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ABSTRACT

This document contains a set of instructional materials about photosynthesis that were used in a research study of middle school science teaching during 1985-86. The Middle School Science Project investigated ways to help middle school science teachers use teaching strategies that were identified in earlier studies as particularly effective in promoting meaningful conceptual-change learning. Such learning requires students to go beyond memorization of facts and terminology and to make sense of scientific explanations of phenomena. For students, such learning in science often requires them to go through a difficult process of conceptual change, reshaping and abandoning ideas or misconceptions that they have developed from experience and have believed for a long time. The materials include an introductory description of students' difficulties related to learning about photosynthesis, a student text with accompanying comments and suggestions to teachers, a set of overhead transparent masters, and suggested laboratory activities. (Author/TW)

Occasional Paper No. 112

THE POWER PLANT: TEACHER'S GUIDE TO PHOTOSYNTHESIS

Kathleen J. Roth & Charles W. Anderson

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Abstract

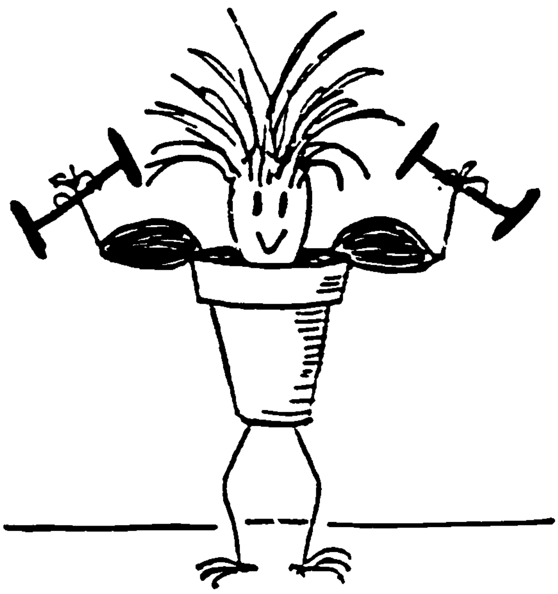
The Power Plant is a se. of instructional materials about photosynthesis that were used in a research study of middle school science teaching during 1985-86. The Middle School Science Project investigated ways to help middle school science teachers use teaching strategies that were identified in earlier studies as particularly effective in promoting meaningful conceptual-change learning. Such learning requires students to go beyond memorization of facts and terminology and to make sense of scientific explanations of phenomena. For students, such learning in science often requires them to go through a difficult process of conceptual change, reshaping and abandoning ideas or misconceptions that they have developed from experience and have believed for a long time.

Two groups of teachers in the study received The Power Plant Teacher's Guide as a major source of support in implementing conceptual-change teaching strategies. They used these materials as they taught a unit about photosynthesis in their classrooms. Researchers observed and interviewed the teachers and gave pretests, posttests and delayed posttests to assess student learning. The Power Plant materials were found to be helpful to teachers, and students using these materials were more successful in undergoing conceptual change than students who did not use the materials.

The materials include an introductory description of students' difficulties learning about photosynthesis, a student text with accompanying comments and suggestions to teachers, a set of overhead transparencies, and suggested laboratory activities.

THE POWER PLANT

Teacher's Guide to Photosynthesis



by Kathleen J. Roth and Charles W. Anderson

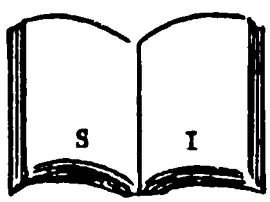
Illustrated by Saundra L. Dunn

About the Authors

Kathleen Roth is a senior researcher in the Science Teaching Project and assistant professor of teacher education at Michigan State University. Charles Anderson, coordinator of the project, is associate professor of teacher education at MSU. Saundra Dunn is a research assistant with the Institute for Research on Teaching.

TABLE OF CONTENTS

ORGANIZATION OF PAGES IN THIS MODULE



Student Pages	Instructor Pages
Pages with instructional materials to be used by students are on the left side.	Pages with information for instructors are on the right side.

I. INTRODUCTION

A. Learning About Photosynthesis: Memorizing or Making Sense?

> Have you ever heard of the word photosynthesis?
> If yes, tell what it means as best you can.

If this question was posed to your middle school students after they had studied photosynthesis in your class, how would you hope your students would respond? What are the most basic, critical concepts that you would want them to remember? Is it sufficient that a student correctly supplies the formula for photosynthesis or states that "photosynthesis is when plants use carbon dioxide, water, and sunlight to make their own food"?

In our research we have found that students can often define photosynthesis in satisfactory ways, but when they are asked questions that test their understanding of photosynthesis, their answers reveal that they have merely memorized a definition of photosynthesis without really making sense of the concept. For example, we asked students to describe what food is for plants. Despite having learned about photosynthesis in class, the students' answers to this question rarely made reference to photosynthesis. In the following student responses, notice the contrast between the seventh graders' accurate descriptions of photosynthesis and their failure to use that concept to explain how plants get their food:

Question:	Tell what photosynthesis means as best you can.	Describe what food is for plants.
Dick	When a plant makes its own food.	Minerals, etc.
Denise	The process by which plants make food.	Minerals, water help the plants grow tall & healthy.
Lauren	How a plant makes food for itself.	Plants need sun and minerals and water for energy and to grow.
Heidi	When a plant uses water, sunlight, and air to make food.	Water and minerals and protein.

These students have "learned" a definition of photosynthesis, but they contradict themselves when they are asked for a definition of food for plants! This is a pattern of thinking that we have seen over and over again in our research. Students can parrot back memorized terms, but they cannot answer questions that require an application of those memorized terms. Why do students have such difficulty making sense of central concepts like photosynthesis?

The teaching materials in this unit are based on one answer to this question. The answer arises from extensive research comparing students' ways of thinking about natural phenomena with scientific experts' ways of thinking about the same phenomena. In general, this research shows that the students think and act in ways that are perfectly sensible to them, but that are incompatible with scientific thought.

For example, many students have trouble learning about photosynthesis because they assume that plants, like people, must take in food from the environment. Scientists on the other hand, emphasize the critical differences between the ways plants and people get food. In their view, plants are unique in their ability to take low energy-containing inorganic matter (water and carbon dioxide) and use energy from the sun to change that matter into high energy-containing organic matter (food). Thus, the food that plants make during photosynthesis is very different in nature from the materials the plants take in (water, minerals, carbon dioxide).

The presence of students' alternate ways of thinking makes the learning of science a far more complicated process than scientists normally imagine. For these students, learning about photosynthesis is not simply a matter of absorbing or memorizing scientific content. Instead, they must reassess and change their commonsense, everyday understandings of the world. Furthermore, they must abandon misconceptions or habits of thought that have served them well all their lives in favor of new and unfamiliar ideas.

This is not an easy task! These old habits of thought often persist even after students have apparently learned the scientific alternatives. Many students become quite good at learning what is expected of them to pass science tests while continuing to use their old ideas in "real world" situations. The students quoted above, for example, memorized a definition of photosynthesis without realizing its implications for their definitions of food. Richard and Daniel, quoted below, show another common pattern of incomplete learning.

Question:	Describe what is food for plants.
Richard	Sun, good soil, water, and the food made during photosynthesis.
Daniel	Glucose, sunlight, and minerals from the ground.

Learning about photosynthesis did change their definitions of food, but not enough! They still do not appreciate the crucial difference between the low-energy materials that plants take in and the high-energy products of photosynthesis.

We have adopted a phrase from David Hawkins and describe students' naive ways of thinking that interfere with their understanding of scientific thinking as "critical barriers" to the learning of science. In our research we have tried to understand the critical barriers to student learning about central topics in the science curriculum and to use those understandings to define teaching strategies that will help students overcome those barriers.

B. Critical Barriers to Understanding Photosynthesis

Four general issues are particularly difficult for most students when learning about photosynthesis. These issues and the reasons for their importance from the students' points of view are as follows:

1. Food. This word is rarely used with precision by either students or biologists. When talking about the food made by plants during photosynthesis, however, biologists are more consistent. In this context, biologists use the word "food" to refer to organic compounds with high-energy molecular bonds that organisms can use for growth and metabolism. Other substances that organisms need, such as water, oxygen, and minerals are inorganic and are not considered food. It is this distinction that makes the statement "plants make their own food" meaningful. The process of photosynthesis provides the only bridge by which inorganic matter can be changed into organic matter.

The biological distinction between energy-supplying organic substances (food) and nonenergy-supplying inorganic substances (not food) is critical to understanding the significance of photosynthesis. Plants and other organisms convert glucose into the millions of other organic compounds that make up the bodies of living things. However, all of those compounds (in other words, all food) are ultimately derived from a single source: glucose made during photosynthesis.

The distinction between plants as producers and animals as consumers in ecosystems cannot be meaningful to students who do not understand that the food made during photosynthesis is different in a very important way from other nutrients such as water or minerals. After all, what is it that plants produce and animals consume?

Students do not think about food in these ways, however. To them, food is whatever plants or animals take in to keep alive and growing. From this perspective, it is easy to see how they could distort instruction about photosynthesis. Their definition of food is sensible, but it misses the essential distinction between organic and inorganic matter.

2. Energy. The significance of the distinction between organic and inorganic substances lies primarily in energy relationships. Photosynthesis captures energy from sunlight and converts it to chemical potential energy stored in organic compounds (food).

Energy, however, is an abstract and difficult concept for most students. They tend to think about energy in vague terms, as part of everything that plants or people need. In order to appreciate the significance of energy in photosynthesis, they must learn to follow the path that energy takes and the changes it undergoes. Students must appreciate the critical importance photosynthesis plays in changing energy from sunlight into a form that is usable by living things.

3. **Matter.** Biologists' conceptions of photosynthesis also depend on a chemical understanding of the nature of matter. The process is viewed as a chemical reaction, and the substances involved are characterized as chemical compounds. In these chemical reactions, matter is changed but conserved. Scientists think of these chemical reactions as involving rearrangements of molecules which result in the formation of new compounds.

Most students, however, are not used to thinking about molecules, chemical formulas, or chemical reactions. These things seem very mysterious to them and only vaguely understandable.

4. **The Functional Nature of Scientific Explanations.** Consider these answers that students gave to another question about food for plants:

Question: Do plants need food? Why or why not?

Susan	Yes.	They need sun, fertilizer, water, and soil.
Brooks	Yes.	It's like people, they can't live without food.
Ryan	Yes.	Because plants have to eat or they would die.

It is notable that the students' explanations don't really explain anything. Susan and Ryan's explanations are essentially circular; they restate in different words that plants need food. Brooks appeals to an analogy between plants and humans.

Scientists, on the other hand, expect <u>functional</u> explanations (for example, "Plants need food because their cells use food as a source of energy.") Biologists think about the function that each substance plays in the internal workings of the plant. They seek to understand not just whether or not a plant needs a particular substance to stay alive; they want to know what happens to that substance inside a plant. How does the plant use it? Thus, an essential part of learning about photosynthesis is learning to develop appropriate functional explanations and definitions.

* * * * * *

We have chosen to emphasize these four issues because the concepts they involve are absolutely essential for students to make sense of photosynthesis. Unfortunately, most textbooks and courses fail to treat these concepts adequately, forcing students to grapple with more advanced and difficult concepts before they have mastered these fundamental ideas.

In an attempt to make sure that students come to understand the central ideas, we have carefully limited the amount of scientific terminology introduced, we have not discussed photosynthesis at a molecular level, and we have omitted discussions of the light and dark phases of photosynthesis. The production of oxygen in photosynthesis is deemphasized. In earlier research, we found that emphasis on these ideas often served only to mask the central issues.

C. Chart of Photosynthesis Issues

The chart on the following two pages is our way of stating the objectives for these materials. Our research indicates that most middle school students begin instruction with beliefs like those in the column labeled "Naive Conceptions." These materials are designed to help them change to the scientific thinking in the column labeled "Goal Conceptions."

Photosynthesis Issues and Conceptions

Issue	Goal Conceptions	Naive Conceptions
Plants' source of food	Plants make their own food internally using carbon dioxide, water, and sun in a process called photosynthesis.	Plants take in their food from the outside environment.
	This is plants' only source of food.	Plants have multiple sources of food.
Nature of food	Food made by green plants is matter that organisms can use as a source of energy.	Food is the stuff that organisms eat, take into their bodies.
Function of food in plants	Food supplies the energy that each cell of a plant needs for internal life processes (functional explanation)	Food is needed to keep plants alive, to grow (nonfunctional explanation)
Matter transformation	Water and carbon dioxide taken into plants is changed into <u>new</u> matter as a result of a chemical reaction. In this chemical reaction, nonenergy-containing matter (carbon dioxide and water) is rearranged and recombined to make energy-containing food (glucose) and oxygen.	Water and carbon dioxide taken into plants are not changed. They are used unchanged to support two separate life processes--drinking and breathing.

Photosynthesis Issues and Conceptions (continued)

Issue	Goal Conceptions	Naive Conceptions
Movement of matter	Water and carbon dioxide travel to cells in leaf where they are involved in one process--photosynthesis.	Water and carbon dioxide trave to plant organs (leaf) where they are involved in two separate processes--drinking and breathing.
	Food travels from leaves to all parts of the plant.	Food enters plants through the roots and travels to all parts of the plant.
Energy transformation	During photosynthesis, energy from the sun is changed into energy stored in the food that plants make.	Plants need sun to live, grow, be green. (No notion of energy being absorbed, needed, or changed.)
Importance of products of photosynthesis for plants	Most important product is food. This food is the plant cells' only source of energy.	Photosynthesis is not important to plants--it is something they do for the benefit of people/animals.
Importance of photosynthesis for people/animals	Animals depend on plants for food as well as oxygen. Only green plants can change energy from sun into energy stored in food. Thus, only green plants can make energy-containing food that all animals need.	Plants are important because they make oxygen for people and animals to breathe. Plants are also an important source of food for animals, but they are not the only source.

D. Teaching Strategies for Overcoming Critical Barriers

What kinds of teaching strategies can help students give up or modify their commonsense ways of thinking about food for plants in favor of the concept of photosynthesis? What can teachers do to encourage students to make sense of scientists' ways of thinking about food for plants and to discourage students from memorizing their way through another science unit?

For many students, the naive ways of thinking described above are deeply ingrained. We have found that for such students even the best explanations are not enough. Replacing easy and familiar ideas with more abstract biological conceptions is a difficult process. It requires that students become actively involved in thinking about the subject, that they receive corrective feedback from teachers about their thinking, and that they have many opportunities for practice and application.

For these reasons, the materials are designed to help teachers use the following general teaching strategies:

1. Getting students involved in thinking about the subject. The materials include questions that will encourage students to think about what they know about real world plants and to make links between their knowledge of real plants and the concept of photosynthesis. The student text, for example, begins with a question asking students for their ideas about how plants get their food. We have found that students are more interested in reading the text once they realize that it is going to discuss something they know about from their personal, everyday experiences. This approach also communicates to students that teaching and learning involve their own ideas and their thinking.

2. Diagnosing student difficulties and providing corrective feedback. Many questions included in these materials are designed to reveal what students are thinking about photosynthesis and food for plants. The commentary for teachers describes what each question is designed to reveal, the appropriate scientific responses for each question, and the range of answers students are likely to give. Suggestions for appropriate feedback to common student answers are given.

3. Creating dissatisfaction with naive ways of thinking. Many students enter science classes expecting to memorize facts and definitions, but not to really change how they think about the world. The activities in these materials provide students with a variety of opportunities to see that their present ways of explaining and predicting scientific phenomena may not work as well as scientific explanations. For example, students are asked to make predictions and later to use new concepts to explain why their predictions were wrong. Making explicit to students such contrasts between their ways of thinking and scientists' ways of thinking is a powerful teaching strategy. By posing an intriguing dilemma in which students' own ideas are challenged, such contrasts capture students' attention and make students more willing to puzzle through problems.

4. Providing opportunities for practice and application. To come to understand the importance of photosynthesis, students need to see how the concept can be used to explain many different phenomena in satisfying ways. In addition, students who are used to memorizing their way through science classes need much practice and support as they are learning how to think at a conceptual level. For these two reasons, the materials include many questions and activities that allow students to practice and apply new concepts. These activities help students see the power of the concept of photosynthesis in explaining a variety of phenomena. Since the basic purposes of scientific theories are to explain and predict, we believe that the questions asking students for explanations and predictions are especially important.

E. Suggested Timeline

These materials are designed to support you in helping students make the transition from commonsense thinking to more accurate scientific ways of thinking. We hope that you will select those activities that would be appropriate for your students. We recognize that you will probably not want to or be able to use all of the materials. In addition, you may have other materials that you believe could effectively complement these materials.

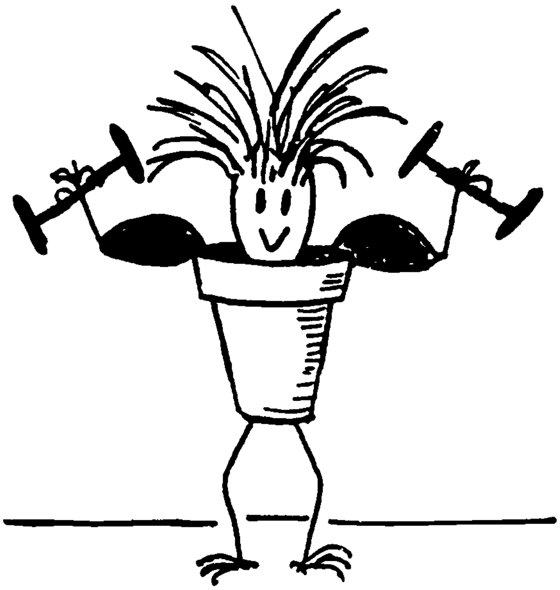
The materials we provide are of three types. Part II of this guide contains student text materials. This workbook format enables students to answer questions directly on text pages. In Part III, a copy of a transparency set and notes for the teacher about their use are provided. Part IV includes two laboratory activities. These activities can be done as a "dry" lab or as an actual hands-on experience. However, the materials are in a format most conducive for actually doing Laboratory Activity One and for drylabbing Laboratory Activity Two. In each part, copy-ready student materials are contained on the left-hand pages and information for teachers on the right-hand pages.

The timeline below suggests one way of using these materials. The actual time taken for various activities, of course, depends on many different factors. This schedule may not allow enough time for thinking and discussion.

The order of activities is flexible, but the laboratory activities (Part IV) are designed to be done <u>after</u> the process of photosynthesis has been explained to the students (pages 22-27 of the student text).

<u>Number of Lessons</u>	<u>Suggested Activities</u>	<u>Pages in the Guide</u>
3-4	Read and discuss Chapters I-III in the student text and Transparencies 1-6	9-28 34-36
1	Laboratory Activity One and Transparency 7	39-49 following 36
1	Chapter IV in the student text and Transparencies 1-6	29-32 34-36
1	(Optional) Laboratory Activity Two and Transparency 8	50-54 37

THE POWER PLANT



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S-9

II. STUDENT TEXT

The Power Plant

Chapter One

INTRODUCTION

In some ways, food for plants is like food for humans. But plants and humans get their food in very different ways. In this chapter we will investigate how plants get their food.

What is food?

In order to understand how plants get their food, you need to understand the scientific meaning of the word "food." Let's start out by considering how we think of food in everyday life.

Write down how you would define food. ________________________________

____

____

____

In your definition, is juice a food? ______________

is water a food? ______________

is sugar a food? ______________

Common Student Answers

This question is designed to elicit and explore students' conceptions of food. Students are likely to define food as anything you eat. Some may contrast food with liquids (food is what you chew, not what you drink). Some students may say that food is something that helps you live and grow.

Although it is true that food is something that helps you live and grow, students using this definition of food tend to consider anything that helps you live and grow as food. Many students, for example, consider water and vitamins to be food just like sugar is food. If they continue to use such a broad definition of food, they will fail to recognize the critical distinction between energy-supplying food made by plants during photosynthesis and nonenergy-supplying materials plants take in from the environment.

Scientific Definition of Food

In contrast to students' definitions of food, scientists define food in terms of a specific function: It provides the energy that living things need to live and grow. By this definition, water is not food because it does not provide energy. Water is needed for life, but it is not energy-supplying food. Both juice and sugar are food because they provide energy.

Students should not be expected to understand the scientific conception of food at this point. The concept is presented to them on p. 10. These questions are designed to help students begin to question their beliefs that water and fertilizer are food for plants. Students will be asked to refer back to this definition again later in the unit.

In everyday life, people have lots of ways of thinking about what food is. Some would say juice is not a food, because you do not chew it. Others would say that juice is food because it is taken into our bodies. Still others would say juice is food because it is good for us. In everyday life we can talk about food in these different ways and no one gets confused. We all know that potatoes are food and stones are not food.

But scientists often need to use a special definition of food. They have found that things we take into our bodies do many different things for the body. Water does not do the same thing for your body that meat or sugar or aspirin or vitamins do. Scientists say that these things we "eat" have different functions, or jobs, in the body.

To talk about the different functions of things we eat, scientists have special words to talk about different types of nutrients. They have a special definition for food. Not everything we eat is food by this definition. In this book we will be using the following definition of food:

> FOOD refers only to materials that contain energy for living things. All living things must use food to grow and to keep all their parts working properly.

The most important word in this definition is energy. Energy is what makes all your cells and body parts work--it is what gives your body the power to breathe, to move blood, to move muscles, to repair cuts, to build new cells, etc. Each cell in every living thing has lots of work to do to stay alive, and energy is needed to get that work done. All cells of all living things need energy. If your cells do not get energy, you will die.

Living things can only get their energy from food. All living things will die if their cells do not get food. Without food they have no energy to continue functioning.

The paragraph to the left, page S-11, introduces the importance of thinking about functions in scientific definitions and explanations.

The definition of food on page S-11 is essential to students' understanding of why the food made by plants during photosynthesis is of special importance. They should also understand that other definitions of food are appropriate in everyday settings.

Look back at your answers to the questions on page S-10. How would you now change your definition of food? ______________________________

____

____

____

Because juice and sugar supply energy to living things, scientists would consider them both food. Scientists would not consider water a food, because it does not contain energy that living things can use. Vitamin pills do not supply us with energy. Would scientists consider them a food?

____

Using the scientific definition of food, explain why you could not live on water and vitamin pills alone. ______________________________

____

____

____

Dirt, or soil, does not contain energy that people can use. But sometimes babies eat dirt. Is that dirt <u>food</u> for the baby?__________

Use the scientific definition of food to explain your answer. __________

____

____

____

This question is designed to make sure students are aware of how their original definitions of food are different from the scientific definition.

This is an application question. Students should use the definition of food to explain that people need energy-containing food to live. Water and vitamin pills do not provide such a source of energy. If students do not make this connection, they will have another chance to apply the same concept on the next question. For that reason, you might want to discuss the answer to this question before having students answer the next one.

Again, students are given a chance to apply the new concept. If many students missed the question above, this will give them another opportunity to try applying the definition of food. They should respond that dirt is not food because it does not supply energy for the baby.

Plants and People: Is Their Food the Same?

How Food for Plants is the Same as Food for Humans

Both humans and plants need food for the same reason. They need food because food gives them energy that they must have to grow and to keep all their parts working properly. Living things get all their energy from food. Food also supplies all living things with materials for growth. Both plants and animals must have this energy-supplying substance.

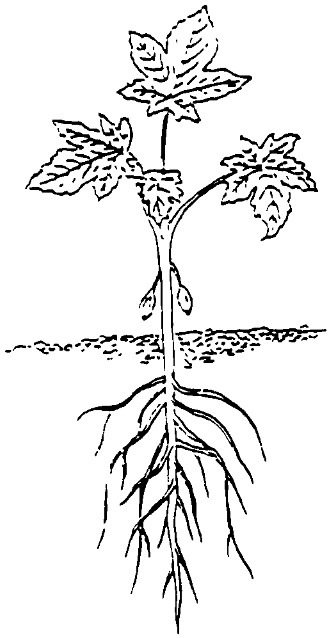
How Plants Get Food Differently from Humans

Plants cannot get food the way we do. They do not have mouths, and they cannot go out and buy food from the store! So how do they get food? What kind of food do they use?

Write down *your* ideas about how plants get food.

Write down *your* ideas about what kind of food plants use.

Draw arrows to show how you think food moves in a plant:



What This Unit is About

In this unit, we will find out what food is for plants and how plants get their food. We will find out about how plants get food that contains *energy* that they can use to live and grow. As we go along, compare what you find out with what you have just written. See if your ideas change in some ways.

Both of the questions on this page are exploratory questions designed to elicit students' ways of thinking about food for plants. Do not expect students to have the scientific conception of food for plants at this point. The question is designed to enable both you and the students to become aware of their naive conceptions.

Common Student Answers

Plants get food by taking it in from the soil.
Sun, water, air, soil, proper care, and fertilizer are food for plants.
Food sticks you buy at the store are food for plants.
Plants' food is minerals in the soil.
Food for plants is what they need to live.

Some students tend to think about anything the plant needs as food for the plant. Others think that whatever plants take into their bodies ("eat") is food for plants. Still others identify only fertilizer or minerals as food for plants.

Scientific Conception

While many students consider raw materials in the plants' environment as the plants' food, the scientific conception is that plants get food by making it themselves by using energy from the sun to change water and carbon dioxide into energy-containing food (glucose). This process, photosynthesis, takes place inside special cells in the leaves. This is the goal concept of the unit.

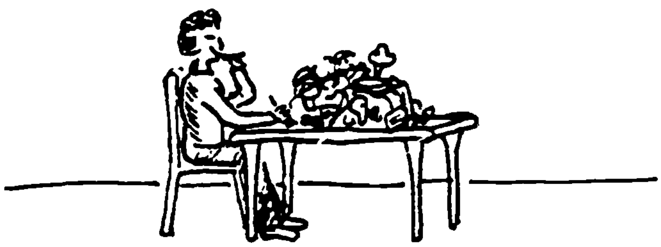
By the end of the unit, students should relinquish their misconceptions in favor of this scientific conception. They will be asked to come back to what they have written on these pages and revise their answers based on what they have learned from the unit.

Chapter Two

USING EXPERIMENTS TO FIND OUT ABOUT FOOD FOR PLANTS

One way to get information about plants' food is by doing experiments with plants. Hundreds of years ago, scientists began doing experiments to find out about how plants get their food. See if you can find out if you were right about how plants get their food as you puzzle through these experiments. (Look back at what you wrote on page 14 if you do not remember what <u>you</u> said about how plants get their food).

<u>Does soil provide food for plants?</u>

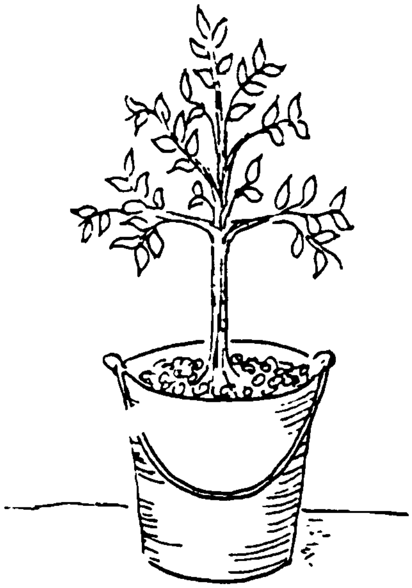


Suppose a child was given 200 pounds of food to eat. Predict what would happen to the weight of that <u>child</u> as he or she gobbled up that food. Write either "goes up," "goes down," or "stays the same" in the appropriate box on the chart below.

Weight of child	Weight of food

What would happen to the weight of the <u>food</u> on the table as the child ate it? Write your prediction (either "goes up", "goes down", or "stays the same") in the other box on the chart.

On the next three pages, students are asked to think about an experiment that should surprise them. The experiment is the well-known experiment done by Van Helmont, in which he demonstrated that plants do not use food from the soil for their growth. The questions on this page are just preparing students to make a prediction about Van Helmont's experiment on the next page.

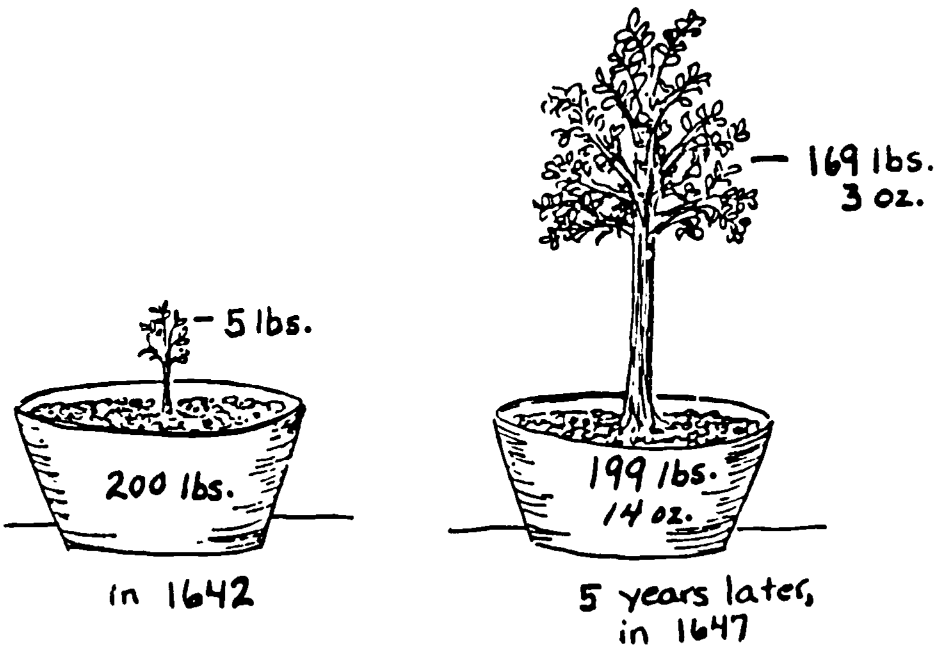


Now think about a young tree planted in a bucket of soil. As the tree grows it gains weight. Does it gain weight from the soil the way a child gains weight from food? Is the soil a kind of food for the plant? What do you think? Write down below whether you think the weight of the soil will go up, go down, or stay the same as the tree grows.

Weight of the tree	Weight of the soil
Goes up	

In the 1600s everyone thought that soil and the minerals in the soil provided food for plants. A scientist named Jean Van Helmont did an experiment to see if this was true. He planted a five pound young tree in a bucket containing 200 pounds of soil. He watered the plant regularly but he did not add any more soil. Look at the picture on the next page and see what happened to the weight of the tree and the weight of the soil after five years.

Students who believe that plants get some or all of their food from the soil should predict that the weight of the tree will go up and the weight of the soil will go down.



Weight gain by tree	Weight loss by soil

The tree gained a whole lot of weight, but the soil lost only a <u>tiny</u> bit! What do you think Van Helmont concluded? Is soil a food for plants? ________

Van Helmont decided that soil is <u>not</u> a food for plants. Plants get almost all of the materials they need to grow from somewhere else.

But what about the little bit of weight that the soil lost? What was that? The tree did take up <u>minerals</u> from the soil. Soil minerals for plants are like vitamins for us. Plants must have them to grow and stay healthy, but they do not supply the plants with energy. Think about our scientific definition of food (see page 11). Are minerals food for plants by the scientific definition? Explain. ____

____

____

The contrast between the students' predictions and what actually happened in the experiment should be emphasized. Make sure that students realize that the experiment provides evidence that plants do not take in food from the soil. You might ask students a question that gets them thinking again about the biologists' definition of food: Do you think that the soil contains energy that plants can use to live and grow?

Students may begin to wonder at this point, if plants do not get their food from the soil, then where do they get it from? This is an important first step in getting students prepared to find the explanation of photosynthesis sensible.

Students may ask about the tiny bit of weight lost by the soil. The weight lost consisted of minerals that plants absorb through their roots. Plants need these minerals in small amounts for a variety of functions in the plant. They are needed to make the enzymes that regulate photosynthesis, for example, but this idea is not likely to have much meaning for students at this point. It may make sense to some students after photosynthesis has been explained (see p. I-25).

Does "Plant Food" from the Store Provide Food for Plants?

Plant food or fertilizer that you buy in the store contains minerals that help the plants grow better, but it does not supply plants with any energy. Is "plant food" really food by the special scientific definition?____________

Is Water Food For Plants?

Van Helmont thought that his experiment proved that water must be food for plants. He figured that if soil and minerals in the soil were not providing food for the tree, the tree must be getting food from the water. After all, he had been watering the tree regularly for five years.

But remember the scientific definition of food. Water helps the tree to grow, but is it a material that supplies the tree with energy? Think about the evidence from an experiment with grass plants. This is an experiment that you may want to try yourself.

In this experiment grass seeds were planted in some soil, given some water daily, and put in the dark. What do you predict would happen to these seeds? ____

____

This is what happened to the seeds: The seeds did grow in the dark. In fact, they grew into very tall plants, but they were yellowish and looked stringy and unhealthy.

Some other grass seeds were planted in the same kind of soil and given the same amount of water. But they were placed in the light. Do you think the seeds grew? ______

They did grow. At first they did not grow as quickly as the plants in the dark, but they were green and very healthy looking.

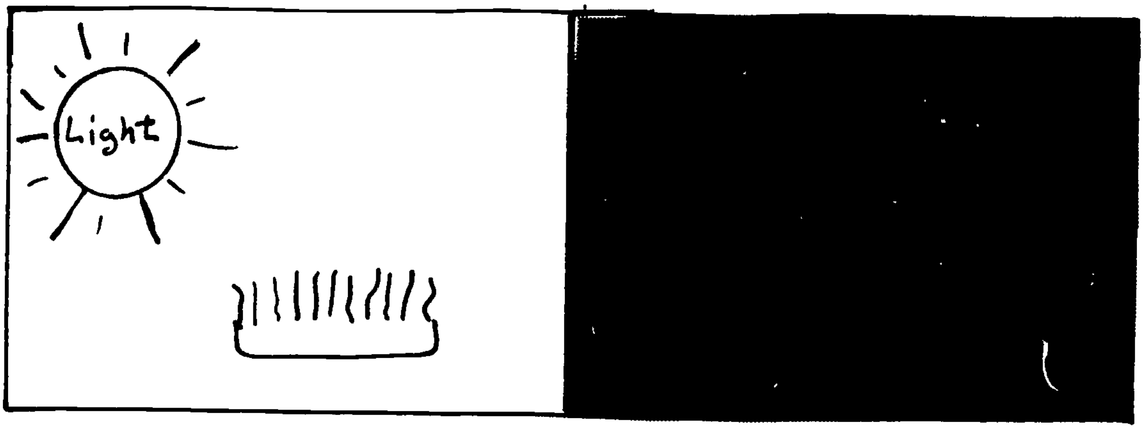
Minerals and Fertilizers

Students may have questions about what minerals and fertilizer do for the plant if they are not food. Why do people spend so much money on fertilizers and minerals? Don't they help plants grow? You might return to the vitamin pill analogy (see p. S-12) in response to such inquiries, emphasizing that minerals are necessary for plants to be healthy, but they do not provide energy for the plant. If the plant had only minerals and not food, it would die. Or you could tell the students you'll return to that question later (see p. I-25).

Students should apply the definition of food to the question about plant food that you buy at the store. They should realize that this material is not food for plants because it does not contain energy that plants can use.

Water is another material that students frequently describe as food for plants. The experiment described here is designed to help students understand that just because something is needed by a plant does not mean that it is an energy-supplying food substance.

Some students may predict incorrectly that seeds will not sprout in the dark. In fact, young plants can start growing using food stored in the seeds.



What do you think would happen to the grass plants that were planted in the dark if they were left in the dark for a long time?__________________

Explain why you think this would happen. ________________________________

____

What do you think would happen to the grass plants in the dark if they are moved into the sunshine?____

Explain why you think this would happen. ________________________________

____

What actually happened in this experiment is that the plants left in the dark died, but the plants that were moved from the dark to the sunshine turned green and got healthy and lived.

The plants in the light and in the dark got the same amount of water. But the plants in the light lived while the plants in the dark died. Read on to find out about how scientists explain these results:

In answering these questions, scientists would talk about the plants dying in the dark because they would be unable to make their own food--they would starve to death. Students, on the other hand, view plants as having multiple sources of food. Thus, in their view the plants in the dark still had food.

Most students will predict correctly that the plants in the dark will die and those moved to the light will live, but for the wrong reasons. Some students associate lack of sunlight and the plants' pale appearance with "poor health" or sickness. Other students engage in circular reasoning: The plants in the dark died because of lack of sunlight, and the reason plants need sunlight is to stay alive. Thus, students do not think about what is happening to the sunlight inside the plant--they just know that it is needed by plants.

Do not try to get students to change their ideas at this point. The contrasts between their answers and those given by scientists are described to students on the next page.

Scientists' Explanation

In the experiment, the grass plants in the light and the grass plants in the dark had the same soil and the same amount of water. Both had the soil and the water, but the plants in the light lived and the plants in the dark died.

The reason the plants in the dark died is that they did not have the energy they needed to continue living and growing. The plants needed water and minerals from the soil, but those things did not supply the energy needed for life and growth. The plants had water and soil, but they had no energy-supplying food. Plants cannot get their energy-containing food from soil or water, so the plants in the dark died from lack of food.

Just like people, plants cannot use water for energy. Water by itself is not food for people, and water by itself is not food for plants.

* * * * * * *

When a plant is looking dry and wilted, what do you do to help it? ______

____

Does this mean that the water is food for the plant?_____Explain.___________

____

____

This question represents an opportunity for students to use the idea that water is not food for plants. If they understood the preceding grass plant experiment, they should respond that water can help a plant in important ways but it does not supply the plant with energy needed for growth and life processes. Refer students back to the definition of food on page 11 if necessary.

This is usually a difficult concept for students to accept. You may need to talk them through the grass plant experiment, pointing out that the plants in the dark had water but still died. You may also want to remind them to think about water for humans--can they live on water alone? The experiment by itself is not always totally convincing to students. Therefore, it is important to emphasize to students that water does not contain energy that living things can use.

Does Sunlight Provide Food for Plants?

The grass plant experiment shows that plants need light to continue living and growing. Does this mean that sunlight is food for plants?

To answer this question we must think back to the scientific definition of food on page 11: Food is only materials that contain energy for living things. Water and minerals are materials that plants need, but they are not food because they do not contain energy. Sunlight is a kind of energy that plants use, but scientists still say that sunlight is not food for plants. Do you know why?

Look carefully at the definition of food again. Sunlight is a kind of energy, but it is not a material. So sunlight does not fit the scientific definition of food, either. It is not itself food for plants.

But sunlight does have something very important to do with food for plants. Scientists have found that plants are able to do something with the sun that no humans or animals are able to do. Neither worms, fish, birds, monkeys, nor people can do what plants can do with the sun.

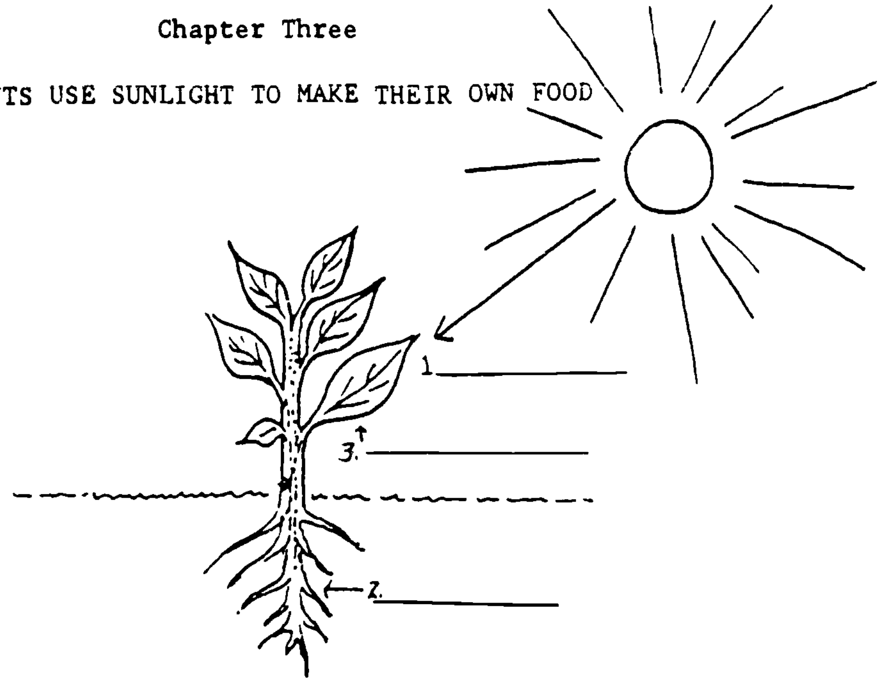
Plants can use the sunlight to make their own food in their leaves.

Read the next section to find out how plants make food inside their leaves.

This discussion is getting students ready for photosynthesis as a reasonable explanation of how plants get food. Each of the things commonly considered by students to be food for plants (water, soil, minerals/fertilizer, and sunlight) is shown not to be food by the scientific definition.

Chapter Three

HOW PLANTS USE SUNLIGHT TO MAKE THEIR OWN FOOD



In order to make energy-containing food, plants need three ingredients: water, sunlight, and carbon dioxide, a gas that is part of the air As you read, label the diagram above to show where each of these three ingredients enters the plant. Then think about what happens to each ingredient when the plant makes food.

The sunlight is absorbed into the leaves. A green pigment (called chlorophyll), that is located in certain cells in the leaves, is able to trap the sun's energy in the leaf. Plants take in water from the soil. The water travels from the roots up tubes inside the plant. Eventually the water reaches the cells in the leaves. Carbon dioxide enters the leaves through tiny holes in the leaves. When all three of these ingredients (sunlight, water, carbon dioxide) are in the leaf cells, the plant can make food.

This food-making process is called photosynthesis. "Photo" means light, and "synthesis" means putting together. Photosynthesis is using light to put together carbon dioxide and water to make food. The energy from the sun is used to split apart the water and carbon dioxide molecules.

On this page photosynthesis is described for the first time. It is described in a different way on pages 23 and 24. In both explanations the important ideas are (a) the transformation of nonenergy-containing matter (carbon dioxide and water) into energy-containing matter (food in the form of glucose) and (b) the change of light energy into energy stored in the food.

Then the pieces of the molecules are rearranged to make a totally new substance. This new substance is energy-containing food, a kind of sugar called glucose.

Only plants are able to use sunlight to make their own food inside their bodies. Imagine if people could make food in this way. All we would have to do when we were hungry is to get plenty of carbon dioxide and water and to stand in the sun. No more trips to the grocery store or to McDonald's! Plants do not get food from the soil, or the water, or the grocery store. They get all the food they need by making it themselves.

Now try using the idea of photosynthesis to explain the experiment with the grass plants on pages 18-19. Why did the plants live in the light but die in the dark? ______________________________

____

____

____

____

A Different Way of Looking at How Plants Make Their Own Food

It is impossible to actually see photosynthesis taking place inside leaf cells. Through a microscope, you an see cells but you cannot see the process of photosynthesis. But to understand photosynthesis, it will help you if you can imagine the kinds of things that are happening inside the leaf cells. If you can make a picture in your mind about photosynthesis, then you will have a good way of understanding and remembering this food-making process.

One kind of mental picture that might help you understand photosynthesis better is a picture of a factory. The leaf of a plant is like a factory in many ways.

Students need to use two main concepts to answer this question: (a) that plants cannot make their food in the dark, and (b) that plants cannot get food from the water or soil.

The students should understand that the only way plants can get food is to make it in their leaves. To do this, they must have sunlight, carbon dioxide, and water. Since the plants in the dark had no sunlight, they could not make food. They starved to death. The plants in the light could make their own food using sunlight, carbon dioxide, and water.

Student answers often focus on plants' need for sunlight without giving any reasons <u>why</u> sunlight is needed. Students should be encouraged to give explanations that focus on the <u>function</u> of light for the plant (to enable them to make their own food).

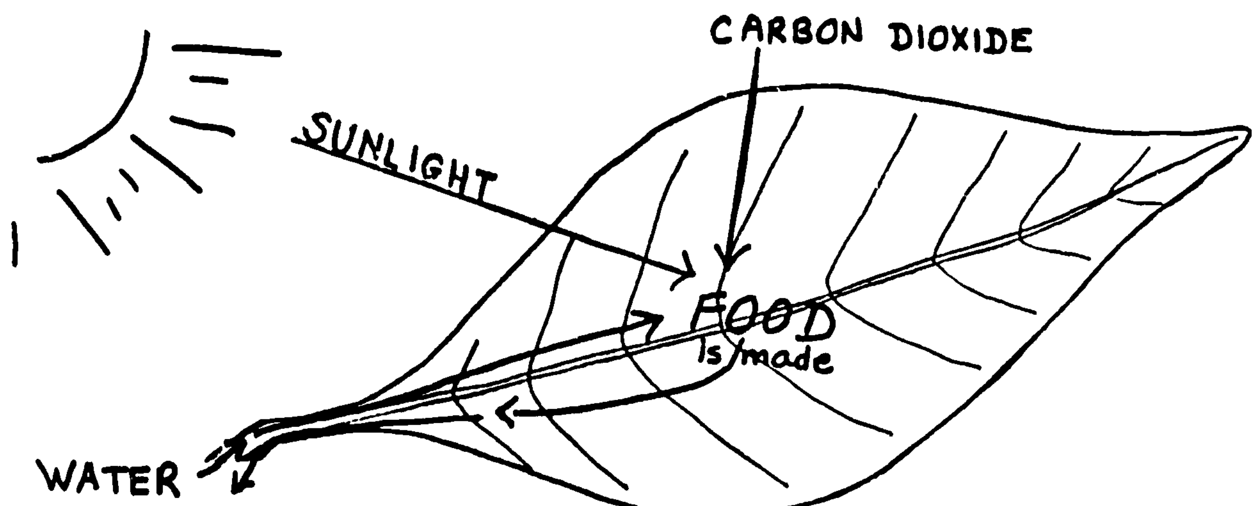
A Food-Making Factory: The Leaf

Steps in making food. First, certain raw materials are taken into the leaf factory. These things will be used to make the food. The raw materials in the food-making process of photosynthesis are carbon dioxide and water. Neither of the raw materials contains any energy that plants can use.

What happens to the nonenergy-containing raw materials when they enter the plant? The carbon dioxide enters the leaf through tiny holes in the leaf's surface. The water enters through the roots and travels up the stem to the leaf. Both the carbon dioxide and the water enter special cells in the leaf that are the only cells that can make food.

These cells have a special ability to absorb and use sunlight. When they absorb sunlight, the energy from the sun causes the carbon dioxide and water to combine in a special way so that a completely new material is formed--food! Unlike water and carbon dioxide this food does contain energy. The energy from the sunlight is now stored in the food! This food can be taken to feed other parts of the plant, or it can be used as food for animals and people.

Another product of photosynthesis is the gas oxygen. Although plants and animals need oxygen, it is not the main product of photosynthesis. The most important thing that the leaf factory makes is food.



Emphasize this transformation of raw materials into food.

The issue of oxygen as a product of photosynthesis is not emphasized in this text because it frequently confuses students who are used to thinking about plants "breathing in" carbon dioxide and "breathing out" oxygen. When these students read about oxygen being a product of photosynthesis, they tend to forget about the food issue. To them, the importance of photosynthesis is in turning carbon dioxide into oxygen, when in fact oxygen is simply a by-product of the food-making process.

We would recommend omitting or downplaying the oxygen issue with most middle school students, but you may want to include it either because you feel your students are capable of handling it (they are not having difficulty with any of the issues being addressed so far) or because you are using other materials that talk about oxygen production.

Check Your Understanding of the Leaf Factory

Check back to the description of the leaf factory on p. 24 if you need help in filling out this chart:

What things go into the leaf factory?	Does it contain energy?	Is it food for the plant?	Is it needed for photosyn?

What things go out of the leaf factory?	Does it contain energy?	Is it food for the plant?	Is it needed by plants?

What Happens to Food from the Leaf Factory?

One special thing about the leaf factory is that it is the only "factory" on earth that can make food out of carbon dioxide and water. People have not been able to steal the leaf factory's secret to build their own food-making factories. People have built bakeries that can take food made by the plant and change its form to make bread, doughnuts, or cookies. But no manmade factory can make food out of carbon dioxide and water! We have not figured out the secret of how to take sunlight energy and change it into food energy. Without the plant and its leaf factory, we would have no food.

Students should fill in the chart in a way compatible with the following:

What things go into the leaf factory?	Does it contain energy?	Is it food for the plant?	Is it needed for photosynthesis?
water	no	no	yes
carbon dioxide	no	no	yes
sunlight	no--it <u>is</u> energy	no	yes
minerals	no	no	no (not directly)

<u>Are minerals needed for photosynthesis?</u>

This is an appropriate place to return to the minerals issue raised on p. S-18. Although minerals are not energy-supplying food for the plant and although they are not directly involved in photosynthesis, they <u>are</u> necessary for the plant's health. Several minerals are critical in supporting photosynthesis. For example, magnesium is part of the chlorophyll molecule. Other minerals are needed to make the enzymes that regulate the chemical reactions of the dark phase of photosynthesis.

<u>Discussion questions</u>: Can plants grow if their roots are not in soil? Explain that plants need minerals they take in from the soil. Without minerals plants will get sickly and photosynthesis may be disrupted, leaving the plant with less food energy. Death can result. Plants can be grown with their roots in water if the necessary minerals are dissolved in the water.

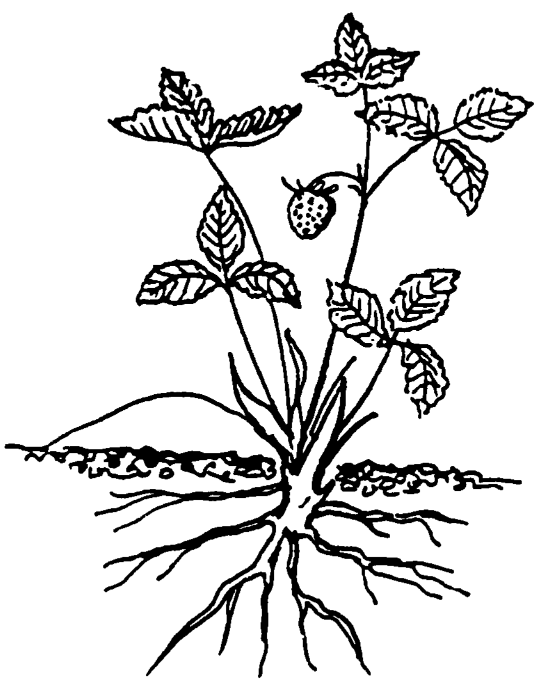
What things go out of the leaf factory?	Does it contain energy?	Is it food for the plant?	Is it needed by plants?
food	yes	yes	yes
(oxygen)	(no)	(no)	(yes)

Photosynthesis makes only one kind of food: the sugar glucose. Sometimes leaf cells use that glucose for their own food, but many other things happen to the glucose, too. This food travels from the leaves to <u>all</u> the other parts of the plant, where it can be used by plant cells for energy and growth. This is the only way cells in the roots or the stems or the flowers can get the energy-containing food that they need.

Plants also <u>store</u> some of the food they make. Potatoes and carrots are plants' ways of storing food underground. Seeds also contain food that the mother plant stores up to help the young plant get started.

When plants store food, they usually change it from glucose to some other kind of food, such as starches or fats. Animals can also change food from one form to another. For example, a cow eats one kind of food--grass--and changes it into another kind of food--milk. <u>All of the food on earth, though, started out as glucose made through photosynthesis.</u> And only green plants can make that glucose.

Draw arrows to show how you think food moves in a strawberry plant:



This section emphasizes that the food made during photosynthesis is the only food for the cells of the plant. Students usually trace food from the outside environment into the plant. Now they should be able to trace the food from the leaf to all other parts of the plant. Some students interpret photosynthesis as the way that plants make food for people and animals. They think about plants continuing to get their own food from the soil or water. These students will need support in understanding that the food for the plant comes from photosynthesis. (See transparencies 4 and 5.)

For comments on why plants need soil, see I-25 and Question 6 on pages S-30 and I-30.

Putting it Altogether--Food for Plants

We have seen that energy-containing food for plants does not come from the soil, or from the water, or from fertilizer, or from minerals. Plants do not take in food from their environment.

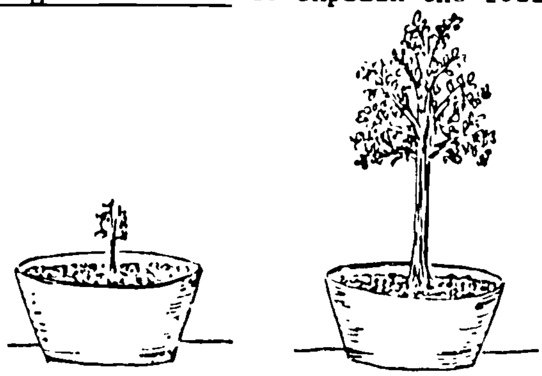
Instead, plants have an unusual ability to use energy from the sun to change water and carbon dioxide into energy-containing food. As long as plants have light, carbon dioxide, and water, they can make their own food in this complicated process called photosynthesis. If plants do not have light, they will die. They cannot make food in the dark. They can only get food by making it themselves in the sunlight.

This is an appropriate place to use transparencies 1-6 and/or the laboratory activities.

Transparencies 1-6 may be found in the chapter that begins on page I-33. The two laboratory acctivities may be found on pages I-39 and I-50.

Now let's try using these ideas to explain the following situations:

1.



Think back to Van Helmont's experiment (pp. 16-17). The tree gained 164 pounds over the five years.

Where did the extra 164 pounds come from? Explain your answer as fully as you can.

2. A box was placed over the top of a plant so that all of the plant was covered except for one leaf. The plant was watered and had plenty of air, but only that one leaf could receive sunlight.

What do you predict would happen?

Why?

3. A drop of rain falls into the soil near the roots of a large bean plant.

Describe what will happen to that water if it is taken into the plant.

In discussing each of the following application questions, listen carefully to students' answers to detect whether any misconceptions are persisting. Do not hesitate to ask students to clarify or develop their answers further. Encourage students to refer back to the goal concepts described on p. 27 of their text.

1. The students should say that the food responsible for the tree's weight gain was manufactured in the leaves from water and carbon dioxide, then distributed to all the growing parts of the tree and either stored or used for growth and the production of new cells.

2. Students should use the concepts that (a) plants need sunlight in order to make their own food and (b) that the food made during photosynthesis travels throughout the plant to "feed" all cells in the plant. Their predictions and explanations might vary, but they should address the issue of the movement of food from the one leaf that can still make food. Students may appropriately argue whether the food made in this leaf will or will not be sufficient to feed the rest of the plant.

3. Students should describe how the water travels from the roots up the stem to the leaves, where it is used to make food. (Much of the water reaching the leaves also evaporates into the atmosphere, but this process, transpiration, is not emphasized in this unit.)

Chapter Four

USING YOUR KNOWLEDGE ABOUT FOOD FOR PLANTS

Now you understand these key concepts about what food is for plants and about where plants get their food:

- Food is materials that contain energy that living things need.
- Plants do not take in food from their environment. Soil, water, fertilizer, sun, and carbon dioxide are not food for plants.
- Plants can only get their energy-supplying food by making it themselves in special cells in their leaves.
- Plants use energy from the sun to change nonenergy-containing water and carbon dioxide into energy-containing food.
- Food made in the leaf cells travels to all cells of the plant. Extra food made by the plant is stored in seeds or other plants parts.

Now use these concepts to explain the following situations. Use explanations that tell what is happening inside the plant and that talk about plants' source of food:

1. Some plants were put in soil, given water, and placed in a tightly sealed bottle so they could not get any air. Will the plants in the jar have a food source? Explain.

____

____

____

____

2. Some large and some small seeds were caught in an animal's fur. The animal went into a dark, abandoned mine. There was no light in the mine. The seeds fell out of the animal's fur. Plants began to grow in the moist mine. Do you think the plants will survive? Why?

____

____

____

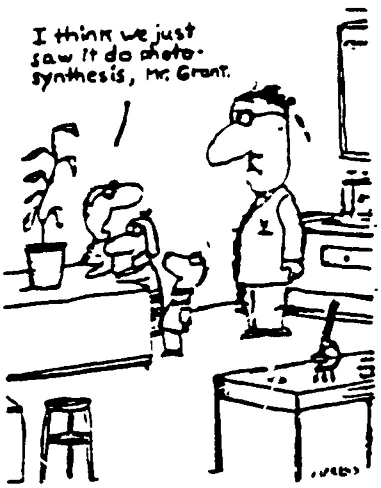
Encourage students to draw from this list of key concepts in developing explanations for each of the following application questions. Again, listen carefully to student answers and challenge students to clarify their answers and to develop their answers more fully.

1. The key concepts are that plants must have carbon dioxide from the air, water, and sun to make food, and that plants have no other source of food. The plants will not be able to make their own food because carbon dioxide is needed for the photosynthesis to take place. Therefore, the plants will have no food when the carbon dioxide in the bottle is used up.

Students who still believe that plants have multiple sources of food may say that the plant has some food (water, minerals) but not enough. Others may ignore the food source part of the question and focus on plants' "need" for air. They will predict that the plant will die because of lack of carbon dioxide, but they will not connect the carbon dioxide issue to the food source issue.

2. This question also concerns a situation in which one of the key ingredients for food making is missing, in this case light. The seeds can start growing with food from the cotyledons, but they must have sunlight when that food is used up.

3. Explain why Mr. Grant is so surprised by what his student is saying in the following cartoon.



4. Some people use an equation to describe photosynthesis. Explain what this equation means:

water + carbon dioxide + light energy --------> food (+ oxygen)

5. When plants make more food than they need, the extra food is stored in a part of the plant called a fruit or vegetable. When you eat a carrot, where did that food originally come from?

6. If plants can make food out of sunlight, water, and carbon dioxide, why do they need soil?

3. The key concept here is that photosynthesis takes place inside the plant, and we cannot see it happening. Scientists have done many experiments to learn about what is happening inside the plant, but we cannot <u>see</u> this process taking place. We can, however, use our knowledge of this process to make sense of what we see.

4. The key concept here is that in photosynthesis, water, carbon dioxide, and light are combined to produce a <u>new</u> substance, food. They are changed into food and oxygen.

5. The key concept is that plants make food inside their leaves and that food then travels to other plant parts. The food in the carrot was made in the leaves by the process of photosynthesis. Carbon dioxide and water were changed into food. Some of that food later traveled to the plant's root and was stored there.

6. Watch out for student answers that talk about plants getting food from the soil! Instead, they should describe the plant's need for nonenergy containing minerals that are essential for plant health (in building enzymes, chlorophyll, etc.).

Summary: How Food for Plants is Different from Food for Humans

On p. 13 we said that both plants and humans need food because it gives them the energy they need to grow and to keep all their parts functioning and living. Both plants and humans need food for the same reason--energy. Now that we have investigated food for plants, it is clear that plants get their food very differently from humans. The next paragraph will describe some of the differences. After you read the paragraph, read it again to help you fill in the following chart:

	How many sources of food?	What is their food?	Where do they get their food?	How do they get their food?	When can they get/make their food?
HUMANS					
PLANTS					

Humans have <u>many</u> sources of food and eat a wide variety of foods. For example, they grow plants, raise cattle, catch fish, hunt deer. They get their food from those other plants and animals and they can get it at any time of the day or night.

Plants have only <u>one</u> source of food. Plants make food inside their bodies. They do not take it in from outside. This process of making food inside the plant requires sunlight. Therefore, plants can only make food in the sunlight.

Transparencies 1-6 can also be used as a good summary activity The transparencies begin on page I-33. Transparencies 1-6 are recommended here as well as on p. I-27.

	How many sources of food?	What is their food?	Where do they get their food?	How do they get their food?	When can they get/make their food?
HUMANS	Many	Meat, vegetables, etc.	From plants and other animals	Growing plants hunting, fishing, etc.	Anytime
PLANTS	One	What they make during photosynthesis	From inside themselves	By making it themselves	In daylight <u>only</u>

SUMMARY: Correcting Your Description of Food for Plants

Look back at what you said about food for plants at the beginning of this chapter (p. 14).

1. How would you change your statements about how plants get food to make them more accurate?

____

____

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____

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2. What did you leave out of your answer about what kind of food plants use that you can now add to tell the whole story about photosynthesis and food for plants?

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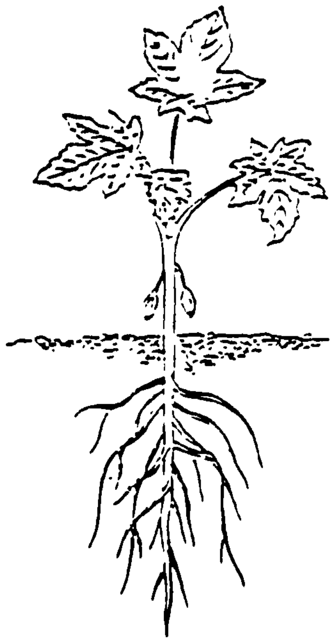
3. How would you now use arrows to show how food travels in a plant?



The students' answers should reflect two main concepts.

1. Students should now be able to state that raw materials (air, water, sun, fertilizer) taken in by plants are not food for the plants, because they do not contain energy that plants can use.

2. Students should explain that plants get food only by making it themselves by combining carbon dioxide and water in the presence of sunlight. This process is called photosynthesis.

It is important that students see the incompatibility between their misconceptions and the scientific conception of food for plants.

As part of this final discussion, you may want to discuss with students the title of the text and the picture of the "Power Plant." We certainly do not want students leaving the unit with the misconception that plants have muscles! You might ask students: Plants don't really have muscles and can't really lift weights, but in what ways is a plant powerful? The plant's unique ability to use energy from the sun, carbon dioxide, and water to produce energy-containing food should be emphasized. (See Transparencies 4 and/or 5.)

III. OVERHEAD TRANSPARENCY SET

This series of overhead transparencies provides opportunities for students to use many of the new concepts that they have learned. They focus students' attention on most of the important issues discussed in the introduction. Class discussions accompanying the use of these transparencies should permit students opportunities to explain and use scientific reasoning about plants and photosynthesis.

Each of the transparencies poses a question for students to answer. During class discussion, you can elicit student responses to each question from a number of different students. Their answers will reflect whether they are using the scientific conceptions described above or whether they are continuing to rely on naive ways of thinking about plants and their food.

After a number of students have responded to a question, flip over the overlay, which gives a scientific answer. For students who answered the question incorrectly, this overlay will provide immediate feedback to them about ways in which their thinking does not match scientific ways of thinking about photosynthesis. <u>Make sure that students notice any differences between their answers and the answers on the overlays.</u> Also help students who give correct answers to recognize how the scientific conceptions are different from what they used to believe.

The last two transparencies can be used by themselves or in conjunction with the laboratory activities in Part IV. These transparencies emphasize that all food for plants and animals ultimately comes from photosynthesis that occurs in the leaves of green plants.

Transparency 5 will be easier for students to follow if you use transparency marking pens to color code the pathways followed by water, light, carbon dioxide, and food.

Transparencies 1A and 1B

Q: What happens to water inside a green plant?

Students usually talk about water being taken in through the roots and up to the leaves, but they often neglect to mention the changes that water undergoes during photosynthesis in the leaf cells. They also frequently do not talk about the function of water as an ingredient in the food-making process.

In discussing Transparency 1A and 1B with the students, you might want to pose questions like the following:

-Do biologists define water as a food? Explain.
(No--it does not contain energy for living things to use.)
-Tell me what is included in the scientists' answer to this question that you did not include in your answer to the question (before I flipped the overlay).
-Some people say that plants need water "to drink." Tell how water is really used inside a plant. (One important function of water inside plants is as an ingredient in photosynthesis.)

NOTE: Much of the water that reaches the leaves also evaporates into the air: the process of transpiration.

Transparencies 2A and 2B

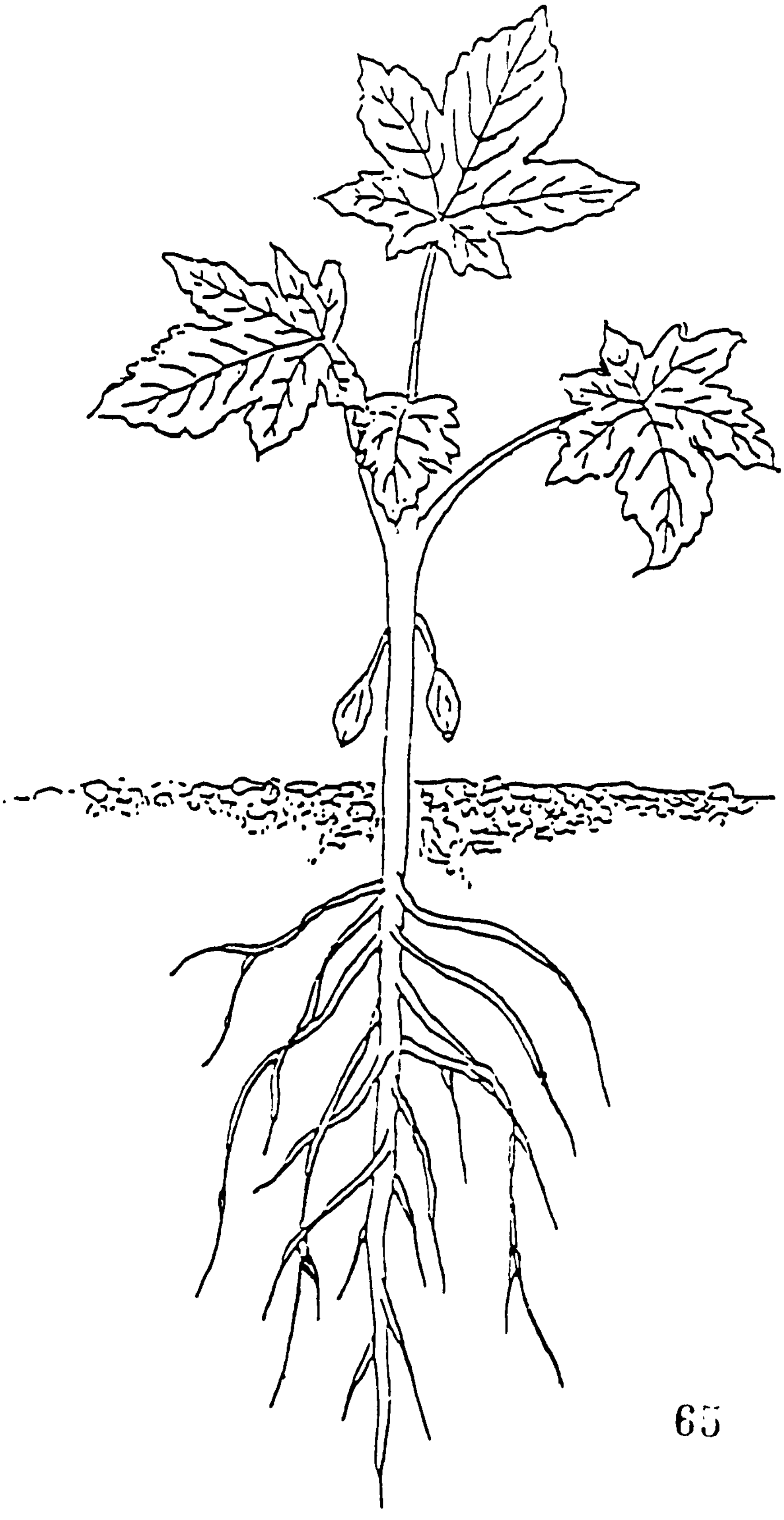
Q: What happens to carbon dioxide inside a plant?

Many students believe that plants take in carbon dioxide to breathe--just the way people breathe oxygen. Other students add that the carbon dioxide is changed into oxygen inside the plant. Most students see no connection between carbon dioxide and other substances such as water and food.

Transparencies 2A and 2B emphasize that carbon dioxide is used to make food during photosynthesis. This is very different from the way people use oxygen! Thus, the analogy between plants' use of carbon dioxide and breathing in humans is a poor one.

Possible additional questions you might ask include:
-Some people say that plants need carbon dioxide for "breathing." What do plants really use carbon dioxide for? (photosynthesis)
-How does carbon dioxide get changed into food? (energy from sunlight is used to combine it with water in leaf cells)
-What is one critical difference between carbon dioxide and food made during photosynthesis? (food contains usable energy)

Q: What happens to water inside a green plant?



Transparency 1A

Photosynthesis

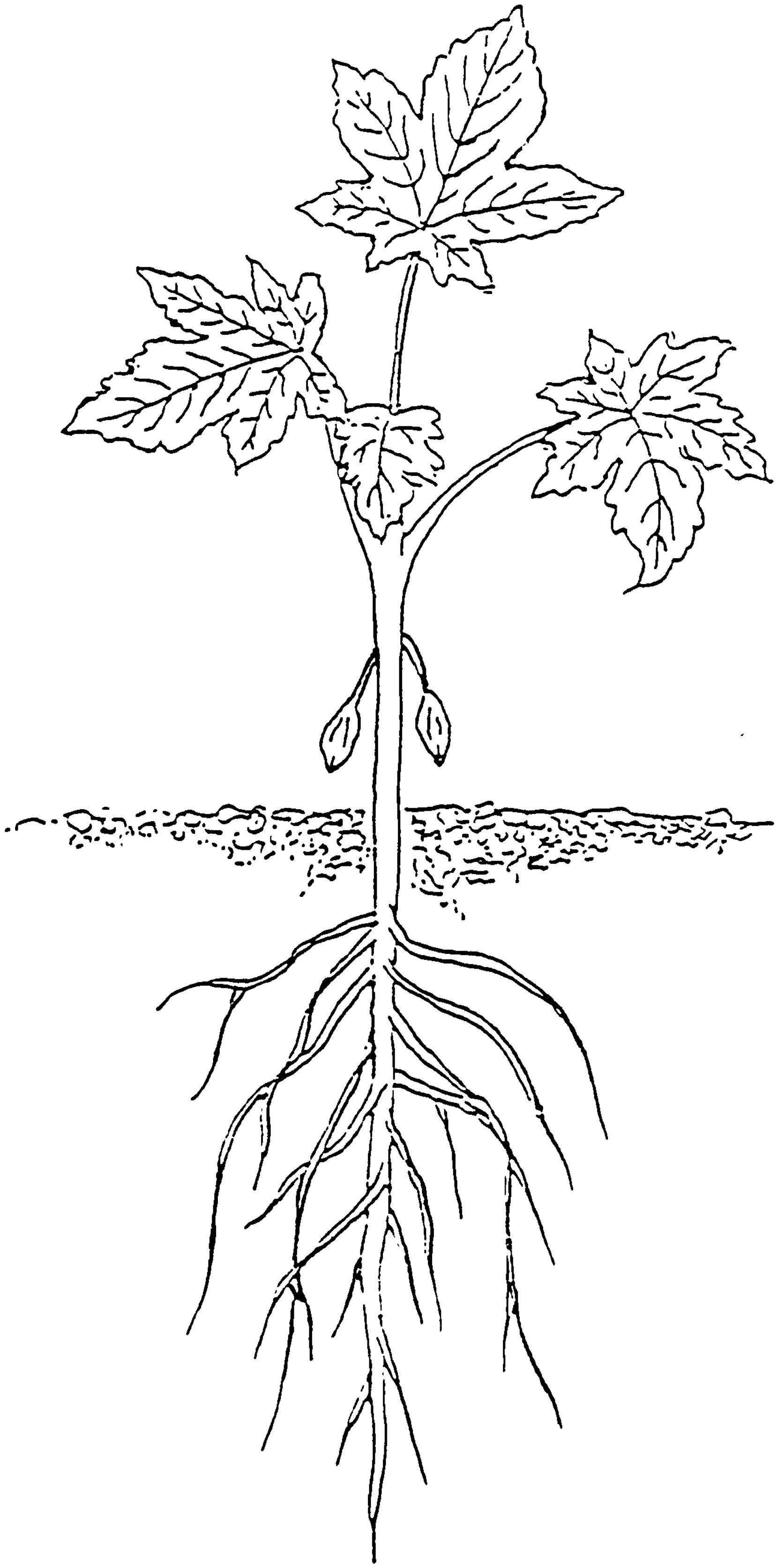
Used to make food

A: Water travels to the leaf cells where it is used for photosynthesis.

(Some water also evaporates from the leaves.)

Transparency 1B

Q: What happens to carbon dioxide inside a green plant?



Transparency 2A

Photosynthesis

A: Carbon dioxide goes into leaf cells
where it is used
for photosynthesis

Used to make food

Transparency 2B

Transparencies 3A and 3B

Q: What happens to light energy inside a green plant?

The first two transparencies showed how matter taken into the plants was changed into food during photosynthesis. Transparencies 3A and 3B focus on the change in energy that occurs during photosynthesis. Light energy from the sun is changed into energy stored in food that is made in plants' leaves and is now available for all plant cells to use for life processes. This energy is in a form that animals can use for their life processes. Only special cells in the leaves of green plants are able to change energy in this way.

Students tend to think about energy from the sun as surrounding the plant and giving it warmth and "things it needs." They do not think about it entering the plant cells and being changed in form. They also do not think about the sun as being plants' only source of energy, so they fail to appreciate the critical importance of plants' ability to make this energy change.

Questions that might be helpful:

- Do other things that plants need provide them with energy? What about water? fertilizer? minerals? carbon dioxide? (No, sunlight is plants' only source of energy.)

- Can anything else besides leaf cells change light energy from the sun into energy stored in food? Can humans do it? (NO - only leaf cells in plants can do it).

Transparencies 4A and 4B

Q: How does food travel in a plant?

Transparencies 4A and 4B focus on the plant's dependence on photosynthesis in making energy-supplying food for itself. It cannot take in such food from the external environment. Students may still be tempted to think about food as moving from the outside environment (soil, air) into the plant. Instead, they should trace the food made in the leaf during photosynthesis as it moves to feed all parts of the plant. They should not draw arrows going into the plant from the soil or air. If they do, they need to think more about the definition of food as materials containing energy.

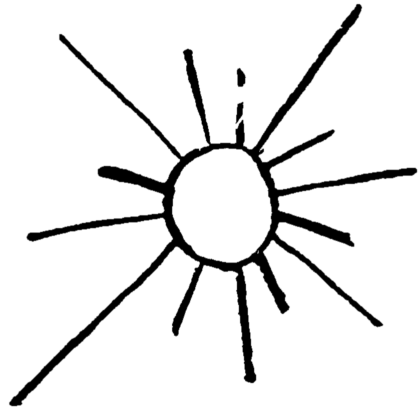
Transparencies 5A and 5B--Putting It Altogether

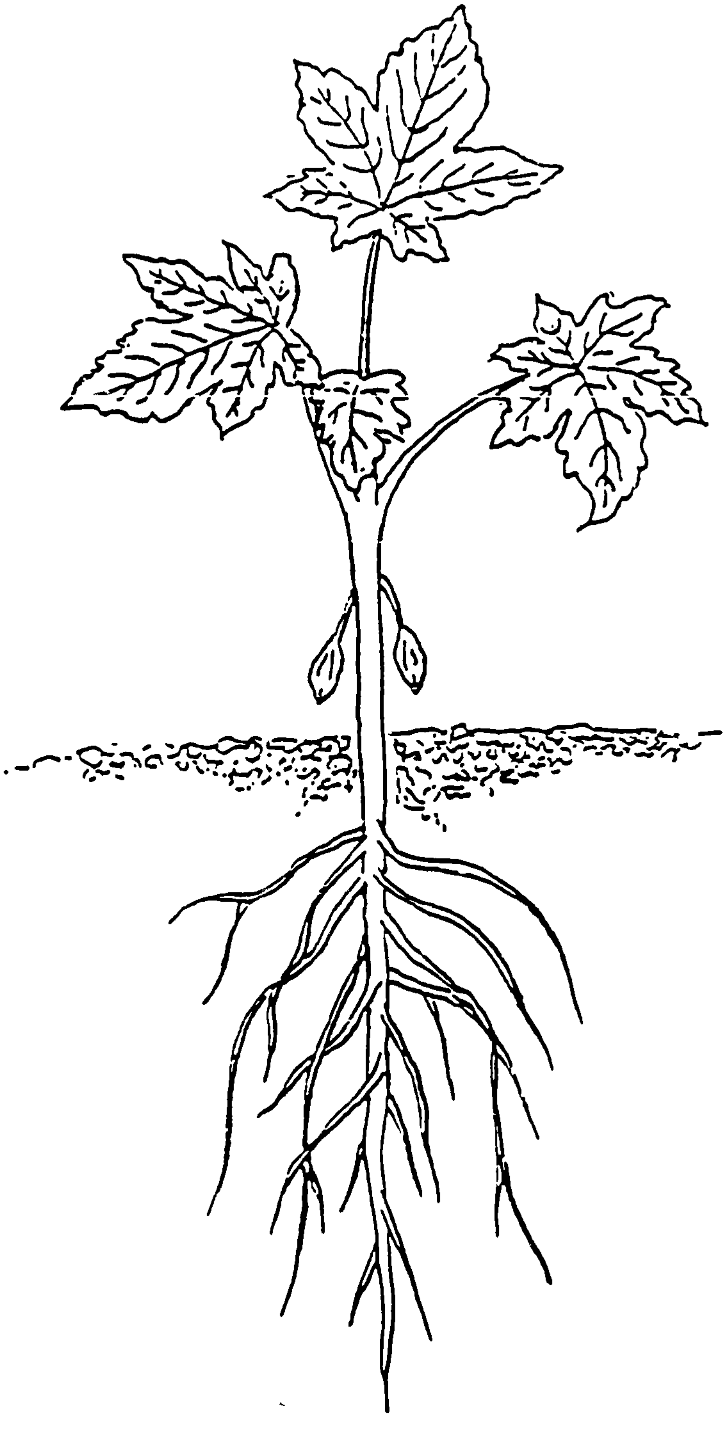
Q: What happens to water, carbon dioxide, light, and energy, inside a plant?

Transparencies 5A and 5B allow students to put several concepts together to make a sensible story about what happens in plants during photosynthesis. With this overhead emphasize the coming together of water, carbon dioxide, and sunlight in the leaf. All three must be present and combine in a special way to make food.

Students tend to think about each one of the three ingredients for photosynthesis as functioning independently within the plant. They talk about plants needing sunlight for warmth, water to drink, and carbon dioxide to breathe. Thus, they are each involved in separate life processes. This overhead should present a graphic contrast to that way of thinking.

Q: What happens to light energy inside a green plant?





Transparency 3A

Photosynthesis

Changed

into food

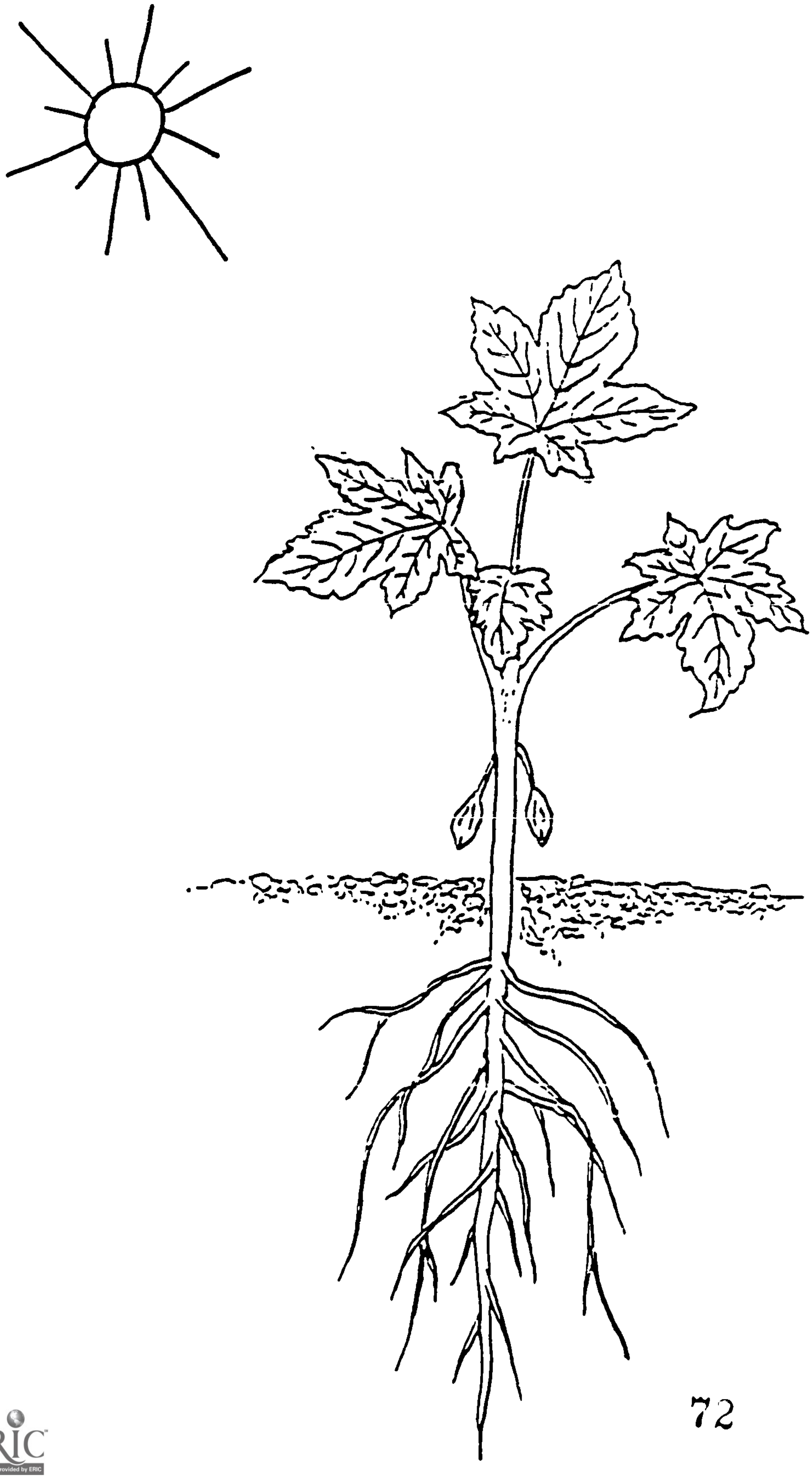
energy

A: Light energy is absorbed by special leaf cells.

During photosynthesis the light energy is changed into energy stored in food.

Transparency 3B

Q: How does food travel in a green plant?

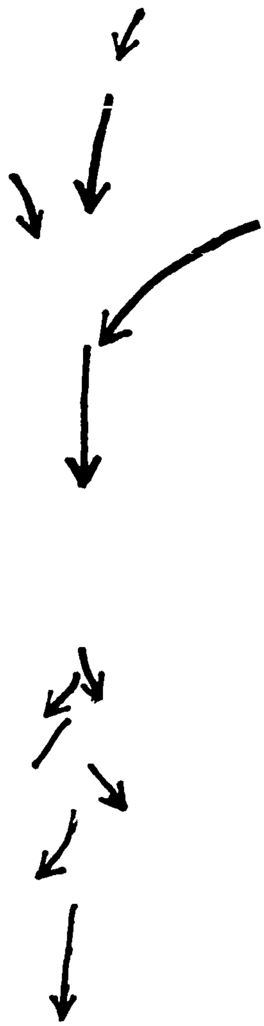


Transparency 4A

A: Food is made by the plant in the leaf during photosynthesis.

The food then travels to all parts of the plant.

made in leaves

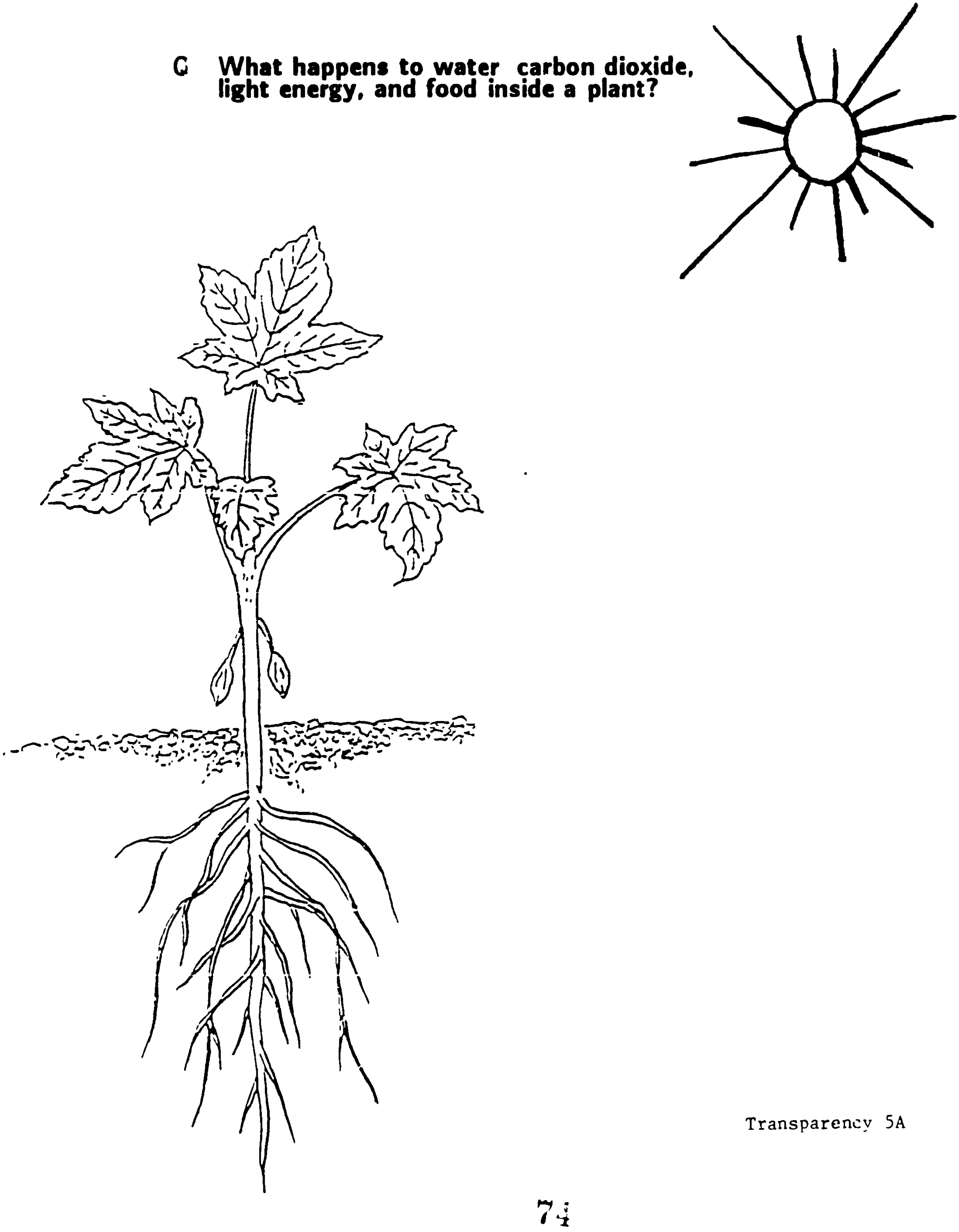


This is the plant's only source of food!

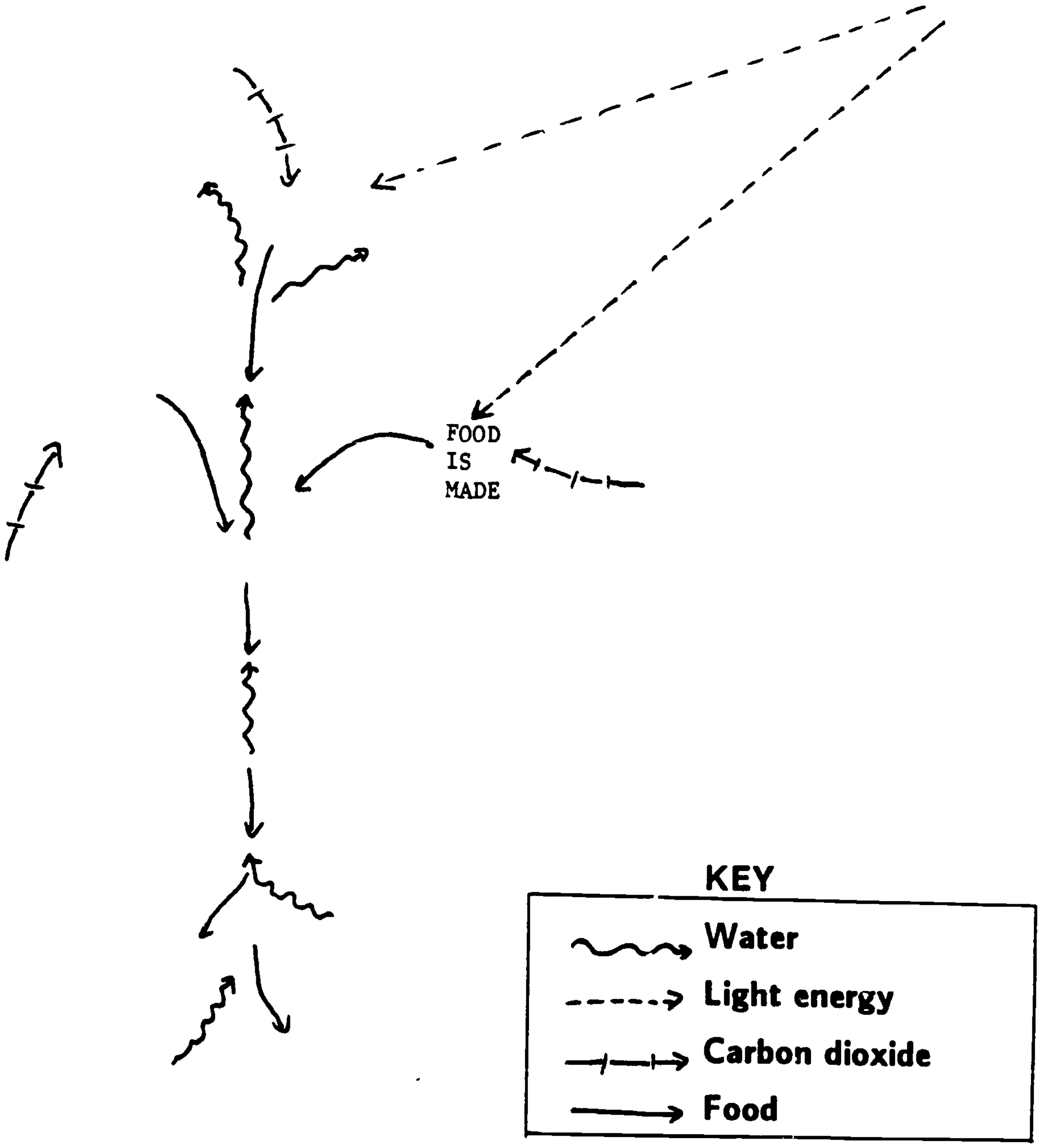
Transparency 4B

PUTTING IT ALL TOGETHER!

Q What happens to water carbon dioxide, light energy, and food inside a plant?



Transparency 5A



Transparency 5B

Transparencies 6A and 6B

Q: How does food travel in a potato plant?

Plants not only produce food for immediate use. They also store some of the food that is made during photosynthesis. Some plants, like the potato, store the excess food made in the leaf cells during photosynthesis in the roots. Emphasize that this stored food, often eaten by animals or people, originated in photosynthesis in the plants' leaves.

Transparencies 6A and 6B trace the food from photosynthesis in the leaves down to the potato root. They should not draw arrows showing food moving into the plant from the external environment.

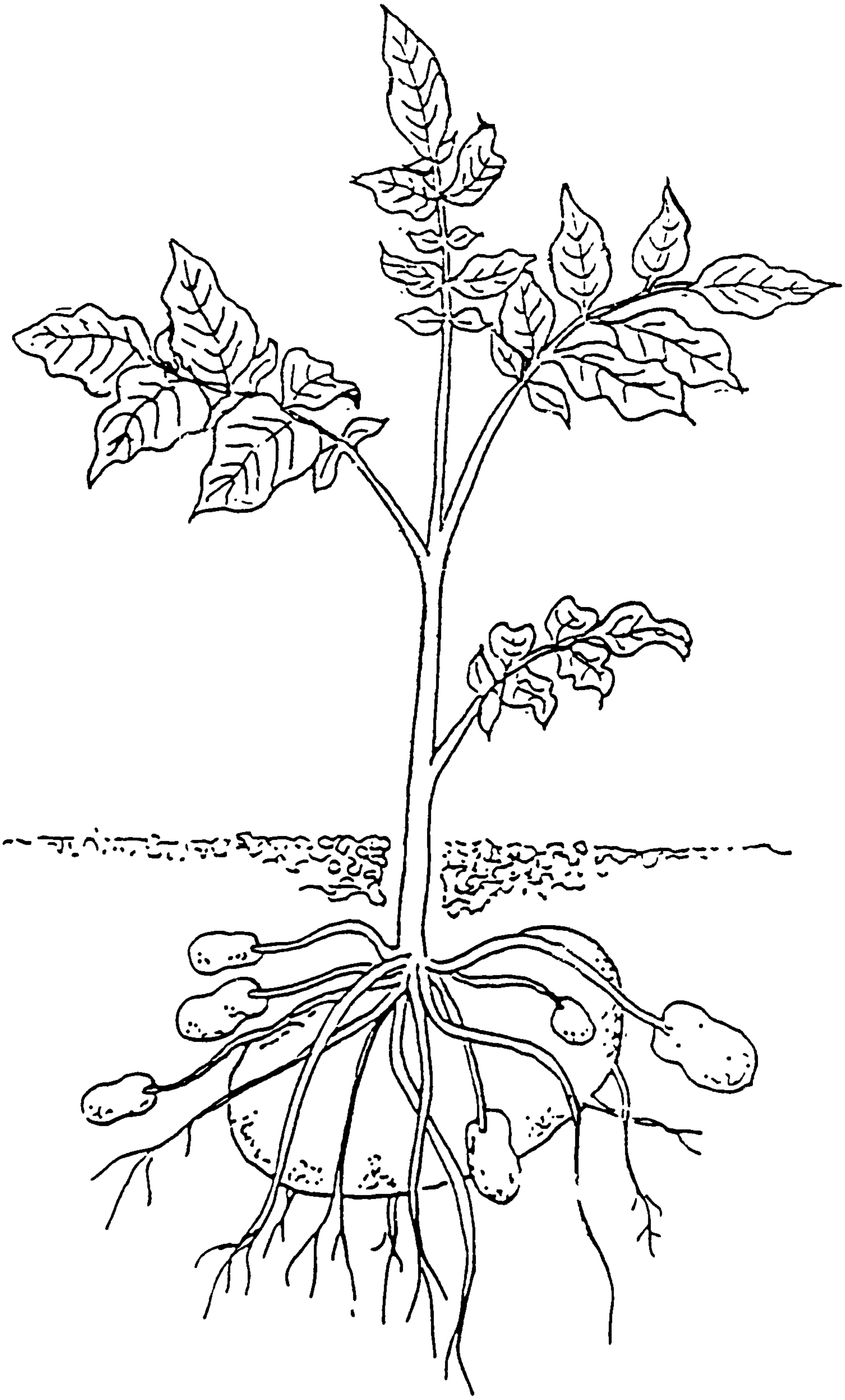
Transparencies 7A and 7B

Q: How does food travel in a young plant?

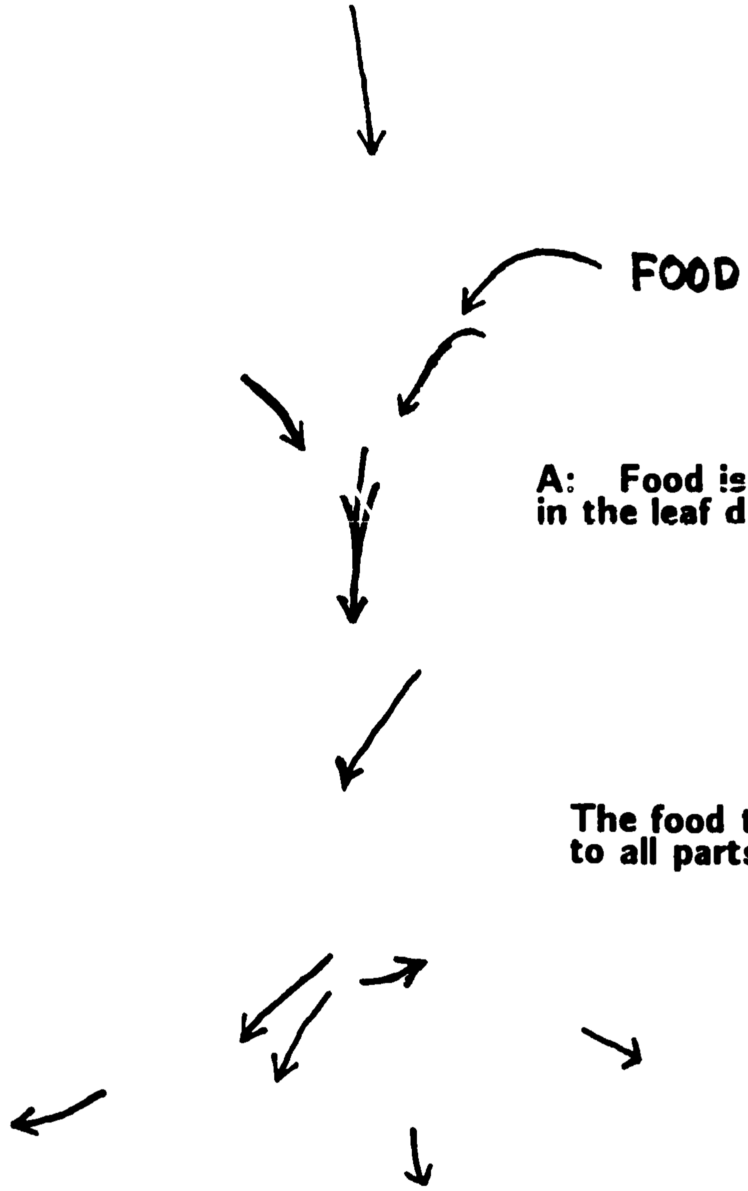
Plants need water, carbon dioxide, and sunlight to make their own food. So how do young plants just starting out from seed get food? At first, they are in the dark and do not have green leaves. These seedlings get food that was made by the parent plant during photosynthesis. When the seed fell off, it contained this energy-containing food in its seed (in the cotyledons). Until the seedling has developed leaves that can absorb sunlight, it gets its food from the seed. Therefore, students should describe food as moving out from the seed to all other parts of the seedling. Soon, however, the seedling will use up all that food and will be able to make its own food through photosynthesis.

Students usually find it easy to believe that food is stored in the seed or cotyledon. It is more difficult for them to understand where that food came from. With Transparencies 7A and 7B be sure to discuss with students how the food in the seed's cotyledon originated in photosynthesis.

Q: How does food travel in a potato plant?



Transparency 6A



A: Food is made by the plant in the leaf during photosynthesis.

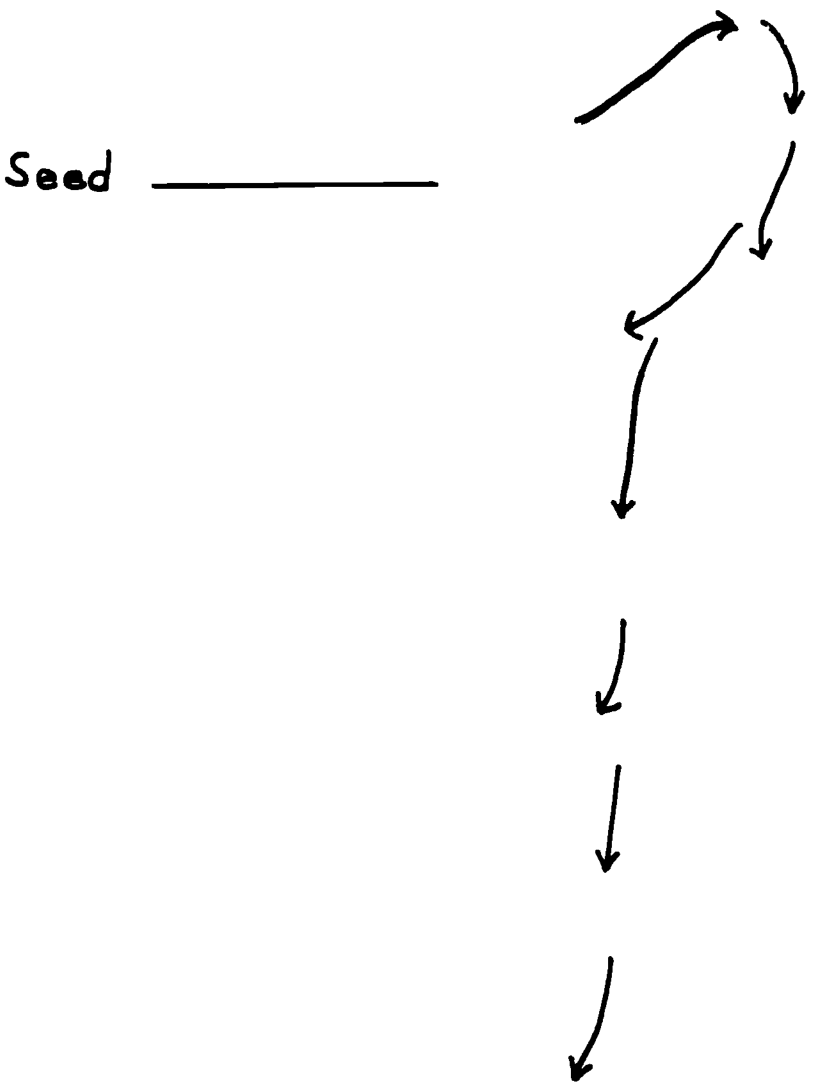
The food then travels to all parts of the plant.

Extra food made during photosynthesis is stored in the roots--you call this food a potato!

Transparency 6B

Q: How does food travel in a young plant?

Transparency 7A



A: An adult plant stores some of the food it makes during photosynthesis in seeds. When the seed falls off it can use this food to begin to grow.

Later, it will have leaves and can begin to grow to make its own food.

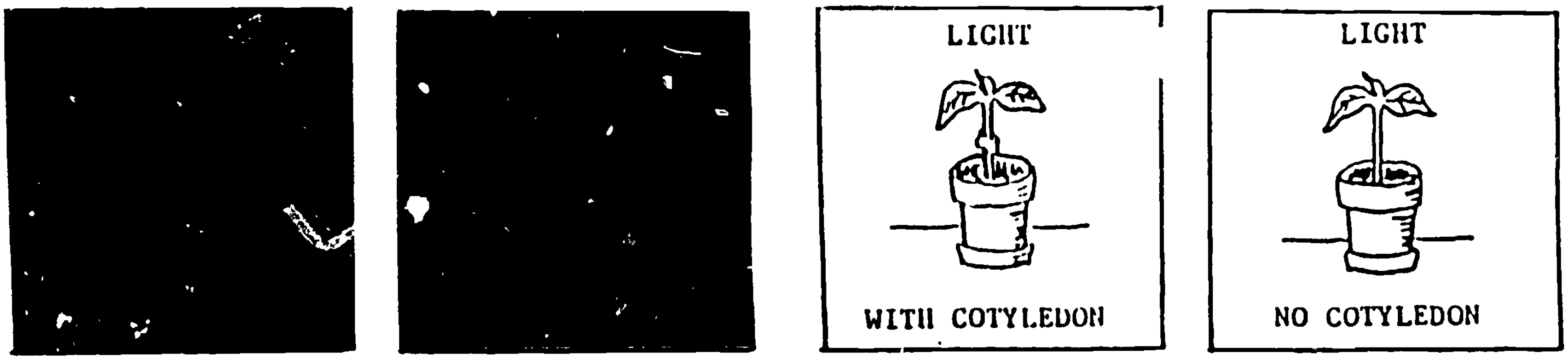
Transparencies 8A and 8B

Laboratory Activity Two:
Using Photosynthesis to Explain an Experiment

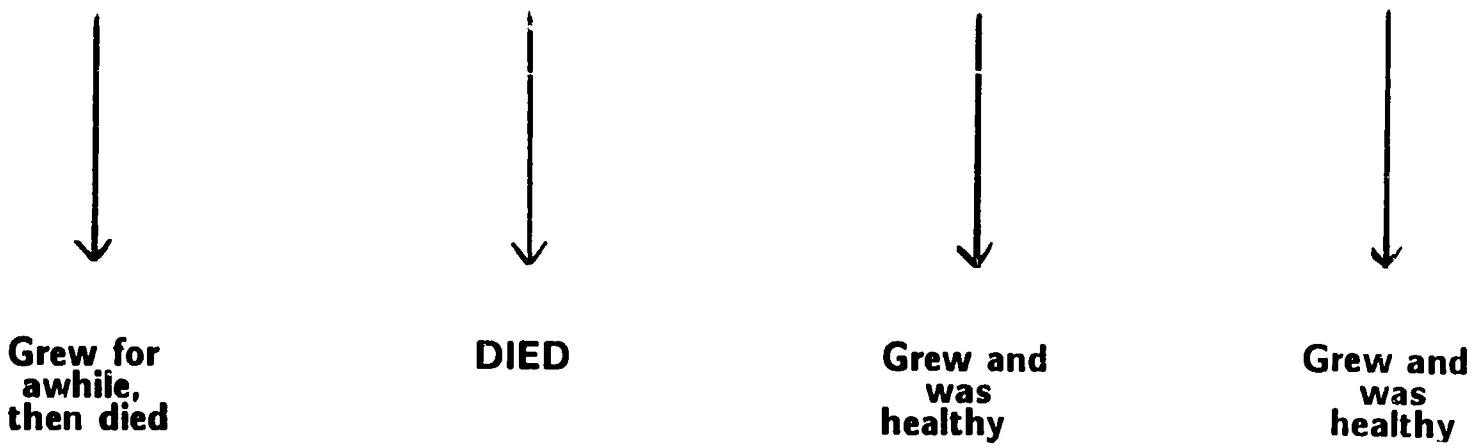
If students are drylabbing this experiment, it will be helpful to use Transparency 8 to make sure that the students first are very clear on the four experimental conditions. After the students have worked through the text to make their predictions, the overlay can be flipped over to show what happened to the four plants.

Laboratory Activity Two

Using Photosynthesis to Explain an Experiment



Transparency 8A



Transparency 8B

IV. LABORATORY ACTIVITIES

Laboratory Activity One: Food in Plants

This lab activity is designed to focus students' attention on the idea that the food made during photosynthesis travels from the leaf to all parts of the plant where it is used as food. This food is the plant's only source of food.

In the lab, students test various plant parts and find that each contains one kind of food--starch. Starch consists of chains of the glucose molecules that were made in the leaf during photosynthesis. Starch is tested for in this lab because of the simplicity of the starch test. However, students should realize that the glucose made during photosynthesis can also be changed into other kinds of food.

The questions that accompany the activities are an important part of the lab. They involve students in tracing the food made in the leaf during photosynthesis to several parts of the plant--the seed, a fruit and a vegetable, and the stem.

Most students have never thought about how the food in a potato or in a banana got there. With their new understanding of photosynthesis, they can explain what is happening inside the plant. Thus, the lab provides a way of showing students that the concept of photosynthesis can help them make better sense of things in their everyday world.

Transparencies 6 and 7 are appropriate accompaniments to a discussion of this lab. They give students an additional opportunity to use and apply the idea that food made during photosynthesis is then used by all the plant's parts as food.

Because each part of this six-part lab is presented on a separate student worksheet, it can be easily shortened by eliminating one or more of the parts. If parts are skipped, make appropriate adjustments in subsequent question-asking.

1. Testing Foods for Starch--basically an opportunity to practice using the indicator.
2. Testing Water for Starch
3. Testing Seeds for Starch
4. Testing a Vegetable and a Fruit for Starch
5. Testing a Stem for Starch
6. Making Sense of the Experiment--series of questions about the activities.

The materials listed below are needed to do the complete lab. Quantities will depend on whether students work in pairs or groups. Some the activities may also be effective as a teacher demonstration.

- medicine droppers
- IKI solution (Dissolve 15 grams of KI (potassium iodide) in 1 liter of water)
- foods to test
  - potatoes, cut in slices
  - bananas, cut in slices
  - celery stalks, cut in slices
  - bread
  - other foods of your choice (including liquids)
- small jars (baby food size) or test tubes; 2-3 per group
- shallow flat dish (petri dish)
- bean seeds (soak in water 24 hours ahead of time)

Testing Foods for Starch

In this experiment, we will test different plant parts to see if they contain food made by the plant during photosynthesis. The plant makes sugar (glucose) during photosynthesis, but the plant cells can change sugar to starch. Plant cells convert extra sugar to starch for storage. Since starch is easier to test for than sugar, we will investigate what plant parts contain starch.

Starch does contain energy. Is it a food for the plant? _____ Explain.

____

____

____

Before testing plant parts, you need to learn how to test for starch. Next you will practice testing for starch using different foods.

Practice Use of the Starch Indicator: Testing Foods

1. Is bread a food for you?______

   Using a medicine dropper, place a few drops of iodide solution (IKI) on a piece of bread.

2. Describe what happens to the bread.______________________________

   ____

   IKI turns blue-black or purple in the presence of starch. Starch is an energy-containing food. You know that plants can make food in the form of glucose in their leaves during photosynthesis. Plants make starch by putting together long chains of glucose molecules. (Plants and animals can also make glucose into many other substances.)

3. Think about your experiment with bread. Does bread contain starch?_____

   Now test other things that your teacher supplies you to determine whether they contain the high energy food called starch. Put yes or no in the following chart to indicate whether or not the substances contain starch:

4.

Substance	Contains Starch?

The point of this activity is to give students practice using the IKI indicator and to allow them to see that not all foods contain starch. Starch is just one kind of food, but like all food it ultimately derives from the glucose made during photosynthesis

Suggested foods to try: saltine crackers, flour, cooked rice, cereal (puffed rice or Rice Chex work well), sugar.

Testing Water for Starch

Does water contain starch?

1. Do you predict that water will contain starch?________

Explain your prediction.____

____

____

How to Test Water for Starch

Put some water in a small jar or test tube. Add a few drops of the IKI solution.

2. What do you see happen?____

____

3. What does this mean? Does water contain the energy-containing food starch?______

Water does not contain starch. In fact, it does not contain any kind of energy-supplying food such as sugar, starch, or fat. It is not food. But some liquids do contain food.

Your teacher may also have you test other liquids for starch.

4. Write down your observations.____

____

____

5. Do very many of the things you normally drink contain starch?__________

6. Starch is not found in most drinks. But many drinks do contain energy-supplying food. Can you think of one energy-supplying food that is in many drinks like pop and juice?

____

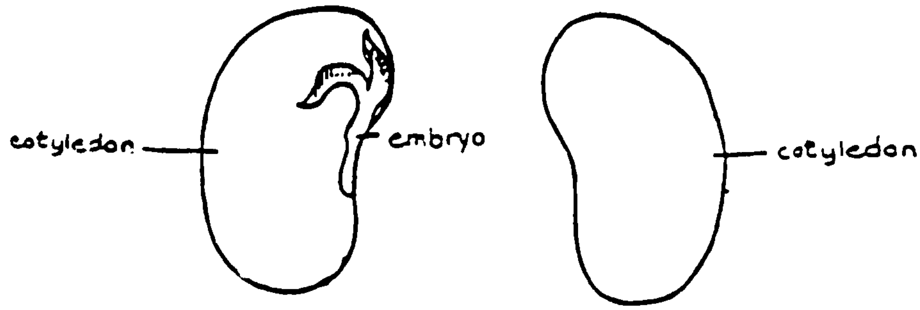
Testing water for starch provides another opportunity for students to think about why water is not considered a food.

4-6. Most everyday liquids do not contain starch. This does not mean they are not food, however. Emphasize to students that we are only testing for one kind of food.

Suggested liquids to try: 7-Up, milk, juice
For a liquid with a positive starch test,
try cornstarch mixed with water

Testing Plant Parts for Starch: The Seed

Test a bean seed to see if it contains starch. Test the part of the seed called a cotyledon. The picture below shows that the cotyledon is the largest part of the seed.



1. Do you predict that the cotyledons of the seed will contain starch?_____

Explain your prediction.________________________________

____

____

If you put yes, where do you think the starch in the seed came from?

____

____

How to Test Seeds for Starch

Use a bean seed that has been soaked in water for 24 hours.

Carefully open the bean seed by gently prying along the slit in the seed with your fingernail or a pencil.

Place the opened seed in a dish. Observe the two parts of the seed--the embryo which will grow into the bean plant, and the large part of the seed which is called the cotyledon.

Use a dropper to cover the seed with IKI solution. Let it sit a minute or two.

2. Write down what you see happen. ________________________________

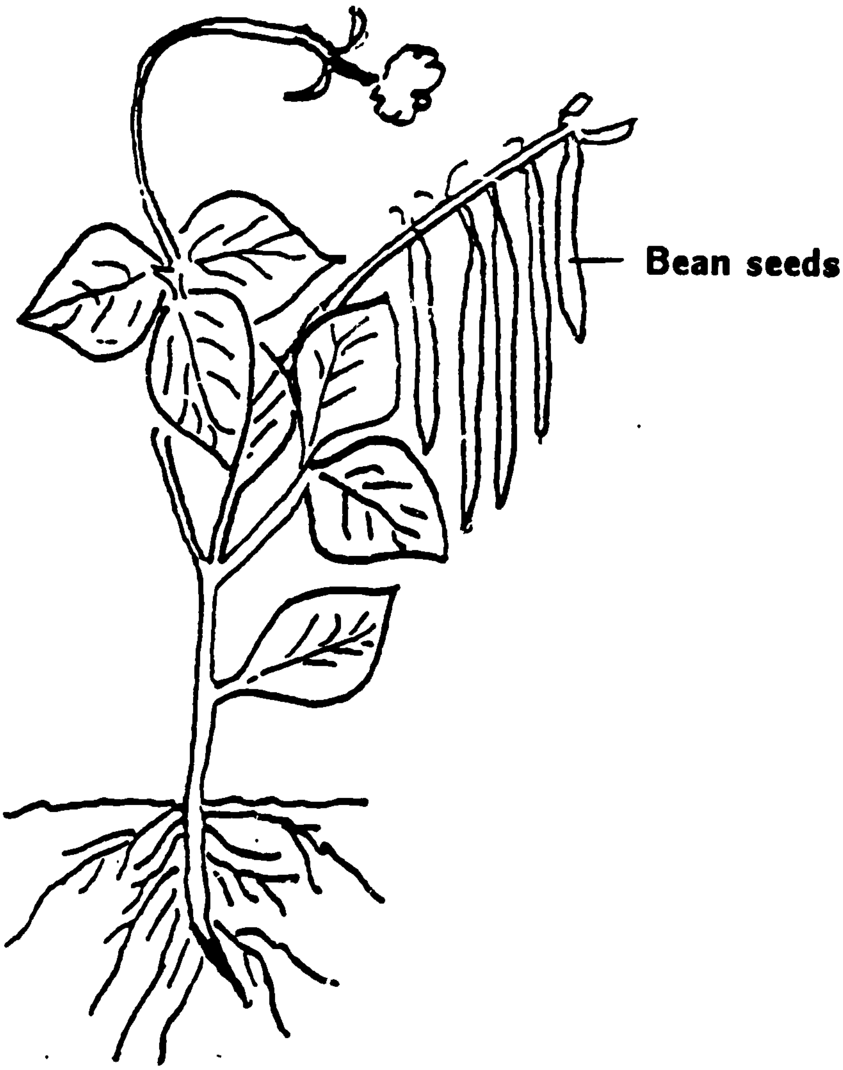
____

3. Does the seed contain starch?___________

Many students will be surprised that seeds contain food. It will be especially surprising that the seed contains the same kind of food we eat in bread. It is easy for students to understand that there is food in the seed. However, students often think that the food in the seed came from the soil or they have no idea how it got there.

Students will need to wait a few minutes for the IKI to be absorbed by the bean seed.

4. Draw arrows to show how starch reached the cotyledons in the seeds. Where did it come from?



Bean plant

Students should draw arrows going from the leaf (where photosynthesis creates glucose) to the bean seeds (where glucose is converted to starch and stored.)

Optional discussion question and activity

Students who have planted seeds in soil and watched them grow often think about the seed as taking in and storing food from the soil. You could check on the persistence of this misconception by showing students a bean seed, planting it in soil, and asking students where that bean is getting its food from at that moment. As the bean grows over the next weeks, you could ask students each day where the plant is getting its food that day. This would provide an occasion for review even after the unit is over. Transparency 7 (following p. I-36) would tie in well with such an activity.

Testing Plant Parts for Starch: Vegetable and Fruit

Test a potato and a banana for starch.

1. Do you predict that the potato will contain starch?______

   Do you predict that the banana will contain starch?______

Explain your predictions.____

____

2. If you predicted yes for either the potato or the banana, tell where you think that starch came from.

____

____

How to Test a Potato and a Banana for Starch

Take a slice of potato and a slice of banana.

Use the medicine dropper to cover the top of the slices with IKI solution.

3. Write down what you see happen.____

____

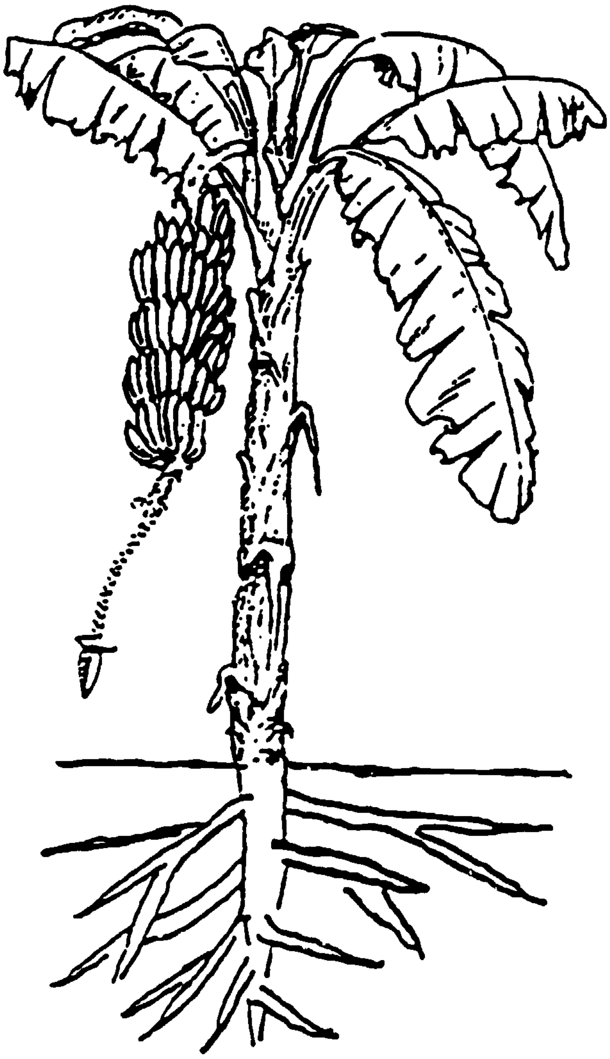
4. Did the potato contain starch?________

   Did the banana contain starch?________

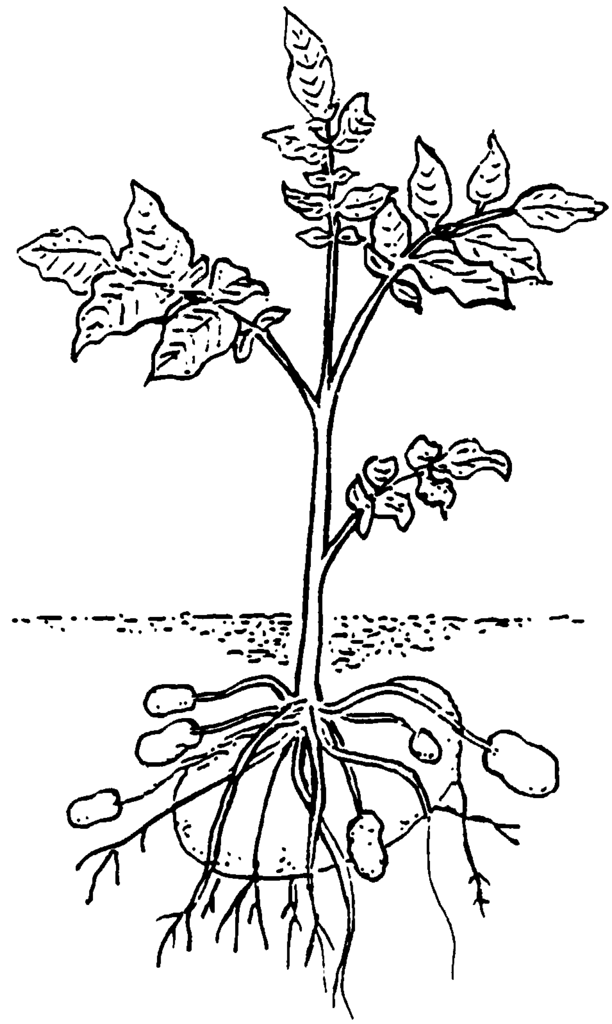
2. Students usually say that the "plant grew it" or "the plant made it" without having any notion of how that might occur. To them, it's just part of how a plant grows. They should refer to photosynthesis in the leaves and the transport of manufactured food from the leaves to all parts of the plant.

4. Both the potato and the banana contain starch.

5. Draw arrows to show how the starch got to the potato and to the banana. Where did the starch come from?



Banana plant



Potato plant

5. Students should draw an arrow from the leaf (where glucose is produced during photosynthesis) to the banana or the potato plant root (where glucose is changed to starch and stored).

Testing Plant Parts for Starch: The Stem

Now test a different plant part for starch--a stem.

1. Do you predict that the celery stem will contain starch?________

Explain your prediction.____

____

2. If you put yes, where do you think that starch in the stem comes from?

____

____

How to Test a Celery Stem for Starch

Fill a small container or jar about 1/4 inch deep with IKI solution.

Get a slice of celery stalk.

Stand the celery stalk in the small container so that one end of the stalk is soaking in the IKI solution. Let it sit several minutes.

3. Write down what you see happen to the celery stalk.

____

____

4. Did the celery stalk contain any starch?_______

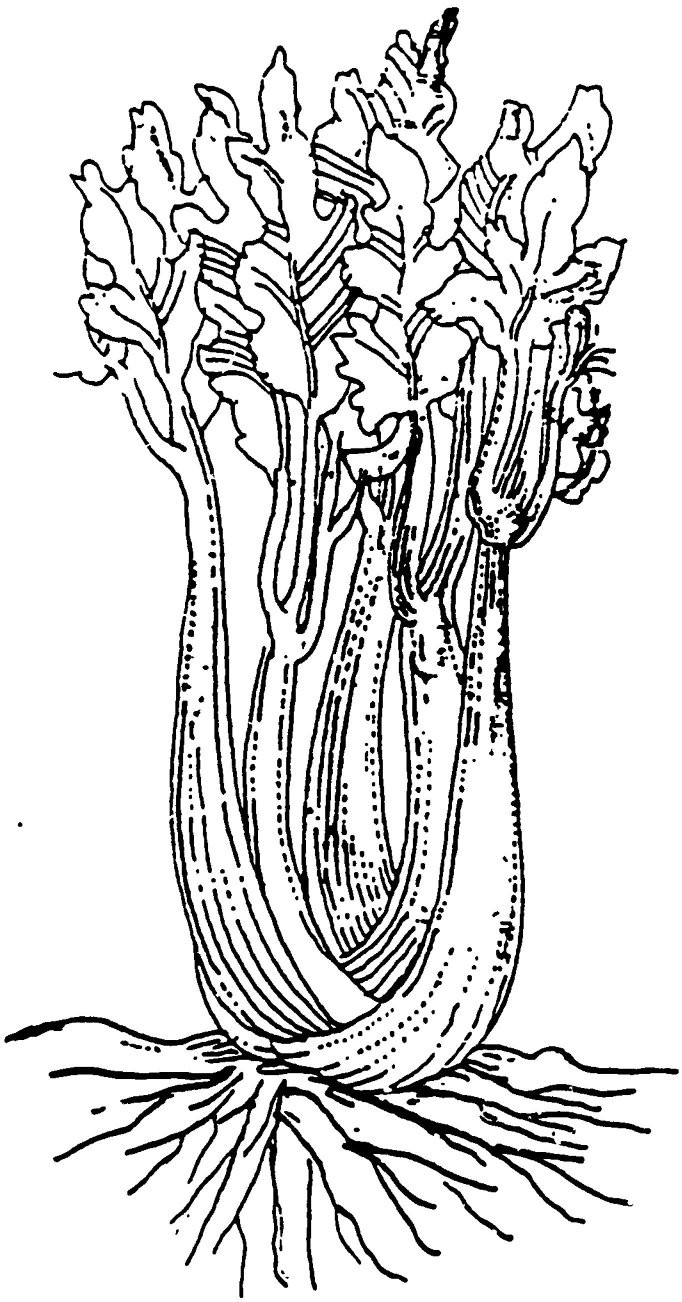
If yes, where was the starch located?________________________________

____

100

The celery stalk contains starch. The starch test is not as obvious as for the other plant parts, however. Usually the starch is concentrated in the vascular bundles in the celery stem.

5. Draw arrows to show how the starch got to the stem:



Celery plant

5. Students should draw arrows indicating movement from the leaves (where the glucose is made during photosynthesis) to the stem (where the glucose has been already converted to starch).

You could ask students if they think the stem would test positively for <u>sugar</u>. In fact, a sugar test might be more dramatic since only a little of the sugar gets converted to starch in stems.

Making Sense of the Experiment

1. Which parts of the plants you tested contained energy-rich food in the form of starch? ______________________________

____

2. Can the cells in these parts of the plant make food? _______ Why or why not? ______________________________

____

____

____

The starch in all these plant parts was made from sugars like glucose, and those sugars came from the leaf! Remember two key points:

a. Plants get all their food by making it inside their leaf cells.

b. Only certain cells in the leaf can make food.

All the other plant cells--cells in the stem and in the roots--must get their food from the leaf cells where the food is made. Therefore, after food is made in the leaf, the food travels to all other parts of the plant. EXTRA food made by the plant is stored in the form of starch.

3. Explain why the seed needs food in the cotyledon to start growing. Why can't the seed just make its own food like the cells in the leaf do?

____

____

____

1. seed, stem, fruit, vegetable

2. Only special chlorophyll-containing cells in the leaf can make food. Students sometimes think seeds can make food. This is not accurate. Food made in the leaves is stored in seeds.

3. The seed cannot make its own food because it has not developed leaves yet and the developing leaves cannot get sunlight at first. The germinating plant needs food from the seed until it is big enough to produce its own.

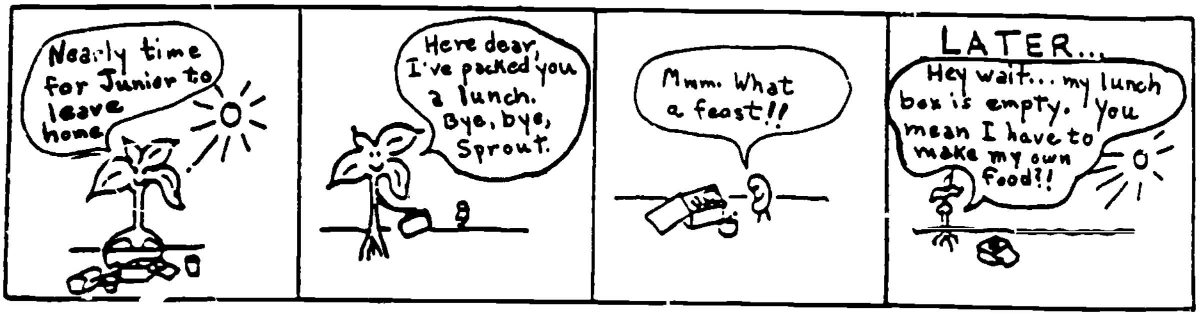
4. In what ways is the following cartoon correct? In what ways is it wrong?

____

____

____

____



5. When grass seeds are planted in the dark, they will begin to grow even though they cannot make their own food in the dark. Where do the seeds get the energy-containing food that they need to begin to grow?

____

____

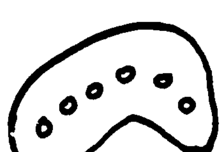
____

6. When you eat a banana or a potato, where did the food (starch) stored in the banana or potato originally come from?

____

____

7. If you look carefully at the cut edge of a celery stalk, you will notice little circles. These are actually long tubes that go the length of the celery stem. You may have noticed that the starch is located in these tubes. The tubes carry food from one part of the plant to another. Do you think that the food in a celery stem moves <u>up the stem</u> or <u>down the stem</u>? _____ Explain your answer. ______________________________



____

____

____

Accurate: The cartoon shows that food made by the parent plant is stored in the cotyledons of seeds. This provides a food source for the new plant. When that food source is used up, the plant must make its own food using sunlight as an energy source.

Inaccurate: Students may note that the food for the young plant is "packed" in the cotyledon, not in a lunch box and that plants don't have hands or feet.

It is also very important to talk about how plants make food; students may think that plants make food just like humans make a lunch. This cartoon shows a plant making a lunch just like people do. In contrast, photosynthesis is a chemical process that occurs inside plants' leaves by which nonfood substances (air and water) are chemically changed into food. When plants make food, they are creating food. When people "make lunches," they are just taking food and rearranging it. They are not creating food. When we talk about plants making food, we mean something very different from when we say that people make lunches.

5. The seeds get food from the cotyledon. The food in the cotyledon was made by the parent plant during photosynthesis and was stored in the seed. Eventually food in the cotyledon is used up. By this time, the developing plant has leaves and can begin to make its own food.

6. The important point is for students to connect the food in the banana and potato with photosynthesis in the leaves. The food originally came from chlorophyll-containing cells in the leaf. During the process of photosynthesis, these cells made food in the form of sugar (glucose). The sugar traveled throughout the plant. Extra sugar was changed to starch and stored either in the root (potato) or in the fruit (banana).

7. Food moves down the stem. Students often think of food as being taken in the roots from the soil and moving up the stem to feed the plant. At this point students should realize that plants make food in the leaves during photosynthesis and then the food travels down the stem to all plant parts.

LABORATORY ACTIVITY TWO:

Using Photosynthesis to Explain an Experiment

NOTE: If students have not performed Laboratory Activity One, you will need to explain to them what a cotyledon is. Transparency 7 would be helpful in such an explanation.

This experiment is quite time-consuming and tricky to carry out. Therefore, it is presented as a drylab. Students can talk through the experiment in one class period. Use overhead Transparency 8 to make sure students are clear on the four experimental conditions. You may want to have the class also grow plants to dramatize the results more powerfully. This could be done before or after this drylab discussion. If you decide to actually carry out the experiment, it will take several weeks to grow and measure the plants.

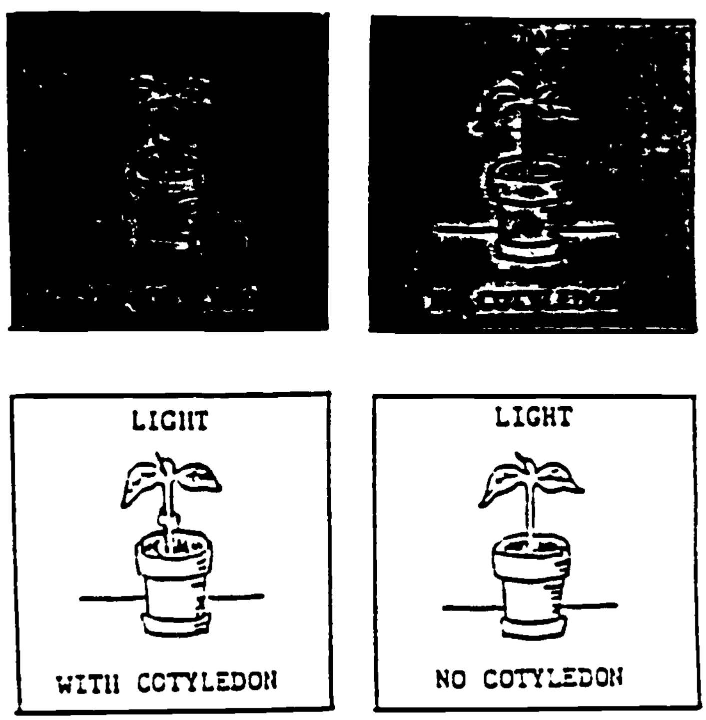
LABORATORY ACTIVITY TWO:

Using Photosynthesis to Explain an Experiment

See if you can use what you have learned about food for plants to explain the experiment described in the next section. **REMEMBER** to think about what is happening inside the plants as well as what can be observed from the outside.

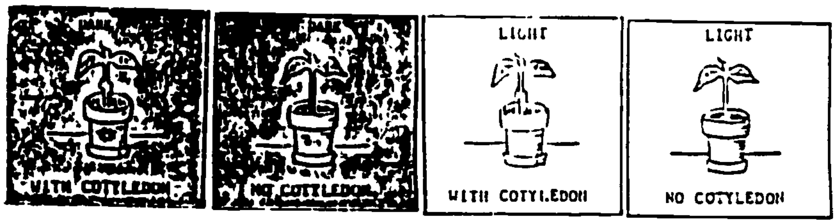
Bean Plant Experiment

Four bean seeds were planted in the dark. When they had each grown about two inches high and had sprouted their first tiny leaves, the cotyledons (seeds containing starch) were ripped off of two of the plants. One of these plants without a cotyledon was put in the dark, and one was put in the light. The plants with cotyledons were also put in light and dark situations:



This experiment asks students to keep track of a number of separate variables. The chart (on p. I-52) was designed to help students coordinate the different concepts they have learned. In class discussion, you can use this chart to help them organize these new concepts to help them make better sense of the experiment. For example, you might suggest that they look down each column in the chart in making their prediction. This would show them that only the plant without the cotyledon in the dark is totally lacking a food source.

Think about the possible sources of food for each plant and fill in the following chart:



Can it make its own food?				
Can it get food from the cotyledon?				
Can it use water as food?				
Can it get food from the soil?				

1. Predict which plant will die first. ______________________

2. Give a reason for your prediction. ______________________

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3. Would it help the plants in the dark stay alive if you put fertilizer on them? Why or why not? (see p. 18 if stuck)

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Can it make its own food?	No	No	Yes	Yes
Can it get food from the cotyledon?	Yes	No	Yes	No
Can it use water as food?	No	No	No	No
Can it get food from the soil?	No	No	No	No

1 and 2. The purpose of this experiment and these questions is to get students to apply what they have learned about food for plants to make accurate predictions and appropriate explanations about plants grown under different circumstances.

There are three main concepts that students will need to use to give appropriate predictions and explanations:

a. The cotyledon is the source of food for the young germinating plant.

b. If plants have light, air, and water, they can make their own food.

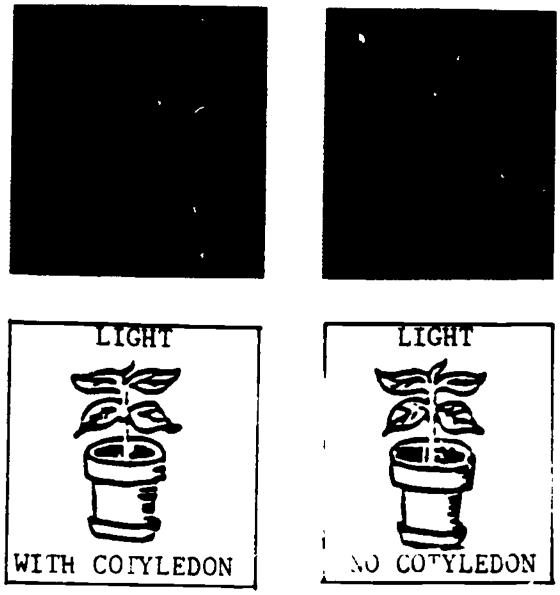
c. Neither water, soil, fertilizer, sunlight, nor air is food for plants. The food for plants is only what the plant makes during photosynthesis.

Students now have enough information that they should be able to predict that the plant in the dark with no cotyledon will die first. They should explain that the plant in the dark with no cotyledon will die because it must have food to provide the energy it needs to live and grow. It can only get food from the cotyledon or by making it itself. Since the cotyledon is gone and there is no sunlight which is necessary for making food, the plant will die of lack of food. All the other plants in the experiment had some source of food, so that they will live for at least a while.

Some students may make the correct prediction, but their reasons may focus only on observable evidence rather than on what they have learned about how plants get their food. For example, students may say the plant in the dark without the cotyledon will die first because plants can't live very long in the dark or because taking the cotyledon off the plant hurts it (like cutting off a person's head). Students should be encouraged to give reasons for their predictions that relate to what they have learned about plants' food.

3. The main concept to be applied is that fertilizer is not food. It does not provide plants with energy. The plants must have food in order to live. They will die without sunlight to make their own food, because they have no other source of food. Fertilizer is something that plants need to be healthy, but it is not food.

Now here are the results of the experiment:



4. Explain these results Using your knowledge about how plants get food.

4. This application question asks students to explain the experimental results using their knowledge about how plants get food. They should integrate the key concepts of the unit:

a. That plants cannot get food from the soil.

b. That the cotyledon provides a temporary food source for new plants.

c. That photosynthesis (plants making their own food) is the only permanent food source for plants, and light is essential for photosynthesis to take place.

Using this knowledge, students should be able to give an explanation similar to the following:

The plant in the dark without the cotyledon had no source of food so it could not grow or live. The plant in the dark with the cotyledon grew for a while because it could get food from the cotyledon. Then it died because the cotyledon was used up, and the plant had no sunlight to use to make its own food. Plants can only get food from the cotyledon or by making it themselves.

Both of the plants in the light could use sunlight to make their own food, so they lived. Since they were in the light, it did not matter whether they had a cotyledon or not.

Comparing Your Explanation to a Scientist's Explanation

Here's how a scientist would have explained the experiment. See how closely your explanation matches the scientist's explanation:'

Young plants can get food from the seed or cotyledon. The food in that cotyledon was made by leaf cells during photosynthesis. After the plant has used up all the food in the cotyledon, the only way plants can get food is by making it their leaf cells. They need sun, water, and carbon dioxide to make their food in the leaves.

The plant in the dark with the cotyledon could get food for a while from the cotyledon. But when the food in the cotyledon was used up, the plant died because its only other way of getting food is to make it. And it had no sun to make its own food.

The plant in the dark with no cotyledon died because it had no way to get food. It had no cotyledon and it had no sun to make its own food. Plants have no other kind of energy-supplying food.

Both plants in the light could live, because they had the three things they needed to make their own food--sun, water, and carbon dioxide.