklet was a reassuring conclusion to his investigation:

Well the (challenge phase) lesson was a summary cos the `Super Air' had told us that plants need carbon dioxide to grow and that's the name for trees making wood. Carbon dioxide and wood. So yeah I'd say that the experiment got us right into the middle of it.

Andrew's perception was closest to the teacher's intention (page 261):

The `Super Air' got us ready for the lesson today thinking about water and heat and carbon dioxide and minerals.

Wendy viewed `Mini-mowing' as an exercise in motivation:

The grass was great. Ripping out to cut the grass and having our own experiment. All science should start off with a fun thing like that. Helps if it's going to get boring.

In Mr R.'s view the responses of Sandra and Rebecca may have reflected those of many class members:

They latched onto the immediate requirements of the investigations ... what they had to do. They may even understand the immediate objective of the investigation, that is, how much they grow, but they can't make the connection between that and the over-all question "Where does the stuff come from in plants?" so their ability to look at the wider issue from the narrower one is somewhat limited.

Perceptions of the relevance of the surveys to the Self-Teach Booklet also varied. For Sandra and Rebecca, their survey responses were useful only in initiating discussion:

The surveys got us going about carbon dioxide and all that but that was just us. Could have been lots of things. No, I don't really see (Rebecca)

Neil and Andrew saw the surveys as a way of monitoring changes in understanding:

The surveys helped you compare what you said in the first place. Check out where you were. You went along and you changed and you changed more when you got the booklet and you knew where you were. Surveys are good like that. (Neil)

It appeared that Wendy had made use of her ideas as intended:

Well I said that's what it was and then the book said that's what it was, more about the carbon dioxide and it all built up I'd say.

However, Mr R. commented:

They bit by bit came up with ideas which they thought were just too simple or too obvious to write down (in the surveys). They thought that the response required was something quite technical or scientific and yet we were really after quite simple ideas ... I think that they probably underestimate their own ideas sometimes. The problem is that they sometimes don't realise that the ideas they do have are actually quite valid. Yeah. They do put themselves down.

In summary, the interviews revealed a diversity of perceptions of the relevance of the focus phase (investigations and surveys) to the challenge phase (the Self-Teach Booklet). Students who saw them as isolated events often did so because they were unable to generalise from their investigation or because they undervalued their own prior knowledge as revealed in the focus phase.

Question 9. Which format (Self-Teach Booklet or teacher's description) did students find most helpful?

The five interviewed students all found the booklet's explanation intelligible and self-contained. However, they also found the class discussion reassuring:

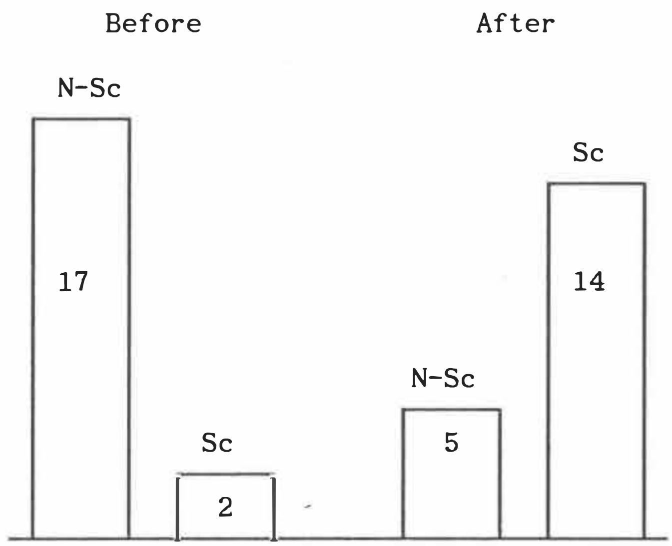
Mr R. helped when he talked about the sugar changing into wood. That was tricky. He made that bit seem more real to me. (Neil)

Yeah he helped a bit. It was good to hear people talk about it and go over it. Good revision I guess. (Andrew)

Question 10. Did learning (construction) occur?

Three survey instruments were used to assess students' constructions:

1. Survey 4 was administered one week before the lesson sequence began and again one week after the challenge phase. The 19 students who were present on both occasions gave either the scientists' view (see question 5, page 215) or non-scientific views as follows:



2. <u>The Self-Check Item</u> "What Is Photosynthesis?", page 313, was administered (N=21) two days after the challenge phase. The responses were analysed according to the procedures on page 161. Seventeen students gave teacher's science responses, 15 in terms of the 'producing carbohydrate' view (six mentioned sugar, one wood, and eight both materials), and two in terms of the 'making food' view. The latter had presumably acquired this view at another school.

Of the 23 students who completed Survey 4 and the Self-Check Item after the challenge phase, 13 gave a teacher's science response both times and 6 gave a teacher's science response on neither occasion.

3. Survey 1 was administered early in the focus phase and again six days after the challenge phase. Analysis of responses to six questions showed that higher numbers of correct post-teach responses were obtained with questions which required integration of existing ideas (refer Figure 50, page 194) about wood, leaves and gases (i.e. questions 4, 8, 15, 20) than with questions where exchange of existing ideas about soil or minerals (i.e. questions 5, 10) was required:

Question		4	5	8	10	15	20
Numbers (N=21) correct:	Pre-teach	10	8	7	10	4	10
	Post-teach	19	12	18	14	15	17

All five of the interviewed students had constructed a teacher's science response to the question "Where does the wood come from?". However, discussion about page 301 revealed that none yet considered that photosynthesis was an answer to the more general question "Where does the stuff in a plant come from?":

I: *What did you think this last page was saying?*
Wendy: *Wood's kind of got all those things to do with it. That's wood* (points to the chair). *That's wood* (bamboo). *That's wood* (guitar). *That's not* (book). *YES! Paper's wood.*
I: *How about that one though? There's not much wood in perfume is there?*
Wendy: *Aw some plants, herbs and that ... No. I don't know about that one.*

At the same point, Neil turned to another photosynthetic product:

No, not really but there's the sugar and stuff. Like some flowers use the sugar to attract the bees to pollinate them and that.

In summary, after the challenge phase about 70% of the students (depending on the assessment instrument) had constructed a teacher's science view of the origin of a specific photosynthetic product. None appeared to have gone beyond the objective of the package and constructed an explanation for the origin of organic material generally.

<u>Question 11. Did alternative constructions occur?</u>

Apart from the five responses to the Self-Check Item "What Is Photosynthesis?" which were classified as `other' and which equated the process either with absorption of sunlight by leaves or with the uptake of carbon dioxide, no alternative constructions occurred. The three students whose pre-teach responses had equated photosynthesis with the `plant breathing/animal breathing' model did not continue to make this construction after teaching.

<u>Question 12. What purpose did students ascribe to the Self-Teach Booklet</u>?

Three of the five interviewed students suggested only that the booklet was designed to provide an answer to the question "Where does the wood come from?":

It was trying to tell you where the wood in trees comes from. How the tree grows and how the trees take in the stuff to produce the wood and so on. (Rebecca)

Neil also saw the booklet as making a more general statement:

to find out that photosynthesis is how plants make wood and put out the oxygen.

Andrew saw the booklet's function as correcting common misapprehensions:

Andrew: *It was telling us where the wood comes from. To give us the true ideas about wood. People have a lot of ideas but half of them weren't true so just giving us the true idea.*
I: *How did you know they were true ideas?*
Andrew: *They must have been true to put them down in the booklet.*

The utilisation of students' own ideas in the booklet was not commented on in the interviews.

In summary, the students saw the booklet as providing an answer to the question posed by its title, i.e. "Where Does The Wood Come From?"

<u>Question 13. Did students use the Self-Teach Booklet individually to construct the teacher's science response?</u>

All five students who were interviewed read the booklet on their own at home. This took about 15 minutes and they did not need to seek help in understanding.

Question 14. Did the students relate activities in the application phase to the previous phases, or did they see them as isolated episodes?

All five students who were interviewed found the checkpoints helpful in "clarifying" (Paul), "revising" (Betty) or "checking" (Helen) their new understandings gained from the booklet:

Yes cos it (i.e. Checkpoint 1, a crossword puzzle) *helps you to sort out your ideas about photosynthesis because it helps you to get some of the answers to the questions you have been trying to figure out.* (Indira)

Yip it had a lot to do with it because of the (checkpoint) questions. They were related to the booklet. It was just an easy way to see what you had learned. (Helen)

Helen then commented specifically about the `paper memory exercise in Checkpoint 1, in which students compared their present responses to the crossword puzzle with their earlier answers to the Survey 1 multi-choice items:

I: *This business here....?* (i.e. the `paper memory' exercise)
Helen: *Just to check your first answers against what you had learnt. It was just to see whether you were right the first time.*
I: *Would it have mattered if you were wrong the first time?*
Helen: *No. You just find out that you'd done wrong and find out why.*

However, Alistair could see no connection between the Checkpoint 1 questions dealing with wood and his `Sand, Seeds, Sprouts' investigation:

Well not at all, like this one with the wood. Our seeds didn't form wood cos they were too small. None of the plants did.

In summary, the students perceived strong links between the checkpoints (application phase) and the booklet (challenge phase) but not between the application phase and the focus phase.

Question 15. Could learners distinguish between their original and new constructions?

Analysis of the 'agree/disagree' responses to the paper memory aspect of Checkpoint 1 (page 316) suggested that students could usually discriminate accurately between their original view and the new construction. Correct discriminations for the six pairs of views occurred in 79%, 85%, 100%, 92%, 55% and 50% of cases.

Question 16. Did students actively appraise their new constructions while they were doing the checkpoint activities?

Classroom observations suggested that there was little active appraisal of the relative merits of the two constructions in Checkpoint 1. Students simply decided whether or not a pair of responses was consistent, wrote this evaluation down, and carried on. Checkpoint 4 (page 322), which required students to apply their new construction to interpret the findings of their investigation, was more successful in this regard. Fourteen students wrote paragraphs which explained plant weight increases in terms of uptake of carbon dioxide and water (four students), or formation of sugar (three), or both (seven). The other 11 students attributed the weight increase to sunlight and/or minerals and/or water (six), or to carbon dioxide only (two), or re-iterated their results (one), or failed to respond (two). Considerable fruitful discussion was observed.

In summary, the checkpoint which could be answered with only a brief written response was much less effective at stimulating active appraisal of constructions than the checkpoint which required a longer open-ended written response.

Question 17. Did the students already possess the relevant knowledge assumed in the checkpoints and apply it to their new constructions?

Prior to attempting Checkpoint 9, the students' (N=26) responses to Survey 2 (page 285) had shown that they classified 10 possible examples of plants as would a scientist. (The 19 positive responses for mushroom was the only exception.) However, responses to Checkpoint 9 (N=25), in which students stated whether or not photosynthesis occurred in the same 10 examples suggested that some students' understandings about green plants may have lead them to non-scientific conclusions about wheat (five negative responses), mushroom (five positive responses) and brown seaweed (21 negative responses). The students' reasons for these had been anticipated (section 8.2.3) and helpful teacher-student discussion ensued.

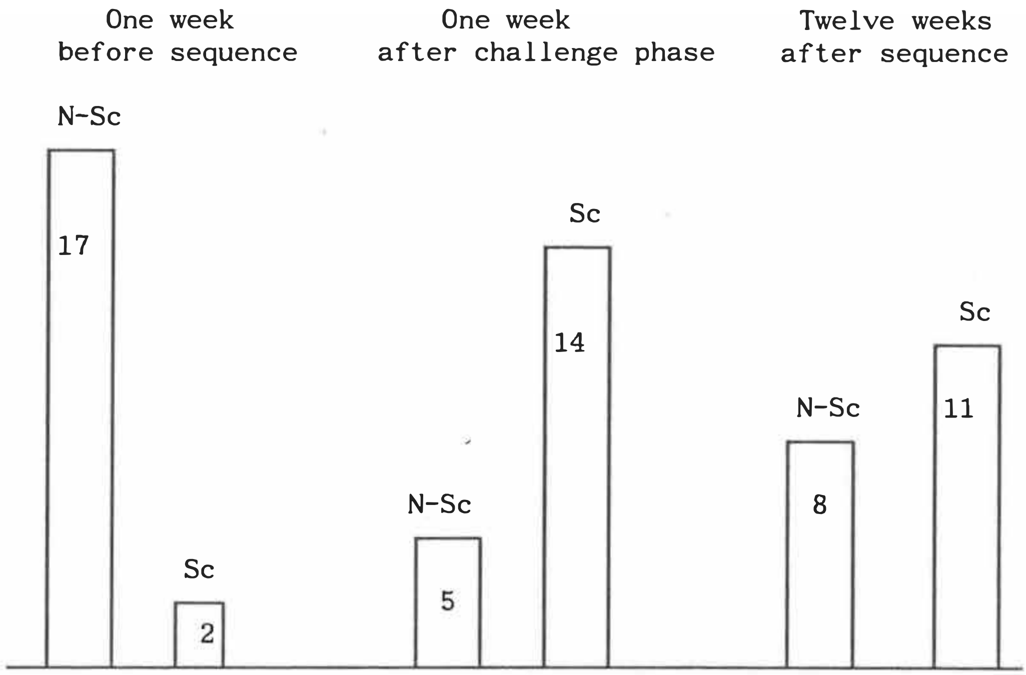
In Checkpoint 8A, page 331, 95% of the students' (N=18) answers to questions 1-5 (concerning background knowledge about chemical elements) were correct. When this assumed knowledge was applied to questions 6-9 (concerning a novel situation involving elements as reactants and products in plant synthesis) correct answers resulted in 90% of cases.

In summary, students nearly always possessed the relevant knowledge assumed in the checkpoints.

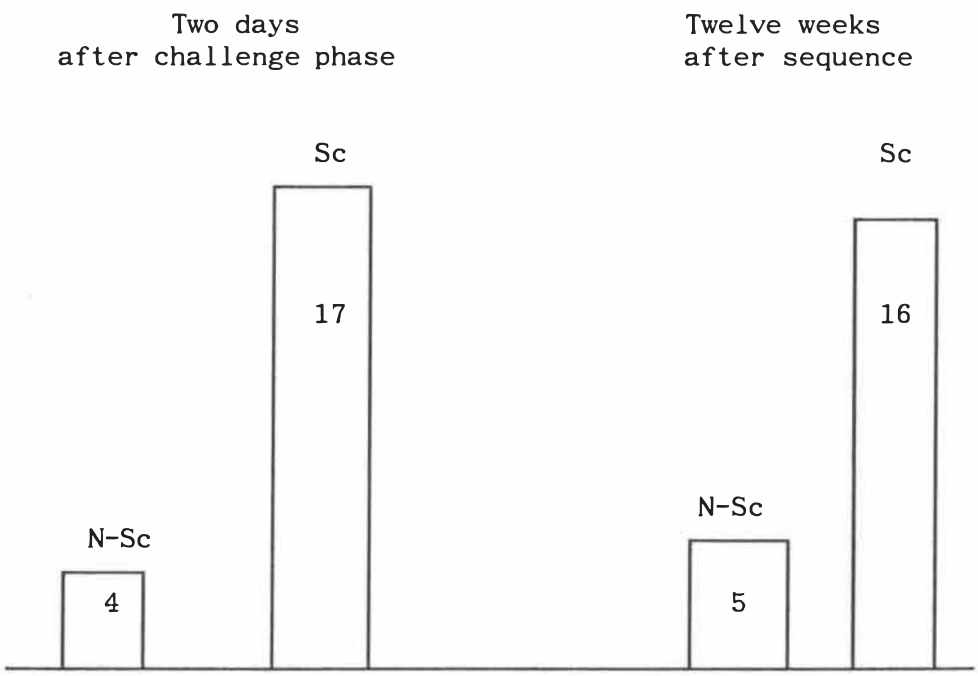
Question 18. For how long did the new construction remain subsumed in memory store?

Survey 4 ("Plants And The Gases In The Air") and `Science Survey 1' from Phase II ("What Is Photosynthesis?") were administered to the class on successive days 12 weeks after the lesson sequence.

The Survey 4 results shown below (N=19) are added to those already described (question 10, page 218):



Similarly, the Self-Check Item results (N=21) are compared with previous data in question 10 (page 219)



Of the 16 students who produced teacher's science responses, 15 gave the 'producing carbohydrate' view (nine mentioned sugar, two wood, and four both materials) and one gave the 'making food' view.

Nineteen students completed both surveys 12 weeks after the lesson sequence. Eleven gave a teacher's science response both times and four gave a teacher's science view on neither occasion.

In summary, given the difficulty of the concept of photosynthesis (section 1.4) and the fact that the students had no reinforcement of the concept over the twelve weeks, a high level of memory retention was achieved as an outcome of the learning experience.

Question 19. Did students perceive the importance of their own prior knowledge as a novel feature of the unit as a whole?

Responses to the interview question "Did the unit seem like what you usually do in science or was it different?" suggested that the five students considered the exposing and examining of ideas to be a key feature:

It was just ideas cos like other things we have to remember a lot of formulas and things like that but here it was just really one idea except we were doing all those experiments to find out what that one idea was. (Indira)

I think it was different cos there was lots more discussion and sort of group work. (Betty)

Paul and Alistair noted that self-reliance was involved:

Seemed a lot different because it was a lot easier to understand and work through cos it gave you something where you were working things out for yourself and like you had, the teacher wasn't, you read it for yourself and worked it out for yourself and you ended up with the final answer. (Paul)

However Helen felt that her own ideas had been relatively unimportant:

Helen: *It was a lot different cos you had to put down your own ideas and you weren't being told what was right and that.*
I: *Was that worthwhile or not?*
Helen: *Yip but it took a lot longer than most units.*
I: *What did you think was the point of putting your own ideas down all the time?*
Helen: *Just a different way of learning it.*
I: *Did you learn much by putting down your own ideas?*
Helen: *Not really cos you knew those ideas in the first place to put them down.*

In summary, the students saw the process of exposing existing ideas and helping oneself to acquire new ones (rather than building on the existing ideas) as the novel feature of the unit.

Question 20. Did students appear threatened by the possibility of individual knowledge restructuring or did they relish the experience?

The five students who were interviewed were asked "Did you change your ideas about plants during the unit? Was it hard to change your ideas?" Paul's answer to the second question was typical:

No. (laughs) *It was all ready there for you and you could work it out for yourself.*

Betty and Helen considered that their initial uncertainty was a factor:

I think it was quite easy cos my ideas weren't all that stable beforehand. (Betty)

It was easy because you weren't sure in the first place whether you were right or wrong and so if you get new ideas you just think about that and put that down. My ideas were a bit vague at the start but the last part, the booklet, helped. (Indira)

Alistair's account of his initial situation was very different:

Yeah it was very hard cos you've already got something in your head and you know what it is and you have to change it to something completely different. It would take someone a lot to make me change my mind. But this unit did cos it in one of them about wood I just said it grew there with everything else, but now I know a sort of in-depth answer to where wood comes from.

In summary, the students described the knowledge restructuring as non-threatening. They attributed this to certain features of the package, i.e. the way the booklet gave them a measure of control over their own learning, and the many opportunities to discuss, clarify and compare ideas.

The students' responses to the unit as a whole took their teacher somewhat by surprise:

It's the first time I've ever had a chance to do a unit based completely on investigative learning and I think the students responded better to it than I expected. In terms of their attention span it's quite demanding for kids of that age and ability to be able to think about ... objectively testing, putting their own ideas down on paper repetitively. I notice some of them took the easy way out still thinking it was a test situation. They didn't like to get it wrong so they copied off one another which is going to affect the results slightly ... but most of the time they were building on their own ideas with guidance from the teacher rather than being spoon-fed. I've done bits of that here and there but this whole unit was based on them coming up with the ideas rather than me giving them substantial segments.

11.3 OUTCOMES FROM THE ACTION RESEARCH

11.3.1 Learning Outcomes About Photosynthesis

Features of the generative learning package which assisted students to construct an answer to the key question "Where does the wood come from?" can be identified. The four investigations generally stimulated students' interest and the empirical results were similar to those anticipated by the researcher. The design features of the investigations coincided with students' ideas about materials relevant to growth (sun, seeds, soil, minerals, water, gases). The four surveys produced the anticipated responses, which were effectively exposed in discussion. Students found the self-teach booklet easy to understand and they had often constructed the teacher's science view before the challenge lesson. Students did possess the knowledge in related areas which the checkpoints required and they used them successfully to distinguish between their new and original constructions.

Students' interactions with the teaching package also provided an insight into the problems which would be involved in assisting students to construct an answer to the more general question "Where does the stuff in a plant come from?" Although the students considered the checkpoints to be a useful way of consolidating knowledge acquired in the challenge phase, they had difficulty relating the results of their investigations to the material in the Self-Teach Booklet. Little connection could be made in some cases between the soft, succulent growth products (or their black dehydrated residues) and wood, the subject of the booklet. This was revealed again later when some students could only relate their knowledge of photosynthesis to materials made of wood (or paper) and sugar (page 220). To summarise, the present study has suggested a means of integrating students' existing ideas (or 'mini-theories', Claxton 1983, 1985a) to form a preliminary concept of the materials of photosynthesis. However a concept of organic materials may require a much more major cognitive restructuring. In Claxton's terms students may need to develop a whole new mini-theory.

It has been pointed out (page 201) that action research generally does not involve the classical comparison of learning outcomes from rival teaching strategies under controlled conditions. In the present study a limited comparison of outcomes was possible because students taught by the generative learning strategy (in Phase III, the action research) and by the guided discovery strategy (in Phase II, the surveys) both responded to `Science Survey 1' (i.e. wrote a paragraph entitled "What Is Photosynthesis?") 12 weeks after teaching. Both the generative learning students (N=21) and the guided discovery students (N=101) were from middle-ability, mixed-gender classes of similar ethnic composition, in junior secondary schools. The teachers of both groups were supportive of the strategy they were using. Some important differences between the groups, and the learning outcomes, follow.

The one class of generative learning students (fourth formers, i.e. 14-year-olds) received four week's tuition from a competent teacher, who focussed only on the biochemical theme. As a result, 16 (76%) students acquired a teacher's science view. Fifteen (71%) of these held a biochemical view and one (5%) held a trophic view.

The four classes of guided discovery students (third formers, i.e. 13-year-olds) received two weeks' tuition from teachers of varying competence, who focussed on the biochemical, trophic, and ecological energetic themes. As a result, 54% of students acquired a teacher's science view. Nineteen percent of these also held a biochemical view, and 3% also held an ecological energetic view.

Further research, of the "experiment and quasi-experiment" type (Cohen and Manion, 1980) would be needed to identify the precise significance of the variables in determining the learning outcomes.

11.3.2 Generative Learning And Instructional Design

The findings of the action research programme have implications beyond the teaching of photosynthesis.

Few studies have prepared guidelines for constructivistic instructional design (section 10.4.2). The present study has identified four design features appropriate for use with one constructivistic approach, the generative learning strategy:

(1) Investigations (moderately long-term practical situations, selected by students) can serve to focus students on their existing knowledge, formulate and discuss theories about the outcome, and become aware of the possibility of more fruitful answers to a clearly-defined problem. Investigations contrast with 'experiments' from which students are expected to discover the teacher's science view, but which leave their prior knowledge largely undisturbed.

(2) Surveys can help students expose and discuss prior knowledge which will later be used to construct the teacher's science

view. They contrast with 'tests' which place a negative judgement on non-scientific views. Surveys used in the initial research can be incorporated directly into a teaching package.

(3) A Self-Teach Booklet (which introduces the new concept in terms of a student's existing ideas) can help students feel that they are in control of their own learning. Research findings can be used directly in the booklet.

(4) Checkpoints (post-teach task sheets which take familiar situations and relate them to the new concept) can generate multiple links between the new construction and memory store. Checkpoints can be used in conjunction with surveys (now serving as 'paper memories', Rowell and Dawson, 1984).

11.3.3 Generative Learning And Change In Conceptual Understanding

Considerable evidence suggests that in many contexts students find change in conceptual understanding a personally threatening process, and that they value and adhere strenuously to their existing ideas (section 9.2). By contrast the present study has described a context in which students:

(1) found change in conceptual understanding relatively non-threatening, and

(2) placed little value on their prior knowledge.

The non-threatening nature of the experience could have derived from at least two factors:

(i) Conceptual resolution (section 9.2), especially integration of existing ideas about gases, water, and growth was a major aspect of the teaching package relative to the need for conceptual change of existing ideas about minerals and growth. It has been suggested that conceptual change can be more ego-threatening than conceptual resolution (section 10.3.3).

(ii) Students suggested that being given time to focus on the issue and discuss it, and having the means to discover the answers for themselves (the booklet), contributed to the non-threatening nature of the experience.

The students did not consider that their own prior knowledge was an important feature of the experience as a whole. For them, the surveys were mainly of value in hindsight, i.e. as indications of how much their ideas had changed, and the first four pages of the booklet were similarly, relatively unimportant. Generative learning in this case has been successful because the researcher and the teacher, not the students, were aware of the potentialities for further understanding which reside in prior knowledge. Many students seemed surprised that anyone would encourage them to rely on their own ideas as a foundation for constructing the scientists' view. This is especially ironic in view of the considerable evidence (section 9.2) suggesting that in other contexts pupils value, and adhere strenuously to, their existing ideas.

CHAPTER 12 SUMMARIES, DISCUSSION, IMPLICATIONS

The best answer to a good question is two better questions.

(Anon)

12.1 SUMMARIES

12.1.1 The Results Of Part 1 (Phases I And II)

1. Scientists describe photosynthesis in terms of carbohydrate production (a biochemical theme) and energy storage (an ecological energetic theme). However, in secondary schools the teacher's science view emphasises food-making (a trophic theme) at the expense of the other two themes (section 1.2).

2. The teacher's science view reflects the changing emphasis in New Zealand science syllabi which (over the primary and secondary school years) suggest an initial approach to photosynthesis through the trophic theme, followed by a consideration of the biochemical theme, and leading to a discussion of the ecological energetic theme (section 1.3).

3. Students have difficulty relating photosynthesis to other school topics (respiration, energy flow, food chains, plant growth). Within the topic, accommodating excessive biochemical detail and coping with unfamiliar experimental situations can also create learning difficulties (section 1.4).

4. Pre-teach pupils possess no single conceptual framework as an alternative to photosynthesis. However, they do possess children's science views about plant activities and plant structures which are

related to photosynthesis, i.e. views about plant nutrition (section 2.3).

5. Children's science views about plant materials (corresponding to the scientists' biochemical theme) exist. Children often consider that plants drink water, which is needed for growth. In their view, we (i.e. humans) breathe in a gas and breathe out another gas, plants do the reverse, and this situation is essential for our continued survival. Although children do not relate leaves to plant feeding, they do ascribe a variety of functions to leaves (absorbing water and/or sunshine, to look beautiful, etc.). Children know little about chlorophyll. Sugar, but not starch, is well known to children. Plant growth (visible enlargement) and where wood comes from are difficult for children to explain. Fertilizers (compost, manure, maxi-crop, minerals, nutrients, etc.) are food for plants (section 4.6).

6. Children's science views about plants and energy (corresponding to the scientists' ecological energetic theme) exist. Children consider that plants obtain energy from the sun, but also from the soil and its contents (e.g. minerals), water, air, and wind. The terms 'light' and 'heat' are often used apparently interchangeably. Older pre-teach children often consider that the energy which a plant receives from the sun is used immediately and directly to sustain vital plant processes (section 5.4).

7. Children's science views about plants and food (corresponding to the teacher's science trophic theme) exist. Children consider that materials which plants absorb are food, e.g. water, fertilizers, gases. This contrasts with the views of secondary school teachers and texts which regard sugar and starch (i.e. photosynthetic products) as food (section 6.4).

8. These children's science and scientists' views show varying degrees of overlap. Sometimes knowledge is shared, sometimes there is partial concurrence, and in other cases the views are irreconcilable or find no point of correspondence (sections 4.6, 5.4, 6.4).

9. The teacher's science view of photosynthesis is a single unified theory expressed in precise terminology using non-personal objective language (section 7.2). The children's science view of plant nutrition comprises ideas about plant drinking, plant breathing, plant growth, about how plants get energy, and about plant feeding. These children's science views, held in isolation from each other, are expressed in everyday, often generic, language and are sometimes egocentric in origin (section 7.3).

10. The views of children and earlier scientists about plant nutrition have some similarities. Processes of metaphor-making and analogy appear to be a common source (section 7.4).

11. Post-teach junior secondary school students with a concept of photosynthesis describe it as a food-making process. Some of these students also view it as a carbohydrate (i.e. sugar and/or starch) - producing process. A small number also regard photosynthesis as an energy-storing process. The concepts of green plant, photosynthesizer, and food-maker are not seen as equivalents by most post-teach students (section 8.3).

12.1.2 The Results Of Part 2 (Phase III)

1. A cumulative teaching/learning framework for photosynthesis was proposed which addressed the biochemical theme first, then the ecological energetic theme, and then the trophic theme (section 10.2).

2. Three existing strategies for teaching photosynthesis (guided discovery, element analysis, trophic conflict) were rejected

on the grounds that they fail to reflect the scientists' view and/or do not take pupils' prior knowledge into account (section 10.3). A generative learning strategy, derived from the model of Osborne and Wittrock (1985) was proposed (section 10.4).

3. The generative learning model suggested realistic cognitive objectives and practical experiences for students, and its application promoted meaningful long-term memory. However, problems were encountered in matching the generative learning model to the three phase teaching sequence of Cosgrove, Osborne and Tasker (n.d.), in distinguishing between selection and attention, and in implementing postulate (iii) of the generative learning model (section 10.5).

4. A teaching package, designed to trial the generative learning strategy, assisted students to produce an answer to a specific form of a key question, i.e. "Where does the wood come from?" but not to the more general form: "Where does the stuff in a plant come from?" (section 11.3.1).

5. Students taught by the generative learning strategy acquired a view of photosynthesis as a carbohydrate-producing process. This contrasted with the usual guided discovery strategy where a food-making view was the major outcome (section 11.3.1).

6. Investigations, surveys, a self-teach booklet and a series of checkpoints were novel and successful features of the teaching package. These may have wider application in constructivistic instructional design (section 11.3.2).

7. Students considered that the acquiring of a concept of photosynthesis had been a non-threatening experience. This may have been because integration of existing ideas was a major aspect of the strategy, and because students were given time to discover answers for themselves (section 11.3.3).

8. Students generally did not perceive the importance of prior knowledge as a novel feature of the strategy because they undervalued their own existing ideas (section 11.3.3).

12.2 DISCUSSION

12.2.1 The Nature Of Children's Prior Knowledge

Previous studies have stressed that children's prior knowledge is strongly held and enduring. For example, Ausubel (1968) states that "preconceptions are amazingly tenacious and resistant to extinction". Again, the studies have always described situations where children's prior knowledge exists and can be contrasted with teacher's science views. For example, Anon (1983) states that "Constructivism holds that an individual invariably approaches every situation in life with a personal theory of explanation".

By contrast, the present study has revealed that a wide variety of types of prior knowledge may exist. On some issues in plant nutrition the views expressed were uniform and strongly held, but this graded through issues where a variety of less strongly held views was apparent, to issues where views were largely absent. For example, the 'plant breathing/animal breathing' model was widely and uniformly advanced. On other issues, the general approach was always the same (e.g. plant food is absorbed material) but the specifics varied (e.g. the plant food was identified as water, or manure, or minerals, or gases, etc.). These views were always readily forthcoming and appeared to be long rehearsed. In other cases, responses were variable and idiosyncratic. These views were advanced tentatively and were withdrawn in the discussion which followed (e.g. the origin of wood). Long initial pauses and sudden exclamations suggested an appeal to on-the-spot invention. Sometimes this was fruitful (e.g.

the function of leaves) but on other occasions it was not and a view did not emerge (e.g. why leaves are green).

In summary, this study has suggested that it may not be possible to generalise about the conviction with which children state their views, or that such views necessarily even exist. This suggests that it may not be fruitful to search for a generalised strategy to achieve change in conceptual understanding. Instead, elucidating the particular features of the prior knowledge in question (i.e. establishing their existence and the child's level of commitment to them) may need to be followed by an appropriate selection from a range of strategies.

12.2.2 Science History In The Classroom

This study has suggested that the history of science sometimes reveals views similar to those held by children now (section 7.4). In the case of plant nutrition a possible common source for these ideas has been suggested.

The use of science history directly in the classroom has been discussed by Gauld (1977) and Russell (1981). They consider that there is little justification for classroom treatment of science history on pedagogical grounds (e.g. as a way of introducing today's scientific knowledge), but the approach can help develop an appreciation of the cultural context of science. Brush (1974) agrees with the latter point but Lucas (1977) argues for a clear separation because "the mode of thinking and the nature of evidence is quite different in science from that used in studies of the scientific approach(es)".

The present study has used material from the history of science for another purpose, namely, as a way of assisting students to expose and discuss their own ideas, to raise the status of these ideas by showing that eminent scientists once considered them to be plausible and fruitful, and to contrast them with the modern view (Checkpoint 2). Achieving this objective by re-iterating a classic historical experiment (Checkpoint 7) has also been suggested. [24]

12.2.3 The Generative Learning Model In The Classroom

Producing the teaching package necessitated some pragmatic decisions about the ordering of the eight postulates in the model, i.e. whether the postulates were to be treated in a linear fashion.

The outcome was that postulates i ("the brain ... actively select(s) sensory input") and ii ("existing ideas ... influence what is attended to") were considered jointly when devising the investigations. Postulate iii ("the input selected or attended to has no inherent meaning") did not suggest specific learning outcomes or consequent activities Postulate viii ("... individuals accept a major responsibility for their own learning") became a guiding principle for the whole teaching strategy.

In summary, the focus phase of the teaching package was compiled from a joint consideration of postulates i and ii using postulate iii as a guiding principle, the challenge phase arose from postulates iv and v, and the application phase was based on postulates vi and vii. Postulate viii was used as a guiding principle throughout.

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24 These checkpoints are yet to be trialled, i.e. they were not selected by the teacher and the researcher in the present study.

12.3 IMPLICATIONS

12.3.1 Implications For Further Research

1. Action research on the ecological energetic theme of photosynthesis is needed as an extension to the focus on materials in the present study (section 10.2).

In terms of the alternative frameworks proposed by Watts (1983a), which are described in section 5.3.1, it is possible that many children may be using a 'fluid transfer' framework when they think about plants and energy, rather than a 'depository' (i.e. storage) framework. The former view, in which energy is used and rapidly dissipated, does not allow that energy may be stored in plant material for long periods of time. Presumably this makes it difficult for children to view trees in a forest as fuel creators. Science syllabi which advocate an understanding of "the flow of energy through the community" (section 1.3) may reinforce this view. The relevance of energy release from plant products through combustion is apparently not appreciated by many learners.

Teaching about fuels and their creation undoubtedly has its pitfalls. Warren (1982) warned of the dangers in promoting a 'materialist' view of energy, i.e. that energy is like a substance travelling through wires, changing its appearance at various points, and being stored in fuel or food. Mitchell and Gunstone (1984) reported students views that the sun's energy was converted into mass or atoms or both during photosynthesis. The present study has revealed similar instances where students failed to distinguish correctly between the material and non-material components of photosynthesis. Nevertheless, an intuitive view of plants and energy which considers the acquiring of energy and the material growth of plants as isolated phenomena requires modification if a pupil is to gain an insight into the scientists' view of photosynthesis. There is a related need for a more effective consideration of chlorophyll as a unique light-absorbing substance. This cannot be inferred from the guided discovery strategy of starch-testing variegated leaves.

2. The present study has revealed certain features of children's explanations about plant functions which may also be features of their thinking in the under-researched area of animal physiology, e.g. digestion, movement, energy release in animals (section 2.2). Apart from the frequent use of analogy and metaphor (section 7.3.3), children's explanations about plants often lacked connections between inter-related functions, e.g. plant gaseous exchange and growth.[25] Younger children's explanations about plant activities tended to be non-localised, e.g. they often considered that 'plant breathing' occurs throughout the whole plant (section 4.3.3.2). Children's explanations were frequently teleological, e.g. their explanations about leaves and why they are green (sections 4.4.2.2, 4.4.2.3) were always in terms of purpose and adaptation rather than biochemical, developmental, or genetic origins. Teleological explanations in biology (Ruse, 1973; Hull, 1974; Medawar and Medawar, 1977) have been noted in children (Matthews, 1980; Symington and White, 1983) and the place of teleology in the classroom has been considered (Lucas, 1971; Jungwirth, 1975).

3. Pre-teach children's understandings about growth in plants and animals merit further research, particularly the latter. The interview-about-instances and interview-about-events techniques (section 3.2.1) could be useful in these investigations.

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25 An unpublished post-graduate study on children's ideas about blood has suggested that they view breathing, digestion and blood circulation as separate activities (Raghaven, pers. comm.).

4. This study has revealed that students can have difficulty with experiment/control situations and chemical testing (section 10.3.1). More knowledge of students' understanding of the terms 'control' and 'test' and what they perceive as the purpose of these features of practical work may suggest improvements in classroom practice.

12.3.2 Implications For The Classroom

In addition to the findings of the action research programme about the teaching of photosynthesis, this study has implications for:

1. Teaching about transpiration. Teachers need to be aware that the upward passage of water through plants is not self-evident to students. As many as 20% of junior secondary school students may consider that plants absorb water through their leaves (Barker, 1985b). Checkpoint 5 was an initial attempt to address this misconception in the classroom.

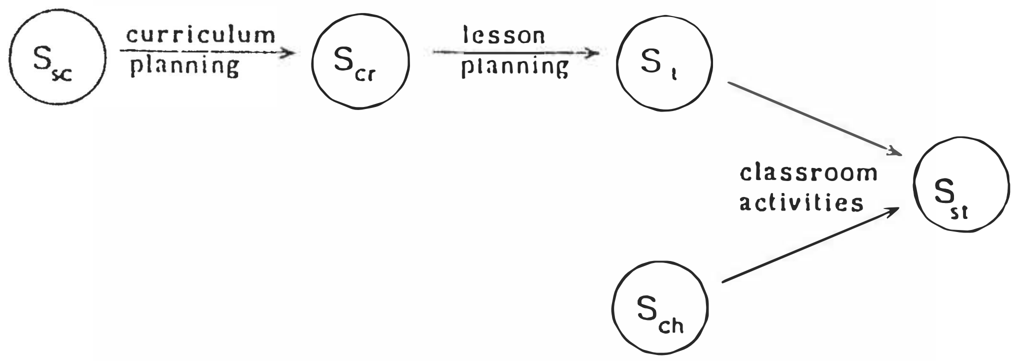
2. Teaching about respiration. Teachers may underestimate the difficulties students have in weighing up the relative importance of three pairs of variables which govern the atmospheric concentrations of oxygen and carbon dioxide, i.e. plants and animals, respiration and photosynthesis, and night and day. Teachers may need to pay more attention to discussing the joint influence of these variables on our atmosphere. When learners have an integrated view of photosynthesis and respiration they may cope better with biochemical detail.

3. The use of analogy in the classroom. This study has shown that attending to the analogies which students use can reveal much about their understanding (section 7.3.3). Other studies have suggested this as a fruitful classroom activity (Denicolo, 1983a, b; Munby, 1984, 1985). The present study, however, suggests that

counter-productive analogy-making may prevent students from appreciating the significant differences between plant and animal nutrition. Classroom strategies need to be explored further in this area.

12.3.3. Implications For The Curriculum

Zylbersztajn (1983) includes 'curriculum science', S_{cr}, as one of the perspectives in science education, and sees the flow from scientists' science to students' science as:



The present study has suggested that for the topic of photosynthesis a serious discrepancy exists between scientists' science (S_{sc}) and curriculum science (S_{cr}). An emphasis on the trophic theme is the dominant learning outcome about photosynthesis among junior secondary school students (S_{st}) and this reflects the teacher's science view (S_t) and the emphasis in classroom texts (S_{cr}). These, in turn, faithfully reflect trends in New Zealand science syllabi (S_{cr}). However, the trophic theme plays little part in the scientists' view of photosynthesis (S_{sc}). Neither can the curriculum science view be justified on the grounds that it takes children's science (S_{ch}) into account, because this study has shown that children have a very different view of plants and food compared with the curriculum science view.

This suggests that a re-assessment of the Forms One to Four Draft Science Syllabus (Department of Education, 1978b), in particular, may be necessary. A key question to address is whether photosynthesis should be introduced as a process of plant nutrition (or feeding) or as the origin of plant growth. This study has suggested that the latter approach fits better with both children's existing ideas and the scientists' view.

APPENDIX A:

SCHOOL TEXT-BOOK STATEMENTS

ABOUT FOOD

Appendix Table : Statements about food in ten text-books in current use in science and biology classes in forms three to five in some New Zealand secondary schools. (Continued on next page.)

Title Of Text-book Author(s), Year Of Publication Publisher	Food/Nutrition Context	Photosynthesis Context	Ecological Context
1. "Science For The Eighties, I" Petchell, M.J., 1979. Auckland : Coronet	"So far, food substances studied have been sugars, but these are only one of an extremely wide range of substances which are made by living things ... the substances made by living things could be called organic" (p.189). "Organic compounds comprise carbohydrate, fats and oils, protein"(p.190-198). "Most people know that they need food to give them energy ... and to enable them to grow. Fats and carbohydrates can be regarded as 'energy foods'. Protein yields energy also (but) is most important ... in growth" (p.196).	"The most important difference between plants and animals lies in the ability of plants to use the sun's energy to make food". (p.123) "Leaves use the sun's energy, carbon dioxide and water to make energy containing compounds i.e. foods such as starch and sugar" (p.146) "This energy-trapping and food-making process is called photosynthesis" (p.121)	"... herbivorous animals digest their plant food and change it into their own flesh which in turn becomes a source of food and energy for other, bigger or fiercer animals ... This simple pattern of eating and being eaten is called a food chain" (p.57).
2. "Life Study - A Textbook of Biology" Mackean, D.G., 1981 London : John Murray	"All living organisms need food. An important difference between plants and animals is that green plants can make their food in their leaves but animals have to take it in ready-made by eating plants or the bodies of other animals. ... There are three classes of food : carbohydrates, proteins, and fats" (p.92).	"Plants actually make the food they need and then use it for energy and growth... The process by which plants make their food is called photosynthesis ... A working definition of photosynthesis is the build-up of sugars ... (p.24). In many leaves as fast as sugar is produced it is turned into starch" (p.26).	"Basically, all animals depend on plants for their food. Foxes may eat rabbits, but rabbits feed on grass. This relationship is called a food chain" (p.33).
3. "Reading In Secondary Science Biology". Cooper, A.F.P. (ed.), 1972 Wellington : Reed Education.	"Your digestive system . . . changes the food you eat into a form which is easily transported. Food can be classified according to the use the body makes of it. The main body builder is protein. The carbohydrates are the energy foods. Fats are required for both structure and energy" (p.44). "In addition to the main categories of food-carbohydrates, fats and proteins - other material must be present in your diet to keep you healthy. These are vitamins and essential minerals" (p.52).	-	-
4. "Exploring Science, Book I". Stannard, P. & Williamson, K., 1979. Melbourne : MacMillan.	"Foods are made up of three main food types : carbohydrates, proteins, fats" (p.154). "Vitamins and minerals are not really foods. The body does not use them to produce energy" (p.142). "All food is made from carbohydrates, proteins, fats, minerals, vitamins, water" (p.141). "All animals and plants have the same inputs as you do. Your bodies inputs (are) food, air, water" (p.141).	"Green plants use sunlight, water, carbon dioxide, and chlorophyll to make sugars (food) and oxygen. This is called photosynthesis" (p.154). Then these sugars are turned into starches for storage" (p.148). "They (the leaves) can also make protein" (p.153).	"The plant foods stored in nuts, fruits, and roots (like potatoes, carrots, turnips) are used by animals. Sometimes we eat the plant itself, for example, lettuce, spinach, and celery. But mostly we eat the part of the plant that stores the food" (p.150).

Appendix Table : Continued from previous page.

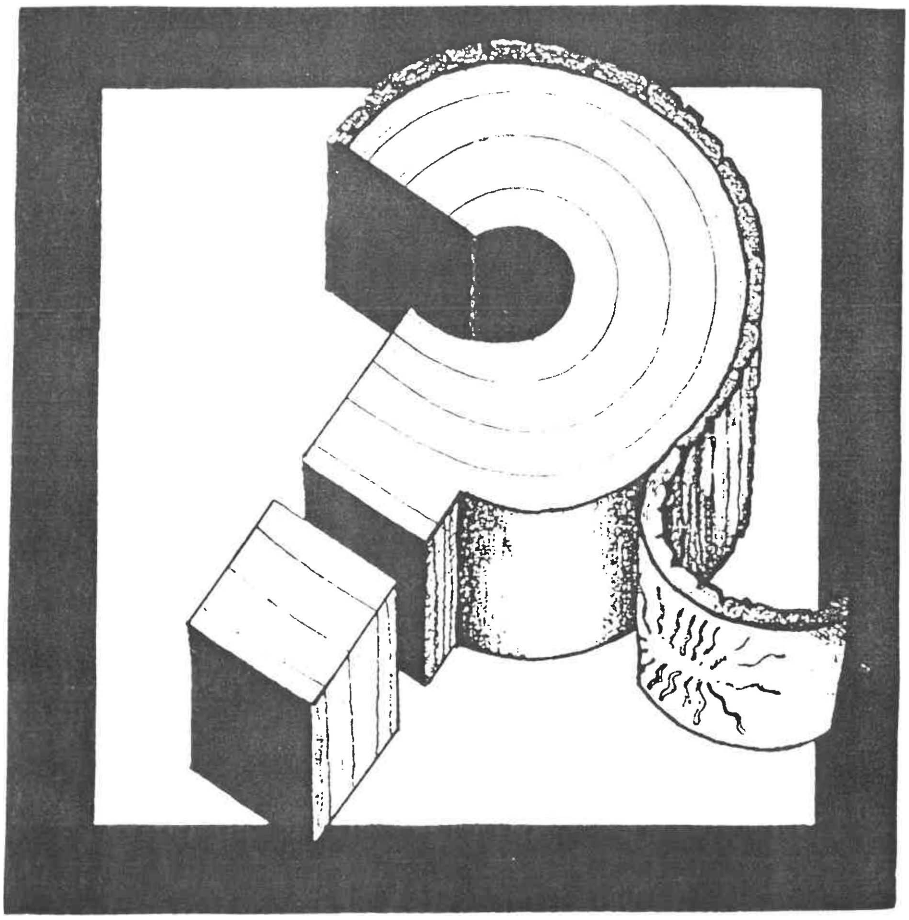
Title of Text-book Author(s), Year of Publication Publisher	Food/Nutrition Context	Photosynthesis Context	Ecological Context
5. "Biology" Epp, D. & Relph, D., 1983 Auckland : Heinemann.	"Unit 31 : Why Food? In this unit we will try to find out more about why food is so important to animals (and what) happen(s) after it is eaten" (p.116). "Different classes of food (are) : carbohydrates, fats, proteins, vitamins and minerals" (p.119-120).	"Photosynthesis is the name of the food making process of green plants. The food made in photosynthesis is starch" (p.69). "Light energy from the sun is trapped by the chlorophyll in the leaf. This energy is used to combine water and carbon dioxide into a new chemical starch. The starch is food" (p.79).	"Because green plants trap energy from the sun and make or produce their own food molecules they are called producers" (p.21). "A food chain is a list of 'what eats what'. Each food chain begins with a producer" (p.24). "As well as showing us what eats what, a food chain shows us how energy is transferred through a community" (p.25).
6. "School Certificate Science - Biology" Relph, D., 1983. Auckland : Heinemann.	"Unit 32 : Food And Health. In this unit we will find out what chemicals the body is made of and study the effects of different types and amounts of food on the body" (p.87). "Unit 33 : Carbohydrates And Calories" (p.91). "Unit 34 : Fats And Obesity" (p.93). "Unit 35 : Proteins, Vitamins And Minerals" (p.96). "Water. This is not food" (p.88).	"Plants usually contain quite a lot of energy in stored food. They must be able to make the large molecules which have large energy stores. They do this by the process called photosynthesis" (p.6). "In the equations for photosynthesis the end product (is) glucose, (which) is very quickly changed into starch" (p.10).	-
7. "Biology Today - A Course For First Examinations", Robson, M.D., Morgan, A.G. 1980. London : MacMillan Educational Ltd.	"As well as these three types of food (carbohydrates, fats, protein), animals and plants need a diet, which includes vitamins and mineral salts. These are needed in very small amounts compared with the other food types" (p.18). "A balanced diet must contain correct amounts of : carbohydrate, fat, protein, vitamins, roughage, water" (p.28).	"Most plants can build their own food from simple molecules. Green plants ... produce food in the form of glucose. The glucose produced during photosynthesis is stored in most plants as starch" (p.20).	"Plants can make their own food from simple chemicals, but animals must eat plants to get their food. They do this either directly, such as rabbits eating grass or indirectly, like eagles eating rabbits which have eaten grass. For this reason, plants are called producers and animals are called consumers. The food is transferred along what is called a food chain" (p.26).
8. "Organisms" (2 vols) Robinson, D.E., Ford-Robertson, J de C., & Godbert, F.D., 1978. Wellington : Reed.	"Feeding methods : These are the most important differences between plants and animals. No plants ever really "engulf" their food ... Most animals engulf complex food and digest" (Vol.1, p.209) "The food of plants is inorganic. That of animals is mainly organic being derived from plants. There are six classes of food : 1. Water 2. Mineral salts (inorganic) 3. Vitamins 4. Carbohydrates 5. Fats 6. Proteins (organic)" Vol. 2, p.30).	"... green plants manufacture food ... The way in which this organic material is made up in the first place ... is in fact done by the method that green plants use to feed. These plants feed on water and carbon dioxide gas and by using the sun's energy turn these materials into simple carbohydrates e.g. glucose. This ... is called photosynthesis" (Vol. 1, p.8). "The glucose ... is converted into starch" (Vol. 1, p.208).	"Plant-feeding animals (herbivores) obtain ... energy directly by feeding on plants : animal-feeders (carnivores) indirectly, by feeding either on herbivores or on other carnivores which feed on herbivores. A food chain describes the feeding relationships of plants and animals ... (Vol.1, p.46).
9. "Biology For Life" Roberts, M.B.V., 1981. Walton-On-Thames, U.K. : Thomas Nelson & Sons Ltd.	"The food we consume each day makes up our diet. Whatever we choose to eat our diet must include the following substances : carbohydrates, fats, proteins, water, minerals and vitamins. These substances give nourishment and we call them nutrients" (p.112).	"Photosynthesis produces food substances such as starch" (p. 187). "Although starch is made in the end, it is not the first substance to be formed. Glucose is formed first and this is then turned into starch" (p.188).	-
10. "Organisms, Structure And Function" Anon, 1982. Perth : Curriculum Branch Department of Education Of Western Australia.	"MAIN FOOD GROUPS : Carbohydrates, protein, fats, vitamins, minerals, water, dietary fibre" (p.324).	"Photosynthesis is the food-making process in green plants" (p.95). "Food is manufactured from other raw materials (not foods) absorbed by the plant in a process called PHOTOSYNTHESIS" (p.99). "The formula for plant food is $C_6H_{12}O_6$" (p.125).	"Food chains show feeding relationships between animals and plants" (p.95). "e.g. wheat → pig → man. The arrows show the transfer of energy" (p.99).

APPENDIX B

THE TEACHING PACKAGE

(Page size reduced by one fifth)

WHERE DOES THE WOOD COME FROM?



AN INTRODUCTION TO PHOTOSYNTHESIS FOR THIRD AND FOURTH FORMERS

Miles Barker
Science Education Research Unit
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Hamilton, N.Z.

WHERE DOES THE WOOD COME FROM?

An Introduction to Photosynthesis
For Third And Fourth Formers

Miles Barker
November, 1985

Science Education Research Unit
University of Waikato
Hamilton, N.Z.

CONTENTS

TEACHER'S INTRODUCTION : IS THIS UNIT FOR ME?

The Problem

If you ask pupils to tell you their ideas about where the wood in a growing tree comes from, they find it very hard to explain. These five responses are typical:

> "Out of the ground maybe... aw... it would be in the seed or from when it was planted and it just sort of sprouts."
> \- Melanie, 11 years

> "Well, the nutrients help it to grow and it could take in more nutrients and more water and puts that towards the growth."
> \- John, 15 years

> "Well, the tree builds it up as it grows like with the rings you get. The wood's organic in itself and it's part of the growing process but I wouldn't be prepared to be more specific than that. I can't really tell where it comes from... I mean, how it gets there."
> \- Peter, 15 years

> "It's just there. There's no sort of, um... It's sort of just there. It's just... it's there."
> \- Nicola, 14 years

> "...(10 secs)... No! Haven't an idea. Not a one."
> \- Jillian, 17 years

The Teacher's Response : Photosynthesis

As teachers, we realise that the concept of photosynthesis is relevant to answering this question, since wood (or cellulose) is the major photosynthetic product on earth. In fact, more than 50% of all the organic matter on earth is cellulose. This unit therefore serves as a first introduction for students to the material changes that occur in photosynthesis.

Learning About Photosynthesis

The idea that green plants can take in a colourless, apparently weightless gas found in minute concentrations in the air, plus ordinary water which we can drink and change them into wood and oxygen must seem pretty unlikely to our students. How can we help them to understand and accept the concept of photosynthesis?

This unit is based on a way of thinking about teaching and learning which may be quite new to you. "Where Does The Wood Come From?" may therefore also serve to provide you with some food for thought about teaching and learning in science generally.

Some key organisational facts about this unit are:

Level of Student: Form 3 or 4 (13 or 14 year olds) of average ability.

The Forms One To Four Draft Syllabus: Relates to level 5, section 5, i.e. "The Plant Way of Life".

Prerequisite Teaching: Nil, except for two exercises near the end of the unit (as indicated).

Timing: A total of 3-4 weeks in September-December or February-March.

Teacher Preparation - Materials And Apparatus: Simple, and all described fully in the unit. Your technician should have no trouble. Weighings play an important part throughout and it would be important to have access to 3 or 4 Dial-O-Gram balances or, ideally, an electronic top-pan balance accurate to 0.01g., e.g. the Mettler PC400 or the Sartorius 1402.

IF THIS UNIT SOUNDS LIKE A STIMULATING
EXPERIENCE FOR YOU AND YOUR CLASS - READ ON!

5

THREE PRELIMINARY ISSUES

1. Photosynthesis What Do Scientists, Teachers, And Students Understand By It?

Scientists everywhere recognise that photosynthesis is a key concept in explaining how plants function. They highlight the fact that photosynthesis, directly or indirectly, creates the sum total of all the organic material on earth, and that it is the only process by which all living things derive their energy. The scientists' definition of photosynthesis stresses two main components of the process, materials and energy. Thus a scientist is likely to define photosynthesis as the process in which, by the input of the sun's energy, the energy-poor compounds carbon dioxide and water are converted to the energy-rich compounds, carbohydrate and oxygen. Chlorophyll in plant leaves facilitates this energy input.

Science teachers, and the text books they use, reflect the scientists' view but teachers almost always add a third component, food (see Fig.1). In fact, the view of photosynthesis as a food-making process appears to dominate our teaching, and research[1] has shown that this is reflected in the learning outcomes of our third and fourth formers.

Students, before they are taught about photosynthesis (and sometimes even after teaching!), do not appear to have anything like a concept of photosynthesis, as such, but like their teachers they do have ideas about plants and materials, energy, and food. Students have ideas about how plants drink water, breathe in carbon dioxide and release oxygen, and grow by producing wood (see Fig.2a). They also have views about how plants receive energy directly from the sun (Fig.2b), and how plants feed on fertilizers, minerals and nutrients (Fig.2c). The important point, however, is that these views are held *in isolation* from each other.

2. Learning About Photosynthesis - How Is This Unit Different?

Especially over the last five years there has been a growing awareness that children's out-of-school understandings which they bring to the classroom have an enormous influence on their learning in school.[2]

Recently, two educators have made suggestions about how we as teachers can better accommodate children's existing ideas into our

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1 The research referred to here, and elsewhere in the unit, is described in S.E.R.U. Working Papers No. 220-229. The final paper in the series, "Photosynthesis : Towards Action Research", summarises the previous papers.

2 "Learning in Science" by Roger Osborne and Peter Freyberg, Heinemann, 1985, gives an excellent account of this perspective on learning.

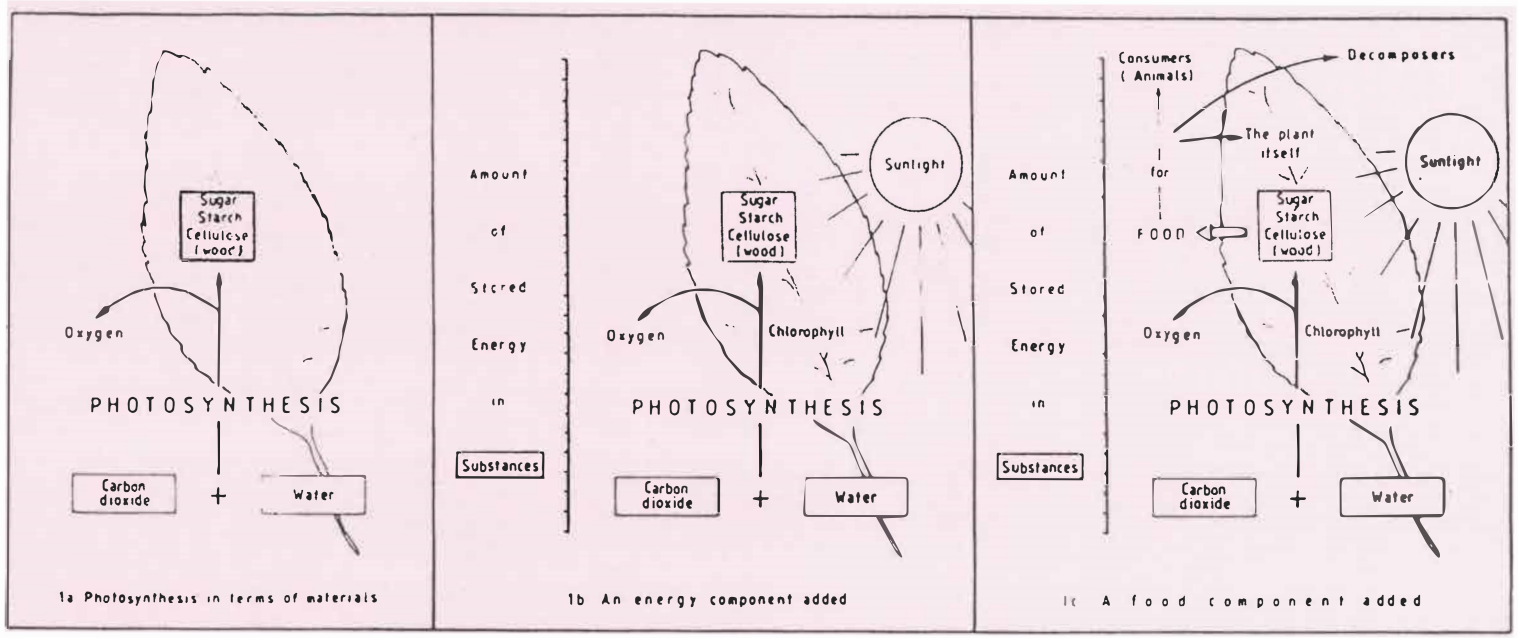

Fig. 1a, b, c. The cumulative teacher's science view of photosynthesis.

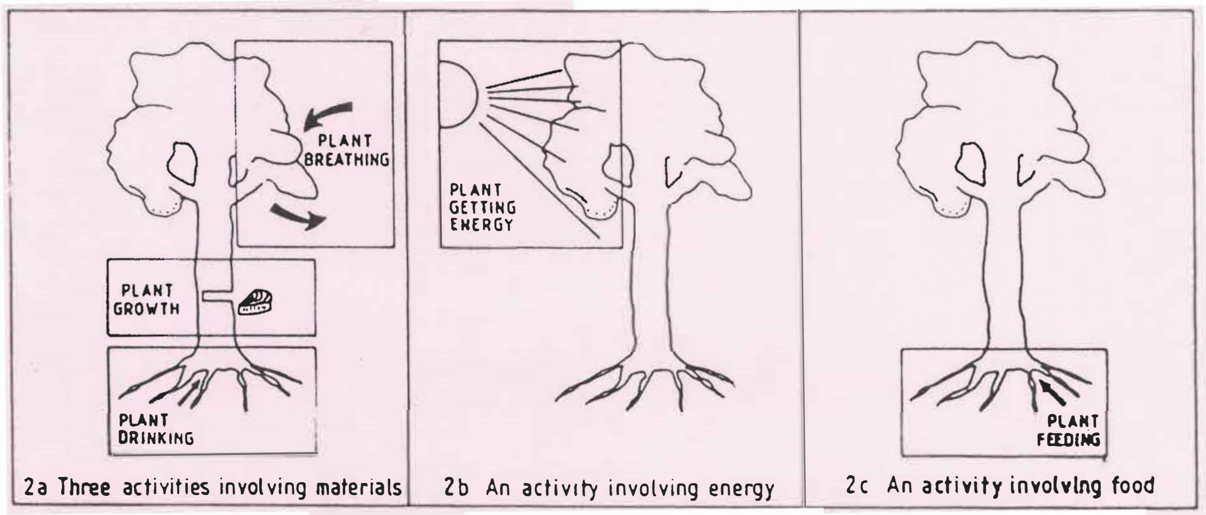

Fig. 2a, b, c. The children's science view - five separate plant activities.

teaching programmes and hence help learners to make use of these existing ideas to promote new understandings. The central idea in this approach[1] is that constructing meaning can be done only by the learner (not by us on his or her behalf) and that this learning involves a learner's generating links between stimuli (which we can provide) and the stored information already in the learner's head. In "Where Does The Wood Come From?" we shall be able to apply this view of learning because we can draw on research which has given us an insight into students' prior knowledge (i.e. stored information) about plant materials. Specifically, we shall be assisting our students to generate links between their existing ideas about plant breathing, drinking, and growing, and to relinquish links between plant feeding and growing.

To approach this link-forming process, we begin the unit by assisting our students to ***select and attend to*** relevant knowledge, that is, their own ideas about plant breathing, drinking, feeding, and growing rather than, say, ideas about flowers and their attractiveness, insecticides, pollination, and so on. (Traditional teaching about photosynthesis has usually involved experiment-and-control situations and chemical testing, but research is suggesting that students often become distracted by these stimuli and fail to attend to the key design feature, i.e. the formation of new carbohydrate.)

In the central section of the unit we anticipate that students will be more likely to ***generate links*** to existing knowledge and *construct meaning* if photosynthesis is portrayed, initially, as a response to the question "Where Does The Wood Come From?" (Teaching about photosynthesis has traditionally highlighted starch formation, but research has suggested that today's students do not think of starch as being a familiar material. On the other hand, they are of course well acquainted with wood as a plant product, and wood <u>is</u> the major material produced in photosynthesis.)

Finally, we shall need to give students ample opportunity to ***evaluate this new construction***, that is, to relate photosynthesis to all his or her other knowledge, in new and familiar situations. Only then will it become ***subsumed (i.e. anchored) in long-term memory***.

In summary, during this unit:

Your students	... will be taking responsibility for their own learning.	... won't be waiting for <u>you</u> to tell them the answers.
You	... will be actively supporting students' efforts to construct their <u>own</u> meaning.	... won't be transmitting <u>your</u> understanding to students.

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[1] The generative learning model, of Roger Osborne and Merl Wittrock.

3. "Where Does The Wood Come From?" - Where Is This Unit Going?

Figure 3 gives an over-view of the three phases of learning which comprise this unit. You will note that this structure is based on the key processes described above, i.e. selecting and attending to relevant knowledge (Focus phase), generating links and constructing meaning (Challenge phase), and evaluating this constructon (Application phase).

The pages in the unit which are intended as Teacher Guide material are printed on pink paper, and materials which are to be removed from this publication, photocopied, and distributed to students are printed on white paper.

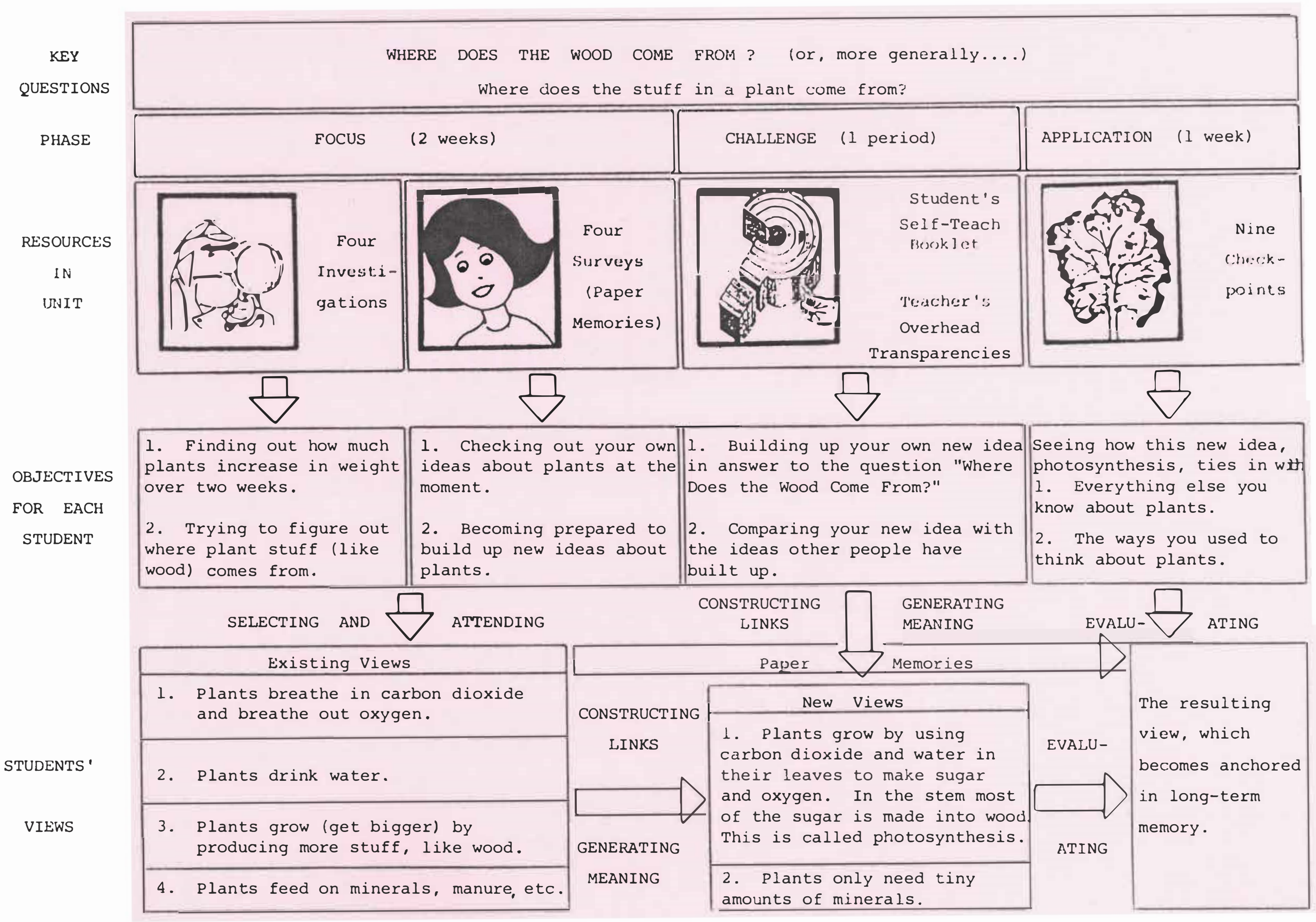
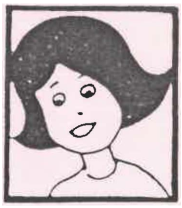


Fig.3. An overview of the unit.

THE FOCUS PHASE :

AN OVERVIEW



Organisation

Student Activities	Group Size	Time Needed	Objectives for Each Student
Task Sheet: "What Do Plants Need to Grow?" (p.14)	Individuals, Then whole class discussion.	Initial period.	- Focus on an easy question and make a free choice from four Investigations.
Four Investigations (p.15-27)	Small groups reporting often to whole class.	Fourteen days.	- Find out how much plants increase in weight over fourteen days. - Attend to the KEY QUESTION "Where does the stuff in a plant come from?"
Four Surveys (p.32-37)	Individuals, Then group and class discussion.	Interspersed with Investigations.	- Become aware of his/her own ideas about plants. With your help they focus on their views about plants and gases, water, growth, and minerals.
Final focussing (p.12)	Whole class discussion.	During final 2-3 periods.	- Is ready to build up new ideas about plants by attending to the SPECIFIC KEY QUESTION "Where does the wood come from?"

Some Comments

Task Sheet: Attach p.13 to the Task Sheet to help students take responsibility for their own progress through this unit. Hopefully two groups of 3-4 students will volunteer for each Investigation. However, you should try to arrange things so that at least one group carries out each Investigation.

Investigations: It is important for you to appreciate that the Investigations are not experiments in the usual sense, and that as a teacher you do not have a vested interest in the physical results. The purpose of each Investigation is to enable pupils to focus on the KEY QUESTION. Your role is to assist in this focussing by discouraging students from becoming distracted by side-issues and bogged down in procedural details. Check that students are sure about the purpose right from the start, and be prepared to modify the format of the Investigation to highlight the KEY QUESTION. For advice about setting up the Investigations, and possible outcomes, see pages 28-31.

Surveys: These are not tests, they are surveys! They are designed to help students become aware of their own views, to value them, to share them with others, and to compare and contrast alternative views. Discussion between students and with you is therefore crucial. See pages 38-39 for comments about each survey.

Final Focussing: You have an essential role in directing discussion towards the SPECIFIC KEY QUESTION, i.e. "Where does the wood come from?" To achieve this you could

a. display chain-saw pine rings around your classroom,

b. decorate your classroom with forestry publications, e.g. from the Forestry Research Institute, Rotorua.

c. liaise with your school Woodwork Department to share their visual aids.

Outcomes: At no point in the Focus Phase are you telling pupils the answers. But at the end of the phase they should

a. have focussed on the question "Where does the wood come from?", and

b. be eager to seek further for answers to this question, and

c. have become aware of their own views that
   plants breathe in carbon dioxide and breathe out oxygen,
   plants drink water,
   plants grow (get bigger) by producing more stuff, like wood,
   plants feed on minerals, manure, etc.

ABOUT THIS UNIT

WHAT Will You Learn From This Unit?

The forests of the world produce millions of tonnes of wood every year, which we use for building houses, producing paper, and making lots of things from a hockey stick to a pencil.

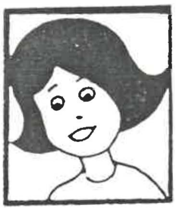
At the end of this unit you will have come up with an answer to the question "Where does the wood come from?" You will also know how plants make the other stuff inside them like starch, sugar, etc.

HOW Is This Unit Different?

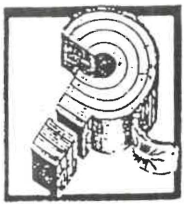
This unit is different from other topics which you have studied in science because this time your teacher won't be telling you the answers. You are going to build up an answer to the wood question for yourself by using some of the ideas which you have about plants right now.

WHERE Is This Unit Going?

You will be going through three steps:



Step 1 - Finding out what your own ideas about plants are. You will be carrying out some SURVEYS, on yourself! Also you will be working through an INVESTIGATION on growing plants, to try and form your own theories about where plant stuff like wood comes from.



Step 2 - Using a SELF-TEACH BOOKLET to build up your own new idea about the question "Where does the wood come from?"

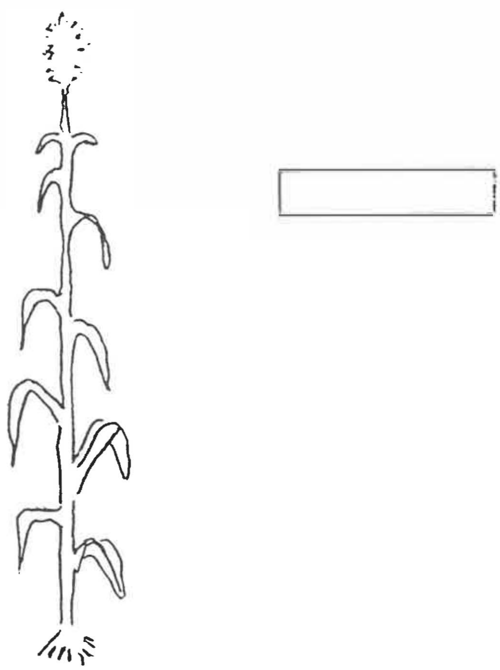
Step 3 - Using a series of CHECKPOINTS to see how your new idea ties in with everything else you know about plants, and the ways you used to think about plants.

14

We start this self-help learning unit by checking out our ideas on a much easier question .....

WHAT DO PLANTS NEED TO GROW?

Write your ideas in boxes around the plant. (One box has been put in for you.) How many ways can you think of to answer this question?



MINI-MOWING

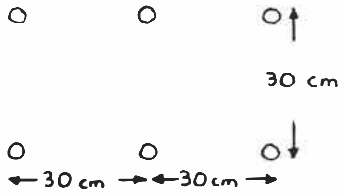
Investigation 1

During this Investigation you will be finding out what weight of grass grows in a rectangle over two weeks. You will be trying to figure out an answer to the key question "Where does all the new stuff in a plant come from?" Be a detective! Come up with your theories. Your ideas are bound to be useful. Talk about your ideas with the others in your group. (At the end of this Investigation you will be able to use your ideas to find out where the most common new stuff in plants-wood- comes from.)

What To Do Today

1. Go outside your classroom, with your group, and select an unshaded area of grass on the lawn.

2. Hammer in six small pegs in the shape of a rectangle like this:



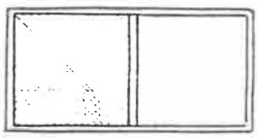
3. Would you say that the grass is growing? ____________ (Yes/No)

   Write down what tells you that: ________________________________

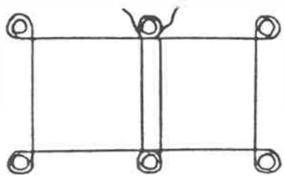
   ____

   ____

4. Now make a light wooden frame, with sides about 3 cm high, and tack 50% shade mesh to one half and leave the other side uncovered. The frame should just sit inside the pegs:



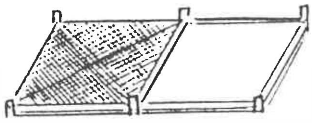
5. Now loop and tie a piece of strong cord tightly around the pegs:



6. With hand shears, carefully clip the grass in each of the square areas down to "bowling green" level.

7. Remove all the grass clippings from the squares.

8. Place your frame down on the grass, inside the pegs.



9. Now, back inside, answer this question: If you come back in two week's time, do you think the grass in each square would have grown? ______________ (Yes/No).

   Write down what would tell you that? ____________________________

   ____

   ____

10. For homework, write down three things about this Investigation that you are not sure of at the moment:

    a. ____

    ____

    b. ____

    ____

    c. ____

    ____

<u>What To Do Over The Next Two Weeks</u>

1. Water the grass squares as necessary.

2. On the seventh day use hand shears to clip the grass in each square down to "bowling green" level again.

3. Carefully collect up <u>all</u> the clippings from each square separately in two labelled plastic bags.

4. Back inside, weigh the two grass samples and record these FRESH WEIGHTS on the table below in the First Harvest column.

5. Grass may get bigger because it has simply taken in water and swollen up. Let's check that by drying the grass out. Cut up both samples very finely with scissors and leave them on trays at the window sill for two days to completely dry out.

6. Weigh each sample again and record these DRY WEIGHTS in the table below.

7. Repeat steps 1-5 after another seven days.

	First mowing Date:	First Harvest Date:		Second Harvest Date:	
		Weight (g.)		Weight (g.)	
		Fresh	Dry	Fresh	Dry
Sunny Square					
Shady Square					

<u>Team Talk</u>

1. Would you say that the grass in each square has grown during the two weeks? ______________ (Yes/No)

   Write down what tells you that: ______________________________

   ____

   ____

2. How close was the prediction which you made back in question 9? _____

   ____

   ____

3. What do you think the stuff that makes up the DRY WEIGHT is? _________

   ____

   ____

4. Where do you think this stuff comes from? ____________________

   ____

   ____

SAND, SEEDS, SPROUTS

Investigation 2

During this Investigation you will be finding out how much bean seedlings grown in sand increase in weight over two weeks. You will be trying to figure out an answer to the key question "Where does all the new stuff in a plant come from?" Be a detective! Come up with your theories. Your ideas are bound to be useful. Talk about your ideas with the others in your group. (At the end of this Investigation you will be able to use your ideas to find out where the most common new stuff in plants-wood- comes from.)

What To Do Today

This Investigation starts by planting 10 dwarf bean seeds as follows:

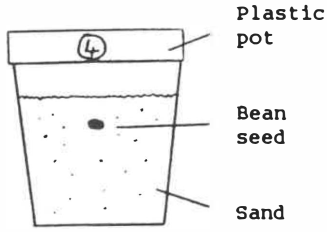
1. Number each of ten plastic pots and then two thirds fill each one with sand (or pumice).

2. Now add approximately 0.05g of minerals into the sand by either:

   - adding one very small mineral pellet

   or - adding a tiny pinch of mineral mix.

   Dip your thumb and finger into the mix and press lightly together. Release this sample and brush off whatever still sticks to your fingers over the sand.



3. Write down what the minerals look like:

   ____

4. Now weigh each of ten dwarf bean seeds, recording the weighings on the table below.

5. Would you say that the seeds are growing? ____________ (Yes/No)

   Write down what tells you that: ______________________________

   ____

   ____

6. Put the seeds on top of the sand and cover with a further 2 cm of sand (see diagram above).

7. Set up the ten pots on a sunny window sill in the laboratory or, preferably, in the glass house if your school has one.

8. Water the sand in each pot until the surface stays damp.

9. If you wait for two weeks, do you think the seeds would have grown? ____________ (Yes/No)

   Write down what would tell you that: ____________________

   ____

   ____

10. For homework, write down three things about this Investigation that you are not sure of at the moment:

    a. ____________________

    ____

    b. ____________________

    ____

    b. ____________________

    ____

<u>What To Do Over The Next Two Weeks</u>

1. Water the sand each day so that it stays damp.

2. In the Observations column in the table below write down anything unusual that you notice about what happens in each pot.

3. At the end of the 14 days, carefully remove each bean plant from the sand, taking special care with the roots.

4. Gently wash the sand off the roots under a trickle of water.

5. Gently dab all the water off the roots with a paper towel.

6. Weigh each bean plant and record these FRESH WEIGHTS in the table below.

7. Bean plants may get bigger because they have simply taken in water and swollen up. Let's check that by drying the plants out. Cut up the ten bean plants very finely with scissors and leave the clippings from each plant on a tray at the window sill for two days to completely dry out.

8. Weigh each of these ten samples of clippings and record these DRY WEIGHTS in the table below.

Pot Number	Planting Date: _______ Weight of Seed (g)	Observations	Harvesting Date: _______ Fresh Wt (g)	Dry Wt (g)
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Team Talk

1. Would you say that the bean seeds have grown during the two weeks? __________ (Yes/No) Write down what tells you that: ______________________________

   ____

2. How close was the prediction you made back in question 9? ________

   ____

   ____

3. What do you think the stuff that makes up the DRY WEIGHT is? ______________________________

   ____

4. Where do you think this stuff comes from? ______________________

   ____

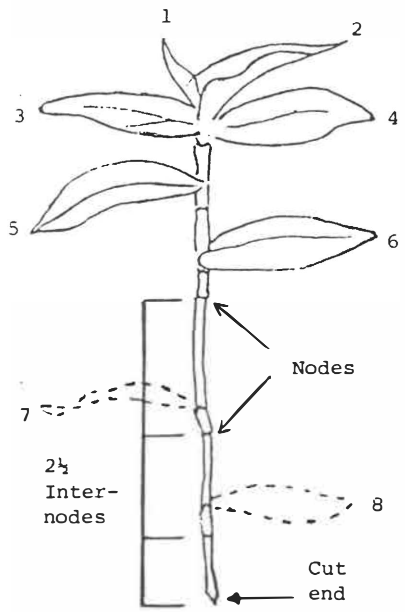
5. Fill out this table and then talk about questions 3 and 4 again:

Pot Number	Fresh Wt-Seed Wt	Fresh Wt-[Seed Wt + Mineral Wt]	Dry Wt-Seed Wt	Dry Wt-[Seed Wt + Mineral Wt]
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

WATER PLANTS

Investigation 3

During this Investigation you will be finding out how much cuttings of a common weed, Tradescantia, increase in weight over two weeks when they are grown in water. You will be trying to figure out an answer to the key question "Where does all the new stuff in a plant come from?" Be a detective! Come up with your theories. Your ideas are found to be useful. Talk about your ideas with the others in your group. (At the end of this Investigation you will be able to use your ideas to find out where the most common new stuff in plants-wood- comes from.)



What To Do Today

Tradescantia is a rambling, dark green plant, usually regarded as a weed, which occurs in unattended gullies, etc. It is a hardy plant juicy when squashed, and often has lots of small white flowers. A purple-leafed variety is sometimes cultivated in gardens.

1. Go outside to a source of Tradescantia. You will need to take a bucket with a small amount of water and a pair of scissors.

2. Pick 30 Tradescantia cuttings of average size by pulling off the seventh and eighth leaves back from the tip (see diagram) and making a cut so that there are two and a half internodes below leaf 6. Put the cut end under water each time.

3. Back in the lab, line the cuttings up on a bench in order of length and select the middle 10 cuttings.

4. Now weigh each cutting and record these FRESH WEIGHTS in the table below in the left hand column.

5. Now number 10 flasks and two-thirds fill each one with water.

6. Now add approximately 0.05 g of minerals to each flask by either:

- adding one very small mineral pellet, or
- adding a tiny pinch of mineral mix. Dip your thumb and finger into the mix and press together lightly. Release the sample and brush off whatever still sticks to your fingers into the flask.

7. Write down what the minerals look like: ____________________

____

8. Place one cutting in each flask and seal the top of the flask with aluminium foil.

9. Would you say that the Tradescantia cuttings are growing? ________ (Yes/No)

   Write down what tells you that: ____________________

   ____

   ____

10. Set up the ten flasks on a sunny window sill in the laboratory or, preferably, in the glass house if your school has one.

11. If you wait for two weeks, do you think the cuttings would have grown? __________ (Yes/No)

    Write down what would tell you that: ____________________

    ____

    ____

12. For homework, write down three things about this Investigation that you are not sure of at the moment:

    a. ____

       ____

    b. ____

       ____

    c. ____

       ____

What To Do Over The Next Two Weeks

1. Check the plants each day and in the Observations column in the table below write down any changes in each plant that you notice.

2. At the end of 14 days gently remove each plant, dab all the water off it with a paper towel and weigh it again. Record these FRESH WEIGHTS in the table below.

3. Tradescantia plants may get bigger because they have simply taken in water and swollen up. Let's check that by drying the plants out. Cut up the ten plants very finely with scissors and leave the clippings from each plant on a tray at the window sill for two days to completely dry out.

4. Weigh each of these ten samples of clippings and record these DRY WEIGHTS in the extreme right hand column of the table below.

5. It would have been interesting to know what the dry weights of these ten plants were when we started, but chopping them up at that stage would have ruined the Investigation. We can get around that problem by using data which other people have produced when they used young plants and measured both their fresh and dry weights (just like you did for older plants). Look up the Appendix to this Investigation and read off from the graph what your plants' dry weights were at the start of the Investigation. Record these starting DRY WEIGHTS on the table below.

Flask	Start Date: ______		Observations	Finish Date: ______	
Number	Fresh Wt. (g)	Dry Wt (g) From graph		Fresh Wt. (g)	Dry Wt (g)
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

<u>Team Talk</u>

1. Would you say that the <u>Tradescantia</u> plants have grown during the two weeks? __________ (Yes/No).

   Write down what tells you that: ______________________________

   ____

   ____

2. How close was the prediction you made back in question 11? ______

   ____

3. What do you think the stuff that makes up the DRY WEIGHT is? _____

   ____

   ____

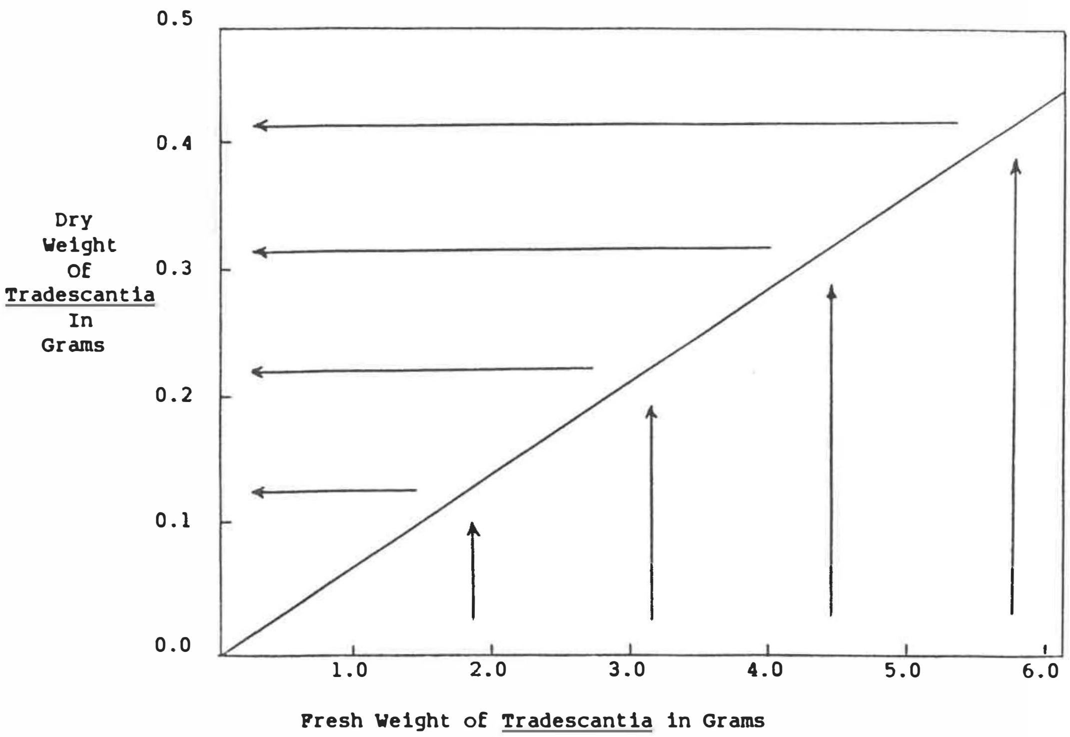
4. Where do you think this stuff comes from? ____________________

   ____

5. Fill out this table and then talk about questions 3 and 4 again.

Flask Number	Increase In Fresh Wt (g) Over 14 days	Increase In Dry Wt (g) Over 14 days	Increase In Dry Wt - Weight of Minerals
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

APPENDIX



SUPER AIR

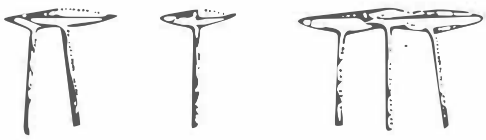
Investigation 4

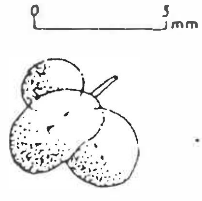
During this Investigation you will be finding out how much duckweed plants, growing in water in a bottle, increase in size over two weeks. You will be trying to figure out an answer to the key question "Where does all the new stuff in a plant come from?" Be a detective! Come up with your theories. Your ideas are bound to be useful. Talk about your ideas with the others in your group. (At the end of this Investigation you will be able to use your ideas to find out where the most common new stuff in plants-wood- comes from.)

What To Do Today

In this investigation you will be using duckweed, the little pale green plant whose leaves float in groups on the surface waters of ditches, tanks and ponds.

LEMNA MINOR Duckweed





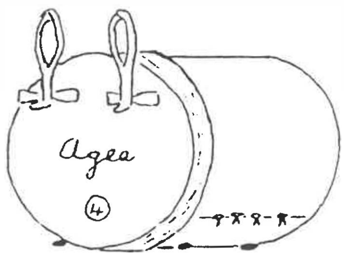
Into some of the bottles where the duckweed is growing you will be blowing the air which you breathe out.

1. Your teacher will provide you with 8 preserving jars, 8 metal lids, and 8 screw tops. The two holes in the lids are so that pieces of rubber tubing can be inserted. The tubing can be blocked off by Mohr clips to make the jar air-tight.

2. Fill the jars to a depth of 3 cm with tap water. Add approximately 0.05 g of minerals to each jar by either:

   - adding one very small mineral pellet, or

   - adding a tiny pinch of mineral mix. Dip your thumb and finger into the mix and press together lightly. Release the sample and brush off whatever still sticks to your fingers into the jar.



3. Your teacher will provide a supply of duckweed. Use a fine paint brush to transfer 15 leaves of duckweed to each jar. (You will need to count carefully - the leaves are in groups).

4. Screw the tops over the lids, fix the Mohr clips onto the tubing and lay the jars on their sides held down by blue-tack, in two lines of four opposite each other, lids outwards. Number each jar.

5. Arrange a strong lamp over the eight jars so that each jar receives equal strength light. The light will be on continuously.

6. Would you say that the duckweed is growing? ____________ (Yes/No)

   Write down what tells you that: ______________________________

   ____

   ____

7. Remove both Mohr clips, insert the blowing tube into one of the pieces of rubber tubing, blow down the tube steadily for one minute and replace both clips. Repeat for the other three jars in the front row.

8. If you let this Investigation run for two weeks, blowing twice daily into the front four jars, do you think that the plants would have grown? ____________ (Yes/No) Write down what would tell you that:

   ____

   ____

   ____

9. For homework, write down three things about this Investigation that you are not sure of at the moment:

   a. ______________________________

   ____

   b. ______________________________

   ____

   c. ______________________________

   ____

<u>What To Do Over The Next Two Weeks</u>

1. Blow into the four front jars, twice a day, as described above.

2. Each day, examine the jars for changes. Write down your observations in the table below, recording the date in brackets after the observation, e.g. (day 11):

Jar No.	Changes We Observed (Dates)
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	

Team Talk

1. Would you say that there has been any growth in the jars during the two weeks? ____________ (Yes/No) Write down what tells you that:

____

____

____

2. How close was the prediction which you made back in question 8? _____

____

____

3. If there is growth, how much is there? ______________________________

____

Where has it come from? ______________________________

____

TEACHER'S NOTES : INVESTIGATIONS 1-4

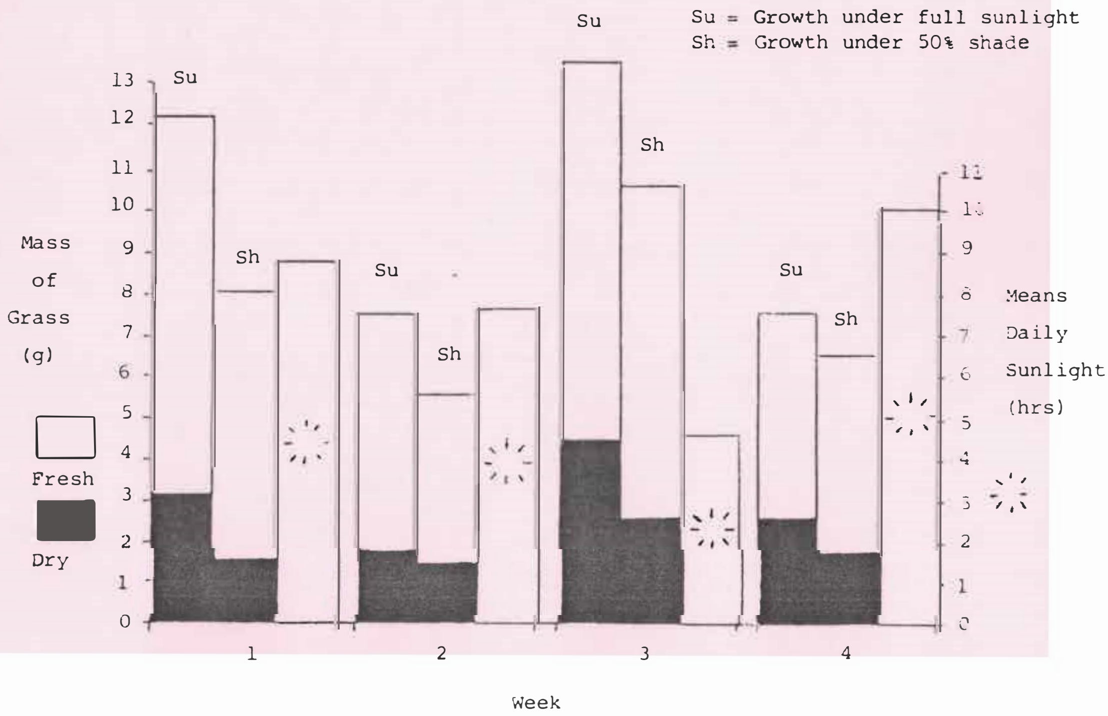
Investigation 1 : Mini-mowing

Equipment: Each group will need:

Six pegs	Hand shears
3m length of cord	Wooden frames
Plastic bags and ties	Drying trays (plastic meat dishes)
Access to a balance (p.4)	Square of 50% shade mesh (from garden supply centres)

Possible Outcomes

The following graph, which shows one typical set of results over an extended period, is included simply to help you visualise the course of the investigation. There is no intention that students present their results in this form, or that the issue of controls to experiments be raised. Instead, students should be thinking and talking about sunshine as an explanation for where the stuff in a plant comes from, i.e. focussing on the KEY QUESTION.



Investigation 2 : Sand, Seeds, Sprouts

Equipment: Each group will need:

10 plastic pots (small yoghurt size)
Sand or pumice
10 drying trays (plastic meat dishes)
Either: 10 Magamp pellets (7% nitrogen, 40% phosphate, 6% potash, 12% magnesium), or another commercial product e.g. Osmakote
5 paper towels

10 dwarf bean seeds
Scissors
Access to a balance
Or: "Homemade" mineral mix which is made up as follows:

KH_2PO_4	0.5g
K_2SO_4	1.0g
NH_4NO_3	1.5g
$CaCl_2\ 2H_2O$	1.0g
$MgSO_4\ 7H_2O$	1.0g

Possible Outcomes

A typical set of results is:

Pot Number	Seed Wt(g.)	Observations	Fresh Wt(g.)	Dry Wt(g.)	Fresh Wt -Seed Wt	Fresh Wt -[Seed Wt + Min]	Dry Wt -Seed Wt	Dry Wt -[Seed Wt + Min]
1	0.59		6.78	0.78	6.19	6.09	0.19	0.14*
2	0.52	Slow germination	-	-	-	-	-	-
3	0.37		5.37	0.65	5.00	4.90	0.28	0.23*
4	0.32		4.07	0.40	3.75	3.65	0.08	0.03
5	0.35	Slow germination	-	-	-	-	-	-
6	0.33		6.90	0.77	6.57	6.47	0.34	0.29*
7	0.58		8.24	1.05	7.66	7.56	0.47	0.42*
8	0.38		7.52	0.99	7.15	7.05	0.61	0.56*
9	0.37		4.48	0.50	4.11	4.01	0.13	0.08
10	0.48		7.01	0.84	6.53	6.43	0.36	0.31*

Results such as these can be used to focus further on the KEY QUESTION, i.e. even when we removed all the water from a plant grown without soil, and took into account the weight of the seed which was there from the start, and the minerals, there was still a significant weight gain in 6* of the plants. However, it is important not to be side-tracked by arithmetic. If completing this table proves difficult for students, use fresh weights to focus on the KEY QUESTION.

I am indebted to Mr Roger Cox of Fairfield College, Hamilton, and Ms Jane Barnett of Melville High School, Hamilton, for their contributions in the devising of this Investigation.

Investigation 3 : Water Plants

Equipment: Each group will need:

Bucket
Scissors
10 150ml Erhlenmeyer flasks
5 paper towels
Magamp pellets or "homemade" mineral mix (see above)
Small quantity of aluminium foil
10 drying trays
Access to a balance

Possible Outcomes

A typical set of results is:

Flask Number	Start Date: 5/2/85 Fresh Wt (g.)	Dry Wt (g) From graph	Finish Date: 19/2/85 Fresh Wt (g.)	Dry Wt (g.)	Increase In Fresh Wt(g) Over 14 days	Increase In Dry Wt (g) Over 14 days	Increase In Dry Wt-Wt of Minerals
1	3.78	0.31	5.75	0.46	1.97	0.15	0.10
2	5.16	0.45	8.89	0.61	3.73	0.16	1.11
3	4.00	0.35	7.20	0.53	3.20	0.18	0.13
4	4.58	0.42	7.82	0.57	3.24	0.15	0.10
5	3.83	0.32	8.91	0.56	5.08	0.24	0.19
6	4.35	0.37	5.84	0.42	1.49	0.05	0.00
7	3.35	0.26	7.22	0.45	3.87	0.19	0.14
8	4.43	0.38	9.15	0.59	4.72	0.21	0.16
9	3.95	0.35	8.27	0.57	4.32	0.22	0.17
10	3.95	0.35	8.82	0.53	4.87	0.18	0.13

Again, don't let the use of the graph in estimating initial dry weights or difficulties with arithmetic side-track students from the KEY QUESTION. If this threatens, use fresh weight data only to focus on the weight increase.

Trials of Investigations 2, 3 and 4 in which no minerals were added resulted in just as much dry weight increase as with minerals. Presumably mineral storage in the plants or seeds was adequate over the two week period. However, the Investigations included the adding of minerals in order to:

(i) emphasise that minerals are needed, but in tiny amounts
(ii) give students hands-on experience of minerals.

Investigation 4 : Super Air

Equipment: Each group will need:

8 pint (600ml) Agee preserving jars
8 perfit seal metal lids
8 screw tops
Paintbrush
Magamp pellets as "homemade" mineral mix (see above)
Blowing tube (20cm of 7mm rubber tubing with eye dropper glass inserted in the end)
16 Mohr clips
16 3cm long, 7mm ext. diameter lengths of rubber tubing
Supply of duckweed
Light source, e.g. double bar fluorescent tubes, mercury vapour lamp

Possible Outcomes

The outcome depends on the intensity of the light source used. At high light intensity, i.e. about 140 micro-einsteins, or 10% of full sunlight (check with your school light meter), results are very different from those at medium intensity, i.e. about 50 micro-einsteins or 2.5% of full sunlight. A typical set of results is:

Jar No.	Treatment	Day 1 Cell Nos.	Day 8 High Intensity Observations	Day 8 Medium Intensity Plant Numbers	Day 14 High Intensity Observations	Day 14 Medium Intensity Plant Numbers	Day 21 Medium Intensity Plant Numbers
1	BLOWING	15	Massive	18	Clumped	27	101
2		15	dispersed	24	green	32	131
3		15	green	26	growth	29	-
4		15	growth	19	Decay	23	-
5	NIL	15		16		17	-
6		15	Cloudy	19	Dispersed	17	-
7		15	appearance	16	green	17	-
8		15		14	growth	12	-

The green growth at high light intensities and blowing treatment is due to a Chlorella-type alga which is usually introduced by chance with the duckweed. Algal growth around the roots of the duckweed inhibits the latter's growth. Medium intensity light and blowing treatment favours duckweed growth.

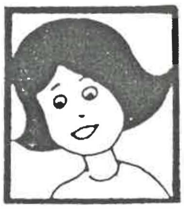
Both of these outcomes provide an opportunity to focus on the KEY QUESTION. An estimate of the dry weight increase at medium light intensity can be found from the relationship:

Duckweed Dry Wt. Increase = Number of new leaves x 0.05 mg.

Survey 1

GROWING PLANTS :

MY IDEAS ALREADY



All of us have got lots of ideas about plants and the way they grow. This survey is to help YOU check out the ideas which YOU have at present. Later you will be able to build on these ideas to understand more about plants. For each question, tick the box which best matches YOUR ideas. N.B. This is not a test!

1. Which part of a big pine tree do you think weighs the most?

[ ] A The bark.
[ ] B The wood in the trunk.
[ ] C The pine needles.
[ ] D The pine cones.

2. Which of these fits how you think about wood?

[ ] A Wood is mainly cellulose.
[ ] B Wood is mainly chloroform.
[ ] C Wood is mainly chlorophyll.
[ ] D I don't know what wood is.

3. Which of these do you think is the best statement about the total amount of wood in a tree?

[ ] A The total amount of wood in a tree never changes.
[ ] B Some wood disappears from a tree in winter and reappears in summer.
[ ] C In most trees the amount of wood increases year by year.
[ ] D The amount of wood in big old trees decreases before they fall over and die.

4. Which do you think is the best statement about where the wood in a tree comes from?

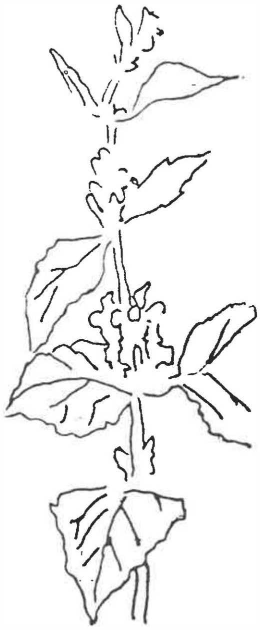
[ ] A The wood comes from the seed.
[ ] B The wood comes straight from the ground.
[ ] C Plants change other stuff into wood.
[ ] D Annual rings are changed into wood.

5. In the way you think about it, where does most of the weight of a tree come from?

[ ] A Air and water.
[ ] B Water and fertilizers.
[ ] C Soil and fertilizers.
[ ] D Fertilizers only.

6. A plant usually takes in water

[ ] A through its leaves only.
[ ] B through its roots only.
[ ] C through its roots and its leaves.
[ ] D through its roots, its leaves, and its stem.



7. Which of these do you think is the right order for the four main gases in the air, going from most to least?

[ ] A Nitrogen, carbon dioxide, oxygen, water.
[ ] B Nitrogen, oxygen, carbon dioxide, water.
[ ] C Oxygen, carbon dioxide, nitrogen, water.
[ ] D Carbon dioxide, oxygen, water, nitrogen.

8. As far as you know, leaves are useful to most plants because they

[ ] A shield the plant from the sun.
[ ] B store water for the plant.
[ ] C take in dew at night.
[ ] D produce sugars for growth.

9. Which one of these do you think is the best statement about plants giving off water?

[ ] A Most plants don't give off any water.
[ ] B Most plants give off water through their roots only.
[ ] C Most plants give off water through their leaves only.
[ ] D Most plants give off water through their trunk and stems only.

10. Which of these is the best statement about growing plants?

[ ] A It is possible to grow some plants without water.
[ ] B It is possible to grow some plants without soil.
[ ] C It is possible to grow some plants without air.
[ ] D The plants we grow all need water, soil and air.

11. Which do you think is the best statement about what a plant needs?

[ ] A A small amount of fertilizer; and a large amount of air and water.
[ ] B A small amount of air; and a large amount of fertilizer and water.
[ ] C A small amount of water; and a large amount of air and fertilizer.
[ ] D About equal amounts of fertilizer, air, and water.

12. Think about an orange, a bean seed, and a walnut shell. Which of these do you think of as being woody?

[ ] A The orange.
[ ] B The bean seed.
[ ] C The walnut shell.
[ ] D None of these are woody.

13. A tree gets bigger over the years because

[ ] A the tree stores up more fertilizer from the ground.
[ ] B the tree grows towards the sun.
[ ] C the wood in the tree expands itself.
[ ] D the tree changes other stuff into more wood.

14. How do you think about the green stuff in leaves?

[ ] A I call it cellulose.
[ ] B I call it chloroform.
[ ] C I call it chlorophyll.
[ ] D I don't have a name for it.

15. Which do you think is the best statement about plants and carbon dioxide?

[ ] A All plants can change carbon dioxide into oxygen.
[ ] B Many plants use carbon dioxide and water to produce wood and oxygen.
[ ] C All plants can change oxygen into carbon dioxide.
[ ] D Many plants use oxygen and water to produce wood and carbon dioxide.

16. Which do you think is the best statement about plants and carbon dioxide?

[ ] A Plants take in carbon dioxide mainly through the leaves.
[ ] B Plants take in carbon dioxide all over their surfaces.
[ ] C Plants take in carbon dioxide mainly through their roots.
[ ] D Plants don't take in carbon dioxide. They give it off.

17. Which do you think is the best statement about a plant and water?

[ ] A A plant doesn't give off any of the water it takes in.
[ ] B A plant gives off all the water it takes in.
[ ] C A plant gives off a little of the water it takes in but keeps most of it.
[ ] D A plant gives off most of the water it takes in but keeps a little bit.

18. Which is the best statement about plants and sugar?

[ ] A All plants contain small amounts of sugar.
[ ] B All plants contain large amounts of sugar.
[ ] C Only a few types of plants ever contain sugar.
[ ] D Sugar never occurs in plants.

19. A plant needs fertilizers like maxi-crop

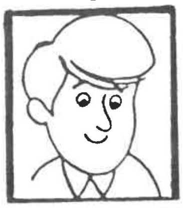
[ ] A as its main source of nourishment.
[ ] B in very small amounts.
[ ] C to change into wood.
[ ] D instead of carbon dioxide.

20. Which part of a plant do you think is most like a factory?

[ ] A The roots.
[ ] B The bark.
[ ] C The wood.
[ ] D The leaves.

> Now look back. Put a ? beside:
> - any questions where you thought MORE THAN ONE idea was right.
> - any questions where you thought NONE of the ideas was right.
>
> Be ready to talk about these when the other students are ready.

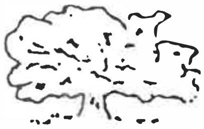
Survey 2



IS IT A PLANT?

What do YOU think at the moment?
Tick the square of your choice each time.

Is a cow a plant?
Yes ☐ No ☐



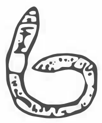
Is an oak tree a plant?
Yes ☐ No ☐

Is a fern a plant?
Yes ☐ No ☐

Is wheat a plant?
Yes ☐ No ☐

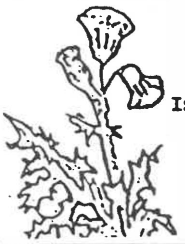
Is a mushroom a plant?
Yes ☐ No ☐

Is a fire a plant?
Yes ☐ No ☐



Is an earthworm a plant?
Yes ☐ No ☐

Is a brown seaweed a plant?
Yes ☐ No ☐

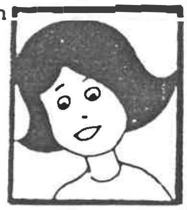


Is a thistle a plant?
Yes ☐ No ☐

Is a carrot a plant?
Yes ☐ No ☐

Survey 3

This survey is to help you check out your own ideas at the moment. In the space below write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.



Plants And Water

Survey 4

This survey is to help you check out your own ideas at the moment. In the space below write a paragraph about the subject given in the BOX. You can continue on the back of this sheet if you need to.

Plants And The Gases In The Air

TEACHER'S NOTES :

SURVEYS 1-4

Survey 1 : Growing Plants - My Ideas Already

This survey is intended as an early opportunity to open up a wide ranging discussion about many aspects of plant growth. During this discussion, however, there are two particular views which students should become aware that they hold at present:

- plants grow (get bigger) by producing more stuff, like wood.
- plants feed on minerals, manure, etc.

Some students may suggest a link between these two plant processes. During the discussion it may be helpful for you to keep at the back of your mind that

(i) questions with content areas in common are:

Water	Questions 6,9,17
Carbon dioxide and oxygen	Questions 7,16
Leaves and chlorophyll	Questions 8,14,20
Fertilizers, minerals, nutrients	Questions 10,11,19
Sugar, wood, growth	Questions 1,2,3,12,18
Chemical change in plants	Questions 4,5,13,15

(ii) the scientists' responses are:

1 B	2 A	3 C	4 C	5 A	6 B	7 B	8 D	9 C	10 B
11 A	12 C	13 D	14 C	15 B	16 A	17 D	18 A	19 B	20 D

Survey 2 : Is It A Plant?

This survey is intended to give students an opportunity to discover what they consider to be included in the set of plants. The responses and ensuing discussion should give you an indication of how students will interpret the motion that green plants perform photosynthesis. Checkpoint 9, which uses the same set of examples, will enable you to follow this point up. In fact, in the scientists' view, the oak tree, wheat, brown seaweed, thistle, and carrot are all classed as plants (and all perform photosynthesis).

Other research[1] has suggested that you may find that your students have a narrower meaning for the word plant than do scientists. If a plant is small, soft, and cultivated, children are likely to agree with the scientists' view. However, weeds, trees, and vegetables are often excluded from what a child considers to be the set of plants.

Survey 3 : Plants And Water

Completing this survey and discussing what they have written should assist students to become aware of their view that

- plants drink water, but that this is unrelated to growth, i.e. the production of stuff like wood.

Survey 4 : Plants And The Gases In The Air

Similarly, this survey should expose the view that

- plants breathe in carbon dioxide and breathe out oxygen but that this process is unrelated to growth, i.e. the production of stuff like wood.

You may need to encourage students to become aware that they have knowledge which enables them to differentiate their concept of air into its components, including carbon dioxide and oxygen.

Outcomes

These four surveys should have prepared students for the Challenge Phase, in which they shall be generating links between their concepts of plants and water, carbon dioxide, wood, and oxygen, and relinquishing links between wood and minerals.

Students should keep their completed surveys carefully filed. They will be using them again in the Application Phase, where the surveys will serve as "paper memories" of how they used to think about plants before the Challenge Phase.

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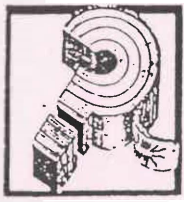
1 Science Education Research Unit Papers No. 24 and 30.



THE CHALLENGE PHASE :

AN OVERVIEW

Organisation

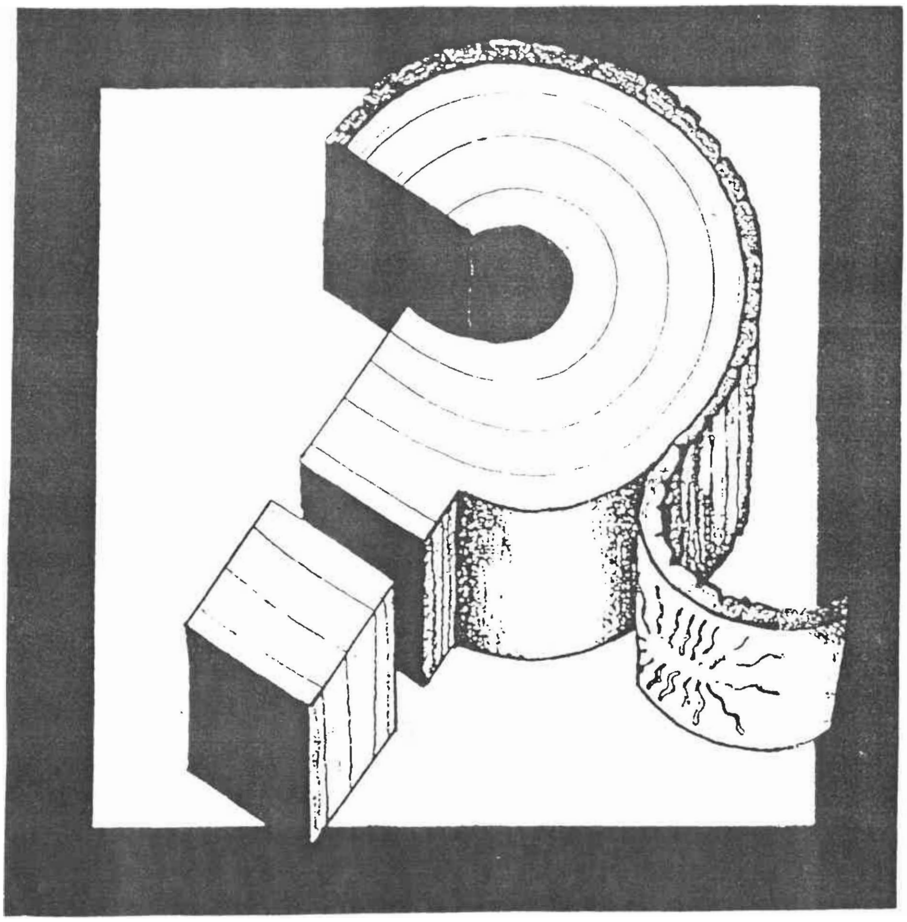
Student Activities	Group Size	Time Needed	Objectives For Each Student
Reading Self-Teach Booklet (p. 41-52)	Individuals, at home	About 15 mins.	Building up his/her own new, idea, photosynthesis, in answer to the question "Where Does The Wood Come From?"
Discussing the new idea with teacher dis-playing 11 OHP transparencies. (p. 53-63)	Whole class, and maybe small groups	One period, the day after the above	Comparing his/her new idea with your view and the views of other students.
Completing the Self-Check item (p.64)	Individuals, then group discussion	About 15 mins, next day	Checking that he/she can build up the new idea for him/herself.

Some Comments

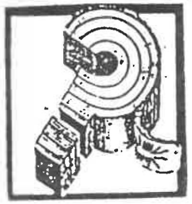
It is important to stress to students that reading the booklet will be an important and worthwhile activity. But also remember that they must take responsibility of their own learning and generate their own links.

Pages in Self-Teach Booklet	Link-Forming Processes
1. Where Does The Wood Come From? 2. Do you Agree?	Forming links between Focus Phase and Challenge Phase.
3. Students Have Useful Ideas 4. Scientists Say 5. Making Sugar 6. Making Wood	Generating links to existing knowledge, and constructing a new meaning : photosynthesis.
7. How Much Is Minerals? 8. Two Percent	Relinquishing links between minerals and wood.
9. The Question Again 10. The Scientists' Answer	Strengthening the links and the construction.
11. Photosynthesis In Our Lives	Linking Challenge Phase to Application Phase.

WHERE DOES THE WOOD COME FROM?

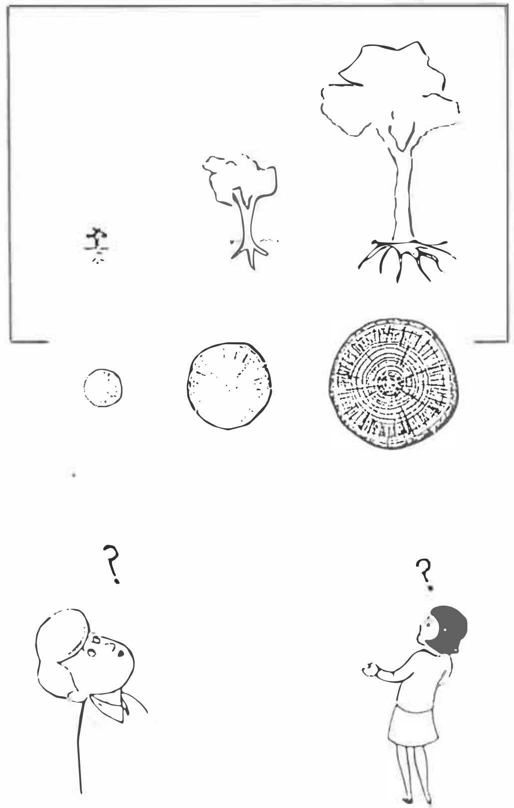


STUDENT'S SELF-TEACH BOOKLET



In the Investigation you have been doing in this unit you have found out how much plants increase in weight over two weeks, and you have been trying to figure out where this new plant stuff comes from. The plants on earth make more wood than all the other plant products put together so, in particular, we have been wondering about the question "Where does the wood come from?"

WHERE DOES THE WOOD COME FROM?

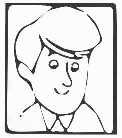


"Where does the wood come from?" is a pretty tricky question and there are a number of possible answers. Melanie, Peter Nicola and John, students about your age, came up with these answers. Do you agree with any of them? Do you think their answers are unsatisfactory? Why? What do you think the answer is?

WHERE DOES THE WOOD COME FROM?

DO YOU AGREE?

MELANIE: "Out of the ground maybe ... aw ...it would be in the seed or from where it was planted and it just sort of sprouts".



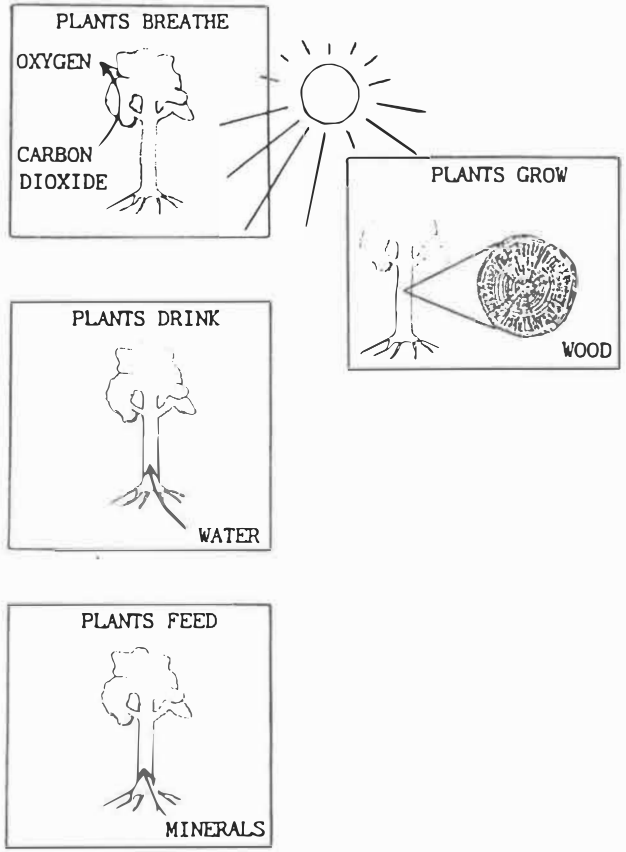
PETER: "Well, the tree builds it up as it grows like with the rings you get ... I can't really tell you where it comes from ... I mean, how it gets there".

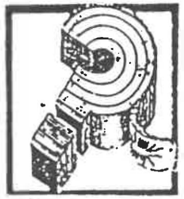
NICOLA: "It's just there. There's no sort of, um ... It's sort of just there. It's just ... it's there".

JOHN: "Well, the nutrients help it to grow and it would take in more nutrients and water and puts that towards the growth".

Let's think about other things which plants do besides growing and producing stuff like wood. Remember the Surveys you did? They probably reminded you that you also have ideas about how plants breathe in carbon dioxide and breathe out oxygen, drink water, and feed on minerals, manure, etc. Turning to the next page will tell you how you can use these ideas of yours to understand the scientists' answer to where the wood comes from.

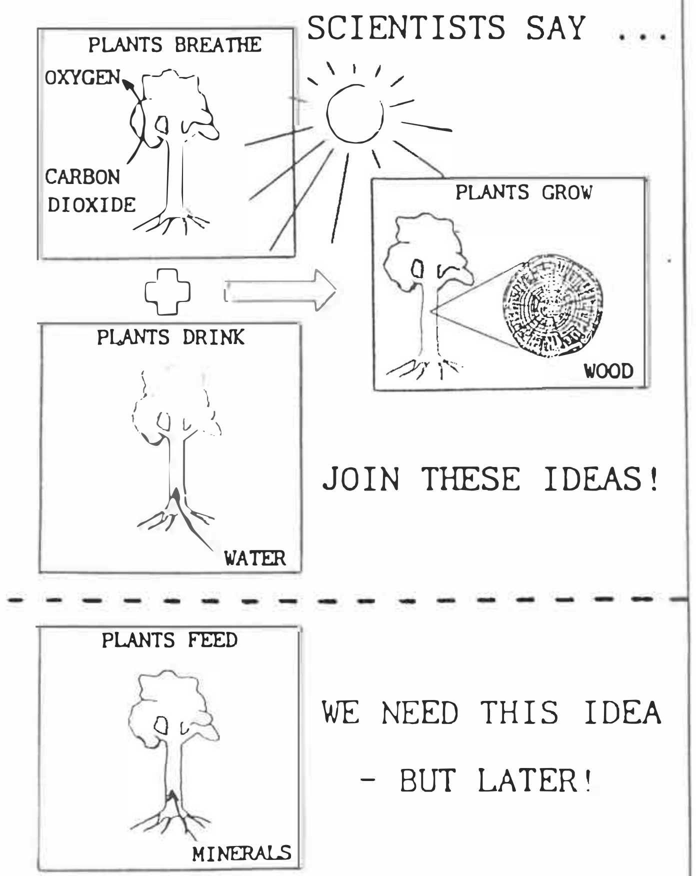
STUDENTS HAVE USEFUL IDEAS ABOUT PLANTS.





Although you may find it surprising, scientists would say that plant breathing and drinking are most to do with making wood! Plants actually use carbon dioxide and some of the water they take in and change them into wood and oxygen. Students sometimes think that feeding up plant roots with minerals will create more wood, but scientists would tell you that minerals are not changed into wood. It's your ideas about carbon dioxide, water, wood and oxygen which you need to link up!

STUDENTS HAVE USEFUL IDEAS ABOUT PLANTS.

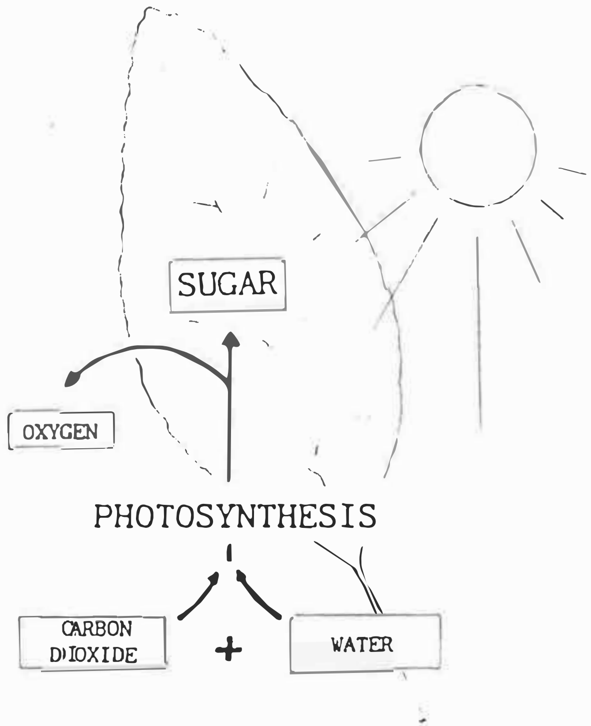


Scientists say that plants start the wood-making process inside green leaves in sunlight. Here, plants use carbon dioxide and water to make sugar and oxygen:

Carbon dioxide + Water ⟶ Sugar + Oxygen

This is called photosynthesis because plants need light ("photo-") in this building up ("-synthesis") process to make sugar.

SCIENTISTS SAY GREEN LEAVES MAKE SUGAR BY PHOTOSYNTHESIS.

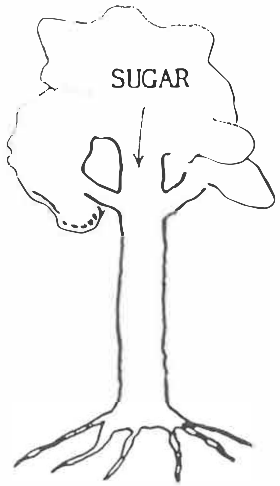


Most of this sugar goes into the stem and is used to make wood. The full photosynthesis process is:

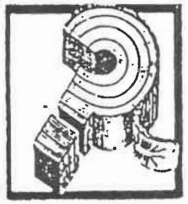
Carbon dioxide + Water ⟶ Sugar + Oxygen
↓
Wood

So photosynthesis ties up a number of your separate ideas, and is the scientists' answer to the question "Where does the wood come from?"

SCIENTISTS SAY THAT MOST OF THE SUGAR GOES BACK INTO THE STEM...

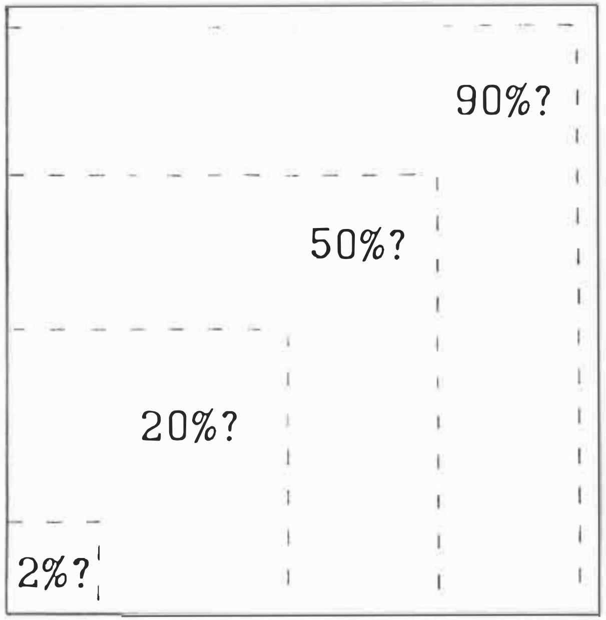


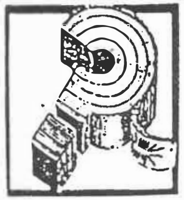
... AND IS MADE INTO WOOD.



But what about those minerals which you see so much about on T.V.? Where do they come in? How much of the mass of a plant do you think is minerals? Decide what you think and then turn to the next page to find out what the scientists' answer is.

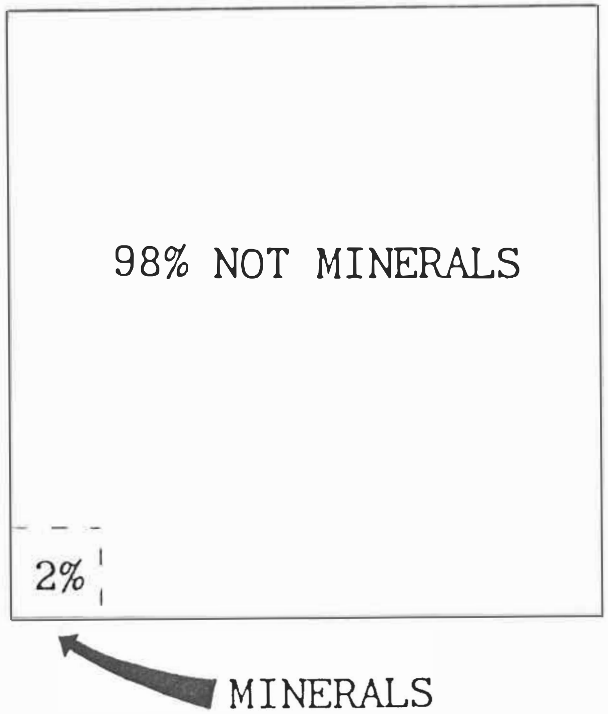
HOW MUCH OF THE MASS OF A PLANT IS MINERALS?



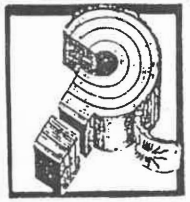


HOW MUCH OF THE MASS OF A PLANT IS MINERALS?

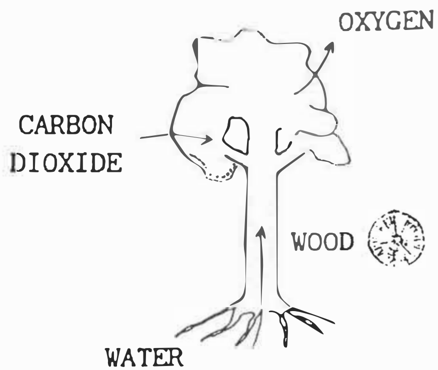
SCIENTISTS SAY...

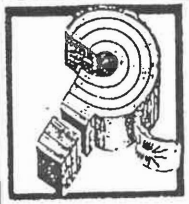


Although different types of plants vary, scientists say that only about 2% of the total mass of a plant is minerals. That couldn't account for all the wood in a tree. The other 98% is liquid water and solid stuff, mainly the wood. Plants <u>do</u> need tiny amounts of minerals, but they use carbon dioxide and water to make wood.



Scientists say that plants grow by taking carbon dioxide, that quite scarce invisible gas, and ordinary liquid water which we can drink, and make them into solid wood and oxygen gas. So how does a small tree grow into a big tree?

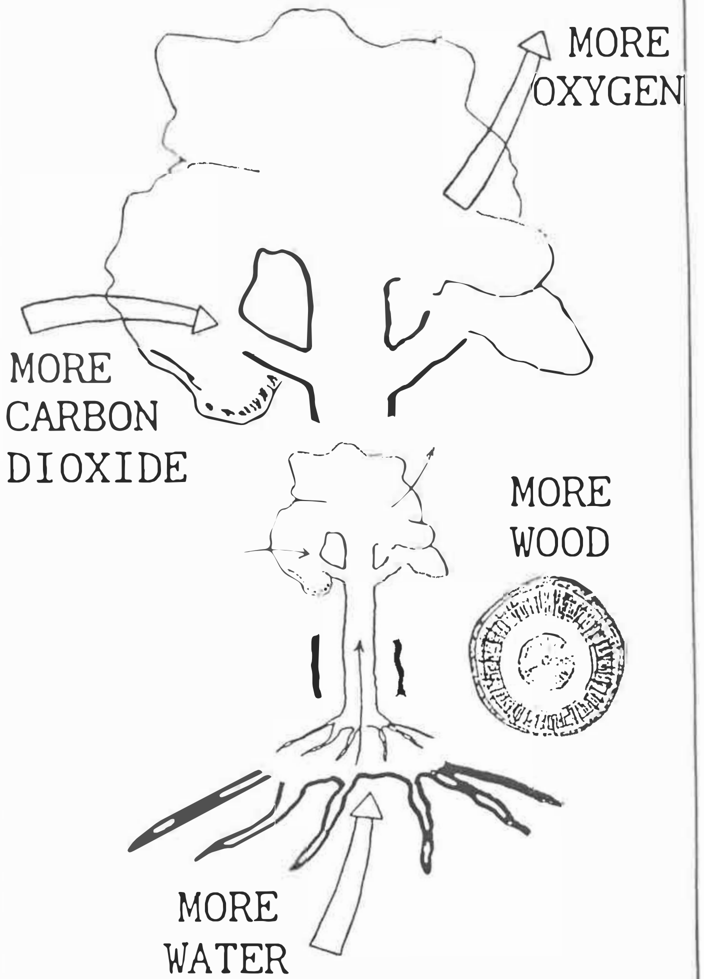


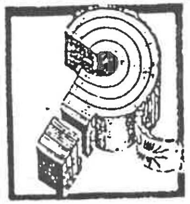


Small trees just keep on and on performing photosynthesis and may grow into huge trees. So it's photosynthesis which is the scientists' answer to the question "Where does the wood come from?":

Carbon dioxide + Water ⟶ Sugar + Oxygen
↓
Wood

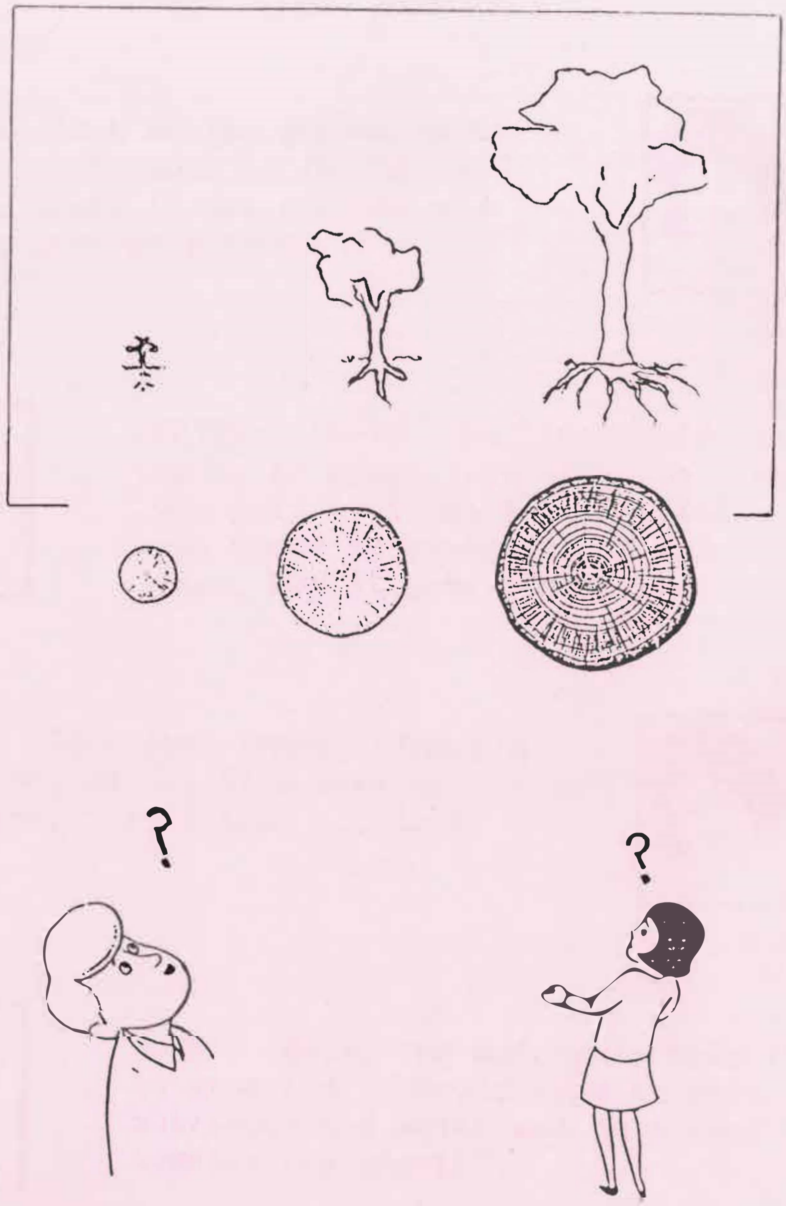
Note: Photosynthesis can only occur in green plants, not in animals. Scientists use words like "breathing", "drinking" and "feeding" only when they are talking about animals, but not when they are talking about plants.





Photosynthesis is a mighty process! It makes all the wood in the world and lots of other plant products as well. We meet the results of photosynthesis every day of our lives. This Self-Teach Booklet has helped you to build up your new idea, photosynthesis, by using your own ideas about plants. You will probably need time to get used to this new idea, and to check it out against your other ideas. Tomorrow you will have a chance to do this, when you will be talking about photosynthesis and starting work on some Checkpoint exercises.

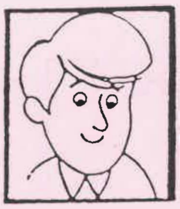
WHERE DOES THE WOOD COME FROM?



WHERE DOES THE WOOD COME FROM?

DO YOU AGREE?

MELANIE: "Out of the ground maybe ... aw ...it would be in the seed or from where it was planted and it just sort of sprouts".

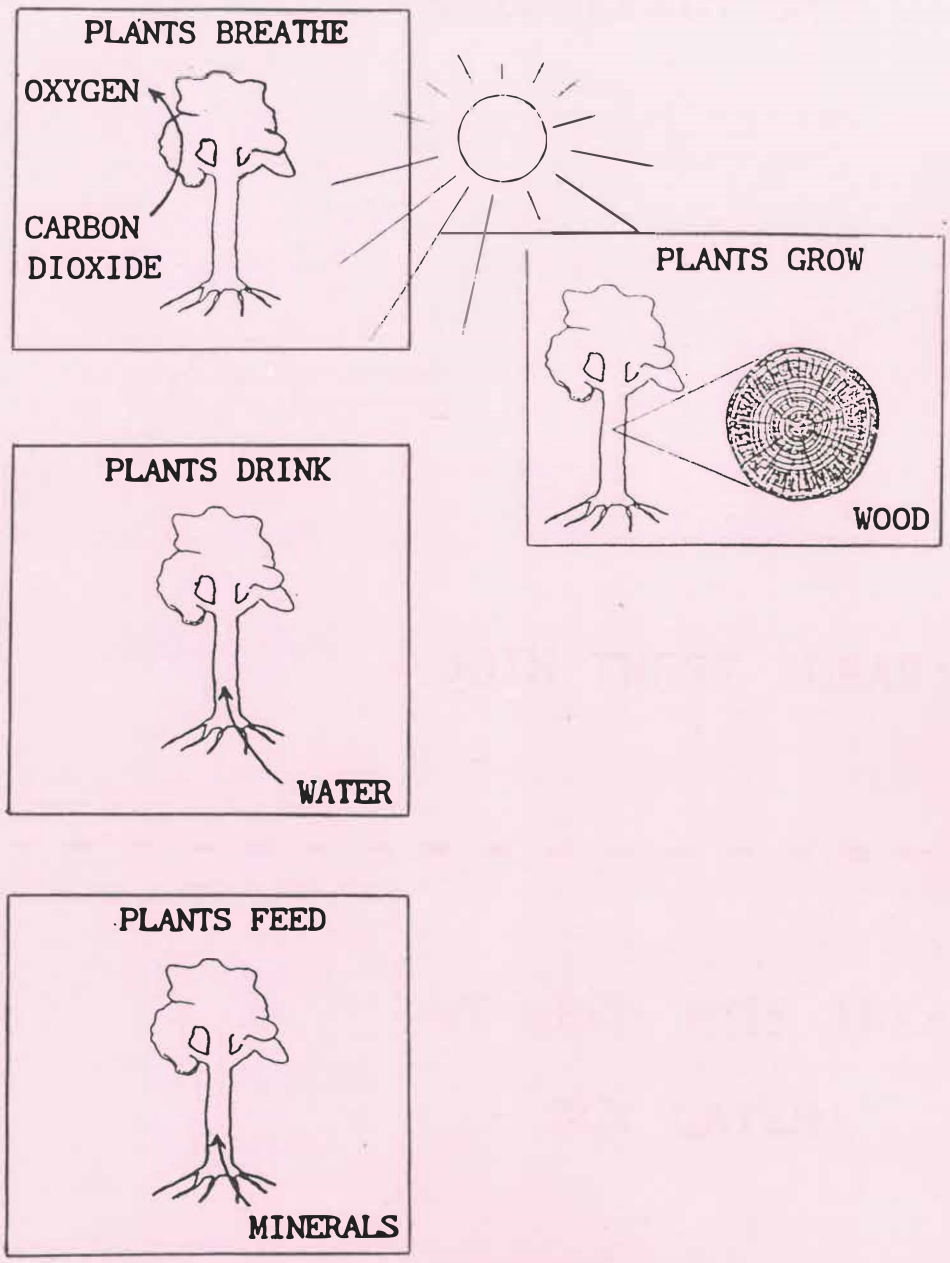


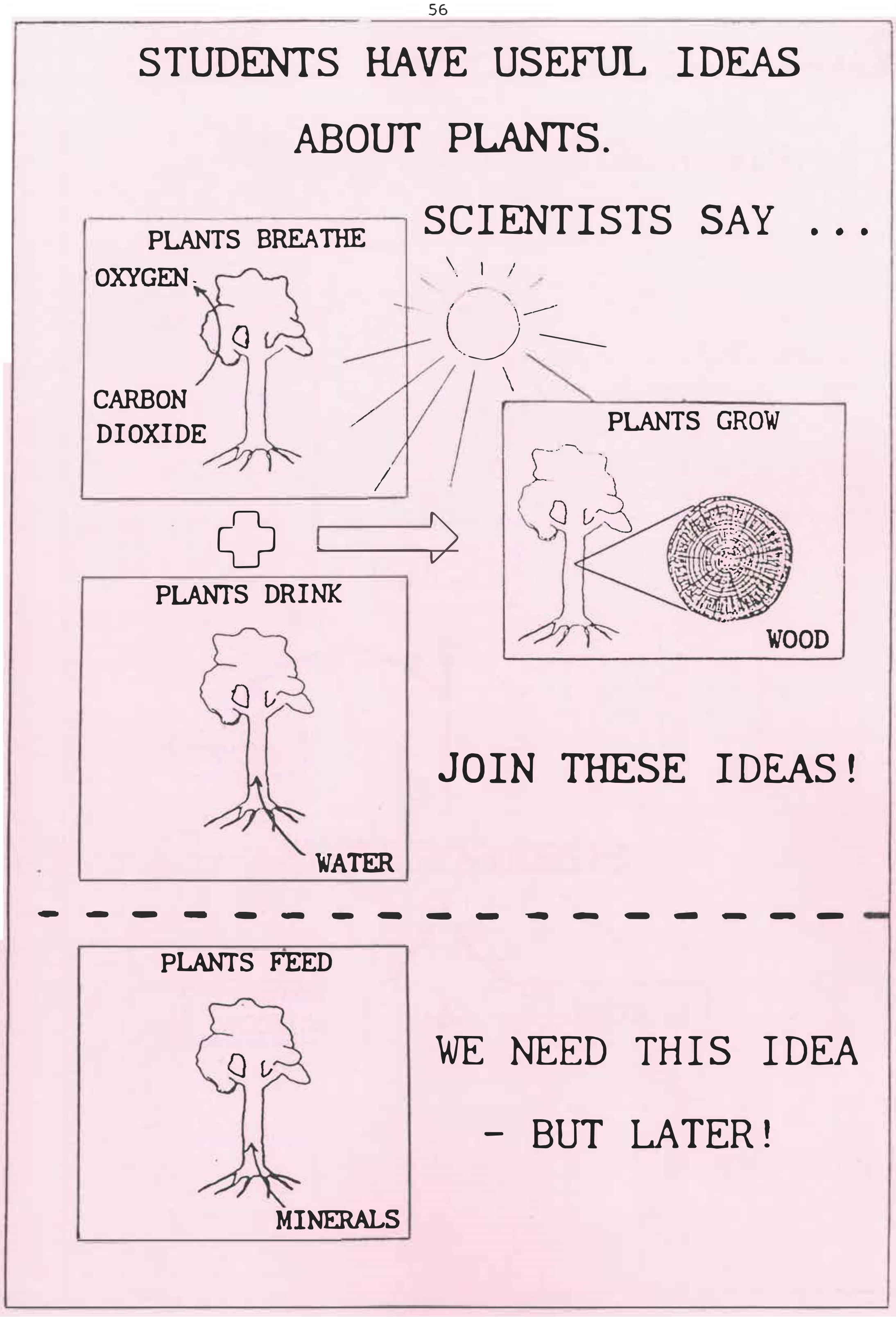
PETER: "Well, the tree builds it up as it grows like with the rings you get ... I can't really tell you where it comes from ... I mean, how it gets there".

NICOLA: "It's just there. There's no sort of, um ... It's sort of just there. It's just ... it's there".

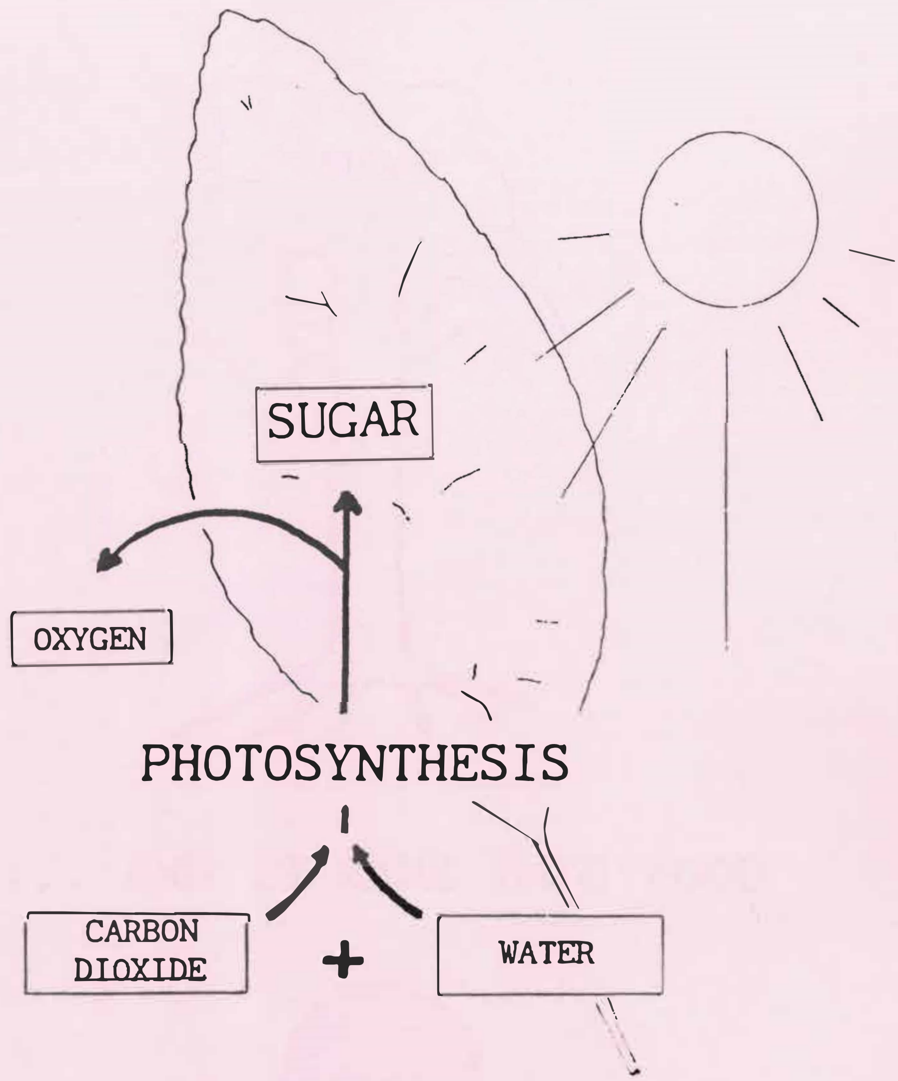
JOHN: "Well, the nutrients help it to grow and it would take in more nutrients and water and puts that towards the growth".

STUDENTS HAVE USEFUL IDEAS ABOUT PLANTS.

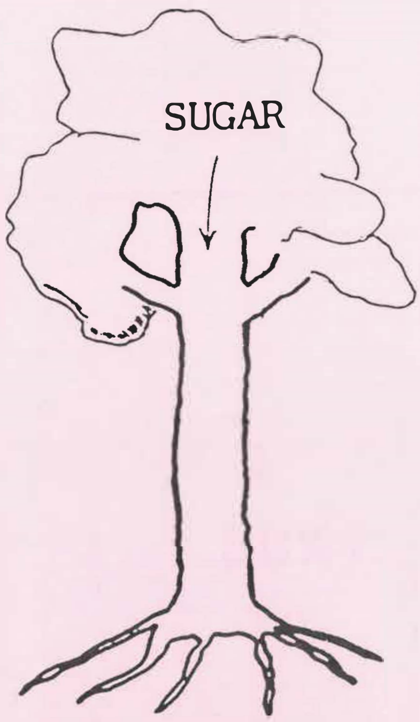



STUDENTS HAVE USEFUL IDEAS
ABOUT PLANTS.
SCIENTISTS SAY ...
PLANTS BREATHE
OXYGEN
CARBON
DIOXIDE
PLANTS GROW
WOOD
PLANTS DRINK
WATER
JOIN THESE IDEAS!
PLANTS FEED
MINERALS
WE NEED THIS IDEA
- BUT LATER!

SCIENTISTS SAY GREEN LEAVES MAKE SUGAR BY PHOTOSYNTHESIS.

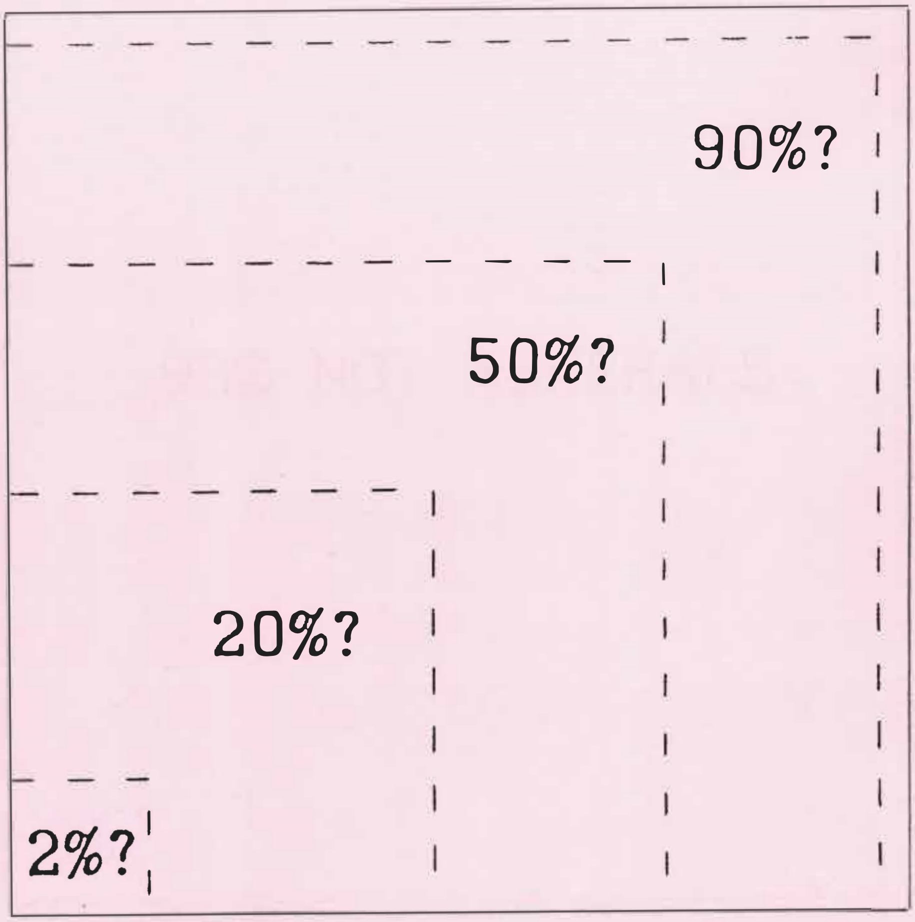


SCIENTISTS SAY THAT MOST OF THE SUGAR GOES BACK INTO THE STEM...



... AND IS MADE INTO WOOD.

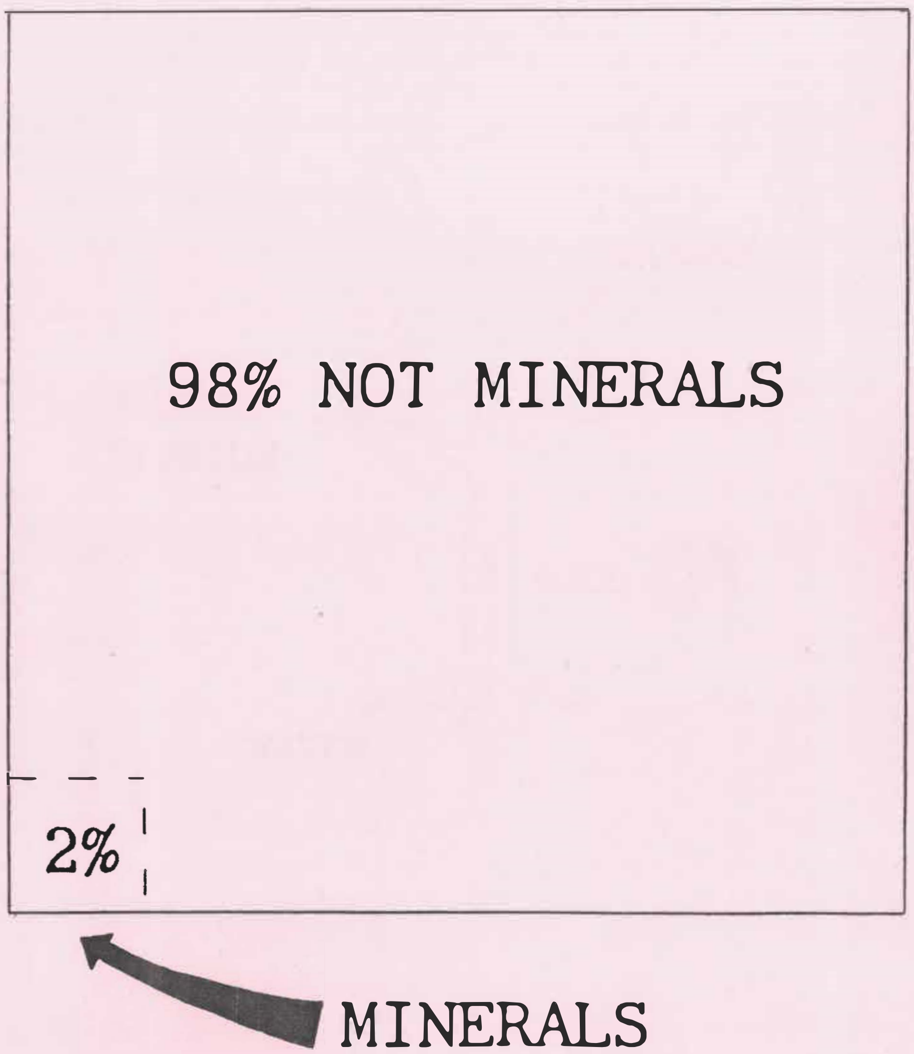
HOW MUCH OF THE MASS OF A PLANT IS MINERALS?

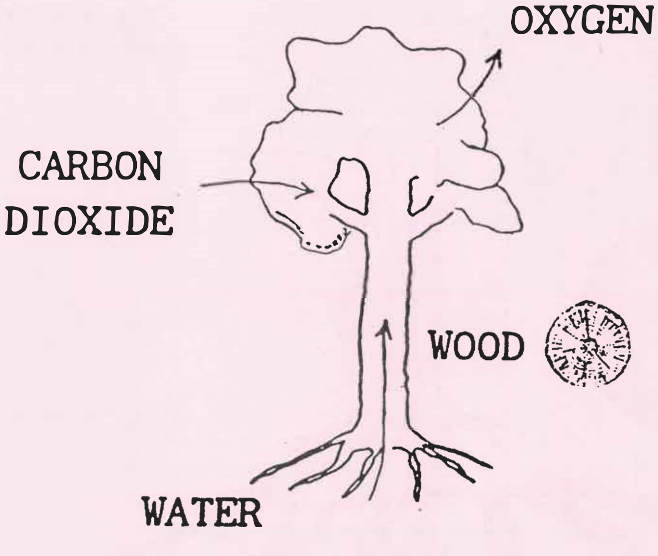


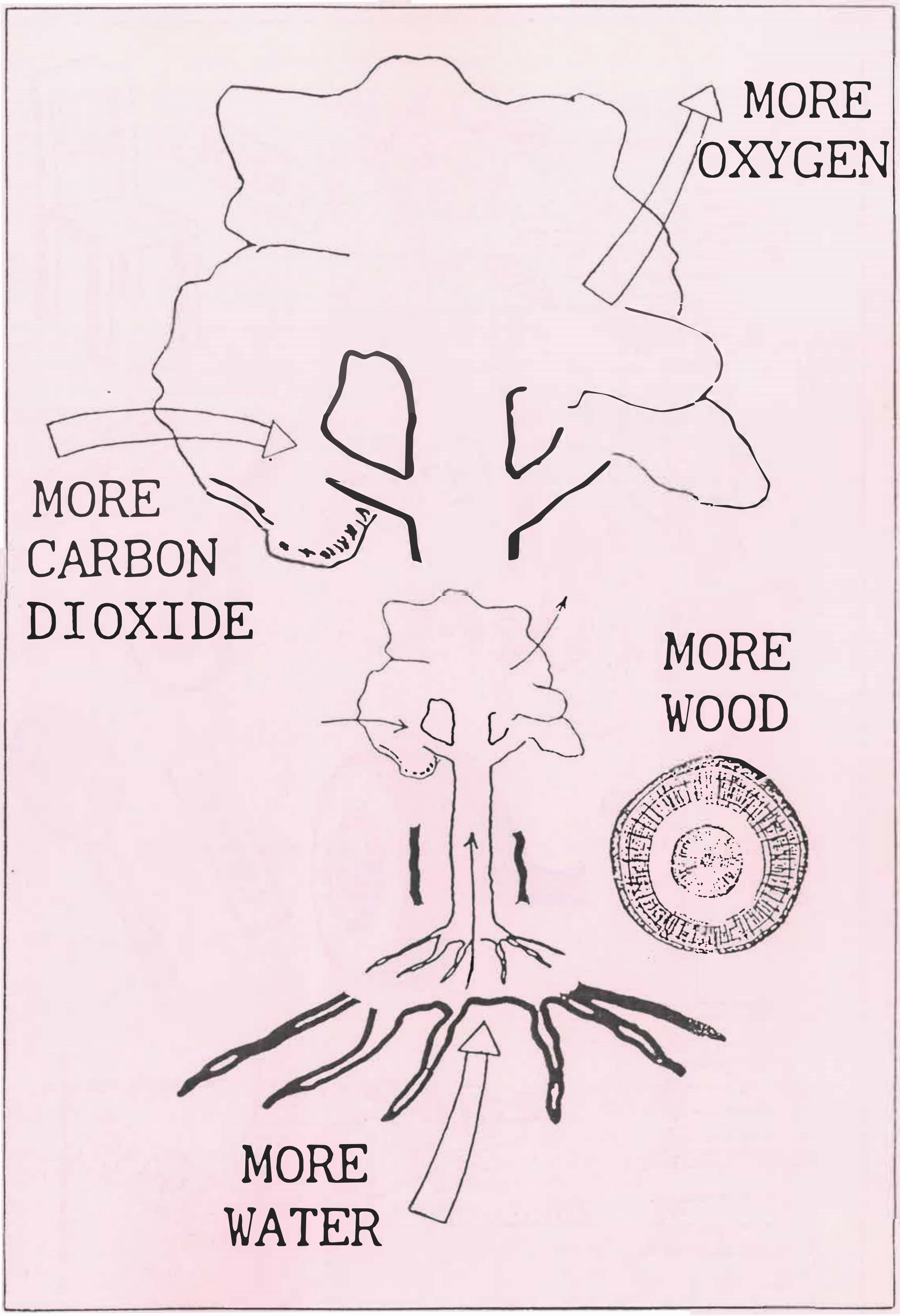
HOW MUCH OF THE MASS OF A PLANT

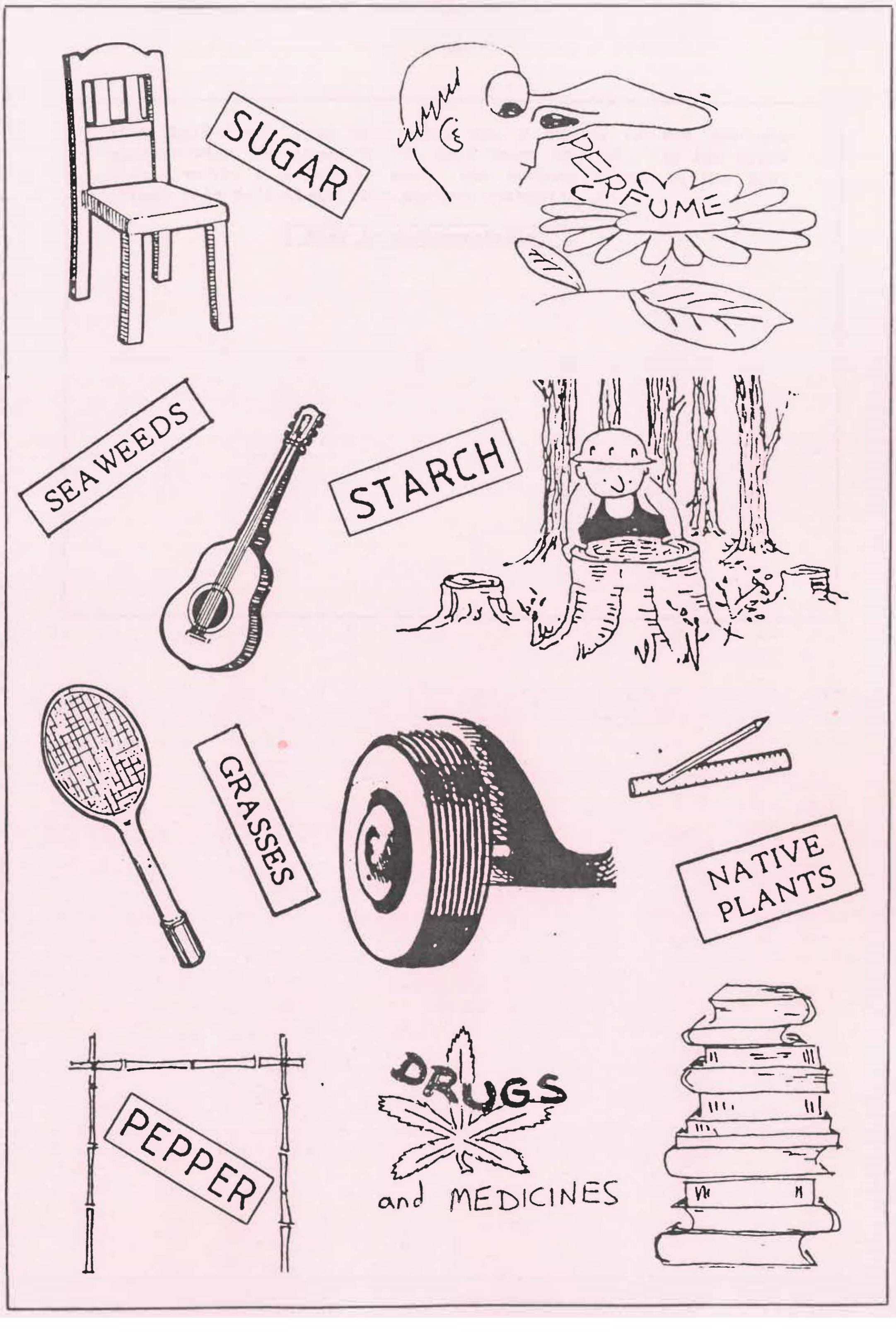
IS MINERALS?

SCIENTISTS SAY...




OXYGEN
CARBON
DIOXIDE
WOOD
WATER


MORE
OXYGEN
MORE
CARBON
DIOXIDE
MORE
WOOD
MORE
WATER


SUGAR
PERFUME
SEAWEEDS
STARCH
GRASSES
NATIVE PLANTS
PEPPER
DRUGS and MEDICINES

64

This **Self-Check** Item will give you a chance to see how you managed with the ideas in the Self-Teach Booklet. In the space below, write a paragraph about the subject given in the BOX. (Treat this Self-Check like another survey!)

What is photosynthesis?

THE APPLICATION PHASE :

AN OVERVIEW

Organisation

Student Activities: Nine Check Points	Group Size	Time Needed	Objectives For Each Student: Evaluating the new construction, photosynthesis, against ...
1. A Plant Puzzle (p.66)	Individuals, then discussion	1/2 period (or home-work)	...a variety of every-day situations ...prior views about plants (Survey 1).
2. Scientists Making Sense (p.68)	Individuals or group discussion	1/2 period (or home-work)	...views of earlier scientists ...some common views today.
3. Funny Factories (p.71)	Individuals or group discussion	1/2 period (or home-work)	...other familiar conversion processes which involve raw materials and products.
4. Case Re-opened (p.73)	Groups from Investi-gations	1/2 period	...constructions made previously while carrying out Investigations.
5. Watering The Plants? (p.74)	Pairs of students	1/2 period	...prior constructions about why plants need water.
6. Running Out (p.76)	Individuals, then discussion	1/2 periods	...alternative constructions about the place of minerals in plant growth.
7. What Van Helmont Didn't Know (p.78)	Groups of 2-3 students	1 1/2 periods	...the possibility that plant material is made from water only and not air.
8. It's Elem-entary (p.81)	Individuals, then discussion	1 Period (or home-work)	...prior knowledge about chemical elements.
9. Photosynthe-sisers (p.84)	Individuals, then discussion	1/2 period (or home-work)	...prior views about what are plants, as revealed in Survey 2.

Some Comments

1. You will need to decide how many Checkpoints, and in what order, each student should attempt. Not everyone need try all of them. Check points 7 and 8 assume some prior teaching about chemical elements.

2. Teacher's Notes about the Checkpoints are to be found on pages 85-88.

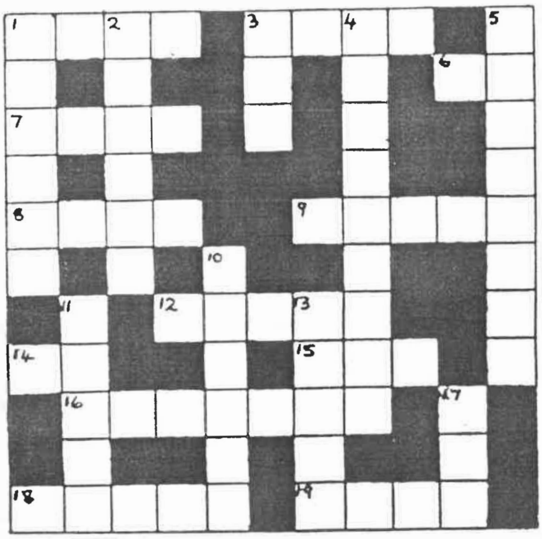
3. Hopefully, this Application Phase will continue for the rest of your students lives! However, you will need to judge the point at which major gains have been made and conclude the unit accordingly.

A PLANT PUZZLE

Checkpoint 1

You have now built up a new idea, photosynthesis, as an explanation for the question, "Where does the wood come from?" Doing this cross-word puzzle should help you check out this new idea with:

- other ideas you have about plants <u>now.</u>
- how you <u>used</u> to think about plants before you started this unit.



Across

1. In ______ weather, leaves fall and photosynthesis stops.
3. Photosynthesis results in more oxygen in the air and ______ carbon dioxide.
6. Pre-fix meaning "two". Occurs in the name of a well-known gas.
7. When we harvest wheat, we ______ the benefits of photosynthesis.
8. When the tiny holes on the surface of leaves are ______, they take in carbon dioxide from the air.
9. A table and ______, made from water and air? Photosynthesis is amazing!
12. Big photosynthesisers.
14. The gas which plants use to make wood is __ __ 2.
15. Where plants get carbon dioxide from.
16. Weather which provides rain-water which plant roots absorb.
18. The ______ weight of a plant includes all the liquid water in it.
19. It is the light rather than the ______ from the sun which drives photosynthesis.

Down

1. First name of the gas which plants use to make wood.
2. The factories of plants where sugar is made.
3. Word meaning "a large lump of wood" (made by photosynthesis!).
4. Word meaning "joining together".
5. Essential to plants but needed only in tiny amounts.
10. Photosynthesis gives rise to ______ rings in the wood of a tree trunk.
11. Chopping down a tree: Are we winner or ______?
13. Another word for "dirt" or "soil". Plants grown hydroponically don't have this.
17. When a log fire is ______, photosynthesis is reversed.

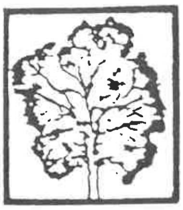
Checkpoint

Now let's check your answers here against those you gave in Survey 1 before you heard the scientists' view. In the table below are some pairs of questions to check. Do your answers on the two occasions agree or disagree with each other? Write "agree" or "disagree" in the right hand column of the table:

A Plant Puzzle	Survey 1	Agree/Disagree
8 Across	Question 16	
9 Across	Question 15	
1 Down	Question 4	
2 Down	Question 20	
5 Down	Question 5	
13 Down	Question 10	

SCIENTISTS MAKING SENSE

Checkpoint 2



> "... all living creatures became dependent on photosynthesis for food, air and protection from destructive radiation... Photosynthesis thus merits its distinction as the most important biochemical process on Earth."
>
> \- Daniel Arnon, 1982

We have been looking at how today's scientists like Daniel Arnon find photosynthesis a very important, useful, and sensible idea. But earlier scientists did not know about photosynthesis and they had other ideas about plants which seemed sensible to them. These earlier ideas sometimes seem sensible to people today, even though the ideas disagree with present-day scientists' ideas about photosynthesis.

Here are statements written by five earlier scientists. Completing the two sentences after each statement should help you become clearer that photosynthesis is a new idea for many people. (It might be worthwhile for you to go back and look at your answers to Surveys 3 and 4 again, before you start this Checkpoint. Remember that these were your ideas before you had learned about photosynthesis.)

1. "The leaf serves to shelter the fruit ... the roots of plants are similar to the mouths of animals, both serving for the absorption of food."

   \- Aristotle, about 335BC

Aristotle's idea could sound sensible to people today because _ _ _ _ _ _ _ _ _

_ _

_ _

_ _

Aristotle's idea disagrees with the modern view of photosynthesis because _ _ _

_ _

_ _

_ _

2. "The leaf serves as a mother to every branch and fruit by bringing them the water of the rains and the moisture of the dew that falls there at night from above, and it often takes from them the excessive heat from the sun's rays."

\- Leonardo da Vinci, about 1490

Leonardo's idea could sound sensible to people today because _ _ _ _ _ _ _ _ _

_ _

_ _

Leonardo's idea disagrees with the modern view of photosynthesis because _ _ _

_ _

_ _

3. "Tis agreed that all the following materials contribute in some manner to the growth of plants but 'tis disputed which of them really causes the growth, i.e. is its food: 1. Minerals; 2. Water; 3. Air; 4. Fire (i.e. heat from the sun); 5. Earth."

\- Jethro Tull, about 1735

Tull's idea could sound sensible to people today because _ _ _ _ _ _ _ _ _ _ _

_ _

_ _

Tull's idea disagrees with the modern view of photosynthesis because _ _ _ _ _

_ _

_ _

4. "Plants tend to keep the atmosphere sweet and wholesome, when it has become poisonous because of animals either living and breathing or dying and putrefying it."

\- Joseph Priestley, 1771

Priestley's idea could sound sensible to people today because _ _ _ _ _ _ _ _ _

_ _

_ _

Priestley's idea disagrees with the modern view of photosynthesis because _ _ _

_ _

_ _

5. "Plants have a breathing system corresponding to the lungs of land animals or to the gills of aquatic ones by which food is exposed to the influence of air. This is done by the leaves of plants or the petals of flowers, those in the air resembling lungs and those in the water resembling gills."

- Erasmus Darwin, 1800

Erasmus Darwin's idea <u>could</u> sound sensible to people today because _ _ _ _ _ _

_ _

_ _

Erasmus Darwin's idea disagrees with the modern view of photosynthesis because

_ _

_ _

_ _

<u>Checkpoint</u>

The five earlier scientists quoted here had colourful and varied lives. What else can you find out about them? Go to the library and look up their biographies. What you find should help you to fill out this table, selecting data from below.

Scientists	Dates	Country	Activities
Aristotle Leonardo da Vinci Jethro Tull Joseph Priestley Erasmus Darwin			

Data to choose from:

Dates: 1674-1741; 1733-1804; 1452-1519; 1731-1802; 384-322 BC

Country: England; Greece; England; Italy; England.

Activities: Agriculturalist, inventor of farm machinery
Artist and inventor
Philosopher and naturalist
Advanced our knowledge of gases in the air
Poet, grandfather of a famous biologist

Checkpoint 3

FUNNY FACTORIES

Why do people sometimes refer to the leaf as the "factory" of the plant? This Checkpoint should help you sort out how far you think it is sensible to think of a leaf as a factory.

A factory takes in raw materials and changes them into products, i.e. new materials which look very different from the raw materials. For example, a concrete block factory takes in sand, cement, and water as its raw materials and changes them into concrete blocks, which are the product.

In the scientists' view, leaves take in water and carbon dioxide as raw materials and change them into sugar and oxygen, the products. Some people think of this view as saying that leaves operate like a factory.

Which of these would you say operate like a factory and which do not, in this sense? Record your decisions in the table below:

> Oven; Hair drier; Supermarket; Shearing shed; Lawn-mower blade chamber; Toaster; Plant roots; Saw mill; Car engine, Freezing works; Computer; Bakery

Operates Like A Factory	Does Not Operate Like A Factory
Leaf	

For the ones which you think do operate like a factory, what are the raw materials and the products? Write your ideas in the table below:

Raw Materials	Factory	Products
Carbon dioxide, water →	Leaf →	Sugar, Oxygen
→	→	
→	→	
→	→	
→	→	
→	→	

Checkpoints

1. Can you think of two ways in which a leaf is NOT like a factory? Record your thoughts below:

   a. ____

   b. ____

2. Look back at how you answered Survey 1, question 20. What do you think now?

Checkpoint 4

CASE RE-OPENED

This Checkpoint gives you a chance to think and talk some more about your Investigation. Since then you have built up the idea of photosynthesis. Now you can go back and see how much your new idea helps explain what happened in your Investigation.

Review the key facts in your Investigation by completing the following:

1. The name of my Investigation was ____________________
2. The plants I used in the Investigation were ____________________
3. The total weight of new plant material from all the plants I grew was:

   ____

4. This total weight increase I am quoting is __________ (fresh/dry) weight.

A real mystery in the Investigation was "Where did the weight increase come from?" Our new information about photosynthesis may provide a solution to that mystery. We now know that plants use carbon dioxide and water to make sugar and oxygen. This occurs in the green parts of plants exposed to sunlight. Plants often change the sugar to wood (which accounts for weight increase) but photosynthesis is responsible for almost ALL the weight increase in all types of plants.

A Possible Reconstruction

In the box below, write a description of what happened in your Investigation but use the idea of photosynthesis to explain your observations, especially where the weight increase came from. (Hint: Use the seven underlined words in the paragraph above.)

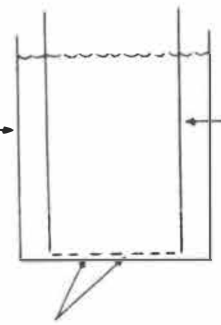
My Investigation:Where The Weight Increase Came From

Checkpoint 5

WATERING THE PLANTS?

How do we go about watering plants? What parts do we water? Why do we do it that way? Do we water the plant itself or its surroundings? In this exercise you will observe carefully how your partner waters a plant and then inverview her or him to see why they went about it that way, and whether or not they were using their new idea of photosynthesis.

Equipment



You will need:

1. Home-made watering can (at left).
2. Notebook and pencil.
3. Your partner's answers to questions 6, 9, and 17 in Survey 1, and Survey 3.

What To Do

1. Read your partner's survey answers.
2. Ask your partner simply to follow your instructions. Don't let on what you are trying to do.
3. Take your partner outside with the filled watering can and select a free-standing garden plant about 50 cm tall.
4. Ask your partner to thoroughly water the plant.
5. In your notebook record the following observations:
   (i) Which parts of the plant were watered.
   (ii) In what order the parts were watered.
   (iii) Where most of the water was used.
6. Now, back inside, interview your partner. Go over each of your observations and ask why she or he chose to water the plant that way. During the interview, form a theory about your partner's view on each of these two KEY QUESTIONS:

Where does a plant take in water?	Roots? Leaves? Roots and leaves?
Why does a plant need water?	Thirst? Cooling? Photosynthesis?

but don't put these key questions directly to your partner yet.

7. Finish the interview, and write down a conclusion to each of these sentences. (These are your theories about your partners views):

   a. My partner appears to think that a plant takes in water through _______

   ____

   b. My partner appears to think that plants need water for ____________

   ____

8. Now put each KEY QUESTION (see 6. above) to your partner.

9. Now decide how accurate your theories were by crossing out one of the two alternatives in each of these five questions:

   (i) My theory about my partner's view on the key question:

   | Where does a plant take in water? | turned out to be *correct/wrong*.

   (ii) My theory about my partner's view on the key question:

   | Why does a plant need water? | turned out to be *correct/wrong*.

   (iii) My partner's views about plants and water *have changed/have not changed* since completing Survey 3 two weeks ago.

   (iv) My partner *does/does not* hold the scientists' view that plants take in water through the roots only.

   (v) My partner *does/does not* hold the scientists' view that plants use water for photosynthesis (as well as for other plant processes).

Checkpoint 6

RUNNING OUT

You have found that only about 2% of the weight of a tree is minerals. And yet T.V. advertisements claim that minerals are essential for healthy plant growth! Reading these two stories, and thinking about how they are similar, should help you to sort this out for yourself.

Just An Excuse?

Craig, Geoff and Warwick were doing the dishes. Craig was washing, Geoff was drying, and Warwick was putting away. There was loads of hot water for Craig, lots of space in the pantry for Warwick, and they were certainly not going to run out of dirty dishes for a long while. But by half-way through they were experiencing intense frustration. Geoff's one tea towel was wringing wet so he couldn't dry any more dishes. Warwick, as a consequence, was out of a job, and there was no point in Craig's washing any more dishes because the dish-rack was full. Their worthy exercise had ground to a halt for lack of one dry tea-towel.

No Grow?

Alison Green was growing tomato plants in soil in pot plants in her sister's glass house. She watered them carefully each day and noted that each plant seemed to be getting enough sunlight and warm circulating air. And yet at the end of three weeks of this loving attention, Alison noted that many of the leaves were becoming depressingly streaked with yellow, and growth seemed to have stopped.

Alison decided to call in her sister June, who was an expert gardener, to look at her sorry plants. "I've given them loads of everything but something seems to be holding them back", said Alison.

June replied, "I'm pretty sure that adding mineral magnesium to the soil will set them growing again".

"Well, they will need a ton of magnesium, I'd say," said Alison. "They really do look sick."

"No", answered June. "You only need to add a tiny amount and then they will have enough of everything."

To Alison's delight, June's advice did the trick. After a week of the magnesium treatment there was nothing holding back the growth of the tomato plants and they were shooting up.

These two stories have a number of points in common. Can you see what they are? The table below picks out these points and it has been filled in for "Just An Excuse?" Can you do the same for "No Grow"?

Story	"Just an Excuse?"	"No Grow?"	
The Activity	Doing the dishes		
Bulk things that didn't run out	Hot water Dirty dishes Pantry space		
The one thing that did run out	Dry tea-towel		
The result	Doing the dishes stops		

Checkpoints

1. Think about "No Grow" and go back and check your answers to Survey 1, questions 5, 11 and 19. Do you still agree with your earlier answers?

2. Can you write a similar story, in which a process is held up because something needed in small amounts runs out? "Stapling Together The School Magazine" might be a good example. Then head up and fill in the last column in the table above using your own story.

Checkpoint 7

WHAT VAN HELMONT DIDN'T KNOW

Have you heard of the elements carbon, hydrogen, and oxygen? Van Helmont was a Dutch scientist who lived in the 17th century. He knew nothing of photosynthesis or the chemical elements. Van Helmont carried out an experiment from which he drew a conclusion about what plants are made of. In this Checkpoint you will carry out a similar experiment to Van Helmont's and you will find that he only had part of the answer.

Van Helmont's Experiment

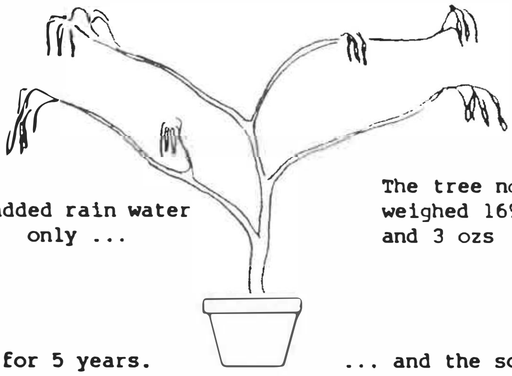
Here's what he did:

He planted a willow tree weighing 5 lbs ...

... in 200 lbs of soil.

He added rain water only ...

... for 5 years.



The tree now weighed 169 lbs and 3 ozs ...

... and the soil now weighed 199 lb 14 ozs.

Van Helmont's Conclusions

Try and put yourself in Van Helmont's place. How do you think he might have completed these sentences:

1. The total weight of new tree (i.e. the wood, bark, roots, etc.) which appeared over the five years was ______________________________

2. The only substance which was supplied to the plant during this time was ____________________

3. Therefore the plant's increase in weight appears to be entirely due to ____

Our Checkpoint Experiment

Part 1 : Getting Thinking

1. What is the chemical formula for water? ____________ What does this formula tell us? ____

2. What is the name for the black stuff present in burnt toast, tyres, and bitumen? ______________________________________

3. What is the ash made of which is left over when wood is all burnt away? ____________________ (Hint: Check page 80 if you really can't find out!)

Part 2 : Drying Out

Here's what to do:

1. Weigh out accurately about 10 grams of grass. This is called the fresh weight (F.W.) _ _ _ _ _ g.

2. Cut it up very finely with scissors and leave it on a tray on the window-sill for 2 days.

3. Describe what the grass looks like now: ____________________

____

4. Weigh the grass again. This is called the dry weight D.W.) _ _ _ _ _ g.

5. Find the weight loss (W.L.) W.L. = F.W. - D.W. _ _ _ _ _ g.

6. Write down the name of the substance which things lose when they dry out (easy!)______________________

7. Find the percentage weight loss $= \frac{W.L.}{F.W.} \times \frac{100}{1}$ = _ _ _ _ _%(W*)

8. Find the percentage dry weight $= \frac{D.W.}{F.W.} \times \frac{100}{1}$ = _ _ _ _ _%(X*)

9. Check that these two answers add to 100%!

Part 3 : Burning Off

Here's what to do:

1. Find the weight of an evaporating dish _ _ _ _ _ g.

2. Now put the dried out grass in it and heat with a bunsen burner.

3. After 2 minutes remove the bunsen and hold a glass flask full of water 3 cm above the evaporating dish for 10 seconds.

4. Write down what you see on the surface of the flask:

____

5. Complete this sentence: This suggests that dried out grass may still contain _______________ and _______________ (See Part 1, question 1). Burning is driving this off.

6. Write down what colour the grass is now: __________ . Look back at your answer in Part 1, question 2. Now write down the name of a substance which the burning grass might contain: _____________

7. Start heating again for another 15 minutes.

8. Now write down what the colour of the ash left in the evaporating dish is: _______________ .

9. Write down what the ash in the evaporating dish is: ______________________ (see Part 1, question 3).

10. Complete this sentence: This colour change suggests that burning dried out leaves drives off all the ____________ .

11. Now weigh the evaporating dish with the ash in it: _ _ _ _ _ g.

12. Find the weight of the ash (A), using Ans. 11 minus Ans. 1 _ _ _ _ _ g.

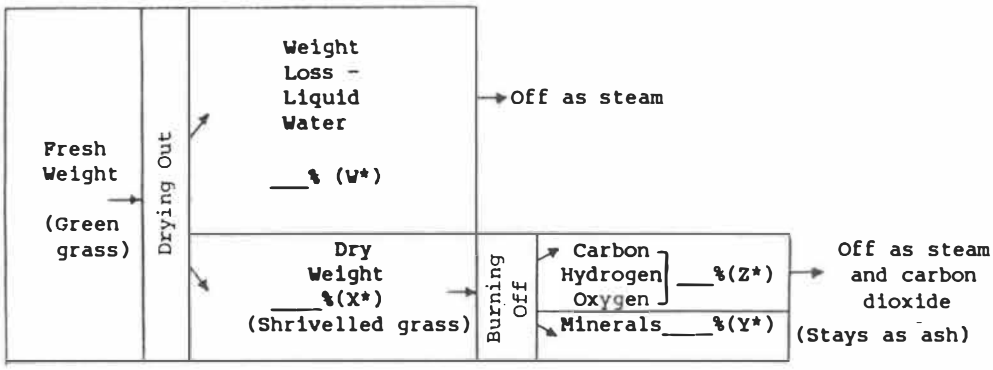
13. Find the percentage of the dry weight that was ash. $= \frac{A}{D.W.} \times \frac{100}{1}$ = _ _ _ _ _ %(Y*)

14. Take this percentage away from 100% to find the percentage of the dry weight that wasn't ash. _ _ _ _ _%(Z*)

15. Check that these two answers add to 100%!

Part 4 : More Thinking

This diagram summarises what has happened in this Checkpoint Experiment. Transfer the four percentages we have calculated onto the diagram. (The letters W, X, Y, and Z will help you.)



Our Conclusions

Van Helmont concluded that a plant's increase in weight appears to be due entirely to the water it takes in.

Our experiment suggests some things that Van Helmont didn't know. By drying a plant and burning it off we have shown that as well as water a plant also contains:

- a lot of black stuff called [ ] and
- a tiny amount of [ ].

Final Checkpoints

1. What does the plant get each of the things shown in the [boxes] from? ______________________________

2. Go back and read what you wrote in Survey 4 again. Does Van Helmont's theory disagree with yours? Do you still agree with what you wrote then?

Checkpoint 8

IT'S ELEMENTARY

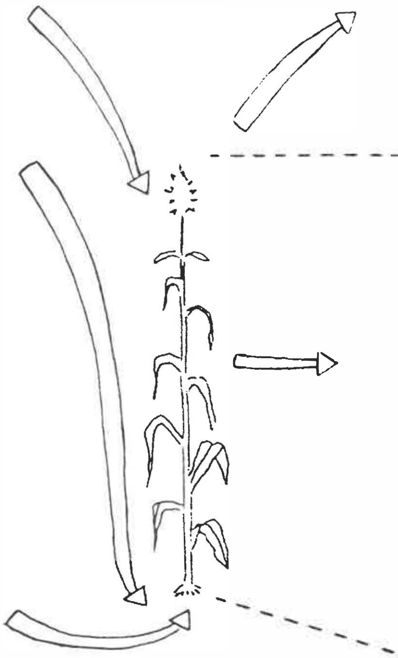
How much can you remember about atoms, chemical elements, and the periodic table? Do you realise that living things, like plants, are made up of chemical elements? It may be helpful in our understanding of photosynthesis to find out about the elements present in the things a plant takes in and the things it produces. Here are some typical data, for a maize plant:

THINGS TAKEN IN

Carbon dioxide Gas	
Elements present	%
C	27.0*
O	73.0

Water	
Elements present	%
H	11.0
O	89.0

Minerals - Elements
N
S
P
Ca
K
Mg
Fe
Mn
Si
Al
Cl
Other



THINGS PRODUCED

Oxygen Gas	
Element present	%
O	100.0

What the whole plant is made of

Elements Present	% **
C	43.6
O	44.4
H	6.2
N	1.5
S	0.2
P	0.2
Ca	0.2
K	0.9
Mg	0.2
Fe	0.1
Mn	0.1
Si	1.2
Al	0.1
Cl	0.2
Other	0.9

* These are percentages of the total weight, not the total volume.

** These are percentages of the total dry weight, after removal of water.

Could you make sense of that maize plant data? If so, you will find this Checkpoint a useful way of getting to know photosynthesis better. You will also see how your ideas about atoms and elements can be useful in explaining where the stuff in a plant comes from.

Checkpoint 8A

1. The data for the minerals which the plant takes in uses the SYMBOLS for the elements. What are the NAMES of the eleven minerals shown? ___________

____

2. Look at the data for the whole plant. Name the three elements present which are not minerals. __________ __________ __________

3. What percentage of the total weight of a plant do these non-mineral elements make up? __________%

4. So what percentage of the dry weight of the plant is minerals? __________%

5. What are the two most abundant minerals present in this plant? __________, __________

6. Think about the carbon in the whole plant data. Which of the things taken in by the plant did it come from? __________

7. Similarly for the hydrogen. Where did it come from? __________

8. The oxygen in the whole plant data could have come from which two things which the plant takes in? __________, __________

9. Where could the oxygen gas have come from which the plant gives off? __________

____

Checkpoint 8B

The chemical elements don't occur free in the whole plant, of course. They are combined into compounds. For example, the sugar in a plant is made up of carbon, hydrogen, and oxygen. Here are some data showing the percentages of compounds in four plants:

Compounds	Elements Present	Plants			
		Lucerne	Pasture	Pinus radiata	Maize (grain)
Sugars	C,H,O	9	14	-	3
Starch	C,H,O	-	1	-	70
Cellulose (and hemicellulose)	C,H,O	27	29	69	12
Complex carbohydrates e.g. pectin	C,H,O	13	4	28	2
Total carbohydrate	C,H,O	49	48	97	87
Total fat	C,H,O	-	-	-	-
Total protein	C,H,O,N	26	25	-	8
Total minerals (ash)	Si,K etc	10	13	2	1
Total other	-	15	14	1	4
		100	100	100	100

See if you can find out the answers to these questions:

1. Write down one major use for lucerne: ______

2. Name three particular plants which may be present in "pasture": ______ ______, ______, ______

3. What is the common name for "Pinus radiata"?______

4. All these data are based on dry weights, but data in one column was not obtained from whole plants. Which column? ______

5. Which type of compound contains the element nitrogen? ______

6. Which figure suggests where a good source of flour is to be found? ______ ______

7. Which figure is demonstrating the (rather well-known!) fact that a tree is mainly wood? ______

Checkpoint 8C

The process of photosynthesis is sometimes represented by a chemical equation. Because glucose is always formed in photosynthesis, regardless of what other compounds are produced later (e.g. cellulose, starch), glucose ($C_6H_{12}O_6$) is shown in the equation as one of the things formed:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Can you answer these questions?

1. Write down in one sentence what the equation is saying happens when photosynthesis occurs: ______ ______ ______

2. Write down three things which you find hard to understand about this equation:

(i) ______

(ii) ______

(iii) ______

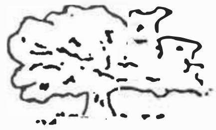
How can you find out the answers?

Checkpoint 9

PHOTOSYNTHESISERS

In this Checkpoint, try and answer the question "Where does photosynthesis occur?" in the way that a scientist would. Tick either the "Yes" box or the "No" box each time. [When you have finished, go back and check your answers to Survey 2. A scientist would have made the same choices on Checkpoint 9 as on Survey 2.]

Does photosynthesis occur in a cow?
Yes ☐ No ☐



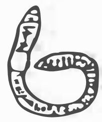
Does photosynthesis occur in an oak tree? Yes ☐ No ☐

Does photosynthesis occur in a fern?
Yes ☐ No ☐

Does photosynthesis occur in wheat? Yes ☐ No ☐

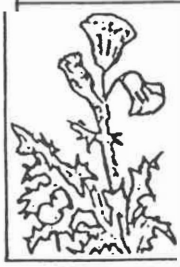
Does photosynthesis occur in a mushroom? Yes ☐ No ☐

Does photosynthesis occur in a fire?
Yes ☐ No ☐



Does photosynthesis occur in an earthworm? Yes ☐ No ☐

Does photosynthesis occur in a brown seaweed? Yes ☐ No ☐



Does photosynthesis occur in a thistle?
Yes ☐ No ☐

Does photosynthesis occur in a carrot?
Yes ☐ No ☐

TEACHER'S NOTES : CHECKPOINTS 1-9

Checkpoint 1 : A Plant Puzzle

Scientists' answers:

Across: 1. COLD 3. LESS 6. DI 7. REAP 8. OPEN 9. CHAIR 12. TREES 14. CO 15. AIR 16. SHOWERS 18. FRESH 19. HEAT.
Down: 1. CARBON 2. LEAVES 3. LOG 4. SYNTHESIS 5. MINERALS 10. GROWTH 11. LOSER 13. EARTH 17. LIT.

Checkpoint 2 : Scientists Making Sense

The sources of the quotations are as follows:

Arnon, D.I. (1982), Sunlight, earth life - the grand design of photo-synthesis. The Sciences, 22(7), page 22. (This valuable article also provided, on page 69, the quotation from Joseph Priestley.)

Aristotle (1952). De Anima, in Great Books Of The Western World, Volume 8, Aristotle:1. R.M. Hutchins, editor in chief. Chicago: Encyclopaedia Britannica Inc., page 642.

MacCurdy, E. (1956). The notebooks of Leonardo da Vinci, Volume 1 (2nd.ed.). London : Jonathon Cape, page 289.

Tull, J. (1751) Horse-hoeing husbandry or An Essay on the principles of vegetation and tillage (3rd ed.). London : Printed for A. Miller, page 14.

Darwin, E. (1800). Phytologia or The philosophy of agriculture and gardening. London : Printed for J. Johnson.

The quotations from Tull (1751), Priestley, and Darwin (1800) in Checkpoint 2 were slightly modified from the original.

Checkpoint 3 : Funny Factories

The items where the analogy with the operation of a factory appears to be most strong are: leaf, oven, toaster, car engine, bakery.

Students may give as reasons why a leaf is not like a factory; factories are mainly non-living machinery; factories are constructed by humans; most factories operate during the winter months, etc.

Checkpoint 5 : Watering The Plants?

Pairs of food cans of appropriately different size can be used in this exercise. A large number of very small holes pricked through the bottom of the inner can ensures a suitably long watering time.

Checkpoint 6 : Running Out

The activity in "No Grow" is growing tomato plants. Air, water, sunlight, and warmth are bulk things that didn't run out. Magnesium was the one thing that did run out. The result was that growth ceased.

This Checkpoint really provides a common-sense introduction to what appears in Form Six Biology courses as Liebig's "Law Of The Minimum", i.e. that the functioning of an organism is limited or controlled by whatever essential environmental factor is present in the least favourable amount.

Checkpoint 7 : What Van Helmont Didn't Know

Van Helmont's Conclusions

A good account of Van Helmont's work, and that of many other investigators since Aristotle in the field of plant nutrition, can be found in A.D. Krikorian's (1975) contribution to "Historical And Current Aspects Of Plant Physiology" edited by P.J. Davies (New York : Cornell University). Krikorian quotes Van Helmont as concluding "Therefore 164 pounds of Wood, Barks, and Roots, arose out of water only."

Our Checkpoint Experiment

Part 1 (answers): 1. H_2O. Contains hydrogen and oxygen 2. Carbon 3. Minerals

Part 2: See page 4 for comments about weighing. See below for results.

Part 3: Each group needs a tray (to catch any ash which spills), 100 ml evaporating dish, tripod, pipe-clay triangle.

Directing the bunsen down onto the grass will cause it to subside gradually into the bottom of the dish. Gentle blowing and careful use of a glass rod to stir may accelerate the process. Final strong heating from below will burn off black material sticking to the walls of the dish. Heating can conclude when a small irreducible white-gray granular mass of minerals remains.

Answers:

4. A mist forming on the flask. (This effect is enhanced if the flask is placed in the freezer for 10 minutes prior to use.)

5. Hydrogen and oxygen (N.B. In fact, the oxygen may have come either from the air during combustion, or have been in the dry matter all along.)

6. Black. Carbon 8. White-Grey 9. Minerals 10. Carbon 13. and 14. See below.

Part 4 - Results

The results below show the results obtained in five trials of this exercise:

Measurement	Checkpoint 7 question	Median results	Range of 5 trials
Fresh weight of grass, F.W.	Part 2, q.1	10.06 g	-
Dry weight of grass, D.W.	Part 2, q.4	2.15 g	-
Percent weight loss, W*	Part 2, q.7	78.0	78.7-77.6
Percent dry weight, X*	Part 2, q.8	22.0	21.3-22.4
Mass ash, A	Part 3, q.12	0.14 g	-
Percent minerals, Y*	Part 3, q.13	6.5	6.2- 8.4
Percent C,H,O, Z*	Part 3, q.14	93.5	93.8-91.6

Our Conclusions

As well as [water] (from the ground), a plant also contains a lot of black stuff called [carbon] (which it obtains from the air) and a tiny amount of [minerals] (from the soil).

Two final comments:

1) This Checkpoint is intended to stress the involvement of air as the key difference between Van Helmont's view and our own. You may like to consider whether or not, for your students, the introduction of qualitative tests (i.e. cobalt chloride paper for water and limewater for carbon dioxide) would highlight this key point.

2) I am much indebted to Mr F.L. Behrent of Melville High School, Hamilton, who provided the basic idea for this Checkpoint.

Checkpoint 8 : It's Elementary!

The data on the analysis of maize by elements used in this Checkpoint comes from "Plant Physiology" (2nd edition). Belmont, California : Wadsworth, by F.B. Salisbury and W.R. Cleon (1978), page 79. The data on analysis of four plants by compounds comes from work done at Ruakura Animal Research Station, Hamilton, by Vaughan et al. (1982). It is published in the Proceedings of the Fifth International Fuel Technology Symposium, University of Auckland.

The scientists' answers are: Checkpoint 8A:

1. Nitrogen, sulphur, phosphorus, calcium, potassium, magnesium, iron, manganese, silicon, aluminium, chlorine.

2. Carbon, hydrogen, oxygen.

3. 94.2% 4. 5.8% 5. Nitrogen, silicon 6. Carbon dioxide gas 7. Water 8. Carbon dioxide or water 9. Carbon dioxide or water or both.

Checkpoint 8B:

1. Fodder crop for cattle.

2. Rye-grass, paspallum, clover, etc.

3. Pine tree 4. Maize (grain) 5. Protein 6. Percentage starch in maize
7. Percentage cellulose in *Pinus radiata.*

Checkpoint 9 : Photosynthesisers

The scientists' response is to tick "yes" for:

Oak tree, fern, wheat, brown seaweed, thistle, carrot. Surveys show that students are most likely to give a non-scientists' response for mushroom and brown seaweed. Investigating conditions and requirements for commercial growth of mushrooms should be a useful approach to changing students' views. The brown pigment, fucoxanthin, in a seaweed like *Hormosira* (Venus's necklace) is soluble in water at 70°C. Immersion for 30 secs. dissolves out the brown pigment, showing that chlorophyll is present but is usually masked by brown pigment.

POSTSCRIPT

Two Final Comments

1. How adequate a view of photosynthesis has this unit provided?

It has addressed the key question, "Where does the stuff in a plant come from?" and it has sought to introduce the concept of photosynthesis in terms of the formation of the single most abundant product, wood. The unit has then broadened the perspective again by suggesting that photosynthesis explains where all the stuff in a plant comes from. This first look at photosynthesis, in terms of materials, can hopefully provide a basis for future understanding of:

(a) The energy component of photosynthesis (see Fig.1b, page 6) including the interactions between sunlight and chlorophyll.

(b) The food component of photosynthesis (see Fig.1c), i.e. the relevance of photosynthesis to food chains, consumers, respiration, etc.

(c) Further aspects of the material component, e.g. the biochemical mechanism of photosynthesis.

The nature of experimental controls, and some traditional chemical tests, e.g. the iodine test for starch have not been introduced to students in this unit.

2. Teaching and learning in science

This unit has adopted a model of learning which views the learner as an active constructer of meaning, and the learning process itself as one involving the generation of links between stored information already in the learner's head, and stimuli (which we can provide). If you have found this a fruitful way of thinking about what goes on in your classroom, you may be challenged to see whether this approach could be useful in other areas of your teaching.

Acknowledgements

I am much indebted to the late Dr Roger Osborne for his guidance and encouragement in the preparation of this unit, and in the research on which it is based, and to Professor Warwick Silvester and Dr Malcolm Carr for their helpful comments and practical suggestions.

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Idle reader, you can believe without any oath of mine that I would wish this book, as the child of my brain, to be the most beautiful, the liveliest and the cleverest imaginable. But I have been unable to transgress the order of nature, by which like gives birth to like.

(Miguel de Cervantes. The Prologue to Don Quixote.)

It took me years to learn to sit at my desk for more than two minutes at a time, to put up with the solitude and the terror of failure, and the godawful silence and the white paper.

(Erica Jong, 1974, Fear of Flying. Granada: London p.48)