The National Strategies
Secondary

Plant nutrition: from common sense to scientific views

Science teaching unit

department for
children, schools and families

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Plant nutrition: from common sense to scientific views

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Contents

Plant nutrition: from common sense to scientific views

Background

This teaching sequence is designed for Key Stage 3. It links to the Secondary National Strategy Framework for Science yearly learning objectives and provides coverage of parts of the QCA Programme of Study for Science. The overall aim of the sequence is for pupils to develop a simple and coherent understanding of plant nutrition, including the process of photosynthesis.

This aim is addressed through interactive teaching approaches where science ideas which are counter-intuitive are explored, made more plausible, and established through appropriate discussion between teacher and pupil;s and amongst pupils.

Teaching design principles

The design of this sequence is based upon a number of key principles. These are listed below:

Working on knowledge

The sequence involves:

- probing, and explicitly working from, pupils' existing ideas about food – what it is for, where it comes from and the differences between plant and animal nutrition;
- introducing a simple model of photosynthesis and making the implausible nature of the science explicit;
- demonstrating that:
  - gas does have mass;
  - a gas and a liquid can combine to form a solid;
  - carbon dioxide and water can combine chemically to produce a sugar (glucose);
  - oxygen is produced as a result;
- introducing the idea of the need for energy and locating the process in the leaves of plants;
- showing that the initial product (glucose) can be converted to other materials, and explaining how the products of plant nutrition are used for growth and respiration.

The first two lessons focus almost exclusively on the pupils' ideas, with the aim of making the implausibility of the science explicit. Lesson 3 is designed to make the implausible plausible and so make pupils more receptive to the science idea. Lessons 4 and 5 focus exclusively on the scientific explanation.

Teaching approach

The sequence involves:

- using diagnostic tasks and other AfL (Assessment for learning) activities to make explicit (and share) pupils' existing ideas about food;
- making explicit the counter-intuitive nature of the scientific explanation and making it more plausible;
- challenging the alternative (but superficially more plausible) conceptions;
- demonstrating that the scientific explanation might be more plausible than it looks – that the scientific concepts can be used to show how a plant produces the materials needed for growth and respiration;
- prompting pupils to reflect on their learning: revisiting and expanding on questions raised during the initial discussion; using 'thinking files' to record developing ideas, in a temporary form which can be easily revisited;
- expecting pupils to apply their developing knowledge (to show that the initial product – glucose – can be converted to other materials and to explain how these products are used).

Across the sequence of lessons, pupils' ideas develop through a series of small group and whole-class activities; it is probably more effective if pupils work in the same small groups throughout the topic. It is advisable to nominate a reliable person in each group to take responsibility for any communal materials that are produced and need to be stored in the thinking files.

Mode of interaction

The sequence has been designed to maximise pupils' learning by incorporating lots of interaction between the teacher and pupils. The sequence involves:

- using different modes of interaction between the teacher and pupils according to the different teaching aims;
- providing opportunities for pupil–pupil talk in pairs and small groups.

In the first two lessons the approach is entirely interactive and dialogic but there is an abrupt change in Lesson 3 and from this point the approach becomes authoritative.

Pupils' curriculum starting points

By the time pupils arrive at their science lessons in Key Stage 3, they will have experienced some teaching which relates to plant nutrition. Most pupils will know that:

- nutrition is one of the life processes in plants;
- light, air, water and temperature all have an effect on plant growth;

- water and minerals are taken in through the roots and transported to other parts of the plant;
- the leaf has an important role in producing material for plant growth;
- nearly all food chains start with a plant.

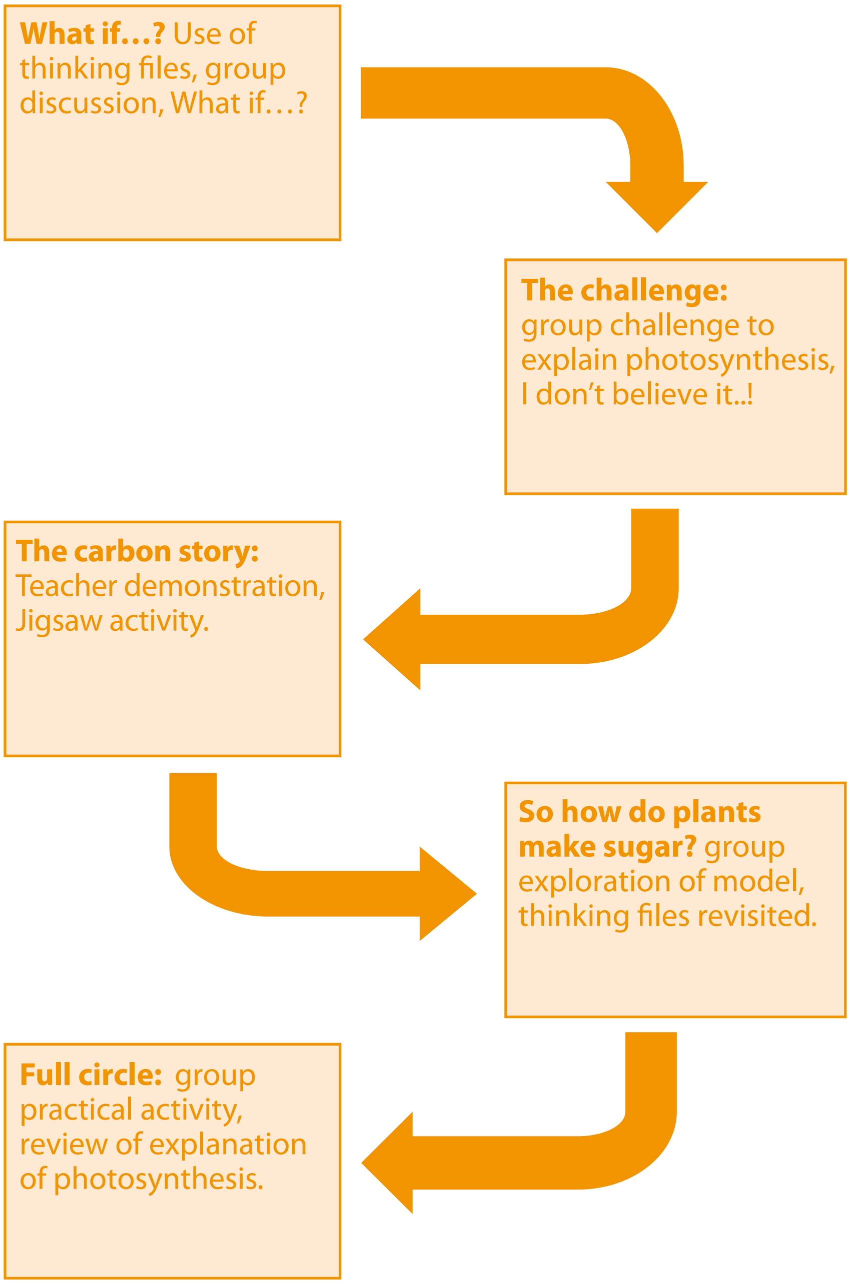
In addition, at Key Stage 3, they may already have experienced teaching about:

- plant cells, including chloroplasts and their function;
- human nutrition;
- respiration;
- elements and compounds;
- atoms and molecules;
- particle theory;
- conservation of mass.

They may also have encountered the idea that materials, even in living systems, are produced by chemical reactions.

What pupils will NOT have is a coherent scientific explanation of plant nutrition. More particularly, they will have difficulty understanding and accepting some of the basic scientific concepts on which this science explanation is based. The overall aim of this sequence of lessons is to show that the science explanation of plant nutrition is plausible, so that pupils are able to understand, accept and apply it.

Plant nutrition: Overview



Lesson 1: What if …?

Teaching 'story'

This first lesson is about getting the pupils to think about their own ideas of what food is for, where it comes from and the differences between plant and animal nutrition. The aim is to make explicit the pupils' conceptions about food and plants before introducing any science ideas, and the focus throughout the lesson remains firmly on pupils' ideas. The teacher's role in this lesson is to encourage the pupils to express their own ideas and to justify these in discussion with other pupils. It is important for the teacher to listen to, and take note of, these ideas as subsequent teaching will be built around them.

Activity 1.1: What if...?

The purpose of this activity is to encourage pupils to articulate their own views about plant nutrition. This is likely to include ideas such as plants getting food from the soil and plants making food 'out of sunlight'. This activity also acts as a primer for the ideas that are developed later in the lesson.

Teaching objectives

- Actively to encourage pupils to think about how plants grow (what plants need for growth).
- To encourage pupils to start making their thinking explicit – to explain their thinking.
- To listen and take note of pupils' ideas so that subsequent teaching can be informed by them.
- To help pupils recognise that there are a range of different views about plant nutrition within their classroom – that there is a problem here to be resolved.

Learning outcomes

By the end of this activity, most pupils will be able to:

- recognise that there is a diversity of ideas amongst the pupils about how plants feed and grow;
- articulate their own ideas and give reasons for these.

What to prepare

- One copy of the three activity cards (1.1a – 1.1c) per group (or three of each, set up as a circus).
- Props to accompany each of these activity cards (see technician's notes, page 12).
- A 'thinking file' and loose paper for each pupil.

Note: 'Thinking files' are personalised A4 envelopes or cardboard wallets in which each pupil stores tentative ideas and reflections which they will revisit and reconsider as they move through the teaching sequence; best to collect these in at the end of each lesson (unless needed for homework) to ensure that they are always available when needed.

Mode of interaction

Small group discussion
Groups of 3–4 pupils discuss the questions before recording their ideas individually. The teacher encourages them to explain or justify their thinking.
INTERACTIVE/ DIALOGIC.

DIALOGIC HOTSPOT

What happens during this activity

Each pupil receives a 'thinking file' and the purpose of this is explained – to allow pupils to record their developing ideas in a way they can revisit and revise during the topic. The benefits of the file are emphasised: that it doesn't matter if the ideas they record initially turn out not to be correct, as they will have opportunities to record the changes in their thinking as they work; that they will be able to see how their thinking has progressed through the lessons.

Working in small groups of 3–4, pupils discuss each of the three 'What if …?' scenarios before recording their individual thoughts in their thinking files. During group discussions, and when pupils are recording their ideas, the teacher encourages pupils to explain or justify their thinking.

The term 'What if…?' has been used to avoid the word 'prediction' and associations with assessed SC1 investigations. It is important in this lesson to get pupils to talk about their ideas without leading them. Some pupils may need encouragement to express their own ideas if these are different from those of their friends and/or they think there is a different scientific answer.

Activity 1.2: Bringing pupils' ideas out into the open

Teaching 'story'

Having encouraged pupils to start thinking about plants and what plants might need for growth, a brainstorming session is used to bring their ideas about food and nutrition out into the open so that they become 'public' and are shared. Working in small groups, pupils are encouraged to distinguish between the purposes of nutrition (respiration and growth; common to plants and animals) and sources of food (external, digested vs internal, synthesised).

Teaching objectives

- To make the range of pupils' existing ideas explicit.
- To distinguish between the function of food (to provide materials for growth and respiration) and the source of these materials (external, digested vs internal, synthesised).

Learning outcomes

By the end of this activity, most pupils will be able to:

- recognise that there are conflicting ideas about food and nutrition and that these need to be resolved;
- distinguish between the function of food and the source of food.

Some pupils will be able to:

- recognise that both plants and animals need food for growth and respiration;
- recognise that plants and animals get their food in different ways.

What to prepare

- Flip chart and pens or interactive whiteboard
- One worksheet 'Purposes of food' per group.

Mode of interaction

The focus remains firmly on the pupils' ideas. The teacher's role is to co–ordinate and summarise these and to continue to encourage pupils to give reasons for their views. Although pupils are beginning to make distinctions, which will support the development of the scientific ideas, the approach is DIALOGIC and INTERACTIVE.

DIALOGIC HOTSPOT

What happens during this activity

The teacher coordinates a whole-class brainstorming session, recording the pupils' responses to the following questions on a flip chart or interactive whiteboard.

- What is food for?
- Where do animals get their food from?
- Where do plants get their food from?

During this brainstorming session, the idea that food is important both for energy (respiration) and growth needs to be considered. If necessary, ask pupils additional questions such as 'What happens if you eat too much or too little food?' or 'How do energy drinks work?'. The aim is to open up pupils' thinking, getting as many of their ideas as possible into the public domain, without (at this point) leading them towards the science view or closing down alternative views.

At the end of the brainstorming session, pupils return to their small groups to consider the class responses to the question 'What is food for?'. The aim is to identify those purposes which are important for animals and those which are important for plants, and to record these on the worksheet, which is then stored in one of the thinking files.

Activity 1.3: 'What if… ?' scenarios revisited

Teaching 'story'

In this activity the focus is specifically on plant nutrition. Pupils review their individual responses to the 'What if…?' scenarios in light of the range of ideas discussed during Activity 1.2 and the lesson is brought to a close with a review of ideas about how plants get their food.

Teaching objectives

- To allow pupils to reflect on the range of ideas about nutrition that has emerged during the previous activities.
- To allow pupils to review their responses to the 'What if…?' scenarios in light of these.
- To review and summarise class views on how plants get their food.
- To recap the purpose of this lesson.

Learning outcomes

By the end of this activity, most pupils will be able to:

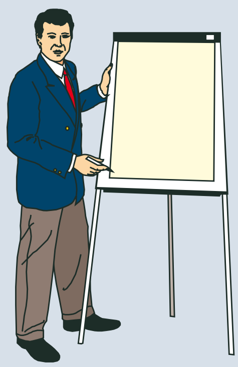
- reflect on the range of views expressed by the class as a whole and recognise that they cannot all be correct;
- consider the implications of the conflicting views for their personal view.

What to prepare

- Flip chart or pens or interactive whiteboard.

Mode of interaction

Pupils reflect on and review their own understanding. The teacher summarises the pupils' final views on how plants get their food and although the approach changes from NON- INTERACTIVE to INTERACTIVE, it remains DIALOGIC to the end.



What happens during this activity

Pupils are asked to review their initial responses to the 'What if…?' scenarios and to change any predictions or explanations they no longer think are correct.

Working with the whole class the teacher then elicits and records their final views on how plants get their food. These should be accepted and recorded uncritically and will be reconsidered during the next lesson.

The lesson ends with a recap of the main aim for this lesson – to explore the pupils' ideas about food:

- where it comes from;
- what it is for;
- the differences (and similarities) between plant and animal nutrition.

In preparing pupils for the next lesson make clear that they will be introduced to, and have a chance to challenge, some of the science ideas about plant nutrition.

Don't forget to collect in the thinking files.

Note: The end of this lesson is very open and this can feel very uncomfortable – both for the teacher who, by this point, may be desperate to correct misconceptions and to present the scientific explanation, and for the pupils who are tired of all this thinking and just want to be told the right answer. Do not give in to temptation! The teaching approach is based on encouraging pupils to challenge both their own ideas and the science ideas. Although it feels uncomfortable at this stage, teachers who have tried this approach note that when you do present the full scientific explanation (Lesson 4) pupils are ready to accept it.

1.1a: What if…?

Sally and Suvinder are growing two squares of turf.

One of the squares is growing in **direct sunlight**.

The other is growing in the **shade**.

The girls are taking care to make sure everything else is the same for both pieces of turf.

After two weeks, which square of turf will have grown the most?

How could you explain your thinking to Sally and Suvinder?

1.1b: What if…?

Ryan is trying to grow cuttings from a plant.

He has put the cuttings in sealed flasks of water on a sunny windowsill.

His friend Richard says:

'They won't grow in just water, silly!'

Who do you think is right?

How might you convince Ryan and Richard that your opinion is correct?

1.1c: What if…?

Tracey and Tim are doing an experiment on pondweed.

They have set up two jars containing water and pondweed and put the jars in a sunny place.

Twice a day Tracey and **Tim breathe** out into the same jar. The other jar is left alone.

Tracey and Tim have discussed what will happen in the jars.

What do you think will happen?

How would you explain your idea to Tracey and Tim?

1.1: Technician's notes

There is a set of props to accompany each activity card:

- activity card 1.1.a needs a square of turf;
- activity card 1.1b needs a plant cutting (eg tradescantia) sealed in a flask of water;
- activity card 1.1c needs a sealed jar of pond weed to which air can be added.

1.2: Purposes of food

a) Important for plants

Purpose:	Important for plants because…

b) Important for animals

Purpose:	Important for animals because…

* add as many lines as you need

Lesson 2: The challenge

Teaching 'story'

This second lesson presents a simple explanation of photosynthesis, in which a chemical reaction involving carbon dioxide and water results in production of a sugar, and encourages pupils to makes explicit the parts of this model which are implausible to them. The intention is to make them receptive to the ideas demonstrated in Lesson 3.

Activity 2.1: Where does the sugar come from?

The purpose of this activity is to develop the idea that sugar is made by plants and to open up the question – How do plants do this?

Teaching objectives

- To challenge the pupils' thinking about where sugar comes from.

Learning outcomes

By the end of this activity, most pupils will be able to:

- accept that sugar comes from plants.

What to prepare

- A selection of sugary foods for pupils to taste (for example maple syrup, sugar cane, sugar lumps, honey, sweet fruits, chocolate, other sweets);
- The thinking files.

What happens during this activity

Working in their groups, pupils are presented with a selection of sweet foods and asked 'Where does the sugar come from?'. Their ideas are recorded in their thinking files.

Through whole-class discussion, explore and challenge pupils' responses to show that, in each case, plants are the origin of the sweetness:

- sugar: refined from the stems of sugar cane or sugar beet plants;
- honey: produced by bees from nectar/pollen collected from flowers;
- fruit: sweet tasting growth containing seeds;
- maple syrup: refined from the sap of maple trees.

Note that the sweetness in all sugary food comes from plants. Some pupils may be reluctant to accept this. Set them a homework challenge – to find a source of sugar that does not come from plants.

Mode of interaction

Initially pupils work in groups to explore their own ideas INTERACTIVE/ DIALOGIC, but in the whole class discussion the teacher is working towards the scientific view INTERACTIVE/ AUTHORITATIVE.

DIALOGIC HOTSPOT

Activity 2.2: How do plants get the sugar?

Teaching 'story'

The next activity raises the question of how plants get the sugar. Pupils' own ideas are summarised and a simple scientific explanation is presented. The purpose is to present this explanation of plant nutrition in a way that encourages the pupils to be open about the aspects of the model which they find implausible. The roles of energy and chlorophyll are deliberately omitted during this lesson.

Teaching objectives

To present a range of views on how plants get the sugar:

- to summarise the pupils' views, based on their ideas of plant nutrition from lesson 1;
- to present a simple scientific explanation of plant nutrition in a way that encourages pupils to be open about its implausibility.

Learning outcomes

By the end of this activity, most pupils will be able to:

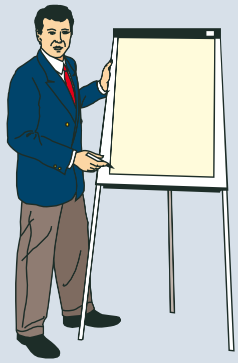
- identify a range of alternative explanations of how plants get the sugar;
- recognise that these different explanations are not compatible and that most, including the scientific explanation, are implausible in some way.

What to prepare

- The record of pupils' views on how plants get their food from activity 1.3 (flip chart paper or interactive whiteboard).

Mode of interaction

Although this activity is predominantly teacher led and NON-INTERACTIVE, pupils' views from the previous lesson are reviewed and the science content is presented in a way which invites criticism (for now, it has the same status as the pupils' ideas) and so the approach is DIALOGIC.



What happens during this activity

Activity 2.1 gives rise to the question: 'Where do plants get the sugar from?'. The teacher suggests that pupils' views about how plants get their food, recorded in the last lesson (activity 1.3) might help to answer this.

Working from a display of these responses the teacher identifies and summarises those ideas which the class now thinks could explain where plants get the sugar from. Assuming that no pupil has presented the scientific view (see note below), tentatively note that there is a scientific answer to the question and go on to explain this, in a doubtful and incredulous manner:

- sugar is produced by a chemical reaction which takes place inside plants;
- during this reaction carbon dioxide (a gas) and water (definitely not sweet) combine to produce sugar (very sweet).

The way in which this explanation is presented is very important. The aim is to encourage pupils to question the mechanism seriously, in a way that makes explicit the difficulties that they have with this model.

Note: Some pupils may suggest 'photosynthesis'. If so, challenge them to explain what they mean by 'photosynthesis' (most will be unfamiliar with anything but the word). This can provide a convenient opening to present the scientific explanation. If a pupil does show a deeper understanding of photosynthesis, the key points can still be presented as a summary of the pupil's ideas ('the key points that we need to consider for now are …'). Some pupils may be aware that energy (or chlorophyll) is needed for the process. Agree that this is the case, but that for now you would like to focus on the basic explanation, you will be returning to these features in a later lesson.

Activity 2.3: 'I don't believe it!'

Teaching 'story'

The scientific model of plant nutrition is counter-intuitive and implausible for most Key Stage 3 pupils. It requires an understanding of broader scientific principles (that gas has mass; that mass is conserved) and a recognition and acceptance that chemical reactions can take place within living organisms. In this final part of the lesson pupils are encouraged to evaluate critically the scientific explanation of how plants get their sugar and to make explicit the difficulties they have with this model. These difficulties are addressed in Lesson 3.

Teaching objective

- To encourage pupils to evaluate critically the simple scientific model of how plants get their sugar.
- To make the pupils' specific difficulties with this model explicit.

Learning outcomes

By the end of this activity, most pupils will be able to:

- present the simple scientific explanation;
- identify the reasons why they find this model difficult to accept.

What to prepare

- One copy of the worksheet ('I don't believe it!') per group.

Mode of interaction

Pupils work in groups to identify those aspects of the scientific model which they find difficult to accept. A teacher led class feedback is used to summarise these in preparation for Lesson 3: INTERACTIVE/DIALOGIC.

DIALOGIC HOTSPOT

What happens during this activity

Working in their groups, pupils read the 'I don't believe it!' worksheet, discuss each of the 'I don't believe it!' statements and record the extent to which they agree or disagree with each of these, giving their reasons.

A whole class feedback, in which each statement is considered in turn, makes the pupils' own difficulties with the scientific model explicit. These will be addressed in Lesson 3 in a way that aims to make the scientific model plausible after all.

Activity 2.4: Homework challenge

Give a reminder of the homework challenge – to find a source of sugar that is not a plant.

'I don't believe it!'

A group of pupils in Miss Smith's class are discussing their teacher's explanation of where plants get their sugar from. She has told her class that plants get their sugar from a chemical reaction which takes place in cells. This chemical reaction uses carbon dioxide and water to make sugar.

Some of their responses are given below. For each response decide if you agree or disagree, and say why you think this.

Response	We think …..
Rohit says: *'This explanation surprises me. I thought plants got their food from the soil.'*	Agree Disagree Can't agree! Because……
Fiona says: *'If chemical reactions are supposed to happen in plant cells, why don't plants get hot and blow up? I don't believe chemical reactions happen in cells.'*	Agree Disagree Can't agree! Because……
Anthony says: *'I find the teacher's explanation very hard to believe because carbon dioxide is a gas and water is a liquid. I don't see how sugar can be made out of carbon dioxide and water.'*	Agree Disagree Can't agree! Because……

Lesson 3: The carbon story

Teaching 'story'

Having encouraged pupils to make their concerns and doubts explicit, this lesson presents activities designed to make these implausible science ideas more plausible. In this way, pupils are made more ready to accept the scientific model of plant nutrition, which is presented in Lessons 4 and 5. The first activity addresses the question 'Can a gas have mass?'

Be aware that you will need about half the lesson for the jigsaw activity (3.3).

Activity 3.1: Heavy gas

This activity aims to address the pupils' difficulty in accepting that gas has mass.

Teaching objective

- To demonstrate that carbon dioxide gas does have mass.

Learning outcomes

By the end of this activity, most pupils will be able to:

- accept that carbon dioxide gas can have mass.

What to prepare

- Balances.
- Balloons which have been blown up once (so that they will inflate more easily in the classroom) and a means of producing carbon dioxide.
- Bottles of cola.
- Copies of the worksheet ('Does carbon dioxide gas have mass?').

Mode of interaction

This activity is designed to make the scientific idea plausible and so the approach is AUTHORITATIVE. Depending on how it is presented (as a demonstration or as small group work) it will be INTERACTIVE or NON-INTERACTIVE.

What happens in this activity

Remind pupils that there were some doubts about the potential for a gas (carbon dioxide) to produce a solid (sugar). One reason for this view was that gas has no mass. Explain that we can test this idea using the two experiments below.

On completion of these experiments, review the outcomes and note that not only does carbon dioxide gas have mass but even a small quantity of it appears to be quite heavy.

Note: These experiments will be more effective if undertaken in small groups but could be conducted as class demonstrations, with individual pupils being asked to read the measurements, record these on the board and complete the calculations (an opportunity to practise numeracy). One or both experiments could be used depending on the particular class and the time available (you need to leave sufficient time for completion of the atomic jigsaw). Both experiments will demonstrate effectively that gas has mass. Experiment 2 is more fun perhaps but because mass is lost rather than gained, it results in a slightly more complicated calculation.

Experiment 1

In this experiment a balloon is weighed, filled with carbon dioxide and weighed again. The mass of the empty balloon and the mass of the balloon filled with carbon dioxide gas are recorded on the worksheet; the increase in mass due to the addition of carbon dioxide gas is then calculated. Pupils may be reluctant to believe this evidence at first and it would be sensible to repeat the experiment 2–3 times.

Experiment 2

In the second experiment a bottle of cola is opened, some of the drink poured out (or drunk!) and the lid screwed back on. The partially empty bottle is weighed and the mass recorded on the worksheet. The bottle is shaken vigorously, the lid opened to release the 'fizz' (the carbon dioxide gas) and resealed and the bottle weighed. Again the mass recorded. The decrease in mass due to loss of carbon dioxide gas is calculated. Again, it is sensible to repeat this experiment 2–3 times.

Activity 3.2: From gas to solid

Teaching 'story'

This second activity demonstrates that a gas plus a liquid can result in a solid. This addresses pupils' reluctance to accept that carbon dioxide and water can react to form a solid (sugar).

Teaching objectives

- To demonstrate that it is possible for a gas and a liquid to react to form a solid.

Learning outcomes

By the end of this activity, most pupils will be able to:

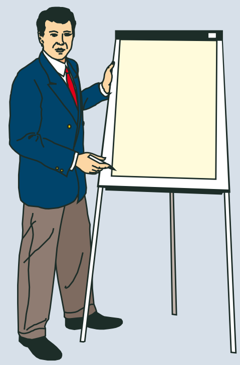
- accept that carbon dioxide and water could react to form a solid (sugar).

What to prepare

- A source of carbon dioxide gas (preferably a gas cylinder)
- Lime water
- A centrifuge (if possible).

Mode of interaction

The teacher demonstrates that when a gas is combined with a liquid, they can react to produce a solid: NON-INTERACTIVE/ AUTHORITATIVE



What happens during this activity

For some pupils, the idea that a liquid and a gas can result in a solid is counter-intuitive and unlikely. Explain that we can find out whether or not it is possible by mixing a gas and a liquid and seeing what happens. Bubble carbon dioxide through lime water and centrifuge the resulting suspension to show that a solid is produced.

Note: Any invisible gas and colourless liquid, which react to form a solid, could be used for this demonstration. Carbon dioxide and lime water are suggested because they are commonly available in school science laboratories, not because carbon dioxide is important in plant nutrition. To avoid mixed messages, or getting side-tracked into details of the chemical reaction and away from the key point (that it is possible for an invisible gas and a colourless liquid to produce a visible solid), it is best not to name the gas or the liquid.

Activity 3.3: An atomic jigsaw!

Teaching 'story'

The final activity in this lesson demonstrates how a chemical reaction between carbon dioxide and water can result in the production of a sugar. It also demonstrates that there is something left over from this reaction (oxygen) thus helping to prepare pupils for Lesson 4, when the full explanation of photosynthesis will be presented.

Teaching objective

- To show that the atoms that make up water and carbon dioxide can be rearranged to make a sugar (glucose).
- To demonstrate that when they do this there is something left over.

Learning outcomes

By the end of this activity, most pupils will be able to:

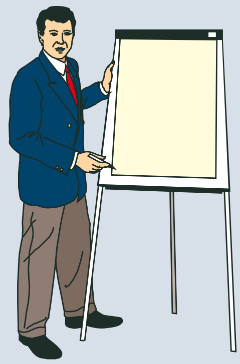
- show how carbon dioxide and water can combine to produce glucose;
- recognise that when this happens, there is something (oxygen) left over.

What to prepare

- A copy of the jigsaw and the instruction sheet per pupil.
- Scissors, glue and a blank sheet of paper per pupil.
- Thinking files.

Mode of interaction

Working individually, pupils use the jigsaw activity to assemble an accurate diagram of a glucose molecule as illustrated in the handout: NON-INTERACTIVE/ AUTHORITATIVE.



What happens during this activity

This activity is designed to show that if carbon dioxide and water react together they can produce a sugar (glucose). The success of this activity depends very much on the way in which it is presented. This will vary to some extent depending on the prior knowledge and/or ability of the pupils.

Give out the worksheets but before allowing anyone to start, provide an explanation of the task that is appropriate to the pupil group. This should include:

- a reminder of the scientific explanation for how plants get their sugar: that carbon dioxide and water react together inside the plant to produce a sugar;
- identification of the carbon dioxide, water and sugar (glucose) molecules on the worksheets;
- noting that the diagram of the sugar molecule is there to help them – like the picture on the lid of a jigsaw; what they will be working with are the carbon dioxide and water molecules;
- noting that the sugar molecule is quite large so that several molecules of water and carbon dioxide are needed to make one sugar molecule – they have exactly the number that they need to make one sugar molecule;
- a reminder that water is made up of hydrogen and oxygen (atoms) and that carbon dioxide is made up of carbon and oxygen (atoms); identification of these atoms on the jigsaw molecules.

The task can then be introduced:

- cut up the water and carbon dioxide (molecules) into their basic parts (atoms) – hydrogen, oxygen and carbon;
- reassemble these elements/atoms into the sugar molecule using the illustration as a guide and stick this onto the blank sheet of paper;
- check – is there anything left over? If so, what? (Make a note of this)

Store the completed jigsaw, plus anything that is left over, in the thinking file ready for next lesson.

Note: Most pupil groups, even mixed-ability Year 7s, can manage this activity if given enough time. The amount of time that is needed can be reduced by showing pupils the un-cut worksheet during the explanation but providing them with ready cut versions for making the jigsaw (remember to include all of the atoms, including the spare oxygen atoms). Working in small groups rather than individually will encourage greater pupil–pupil dialogue, enhance their learning, and provide more support for less confident pupils (who may not actually complete the jigsaw).

Activity 3.4: Review

The lesson finishes with a review of the activities and a reflection on the implications of these, that perhaps the scientific model of plant nutrition is plausible after all.

The following website which provides an animation of the reaction, accompanied by a poem, could be used to consolidate the lesson: (select 'Atomic Shuffle')

www.pbs.org/wgbh/nova/methuselah/phot_flash.html

The jigsaw activity was based on the standard equation for photosynthesis and used just six molecules of water but the animation starts the process with 12 molecules of water to show that all the oxygen comes from the water and none from the carbon dioxide. This could provide an opportunity for some very valuable discussions about the roles of carbon dioxide and water in the process.

Does carbon dioxide have mass?

Experiment 1: Carbon dioxide is added to a balloon

Mass of balloon (g) (M1)	Mass of balloon + carbon dioxide gas (g) (M2)	Mass of carbon dioxide gas (g) (M2 – M1)

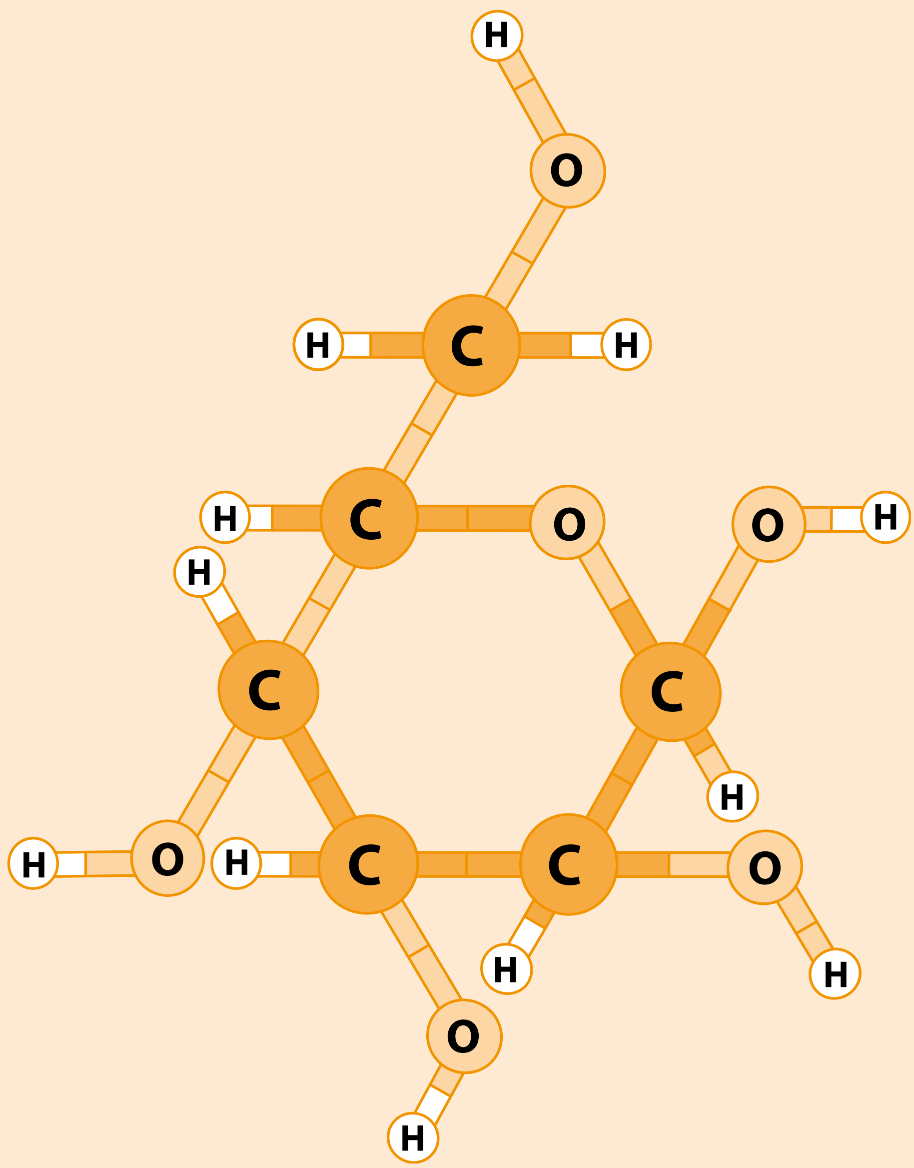
Experiment 2: Carbon dioxide is shaken out of the bottle of cola

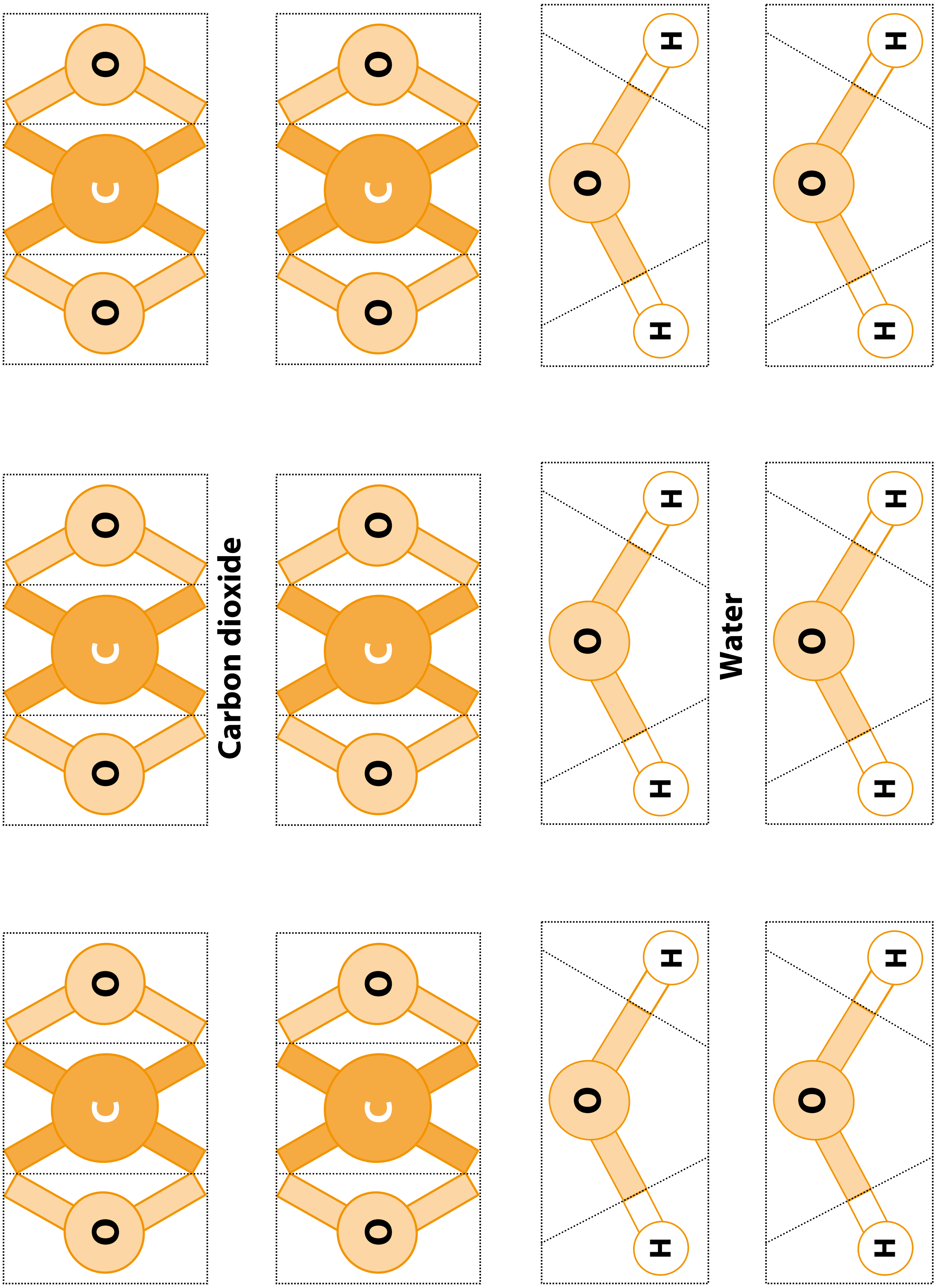
Mass of cola filled bottle (g) (M1)	Mass of cola filled bottle after carbon dioxide gas is released (g) (M2)	Mass of carbon dioxide gas (g) (M1 – M2)

The atomic jigsaw

Instructions

1. Cut out each of the water and carbon dioxide molecules from sheet 2.
2. Cut up each molecule into its separate atoms along the dotted lines to give you the atomic jigsaw pieces you need.
3. The picture opposite is a model of a sugar molecule from the atomic jigsaw pieces you have cut out.
4. If you are successful at making a sugar molecule, stick the pieces on one piece of plain paper. **Keep any left over bits in your thinking file!**




Carbon dioxide
Water
O
C
H

Lesson 4: So how do plants make sugar?

Teaching 'story'

In this lesson the scientific model of plant nutrition is established as the most plausible way to explain how plants make sugar. The explanation is extended to include energy, the role of chlorophyll and that the process is located in the leaves. This full explanation is consolidated through revisiting the 'What if…?' statements and becomes the agreed explanation with the class.

Activity 4.1: The missing link.

This reviews the simple model of plant nutrition and shows that while plausible (as demonstrated in Lesson 3) it is incomplete – there is a need for energy.

Teaching objectives

- To help pupils to recognise that the simple explanation presented in Lesson 2 is incomplete.
- To encourage pupils to draw on prior and informal knowledge to identify the need for energy.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain the role of sunlight in plant nutrition.

What to prepare

- A bottle of carbonated water.

Mode of interaction

The teacher-led demonstration and discussion helps pupils to recognise the important role of energy: INTERACTIVE/AUTHORITATIVE

What happens during this activity

Recap the simple model of plant nutrition introduced in Lesson 2 and present it as a word diagram on the board. Remind pupils of the activities in Lesson 3 which showed that this is a plausible explanation of how plants get their sugar, leading into the following:

> *'We have shown that carbon dioxide and water can react to make sugar, so if we mix carbon dioxide and water, can we make sugar?'*

Take only yes/no answers at this point, **don't** ask for/encourage reasons.

Take a bottle of fizzy water, undo the top and explain that it contains water and carbon dioxide (the bubbles). You might want to demonstrate to pupils that the fizzy water is not sweet. Ask: *'Does anyone know why it hasn't reacted to make sugar? Is there something still missing from our explanation?'*. The main point of this very short activity is to demonstrate that something more is needed, but it also gives any pupils who already know about energy and who may have been desperate to say so for some time, the opportunity to contribute. Taking account of the pupils' responses, establish that what is needed is energy and that sunlight is the source of this energy, and that plants use energy from sunlight to make the reaction happen. Build 'energy from sunlight' into the word equation on the board.

Activity 4.2: Leftovers!

Teaching 'story'

Having dealt with the missing factor, energy, the extra bits (from the jigsaw) are now considered.

Teaching objective

- To highlight the production of oxygen as a *by-product*.
- To present the full equation for photosynthesis.

Learning outcomes

By the end of this activity, most pupils will be able to:

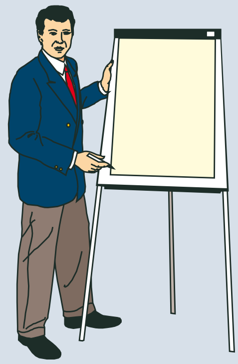
- use a word equation for photosynthesis to explain how a plant gets sugar.

What to prepare

- Thinking files.
- Uncut template and introduction for the jigsaw, perhaps enlarged to A3 (optional).

Mode of interaction

This activity is almost entirely teacher-led and focuses on presenting the scientific explanation of the equation. Pupils are encouraged to identify the leftovers from the jigsaw: NON-INTERACTIVE/AUTHORITATIVE.



What happens during the activity

Wonder aloud if there is anything else missing from the equation on the board and ask pupils if there was anything left over from the jigsaw activity (suggest they look in their thinking files and take the leftovers out). Ask what it is that is left over (oxygen) and where this should go in the word equation. Add the word oxygen to the equation. Note that this is a byproduct – the bit left over once the plant has made the sugar (some pupils think that the main purpose of photosynthesis is to produce oxygen for animals).

Note: In doing the jigsaw activity pupils have already encountered the molecules which match the word equation, so presenting the symbol equation is a relatively straight forward thing to do. If you decide to do this, draw the relevant information from your pupils, using the enlarged jigsaw template as a visual reminder and asking pupils to identify the type and number of atoms in each molecule and the number of each type of molecule that is needed. There is no need to get into a discussion of balanced equations here – the jigsaw ensures this particular equation will balance itself!

Activity 4.3: Locating the process in the leaf

Teaching 'story'

Pupils now have a complete scientific model of photosynthesis, which provides a plausible explanation of how plants get their sugar. Their understanding and acceptance of this model is consolidated and checked in the next activity, which locates the process of photosynthesis in the leaves of a plant and identifies the source of the raw materials.

Teaching objective

- To locate the process of photosynthesis in leaves.
- To consolidate and check pupils' understanding of this process.

Learning outcomes

By the end of this activity, most pupils will be able to:

- demonstrate where the process of photosynthesis takes place and where the necessary materials and energy enter the plant.

What to prepare

- One worksheet ('Where does photosynthesis take place?')
- Handout of the equation
- Glue sticks.

Mode of interaction

The teacher draws on the pupils' existing knowledge to make explicit the location of the process and the source of materials: INTERACTIVE/ AUTHORITATIVE.

What happens during the activity

Note that the equation on the board represents the process of photosynthesis – , the process that enables plants to manufacture their own sugar by combining carbon dioxide and water using energy from sunlight. Provide pupils with a handout of this equation to stick in their books.

Ask the following and record the correct answers on the board (use additional prompt questions if needed but note that the focus of these questions *is the scientific explanation*, not pupils' ideas):

- *'Where does this process take place?'* (in the leaves; supplement with the word chlorophyll if this is not offered by pupils);
- *'Where does the carbon dioxide come from?', 'How/where does it enter the plant?'* (the air/atmosphere; through the leaves);
- *'Where does the water come from?', 'How does it get to the leaves?'* (from the soil/ growing medium; through the roots; transported to the leaves internally through the plant);
- *'What happens to the oxygen?'* (moves out of the leaves and into the air/atmosphere).

Ask pupils to use this information to complete the worksheet 'Where does photosynthesis take place?'.

Activity 4.4: 'What ifs …?' revisited

Teaching 'story'

In this final activity of the lesson, pupils have an opportunity to review their developing understanding of photosynthesis through a reconsideration of their responses to the 'What if….?' scenarios.

Teaching objectives

- To consolidate the learning through a reconsideration of earlier responses.
- To provide pupils with an opportunity to reflect on their learning.
- To provide an informal opportunity to assess the learning.

Learning outcomes

By the end of this activity, most pupils will be able to:

- use their knowledge of photosynthesis to present a scientifically valid response to the 'What if …?' statements.

What to prepare

- 'What if …?' props and statement cards (1 set per group), page 13
- Thinking files
- Homework sheet (per pupil).

Mode of interaction

Pupils are organised in groups but work individually to review their earlier responses to the 'What if …?' statements. The teacher moves around checking pupils with an INTERACTIVE/AUTHORITATIVE approach.

What happens during the activity

Pupils draw on their current understanding of the scientific explanation of photosynthesis to review and revise their earlier responses to the 'What if …?' scenarios. If pupils appear confident about this application of their knowledge they could record their final response in their exercise books. Alternatively, they could continue to use their thinking files.

This activity consolidates pupils' understanding of the scientific model of photosynthesis and shows them how it can be used to explain phenomena relating to plant growth. It also gives them a chance to practise explanations using the scientific model. The homework provides an opportunity to assess whether the pupils have grasped the model of plant nutrition presented in this lesson and can use it to give an explanation.

Activity 4.5: Homework

Pupils' understanding of the process is checked through a homework activity in which they are asked to *apply* their knowledge (see the homework sheet on page 48).

Photosynthesis

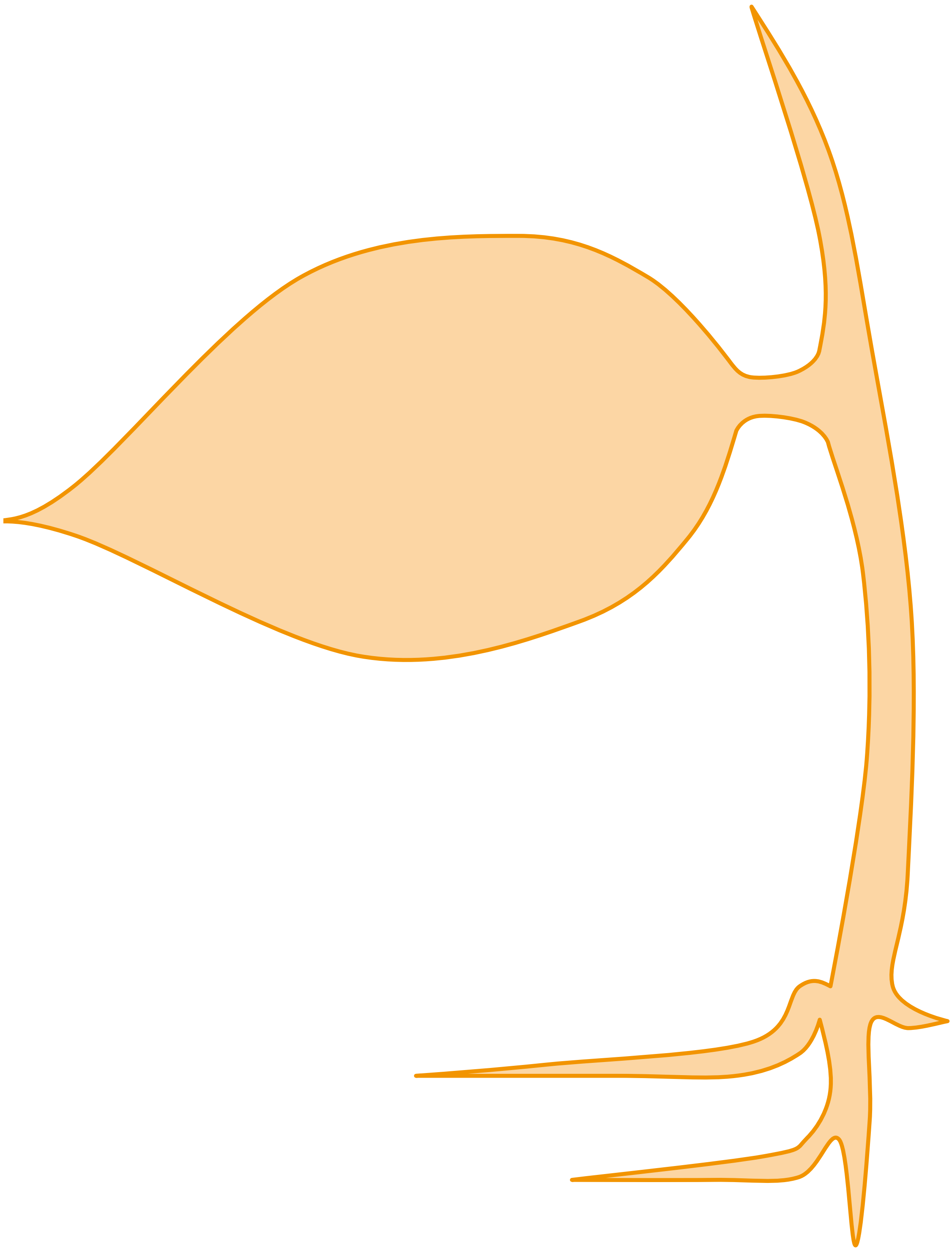
$$\text{Carbon dioxide} + \text{Water} \xrightarrow{\textit{Sunlight}} \text{Sugar} + \text{Oxygen}$$

Carbon dioxide from the air and water from the soil are converted into sugar in a chemical reaction powered by energy from sunlight. Oxygen is a by-product of the reaction.

Where does photosynthesis take place?

On the drawing of a plant below:

1. Write the word equation for photosynthesis at the part of the plant where the reaction takes place.
2. Indicate with labelled arrows where each of the requirements, water, carbon dioxide and sunlight energy, come from.



More tomatoes

Use your understanding of how plants get the food they need for growth to answer the following.

A farmer grows tomato plants in a greenhouse. She keeps bright lights on in the greenhouse during the night. Why does this make the tomato plants grow faster?

The farmer also increases the amount of carbon dioxide in the air in the greenhouse. Why does this make the tomato plants grow faster?

Lesson 5: Full circle

Teaching 'story'

This final lesson completes the story of plant nutrition by reviewing what happens to the sugar that is produced by the process of photosynthesis. The importance of sugar in the production of other materials that the plant needs and the role of minerals in this process, are addressed. Finally, plant and animal nutrition are again compared in terms of function – what food is used for (growth; respiration).

Activity 5.1: Saving it for later

This short activity begins to address the question of what happens to the sugar that is produced by photosynthesis, and demonstrates that if glucose molecules, which are soluble, link together to form starch they become insoluble. It is noted that the insoluble starch can be stored more easily by the plant.

Teaching objectives

- To demonstrate why plants convert glucose into starch.
- To make a link between photosynthesis and the food we (animals) eat.

Learning outcomes

By the end of this activity, most pupils will be able to:

- explain why plants convert the glucose produced by photosynthesis into starch;
- recognise that this starch can be a source of food for animals.

What to prepare

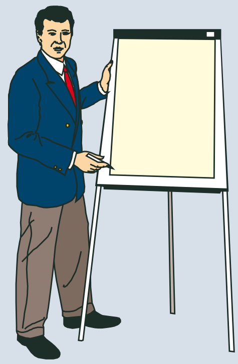
- Two beakers of water; glucose; insoluble starch.
- Some potato, peeled and diced, that has been left to stand in water long enough for the starch to leach out and form a sediment.

Optional:

- Microscope, slides and flexicam.
- Iodine to test for starch.

Mode of interaction

The teacher presents the scientific explanation and demonstrates the consequence: NON-INTERACTIVE/ AUTHORITATIVE.



What happens during this activity

Recap the end point of the last lesson emphasising that the pupils now have a scientific explanation of how plants can make sugar.

Identify the problem of storage and demonstrate the solubility of glucose. The idea to get across is that glucose would be difficult to store in discrete parts of the cell (with able pupils you might want to relate this to the need to keep the concentration of dissolved solutes in the cytoplasm constant to control water movement into the cell).

Suggest that the small soluble glucose molecules can be made insoluble if lots of them are linked together in long chains as starch (you could model this by linking many copies of the glucose molecule from activity 3.3 together). Demonstrate the insolubility of starch.

In summary, explain that the sugar made in photosynthesis is converted into starch, which can be more easily stored in plant cells. Plants, for example the potato tuber, often develop special storage organs for starch and these are a good source of food for animals. Demonstrate the presence of starch in potatoes (options: show sediment from potatoes; mount some of the sediment onto a microscope slide and project to show starch grains; test some of the sediment with iodine to confirm that it is starch).

Activity 5.2: What are plants made of?

Teaching 'story'

Having demonstrated that the basic materials produced as a result of photosynthesis are glucose and starch, pupils are reminded that one use of food is for growth. This highlights another potential implausibility – how these two materials could possibly be used to produce all the different materials needed for a plant to grow.

Teaching objectives

- To show how all the materials needed by a plant for growth can, with the addition of a few minerals, be produced from glucose.

Learning outcomes

By the end of this activity, most pupils will be able to:

- distinguish between the basic food material (glucose, produced by photosynthesis) and minerals (absorbed from the soil);
- give a simple explanation of *how* glucose can be converted to materials required for growth.

What to prepare

- A slide of Fact sheet 1: What is a plant cell made of?
- Copies of the differentiated worksheet 'What are plants made of?', one per pupil.

Mode of interaction

The teacher works with pupils to consolidate and extend their developing understanding of the scientific explanation: INTERACTIVE/ AUTHORITATIVE.

What happens during this activity

Pupils are asked to recall what food is used for (growth, respiration/energy – remember Activity 1.2 in Lesson 1) and their ideas about growth in plants; how growth occurs (cell division); and the sorts of materials that might be needed (carbohydrates, fats, protein, chlorophyll, water). These ideas are summarised, and if necessary expanded, by the teacher (slide: 'What is a plant cell made of?'). This raises a question:

> *'Is it possible that all these different kinds of materials can be produced from just glucose or starch?'*

Explore the pupils' initial ideas, reminding them how they showed that sugar could be made up from the elements in carbon dioxide and water (the jigsaw activity) then provide them with additional information (the fact sheet). What do they think now?

Clearly, glucose does provide the main building material and can be converted to all the other materials that are needed, but something more is needed: minerals. This raises a further question: are minerals food? Allow a brief discussion of this before presenting the scientific view. Note that minerals are very small chemicals that are only needed in very small quantities. Note that animals need minerals too. If someone is anaemic (has too few red blood cells) the doctor will suggest they take iron supplements; although iron is needed in the production of red blood cells, we would not consider this iron supplement to be food. In the same way, the minerals which plants need are a supplement and are not usually considered to be food. Note that minerals (and water) are absorbed from the soil through the roots. Make clear the distinction between food (glucose, manufactured in bulk in the leaves by the process of photosynthesis and converted to other materials by the plant) and minerals (small, simple chemicals absorbed in small amounts through the roots and used as a 'supplement').

Pupils' understanding is then consolidated and checked by their answers as they complete the worksheet ('What are plants made of?').

Activity 5.3: Food and energy

Teaching 'story'

Having shown how the glucose produced by photosynthesis can provide the materials for growth, attention now switches to the other use of food: the production of energy through the process of respiration.

This is a very brief teacher presentation.

Teaching objectives

- To reinforce the idea that plants and animals use their food in exactly the same way: for growth and for respiration.
- To make explicit the idea that plants respire: to counteract the idea that animals respire but plants photosynthesise.

Learning outcomes

By the end of this activity, most pupils will be able to:

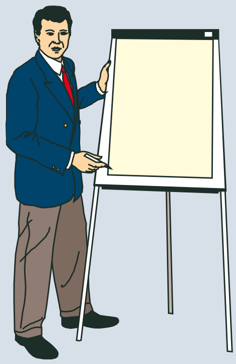
- understand that the *difference* between plant and animal nutrition is in the source of the food, not the use which is made of it;
- recognise that both plants and animals use food in the same way (for growth and respiration);
- recognise that while plants make their own food, starting with the process of photosynthesis, animals must find, eat and digest their food before it can be used for growth or respiration.

What to prepare

- Nothing.

Mode of interaction

This is a brief teacher's presentation of the science: NON-INTERACTIVE/ AUTHORITATIVE.



What happens during this activity

This activity uses a very brief presentation by the teacher to make explicit the idea that the energy needed by plants is provided by respiration, in just the same way as in animals.

Make the point that plants need energy all the time, just as animals do, and that they get this energy in the same way that animals do from glucose and oxygen, through the process of respiration. Note that the only difference between plants and animals is the origin of the glucose: plants make their own, through the process of photosynthesis; animals obtain theirs through the process of finding, eating and digesting food.

Some pupils may wonder why plants use energy from sunlight to make glucose and then use the glucose to release energy: they ask why plants don't just use the sunlight directly for all their energy needs? They might like to consider what would happen at night, or in the winter, or during germination (when the seed is under the soil) if plants relied on sunlight for all their energy needs.

Activity 5.4: Full circle

Teaching 'story'

This final activity takes the ideas full circle and consolidates the lesson by returning to one of the starting points in Lesson 1: the difference between plant and animal nutrition. This time pupils present the scientific explanation.

Teaching objectives

- To consolidate the ideas developed during this lesson.
- To set this lesson in the context of the whole sequence, giving pupils an opportunity to see how their understanding of the correct science has changed.

Learning outcomes

By the end of this activity, most pupils will be able to:

- compare animal and plant nutrition using the scientific ideas.

What to prepare

- One copy of the worksheet per person.

Mode of interaction

Working in their groups, pupils use their understanding of the science to complete the worksheet: INTERACTIVE/ AUTHORITATIVE.

What happens during this activity

Working in their groups, pupils use their knowledge of the science to complete the worksheet ('Where do plants and animals get their food from?'), thus reinforcing the idea that animals must ingest their food while plants can make their own. The answers for plants can be found in the fact sheet.

Answers

- Animals get carbohydrate, fat, protein and minerals by digesting the food they eat.
- Plants make fat from parts of the glucose molecules produced by photosynthesis, protein from parts of the glucose molecules from photosynthesis + nitrogen (in the form of nitrates) from the soil, minerals from the soil.

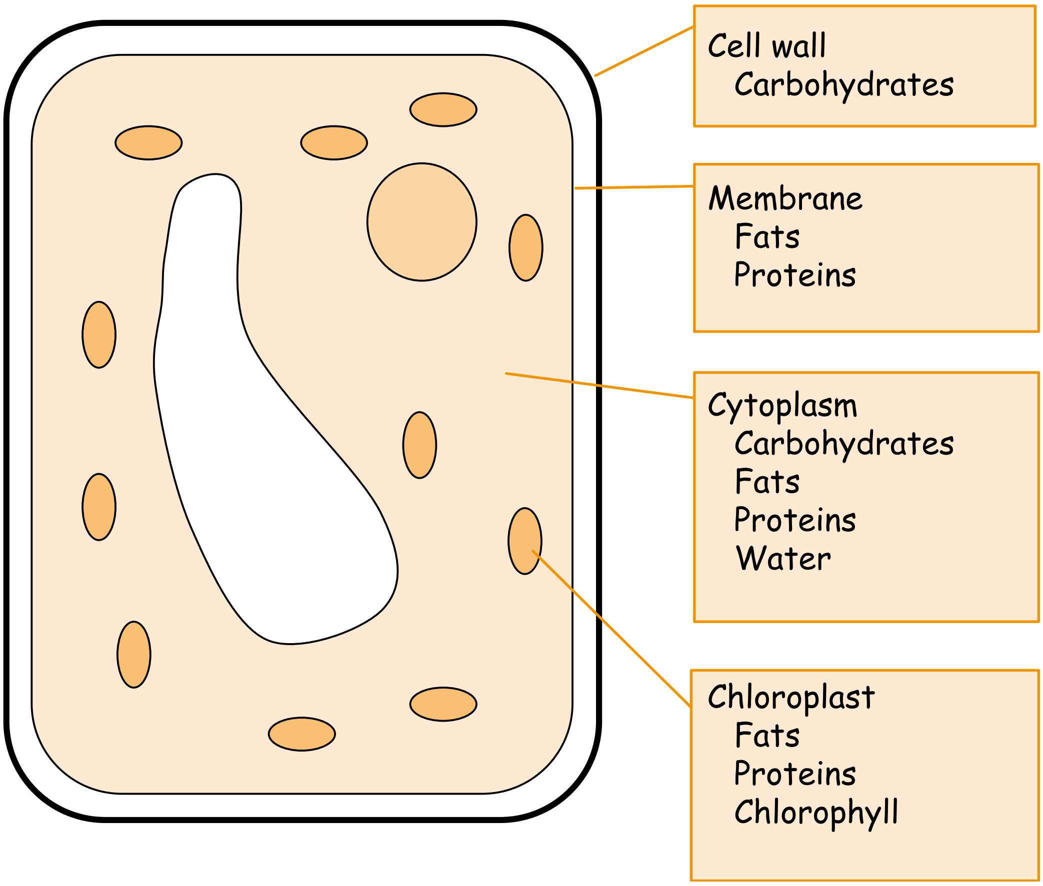
Activity 5.5: Homework

The homework question, based on van Helmont's experiment, is used to assess the extent to which pupils can now apply their understanding of the science to an unfamiliar context and present a coherent explanation.

What is a plant cell made of?

Fact Sheet 1: What is a plant cell made of?

This diagram tells you what chemicals a plant cell is made of.



Fact Sheet 2: The chemicals that plants are made of

This table tells you what is in the chemicals that plant cells are made from.

Name	Composed of:
Carbohydrates	Chains of **glucose** molecules
Proteins	Parts of **glucose** molecules with **nitrogen** added
Fats	Parts of **glucose** molecules
Chlorophyll	Parts of **glucose** molecules with **magnesium** added

What are plants made of?

Fill in the missing words. The words in the box at the bottom of the page might help you.

To make new cells a plant needs these chemicals.

c................................

f............

p..................

ch................................

w............

A plant has to make all these chemicals.

c................................ and f............ are made from g............ that the plant gets from photosynthesis.

To make p............ the plant needs n............, a mineral found in soil, as well as g............ from photosynthesis.

To make ch................................ the plant needs another mineral, m.................., as well as g.................. from photosynthesis.

carbohydrate	**fat**	**protein**	**chlorophyll**	**water**
glucose	**nitrogen**	**magnesium**		

What are plants made of?

Fill in the missing words using the highlighted words on fact sheet 1 and 2

To make new cells a plant needs these chemicals.

c.................................

f.............

p....................

ch.................................

w.............

A plant has to make all these chemicals.

c................................. and f............. are made from g.............

that the plant gets from photosynthesis.

To make p............. the plant needs n............., a mineral found in soil, as well as g............. from photosynthesis.

To make ch................................. the plant needs another mineral, m...................., as well as g.................... from photosynthesis.

What are plants made of?

Use the information on fact sheet 1 and 2 to answer these questions.

1. List the chemicals that a plant cell is made of

....

....

....

2. A plant has to make all these chemicals from other chemicals.

What is needed to make each of these chemicals

carbohydrate ....

fat ....

protein ....

chlorophyll ....

3. Where does a plant get each of the following chemicals from?

glucose ....

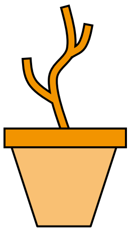
nitrogen and magnesium ....

Activity 5.5: Homework

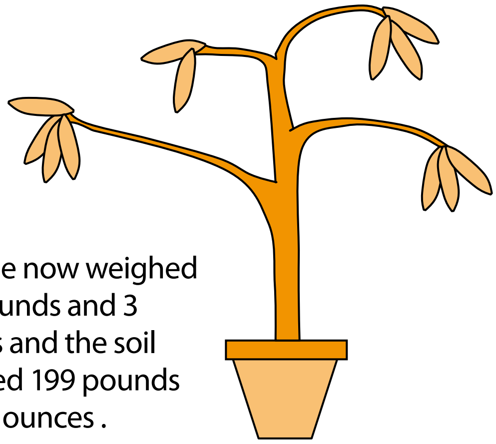
Name ....

Van Helmont was a Dutch scientist who lived in the 17th century. He did not know about photosynthesis or about chemical elements. Van Helmont carried out an experiment to try and find out what plants are made of.

Here is what he did:



2. For 5 years he added only rainwater.



3. The tree now weighed 169 pounds and 3 ounces and the soil weighed 199 pounds and 14 ounces .

5. He planted a willow tree weighing 5 pounds in 200 pounds of soil.

From the results of his experiment, van Helmont concluded that; 'therefore 164 pounds of wood, barks and roots arose out of water only.' This puzzled Van Helmont.

Use your knowledge of plant growth to explain where the mass came from that made up '164 pounds of wood, bark and roots'.

Acknowledgements

Front Cover, Photograph of a *Student measuring water uptake*. Martyn F. Chillmaid / Science Photo Library. Used with kind permission.

Audience: Science subject leaders, teachers of science and higher level teaching assistants.

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