ABSTRACT

ADCOCK, BESS CURRIN. Examining the Impact of Directly Addressing a Major Misconception About Photosynthesis Prior to Instruction (Under the direction of Dr. Glenda Carter)

Science education literature includes many studies of common misconceptions held by science students. But there are fewer studies that address ways of helping students to overcome those misconceptions. This study explored whether making students aware of a major misconception about photosynthesis prior to instruction would provide the dissatisfaction with their current conceptions necessary for helping students to achieve accommodation of new, scientifically more acceptable concepts. This study was framed around the conceptual change model. An experimental group of high school biology students viewed a PowerPoint presentation with slides that revealed the major misconception. The control group of high school biology students viewed a similar PowerPoint presentation with the misconception slides omitted. Students responded to an open-ended question and several multiple choice and short answer questions in pretests and posttests. All students participated in the same unit of study, which included strategies geared toward eliminating misconceptions about photosynthesis. Findings indicated that both groups made gains on the open-ended question, with the experimental group making greater gains than the control group. Posttest results indicated that the majority of all students no longer held the misconception, with varying degrees of sophistication in terms of accommodation of a new conception. Implications for classroom teachers related to instruction geared toward conceptual change are addressed.

EXAMINING THE IMPACT OF DIRECTLY ADDRESSING A MAJOR MISCONCEPTION ABOUT PHOTOSYNTHESIS PRIOR TO INSTRUCTION

by
BESS CURRIN ADCOCK

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the requirements for the
Degree of Master of Science

SCIENCE EDUCATION

Raleigh

2003

APPROVED BY:

____________________________________ ____________________________________

____
Chair of Advisory Committee

PERSONAL BIOGRAPHY

The author was born August 23, 1964 to Richard and Trudy Currin in Oxford, N.C. She graduated from J.F. Webb High School in Oxford, N.C. in 1982, and entered N.C. State University in the fall of 1982. She received her B.S. in Science Education from N.C.S.U. in December of 1985.

After teaching science at Hawley Middle School in Creedmoor, N.C. for seven years, Bess transferred to J.F. Webb High school in 1992, where she currently teaches biology and Advanced Placement Biology. Bess entered graduate school at N.C.S.U. in the spring of 1997 as a part-time student, continuing to teach while pursuing her master's degree in science education.

Bess is married to Michael E. Adcock. They have two children, Nathan and Sarah, and make their home in Granville County, N.C.

TABLE OF CONTENTS

LIST OF TABLES

PAGE

LIST OF TABLES (CONTINUED)

LIST OF FIGURES

PAGE

INTRODUCTION

Many studies in science education have focused on students' misconceptions in the area of biology, especially those related to photosynthesis. Studies of students from age 11 to college age indicate that students hold similar misconceptions about photosynthesis regardless of the amount of science instruction they have received (Amir & Tamir, 1994; Anderson, DuBay, & Sheldon, 1990; Barker & Carr, 1989; Bell, 1985; Canal, 1999; Eisen & Stavy, 1988; Eisen & Stavy, 1992; Simpson & Arnold, 1982; Waheed & Lucas, 1992). A particularly widely held misconception related to photosynthesis is the belief that plants get their food from the soil. Even after studying photosynthesis, students hold on to their belief that plants get their food through their roots. Perhaps this occurs because instruction about photosynthesis tends to focus on the gas exchange (plants take in carbon dioxide and give off oxygen) rather than on carbohydrate production. This is understandable, as photosynthesis is a challenging topic to teach, particularly to students with little or no prior instruction in chemistry. A study of the prerequisite concepts required for understanding photosynthesis suggests that students may not be able to distinguish between common gases such as carbon dioxide and other compounds, such as carbohydrates (Simpson & Arnold, 1982). In addition to confusion about gases, studies indicate that students—even some with over a year of prior biology instruction—do not know what plants use for food. Most view food for plants as substances the plants take from their environment (Anderson, Smith, & DuBay, 1990; Roth, Smith, & Anderson, 1983). With so much confusion about gases and food, it is not surprising that students also have difficulty understanding the energy transformations that are critical to understanding photosynthesis. Studies have shown that many students view light as a reagent in the photosynthetic process rather than as the energy source that is required to initiate the process (Anderson, Sheldon, & DuBay, 1990; Barker & Carr, 1989; Eisen & Stavy, 1988; Roth, Smith, & Anderson, 1983). Thus, students may begin a study of photosynthesis with misconceptions that will be obstacles to their truly understanding the process.

Why do students enter biology courses with so many misunderstandings about very basic science concepts such as matter and energy? Surely most students have several years of science instruction prior to taking a course in biology. And though the type and quality of instruction may vary widely, it appears that the majority of students at all ages—from elementary to college level--hold similar misconceptions when tested on their understanding of photosynthesis. Could it be that students hold these misconceptions because these misconceptions are never addressed directly? Students may appear to understand a topic, and indeed perform very well on a test, yet perform very poorly if questioned in a different manner. Perhaps students need to be carefully questioned prior to instruction to raise their awareness of their own lack of understanding of a topic. Further, would it be beneficial to not only question students to get at their own misconceptions, but to also make them aware of misconceptions commonly held by others? While some studies have addressed strategies for teaching photosynthesis, including a guided discovery approach and a generative learning strategy, none were found that involved making students aware, prior to instruction, of the major commonly held misconception that plants obtain food through their roots. Given the lack of knowledge of prerequisite concepts, and the number of potential learning objectives related to photosynthesis, a teacher may need many hours of instructional time in order to effectively facilitate student learning about this complex process. Realistically, though, a teacher has a limited amount of time to devote to a given topic, especially in an age of content-driven standardized testing. The challenge, then, is to decide which objectives are most important and most likely attainable, and plan instruction accordingly. Rather than teaching strategies that focus solely on students' awareness of their own lack of understanding, perhaps it would be beneficial to make students aware of misconceptions that are held by many people, and to do so at the beginning of the unit. Then, hopefully, as the unit progresses students will be more likely to ask "if plants do not get food through their roots, then how do they get their food?" And, "if plants do not get most of their material for growth from the soil, then where do they get it?" To facilitate conceptual change, the teacher would present students with information that disrupts their equilibrium at the very beginning of the unit, in hope of fostering their building of a new conceptual framework.

Purpose of the Study and Research Questions

The purpose of this study was to evaluate the effectiveness of making students aware—prior to instruction--of a commonly held misconception related to photosynthesis, i.e., the belief that plants obtain food from the soil through their roots. The research questions explored were:

1. Are students who are made aware of major misconceptions related to photosynthesis prior to instruction more likely to overcome those misconceptions themselves?
2. How do students' conceptions change when instruction is planned with a focus on eliminating misconceptions?

Theoretical Framework

According to the conceptual change theory, in order to facilitate conceptual change in her students, a teacher must create certain conditions in the classroom. These include: providing experiences that cause students to be dissatisfied with their current conceptions; spending time identifying students' misconceptions and the most likely barriers to their forming new conceptions; implementing strategies that help students overcome their misconceptions; presenting content in a variety of ways; and using forms of evaluation that allow the teacher to measure students' progress toward achieving conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). When students are found to hold misconceptions, the teacher must determine which experiences will be most effective in getting students to change the way they think and thus to construct new, more scientifically sound ideas—part of the conceptual change theory known as "accommodation."

Review of Literature

A search for journal articles reporting methods for identifying students' misconceptions related to photosynthesis yielded several different approaches, and a number of commonly-held misconceptions. These misconceptions can be placed, though not neatly due to their interrelatedness, into three categories: misconceptions about the relationship between photosynthesis and respiration; misconceptions related to what a plant's food is, the origin of that food, and how the food is used; and misconceptions related to the role of light and chlorophyll in photosynthesis, including the energy conversions that are key to understanding photosynthesis.

Students' misconceptions about the relationship between photosynthesis and respiration are widespread and well documented. The prevalence of these misconceptions is understandable, if the results of a study by Mary Simpson and Brian Arnold (1982) are typical of many students worldwide. In this study conducted in Scotland, the researchers gathered data on concepts prerequisite to understanding photosynthesis from 465 students, ranging from age 11 to age 16. Based on the data related to students' understanding of gases, the researchers concluded "teachers . . . may make grossly optimistic assumptions concerning the level of pupils' understanding... Pupils who believe that carbon and carbohydrate are gases obviously start off the topic with severe disadvantages" (Simpson & Arnold, 1982, p. 71). If students do not have at least a basic understanding of what gases are and the ability to distinguish between common gases and other compounds, it is not surprising that the gas exchange that is a part of both photosynthesis and respiration creates such confusion.

One cannot effectively teach about photosynthesis without including respiration, too. Unfortunately, the inevitable comparison of the gas exchanges involved in both processes creates fertile ground for the unintentional growth of misconceptions among students. Amir and Tamir (1994), in a study involving 11^{th} and 12^{th} graders' understanding of photosynthesis, designed a special paper and pencil test which included multiple choice items, multiple choice items requiring justifications, open-ended questions, and proposition-forming tasks. The test was used to identify misconceptions held by students who had recently completed a study of photosynthesis. Samples from the test included items about the relationship between photosynthesis and respiration. Of particular interest were items about the cycling of carbon dioxide and oxygen in nature. Students answered a multiple choice item, then were asked to justify their response. Analysis of results showed that only 43% of students fully understood that photosynthesis is carried out by plants, but respiration is carried out by both plants and animals. In a paper examining misconceptions perpetuated by biology textbooks and teachers, Robert Barrass suggests that misconceptions about which organisms respire and which organisms photosynthesize may be due in part to "the fact that animals are used in many demonstrations of the occurrence of respiration; and to the fact that light must be excluded if green plants are used" (1984, p. 202). Barrass also suggests that "the use of summary equations, in which photosynthesis is represented simply as the opposite of respiration, may cause some pupils to think that they are alternatives—that both processes could not occur at the same time" (p. 202). Pedro Cañal refers to this misconception as "inverse respiration," and cites numerous studies that indicate that this misconception, common in primary and high school, persists even in university students (1999, p.364). The persistence of this misconception is also noted by Eisen and Stavy (1988), who administered a 14-item open-ended assessment to two groups of high school and university students in Israel, the two groups distinguished as biology majors and non-biology majors.   From their study, Eisen and Stavy conclude that

> It seems that most adults (including non-biology majors) understand the oxygen cycle in nature—plants release oxygen and animals absorb it. But there is no awareness of the mechanism involved in these processes. Both photosynthesis and respiration are perceived only as gas exchange (p. 211).

If photosynthesis is viewed by students as merely the "taking in of carbon dioxide and release of oxygen by plants," then it is easy to see why students have problems understanding how the carbon dioxide is used by the plant--how a gas can be incorporated into other molecules that are then used by the plant as food. Or, how energy is released from some of that food in the process of respiration in the cells of the plant.

If students are to understand that photosynthesis is about "food-making," then they must be clear about what food is, and about the role of food in organisms. But what do students think about plants and food?   As a result of a study of 11-year old students' ideas about photosynthesis and food for plants, Roth, Smith, and Anderson (1983) reported that

> . . . the students are focusing on food for plants as the raw materials that plants take in from their environment. About 80 percent (of 229)

> students shared this belief that plants take in their food, most indicating soil as a source (72 per cent) but some indicating water (25 percent) and air (5 per cent), as additional or alternative sources (A paper presented at the American Educational Research Association).

Anderson, Sheldon, and Dubay (1990) used a written pretest which they administered to 105 university students enrolled in a biology course for non-majors to investigate students' understanding of photosynthesis and respiration. Two open-ended items from the pretest asked students "How do you define food for a bean plant?" and "How do you define food for a person?" These questions were followed with "What portion of their food do bean plants get by making it inside their bodies?'" and "What portion of their food do bean plants absorb through their roots?" and "What portion of their food do bean plants absorb through their leaves and stem?" (Anderson et al., 1990). Students were to respond to the questions above by circling *all*, *some*, *none*, or *?.* The researchers found that most students indicated that food for plants, like food for animals, is taken from the environment. Only 2% of students responded that plants take in no food through their roots. Overall, 86% of students could not provide correct definitions of what constitutes food for a bean plant. This should not be surprising, though, as 75% could not provide acceptable functional definitions of what constitutes food for a person. Interestingly, the students included in this study had, on average, 1.9 years of previous biology instruction. Clearly in their prior instruction misconceptions were either not addressed or were not addressed in such a way that students constructed a scientifically acceptable understanding of the source of food for plants. The responses given by eleven year olds in the study by Roth, et. al are very similar to the responses of university students in the study by Anderson, Smith, and Dubay. Likewise, Eisen and Stavy (1988) found similar results in their study comparing biology majors' and nonmajors' understanding of photosynthesis. A majority of both groups exhibited difficulty identifying what is food for a plant, as the most frequently occurring answer was water. If students are to understand that plants produce their own food through photosynthesis, they must first have an understanding of what food is and what food provides.

Understanding that food provides organisms both with energy and building materials is critical to a thorough understanding of the processes of photosynthesis and respiration in plants. But this presents the instructor with another challenge; that is, to help students understand the role of light in photosynthesis—that plants convert light energy to energy stored in food molecules. While most students would be expected to be aware that plants need light, many likely will not be able to explain why. In a study by Roth, Smith, and Anderson (1983), eleven-year old students were asked why plants need light. The most frequently occurring answers were that plants need light to live or grow, or for good health and color, while 8% of students gave no explanation at all. While these responses may not be surprising coming from elementary students, explaining the function of light in plant growth is also difficult for older students. In their study involving university students, Eisen and Stavy (1988) found that many students "treat energy (or sunlight) as a material that plants absorb in order to build their bodies." Likewise, Barker and Carr found in a series of interviews with secondary school students in New Zealand that "pupils frequently construed the equation for photosynthesis to be suggesting that sunlight ranked alongside carbon dioxide and water as a reagent" (Barker & Carr, 1989, p. 42). So students' inability to explain the role of light in plant growth likely stems from their lack of understanding of energy, especially the relationship between energy and matter. In the study by Anderson, Sheldon, and DuBay (1990), the authors' evaluation of questions related to energy in their words "reveal serious deficiencies in the understanding of most students" (p. 769).   Of these students, who were nonscience majors enrolled in a biology course, 90% did indicate that the sun is a source of energy for plants, but only 10% indicated that the sun is the sole source of energy for plants. Ninety percent of students included other substances such as water, soil, and fertilizer as sources of energy. The authors note that the students' responses tend to be too inclusive (listing as energy things that are not energy forms), and conclude that

> The students' commitment to such a broad and vague conception of energy has serious consequences of biological understanding. It renders them unable to see how energy is transformed and conserved during biological processes or to appreciate the uniqueness and importance of energy conversion processes" (p. 770).

If students are to truly understand photosynthesis, and understand it in such a way that they can then relate to energy flow in ecosystems, they must first have an understanding of what energy is and how energy is converted from one form to another.

Clearly, there are numerous, persistent misconceptions held by both younger students and by adults about photosynthesis. After identifying these misconceptions, the challenge for the teacher is how to approach the topic to effectively eliminate students' current misconceptions, while being careful not to inadvertently foster the development of new misconceptions. The results of a study by Simpson and Arnold (1982) involving prerequisite concepts required to understand photosynthesis-a complex concept--suggest that the teacher might best begin by addressing students' understanding of constituent concepts such as living versus nonliving, food, gases, and energy. But once the teacher has addressed these constituent concepts with students, what is the best way to proceed with instruction on photosynthesis? Many teachers are reported to use a guided discovery approach (Barker & Carr, 1989). In this approach, students set up various experiments after which they are expected to use inductive reasoning to link the outcomes of the experiments to achieve a meaningful understanding of photosynthesis. But Barker and Carr, through the use of written surveys and classroom observations, found that

> The usual classroom guided discovery approach to teaching and learning about photosynthesis frequently fails in its major objective, that is assisting pupils to understand photosynthesis as a carbohydrate-producing process. Many pupils are distracted by other unclarified teacher objectives (e.g. photosynthesis as food-making) and by problems with experimental procedures" (1989, p. 41).

As a result, the researchers suggest a different approach, a "generative learning strategy" developed by Barker. Barker's strategy is in the form of a unit titled "Where does the wood come from?" The three-week unit designed for use with 13 to 14 year-olds, includes investigations, student surveys, a student self-teach booklet, and teacher transparencies. In keeping with a constructivist approach, students assess their views prior to, during, and at the conclusion of the unit, comparing their ideas with those of others, and linking their "new" views together with the goal of acquiring a view of photosynthesis as a carbohydrate-producing process. Barker and Carr (1989) report that with this generative-learning approach, “71% of pupils had acquired a carbohydrate-producing view of photosynthesis.” The researchers also report that, based on interviews, students

> ... had relished the opportunities to discuss, clarify, and compare their own ideas and they like the way the Self-Teach Booklet had given them a measure of control over their own learning. They also felt gratified that their ideas were an integral part of the unit, and that their alternative views (e.g. that plants mainly use minerals and/or soil to increase their mass) were addressed. (p. 42).

This study suggests that student self-assessment at different stages of the instructional process is critical to their gaining an understanding of photosynthesis.

The results of these studies imply that to teach effectively about photosynthesis involves far more than one might expect. The teacher cannot assume that students, though they may have a number of years of science instruction, possess the prior knowledge that is crucial to truly understanding photosynthesis. The teacher must consider students’ background knowledge about a number of topics, including gases, food, respiration, and energy when teaching about photosynthesis.

Is there one question that students may be asked to respond to prior to instruction that would give the instructor insight into their ability--or inability--to show the relationship of all of these topics to photosynthesis? A segment from the video series “A Private Universe” (Schneps, M.H., & Sadler, P.M. (1987), reveals that students, even those with an extensive science background, may not truly understand photosynthesis. Particularly telling are the interviews with Harvard graduates on graduation day. These graduates, though brimming over with scientific jargon, are unable to satisfactorily answer what, on the surface, appears to be a simple question. The interviewees are shown a piece of wood and asked what was the source of most of the mass of the wood. This question requires that students understand, among other things, that during photosynthesis, carbon dioxide from the atmosphere is used by plants to produce carbohydrates. Sounds simple, but even students who have taken college level biology often hold the misconception that plants gain most of their mass by taking materials from the soil. Did these students lack the ability to understand photosynthesis? If they are graduating from Harvard that is highly unlikely. The problem may be that if students are never questioned in this manner, it is likely that neither they nor their instructors will be aware of their misconceptions. It is possible to memorize many facts about photosynthesis without truly understanding how they all relate. Perhaps, then, instructors need to make students aware of commonly held misconceptions prior to instruction, as opposed to teaching and hoping that students will construct meaningful knowledge. With an awareness of these misconceptions from the start, students may be more likely to reflect on their own ideas about photosynthesis, and will hopefully be better prepared to construct new knowledge as they participate in a unit of instruction on photosynthesis.

Methodology

A necessary condition for conceptual change is the creation of "dissatisfaction with existing conceptions" (Posner et al., 1982, p. 214). The study described in the pages that follow involves a very direct way of creating dissatisfaction among students in the experimental group. Prior to instruction on photosynthesis, two high school biology classes (identified as periods 1 and 3) viewed a PowerPoint presentation with slides that targeted one of the most widespread misconceptions about photosynthesis—the belief that plants achieve growth primarily by taking in materials from soil. The two biology classes comprising the control group (identified as periods 2 and 4) also viewed the PowerPoint presentation, but with the misconception slides omitted. Both classes then participated in an instructional unit planned with a focus on strategies aimed at conceptual change.

Participants in the Research Study The research participants were students enrolled in a high school biology course in rural North Carolina. Four classes were involved in the study. Two of the classes were "honors" biology classes, the majority being sophomores who completed earth-environmental science as freshmen. The other two classes were "regular" biology classes comprised of juniors who had completed classes in earth-environmental science and physical science and sophomores who had completed earth-environmental science as freshmen. Period 1, an honors biology class, and period 3, a "regular" biology class made up the experimental group of participants. Period 2, an honors biology class, and period 4, a "regular" biology class, served as the control group. This grouping of students allowed for the most similarity in the control group and experimental group in terms of the mix of students in each, as each includes both "honors" and "non-honors" students, students who had taken physical science and those who had not, and a fairly even mix of students in grades 10 and grade 11 (see Table 1).

Table 1 *Participants—Breakdown of Grade Level and Previous High School Science Courses by Percent*

Grade level	Control Group *n=32*	Experimental Group *n=32*
10	66	59
11	34	38
12	0	3
Earth-environmental science	97*	100
Physical Science	31	41
Chemistry	3	0
Repeating biology	0	3

*one student in the control group had been home-schooled until this year

Instructional Strategies--Related Instruction Prior to the Photosynthesis Unit

If students are expected to understand photosynthesis as a carbohydrate-producing process, they need some background understanding of carbohydrates Eight weeks prior to the unit on photosynthesis, students completed a brief unit on biological compounds, which included a discussion of characteristics, functions, and examples of carbohydrates. As part of this unit students completed a "Survey of Biological Compounds" in which samples of compounds were placed around the classroom, with students using their notes and each other to try to determine the class of compounds to which each belonged. Glucose in both solid form and solution was included. Cellulose as paper, cotton, a block of wood, and a plant cell slide in which the cell wall was indicated was also part of the survey. Additionally cornstarch in a box and a potato representing starch were among the samples. In addition to discussing and showing examples of these compounds, the teacher repeatedly demonstrated, using pop beads, that many molecules of a monosaccharide such as glucose could be linked together to form polysaccharides such as starch and cellulose.

In addition to having knowledge of carbohydrates, students need some knowledge of cell structure to understand photosynthesis as a process that takes place in specialized organelles in certain cells. As part of a unit on cells, students were expected to be able to identify and give the function of chloroplasts. They prepared and viewed slides of *Elodea*, in which many chloroplasts were visible, giving them some prior knowledge on which to build when they began the photosynthesis unit.

In order to understand the cycling of gases that is a part of photosynthesis, it must be contrasted with aerobic respiration. Immediately preceding the unit on photosynthesis, students studied cellular respiration. This included learning the overall equation for aerobic cellular respiration, with a focus on the transfer of energy from glucose to molecules of ATP. Mindful of the common misconception that animals carry out respiration and plants carry out photosynthesis (but not respiration), the fact that all organisms carry out some form of respiration was emphasized, with animals, plants, and members of other kingdoms used as examples.

The Photosynthesis Unit One day prior to instruction about photosynthesis, students were given a two-part pretest consisting of multiple choice with explanation, short answer, and an open-ended essay question. Immediately after administration of the pretest, classes went to the school computer laboratory to view either the experimental or control version of a short PowerPoint presentation "Introducing Photosynthesis." Classroom instruction began the next day, with a study of leaf structure. Students were given a handout with a leaf cross-section to label, and an illustration of stomata. Students filled in information about the function of leaf parts, including upper and lower epidermis, spongy layer, palisade layer, and the vein, including xylem and phloem. Students examined prepared slides of leaf cross-sections. To demonstrate the function of guard cells, students were instructed to curve their hands and put them together so that the hands represented guard cells. They flattened their hands, illustrating the effect of water diffusing out of the guard cells and closing the stoma. They curved their hands, illustrating water diffusing into the guard cells, causing them to swell and bow outwards, opening the stoma. The term transpiration was introduced at this time. The next day, students did a lab activity (see Appendix A) in which they prepared slides of lower epidermis from three types of plants (Wandering Jew, water hyacinth, and lettuce). They counted the number of stomata in three fields of view for each plant type, and answered questions, working with their lab groups. The following day the teacher presented a brief lecture which included a definition of photosynthesis and a discussion about the overall equation for photosynthesis. Each component of the equation was addressed individually, with the teacher questioning students about how the plant obtains the raw materials, carbon dioxide and water, and about how they are used by the plant. As the class discussed the parts of the equation, they added notes to the equation in their notebooks as shown in Figure 1.

Overall Equation for Photosynthesis

$$6\,CO_2 + 6\,H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6\,O_2$$

carbon dioxide + water → glucose + oxygen

carbon dioxide— gas from the atmosphere that diffuses into the leaf through the stomata; used to make glucose.

water—taken in through the roots, travels through xylem to the leaves. Water molecules in the chloroplasts split, providing H^+ needed for photosynthesis and releasing O_2

light—form of energy that powers photosynthesis

chlorophyll—pigment that traps light energy, making it available for photosynthesis

glucose—sugar, food for the plant, some of which is used in cellular respiration to provide the plant with ATP, and some of which is used to make other compounds, such as sucrose, starch and cellulose.

oxygen—gas produced when water molecules split. Some is used by the plant in aerobic respiration; some diffuses out through the stomata.

Figure 1. Student Notes about the Photosynthesis Equation.

As part of the discussion about the equation, the role of chlorophyll was illustrated by having a student play the role of a chlorophyll molecule. Balls of red, blue, and green paper were thrown at the student, who was instructed beforehand to catch the red and the blue, but to allow the green to bounce off of him. This illustrated that chlorophyll mostly absorbs light in the red and blue part of the spectrum, (and thus uses this part of the spectrum in photosynthesis), but mostly reflects the green part of the spectrum. Also, the teacher showed the class a transparency of the electromagnetic spectrum, pointing out the visible light spectrum and discussing how different colors of light corresponded to different wavelengths. The role of chlorophyll in photosynthesis was reviewed the next day as students did a laboratory activity in which they used paper chromatography to separate pigments in spinach leaves (see appendix B). As part of the laboratory discussion, the function of chlorophyll was debated. Some students said that the function of chlorophyll is to make plants green, while others disagreed, saying that chlorophyll traps light. The teacher used an analogy of a receptionist in an office, stating that while it may be true that the receptionist looks pretty, her function is to answer the phone, make appointments, etc. Likewise, while chlorophyll may reflect green light causing the plant to appear green, its function is to trap light energy needed for photosynthesis. As discussion of the photosynthesis equation continued, students were reminded that glucose, the plant's food, is a simple sugar that serves as an energy source in cellular respiration and also as a building block for larger molecules. The teacher again used the pop beads to illustrate that glucose molecules could form chains--molecules such as starch and cellulose. A cross section of a tree was shown to the class. The students were asked what compound made up most of the wood, to which some responded "cellulose." They were then referred back to the photosynthesis equation and asked which compound the plant used to make the cellulose, to which some responded "glucose." The class was then asked "which raw material provides the carbon and oxygen found in the glucose" to which a number of students responded "carbon dioxide." The teacher then, working backwards, showed the students how the cellulose in the wood came from the glucose which was produced largely from the carbon dioxide taken in by the plant. This was emphasized by the teacher, who attached a label to the tree cross-section which read "most of this wood was once CO_2 in the air" and passed this around the classroom. To further emphasize that glucose is plant food, the teacher showed the class a box of "plant food" such as is found in the gardening section of most stores. Discussion followed pointing out that while the compounds in the box are required for the plant to carry out its life processes, such as making proteins and other molecules, they are not food for a plant anymore than a vitamin pill is food for a person. In addition, students were given a homework assignment in which they read about Van Helmont and the Willow Tree (see Appendix C) and answered questions related to Van Helmont's experiment. The students' responses were discussed the following day in class.

To illustrate the cycling of carbon dioxide that takes place during photosynthesis and respiration, students conducted a laboratory activity titled "Photosynthesis Makes Me Blue" (see Appendix D). This was a teacher-modified version of a laboratory exercise that appears in lab manuals accompanying many biology textbooks. Bromothymol blue, an indicator which changes from blue to green then to yellow as pH drops, was added to four tubes. Tube 1 was capped, and served as a control. Students used straws to blow exhaled air into tube 2. The carbon dioxide bubbled through the tube produced a weak solution of carbonic acid, changing the solution from blue to yellow. This tube was capped and also served as a control. A sprig of *Elodea*, an aquatic plant, was added to tube 3, which was capped. Students added a sprig of *Elodea* to tube 4 but did not exhale into this tube, so that its initial color was blue. This tube was capped and covered with aluminum foil. Each group's set of four tubes was placed under a light bank for 24 hours. The next day, when students checked results, most groups observed that the solution in tube 3 had changed from yellow to blue over night. (For the few that did not, we discussed reasons why their results may have differed.) Discussion about the reason for this color change revealed that most students knew that photosynthesis was involved, but some suggested the reason for the color change was that the *Elodea* released oxygen, causing the color to change from yellow to blue again. Others pointed out that rather than the released oxygen causing the color change, it was the carbon dioxide being taken in by the plant. They reasoned that if adding carbon dioxide to bromothymol blue caused it to change from blue to yellow, then removing carbon dioxide from bromothymol yellow should cause it to return to the initial blue color. All groups observed that the solution in tube four, the one that did not receive light, had changed from blue to yellow or greenish-yellow over night. After some discussion, students suggested that the *Elodea* must have released carbon dioxide into the solution. The teacher prompted them by asking "what process have we studied recently that has carbon dioxide as a product?" Students recalled that cellular respiration releases carbon dioxide. There was then brief discussion about plants carrying out respiration, and how, though we could see evidence of this in tube four (the one that did not receive light), plants carry out respiration in both light and dark. The difference being that in the light, the amount of carbon dioxide being used by a photosynthesizing plant greatly exceeds the amount of carbon dioxide produced during respiration.

In addition to the introductory lecture and laboratory activities, students completed several worksheets for homework for reinforcement. They also took a short quiz early in the photosynthesis unit that was designed primarily to motivate them to learn the overall equation for photosynthesis. At the end of the unit, an EOC (end-of-course) style multiple choice test incorporating both photosynthesis and respiration was given. (Interestingly, none of the photosynthesis-related questions found in two different test bank software programs would reveal the types of misconceptions that are the focus of this study, again suggesting that students may do quite well on certain types of test items but still hold major misconceptions about photosynthesis.) Several days following the unit test, students were given a post-test consisting of the same items used on the pretest at the beginning of the study. They had neither seen the pretests since the day they took them nor been given their results on them. A summary of the instructional unit and research design is given in Figure 2.

CONTROL GROUP	EXPERIMENTAL GROUP
Pretest	
PowerPoint presentation without misconception slides	PowerPoint presentation with misconception slides
Leaf structure worksheet and lab activity Stomata lab Photosynthesis equation discussion and notes Plant Pigment Chromatography lab and follow-up worksheets Quiz—Overall Equation for Photosynthesis Van Helmont's Willow Tree Assignment "Photosynthesis Makes Me Blue" (BTB) lab Multiple Choice Test (from test bank software)	
Posttest	

Figure 2. Photosynthesis Unit Summary and Research Design.

Instruments/Assessments All students were given a two-part pretest on the day before the first day of the photosynthesis unit. This pretest was given to gather data about students' prior knowledge about photosynthesis; to identify misconceptions held by students and the prevalence of those misconceptions; and to promote students' self-evaluation of their own understanding of photosynthesis. Two weeks after completion of the unit, the posttest, the same instruments used for the pretest, was administered.

Open-Ended Question. The first part of the assessment was an open- ended question:

> The wind is howling, snow is blowing about, and the temperature is steadily dropping. You pick up another log to throw on the fire. You recall that this particular piece of wood was once part of a massive oak tree that toppled to the ground during Hurricane Fran. To think that what started as a tiny acorn is now a huge stack of dry wood that will warm your family for many nights!
>
> You look at the piece of wood in the fire and think "Where did all the building material come from to grow such a big oak tree from such a small seed?"
>
> HOW WOULD ***YOU*** EXPLAIN THIS? Write your response below, being as thorough as possible. Feel free to use **labeled** drawings in your response.

The analysis of the data included a first reading of the responses to the open-ended question and a listing of the various student responses. These responses were then categorized and a scoring system of 0-3 was devised. Keeping in mind that the primary goal of the research focused on how to help students overcome the misconception that plants obtain food from the soil through their roots, the following rubric for scoring students' responses to the open-ended question on both pre- and posttest was developed (see Figure 3).

Score	Type of Response
0	No response, "I have no idea" Time--over time the acorn grows into a huge oak tree The seed got bigger, cells divided
1	Responses included--stuff inside the acorn, the seed itself dirt, soil, earth, soil nutrients, rain, water, sun, sunlight, but **no** mention of photosynthesis or food-making
2	Response mentions photosynthesis or food-making but does **not** include the use of carbon dioxide to produce carbohydrates (Response may also include some of the ideas listed above for scores of one)
3	Response includes photosynthesis/food-making--the taking in of carbon dioxide and/or the production of carbohydrates

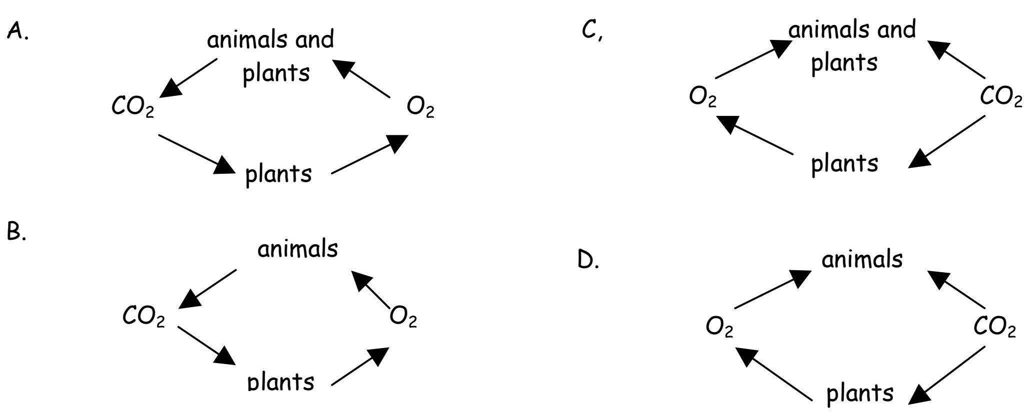
Figure 3. Rubric Used to Score Student Responses to the Open-ended Question.

A score of zero or one indicated that the students either had no concept regarding "where all the building material came from to grow such a big oak tree from such a small seed" or that they held the misconception that the building material came from the soil, water, light, or some combination of these. A score of 2 indicated students were somewhat familiar with photosynthesis, though they may not be clear about what the plant takes in during the process that adds most of the mass to the plant. They know that the process of photosynthesis is important to plant growth, but fail to communicate the connection between the process and the raw materials and products. They may also include some mention of soil, water, or other ideas listed as score one responses, indicating that, though they know photosynthesis is important, they may not realize that the plant makes all of its food through this process. A score of 3 was reserved for those responses that included the use of carbon dioxide in photosynthesis to produce other compounds such as glucose, starch, and/or cellulose. Each student's response was assigned a score. After the photosynthesis unit, pre- and posttest scores were compared.

Multiple-Choice/Short Answer Questions. The second part of the assessment consisted of multiple-choice items, some with explanation (question 1 was adapted from Amir & Tamir, 1994, and question 9 was adapted from a draft of the NCPDI classroom assessment materials for teachers, see Figure 4). Two weeks after the photosynthesis unit, students were given the same multiple choice items used on the pretest in order to evaluate any gains made by the students and to evaluate the effectiveness of the slide show targeting misconceptions. Would there be any significant difference between the posttest results for the control group and the experimental group? The multiple choice component of the pretest, shown in Figure 4 below, was checked, with students' responses to all items recorded in a table. This was repeated for the posttest.

---

1. Which of the following best shows the cycling of carbon dioxide and oxygen in nature?



Briefly explain your answer choice.

2. What percent of their food do plants get by making it themselves?

A. 0% B. 50% C. 75% D. 100%

Briefly explain your answer choice.

3. What percent of their food do plants get by absorbing it through their roots?

A. 0% B. 50% C. 75% D. 100%

Briefly explain your answer choice.

4. Like all organisms, plants need energy to live and to grow. Which of the following may be an energy source for plants? (Circle any that apply).

water sunlight soil fertilizer worms and insects

5. What is "food" for a plant?

6. What is the function of chlorophyll in plants?

7. Would animals be able to live in a world without plants? Explain your answer.

8. Which of the following equations best summarizes the process called photosynthesis?

A. glucose + oxygen $\xrightarrow[\text{chlorophyll}]{\text{light}}$ carbon dioxide + water

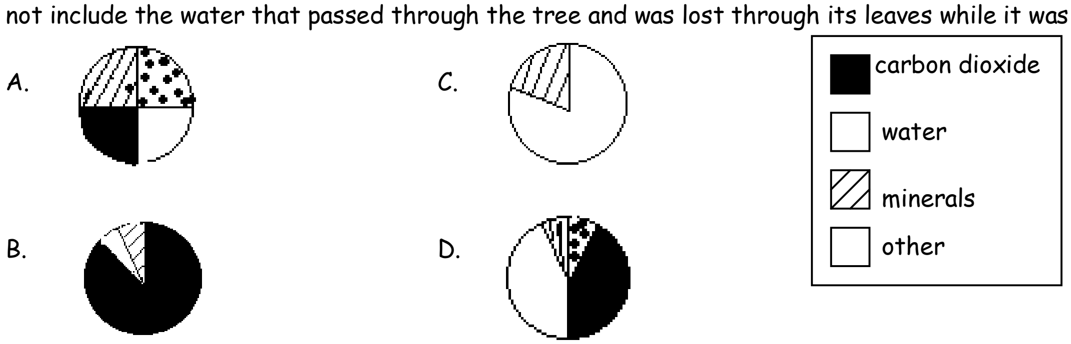
B. carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{light}}$ glucose + oxygen

C. light + chlorophyll + carbon dioxide + water $\longrightarrow$ glucose + oxygen

D. light + chlorophyll $\longrightarrow$ glucose + oxygen

Explain your choice.

9. Richard has an old wooden baseball bat that his father made when he was a young man. The wood in the bat is dry wood—nearly all of the moisture that was in this piece of wood from a white ash tree when it was first cut, or "green" has long been gone, leaving just the wood itself. Select the graph below that best represents the amounts of materials used by the ash tree to produce this wood. (Do not include the water that passed through the tree and was lost through its leaves while it was alive.)



Explain your choice.

Figure 4. Multiple Choice/Short Answer Assessment Instrument.

Results

Open-Ended Question Pretest Results In response to the open-ended question about where the building material came from to grow such a big oak tree from such a small seed, student answers varied widely, and included the following:

stuff inside the acorn/from the seed itself	sun/sunlight
dirt, soil, earth, soil nutrients/fertile ground	time
rain/water	oxygen
nutrients (with no indication of the source)	photosynthesis
vitamins	

Pretest results for the open-ended question are summarized in Table 2.

Table 2 *Open-ended Question Pretest scores by Percent for Control and Experimental Groups*

Score	Control group (*n*=32)	Experimental group (*n*=32)	Total (*n*=64)
0	25%	28%	27%
1	66%	63%	64%
2	9%	9%	9%
3	0%	0%	0%

Pretest results for the open-ended question were very similar for both groups of students. Twenty-seven percent of all students tested received scores of zero. These scores included students who did not respond-or who responded "I don't know," as well as those who did not really address the question in their answer.

Representative samples of student responses assigned a score of 0 are listed below.

> The cells in the acorn were designed to create a tree. They reproduce to form the tree. They have a small plant already in it. They grow by splitting, a type of reproduction. They in a certain (way) form to produce a tree. They continue to reproduce until the tree is large.

> The seed went into the ground and started to grow as a tree but someone knocked it over or pulled it up and now it is a log.
>
> I think that the tree grows up and out. The roots grow in the ground and as they grow they make the tree wider so the tree will get bigger. I think that the tree expands outward and grows upward.
>
> Every acorn has the ability to grow into a tree. It has enough seeds to produce a tree. Just like a human is born as a tiny baby and grows into an adult. It has cells in it to make it grow.
>
> I guess if you nurture the acorn it will start to grow. It keeps growing and growing until it becomes a giant oak tree.
>
> Given the right environment and conditions, the seed begins to grow. The seed will begin to get larger and sprout and as the years go on, if conditions are favorable, the roots will get larger and so will the tree. It will begin to look more like a tree than a seed and keep getting bigger. Then it will be a huge oak tree.
>
> Well I think it took at least 10 years for the oak tree to grow and develop.

Sixty-four percent of all students tested received a pretest score of one on the open-ended question. Representative samples of students' responses receiving a score of one are given below.

> The oak tree grows as it gets the water and nutrients that it needs. Water comes from rain and nutrients come from the ground.
>
> I think it comes from the soil. The soil gave the acorn a place to grow and its nutrients. The sun and water help the tree grow larger too.
>
> The seed goes into the ground and the earth nourishes it with all its minerals. The sun and water help the seed grow. Over a time the tree gets bigger and bigger.
>
> I think all the building material came from the soil. The minerals and nutrients provided the material necessary for growing that large tree. The acorn has all the genetic material needed to shape its growth. The dead wood in the fire is left over cell walls from the dead cell.
>
> The acorns lay on the ground and as the months/years pass they feed off all the nutrients and proteins in the soil and soak up the rain. The acorn then seeds and the tree begins to grow.

Of all students tested, 91% received scores of 0 or 1. Though their responses varied widely, all shared the criterion of including no mention of photosynthesis/food-making by the plant. Too, student responses showed a wide range of sophistication in terms of their knowledge of biological processes and use of science vocabulary.

Of all students tested, only 9% (6 students out of 64 tested) mentioned photosynthesis or food-making in their pretest response, receiving a score of 2. And of those, four included photosynthesis, but also included other sources of building material, such as soil, or emphasized the role of roots in taking in nutrients. These four responses are listed below.

> The building material comes from the ground as nutrients and from photosynthesis. Without these things the seed could (not) grow and function into the huge oak tree it once was.
>
> The seed is designed to build up into a large tree. It grows roots and sprouts up. Once sunlight hits the small tree, it begins to use photosynthesis to grow bigger. Its root system gets larger and it draws more nutrients. The tree grows larger and larger through the process of photosynthesis.
>
> The acorn grows roots and the roots absorb minerals and other substance that help the tree grow, it also uses photosynthesis to grow too.
>
> It comes from the process of photosynthesis gathering CO_2 and solar light and some other stuff to get food also from all the proteins in the soil to create the bark also from other minerals and water.

One student who received a score of two mentioned photosynthesis, but did not specify any substance taken in or produced by the plant.

> The tiny acorn goes through photosynthesis and matter built up. Eventually it growed into a big oak tree.

Of all 64 responses, only one included photosynthesis and the raw materials used in photosynthesis, with no evidence of the "food through the roots" misconception. The only reason this response was not given a score of 3 was that it did not include any mention of a specific photosynthetic product such as glucose (the student does not explain what light, water and CO_2 are "converted" to).

> The DNA for the tree was already in the acorn, but the actual wood and branches came from light, water, and CO_2 that were converted through photosynthesis. Every year the tree gets a little bit taller and a little bit thicker, this is why there are rings on a tree stump and why you want to cut "with the grain.

Multiple Choice/Short Answer Pretest Results

Students' responses to multiple choice question 1 are summarized in Table 3 below.

Table 3 *Student Responses to Item 1 about the Cycling of CO_2 and O_2*

Responses	Percentage of control group *(n = 32)*	Percentage of experimental group *(n = 32)*	Total *(n = 64)*
Desired response (A) Animals and plants both produce CO_2. Plants take in CO_2 and release O_2, which is used by animals and plants.	19%	19%	19%
Response (B) Animals give off CO_2 which is taken in by plants. Plants give off O_2 which is taken in by animals.	63%	66%	64%
Response (C) Plants take in CO_2 and release O_2 which is taken in by animals and plants. Animals and plants take in CO_2.	9%	6%	8%
Response (D) CO_2 is taken in by plants and by animals. Plants give off O_2 which is taken in by animals.	9%	9%	9%

Nineteen percent of students in both groups selected the desired response, but the explanations given by most of these students did not indicate that they really distinguished choice (B) from choice (A). For example, one student explained his answer choice: "Plants give off the oxygen for the animals to get and animals give CO_2 to a plant and starts the cycle back over." Another explained choice A by stating, "The plants give off oxygen that are needed by the animals and the animals give off carbon dioxide that the plant needs to grow." Another student explained choice A the following way, indicating an understanding that plants require oxygen for respiration. Still, this student has a misunderstanding about the source of the oxygen given off during photosynthesis. "I think plants need O_2 and CO_2. O_2 is for respiration. The plants change CO_2 into O_2." Of six students in the control group responding correctly, five did not give explanations that matched their answer choice. Only one student gave a response that indicated an understanding of the difference between choices A and B, namely, that plants and animals use oxygen in respiration. In the experimental group, three students out of six who selected choice A gave an acceptable explanation, while the other three students gave no explanation or one that did not explain the diagram they chose. In all, eighty-three percent of students taking the pretest chose answers, and most gave explanations, that indicated an understanding of the net effect of plants and animals on the cycling of carbon dioxide and oxygen.

Items 2 and 3 dealt with the source of a plant's food. Question 2 asks "What percent of their food do plants get by making it themselves?" Students were then asked to explain their answer choice. Responses are summarized in Table 4.

Table 4 *Student Responses to Question 2 "What percent of their food do plants get by making it themselves?*

Responses	Percentage of control group *(n = 32)*	Percentage of experimental group *(n = 32)*	Total *(n = 64)*
(A) 0%	9%	13%	11%
(B) 50%	34%	66%	50%
(C) 75%	13%	9%	11%
(D) 100% (desired response)	41%	13%	27%
no response	3%	0%	2%

Forty-one percent of the students in the control group selected the desired response (plants make 100% of their food) whereas only 13 % of the students in the experimental group selected this answer. This difference probably did not indicate a significant difference between the control group and experimental group in terms of the students' prior knowledge, however, as evidenced by students' answers to item 3 (see Table 5) and their explanations for both items.

Table 5 *Student Responses to Question "What Percent of Their Food do Plants Get by Absorbing it Through Their Roots?"*

Responses	Percentage of control group *(n = 32)*	Percentage of experimental group *(n = 32)*	Total *(n = 64)*
(A) 0%	13%	3%	8%
(B) 50%	41%	60%	50%
(C) 75%	16%	25%	20%
(D) 100%	22%	6%	14%
no response	3%	2%	8%

Thirteen percent of the control group selected choice A, that plants get 0% of their food through their roots compared to only 3% of the experimental group. To examine whether there was a significant difference in the prior knowledge of the two groups, the responses to questions 2 and 3 should be considered together. For example, a student who responds that plants make 100% of their food and also responds that plants take in 50% of their food through their roots clearly has a misconception. How many students in the pretest answered both questions 2 and 3 correctly? Only 3 students out of 32 (9%) in the control group and 1 student out of 32 in the experimental group responded that plants make 100% of their food *and* absorb 0% of their food through their roots. All four of these students gave acceptable explanations—that plants make all of their food through photosynthesis, with two students including that plants absorb other substances through their roots, but not food. Some students who chose the correct answer for question 2 revealed misconceptions in their explanations. For example, one student in the control group who responded that plants make 100% of their food gave this explanation: "Plants are not given any food, so they take the nutrients from the earth and create their own food." This same student responded that plants absorb 100% of their food through their roots. Another student in the control group responded that plants make 100% of their food and also absorb 100% of their food through their roots. This student's explanation for question 2 read: "If they make their own food, then they must get 100%. They are using what they already had to make it, so they aren't losing or gaining anything." And in response to question 3 said, "They still must get all of their food. Since the food goes through their roots and comes to them. The plant gets 100%. What is in the roots comes to the plant."

It is clear that a correct response to question 2 alone does not indicate that a student understands how plants get food. The majority of students in both groups (81% in the control group, 69% in the experimental group) selected answers to questions 2 and 3 that indicated that though they thought that plants make some of their food (though many did not indicate the process), they also thought that plants get some of their food through their roots. Samples of their explanations are below.

> They get a lot of their food from photosynthesis. The roots also draw in nutrients.
>
> They get food from air and sunlight but other food comes from the soil.
>
> Plants make most of their own food but the water is supplied as well as the few carnivorous plants that exist. Water is taken through roots as well as nutrients from the soil.
>
> They photosynthesize half of their food. They get the other half in other ways.
>
> Some food they get from nutrients in the ground but some come from photosynthesis.
>
> I'm not really sure. They have photosynthesis? The food permeates through the roots.

> They make half of their food, but they get the rest from the soil.
>
> Plants can't just go out there and kill something or actually eat nothing so it has to produce its own food. Nutrients through roots help it grow.
>
> I think they get a good percent from their roots.
>
> I think they convert the starch in they bodies to food. All the water, minerals, nutrients in soil may be used as food for plants.
>
> Plants use photosynthesis to make and process their own food, but they also get some nutrients from the soil. And now this doesn't work out because 50% and 75% equals 125%. But plants do get some essential nutrients from the ground.

For most of these students, their main misconception appeared to be directly tied to their inability to define what constitutes food for a plant. Only a very small number of students (9% of the control group, 13% of the experimental group) indicated that they thought that plants do not make any of their food, but absorb all their food through their roots. Some of their explanations are below.

> Plants don't eat. They need oxygen and minerals from earth's environment. They use their roots to eat.
>
> Plants don't make food. Their food comes from the soil.
>
> Because if you take a plant out of the soil and put it on a glass table to sit its going to die. So plants live and feed off of soil and H_2O.
>
> They get all of their food from soil.
>
> The food they make isn't for themselves. Cause the roots absorb all food.

Students' responses to questions 2 and 3 revealed that most of them did not know what constitutes food for a plant. And most of the students who demonstrated an awareness of photosynthesis as a food-making process still indicated that plants get at least some of their food from the soil/through the roots.

Just as responses to questions 2 and 3 revealed misconceptions about what plants use for food, responses to question 4 (see Table 6) indicated that most students were unclear about the energy source for plants. Only 9% of students selected sunlight as the only energy source for plants. Ninety-one percent included sunlight among other choices, with the majority of students circling all five choices. This indicates a lack of understanding of what energy is and how plants obtain energy.

Table 6 *Student Responses to "Which of the following may be an energy source for plants? "*

water sunlight soil fertilizer worms and insects

Responses	Percentage of control group *(n = 32)*	Percentage of experimental group *(n = 32)*	Total *(n = 64)*
sunlight only (desired response)	13%	6%	9%
sunlight plus other choices circled	87%	94%	91%

Item 5 asks students to respond to the question "What is food for a plant?" A botany textbook defines it this way. "A food is any organic material that serves the plant as a source of energy and as a source of carbon from which new compounds may be made" (Weir et al., p. 63). So food for a plant includes carbohydrates, fats, and proteins. However, the primary food molecules are the sugars produced during photosynthesis from which other carbohydrates, fats, and proteins are ultimately derived. Results as given in Table 7 indicate that few students had prior knowledge regarding what a plant's food is.

Table 7 *Summary of Student Responses to Item 5 "What is food for a plant?"*

Response	Percentage of Control Group *n=32*	Percentage of Experimental Group *n=32*	Percentage of Total *n=64*
Glucose/sugar/carbohydrate	6%	6%	6%
Other responses	94%	94%	94%

Only two students in the control group and two students in the experimental group answered that food for a plant is carbohydrate (sugar, glucose, starch). The remaining 94% of students' responses included answers such as sun/sunlight/light, water, fertilizer, soil/dirt/ground, nutrients, minerals, energy, worms, and functional definitions such as "what it needs to grow." Forty-five percent of students included water in their response. Thirty-four percent included soil or earth as a food for plants. And thirty-nine percent listed the sun or light as food for plants.

Item 6 on the pretest concerned the function of chlorophyll. Results are summarized in Table 8.

Table 8 *Student Responses to Item 6 "What is the function of chlorophyll?"*

Responses	Percentage of Control Group *n=32*	Percentage of Experimental Group *n=32*	Percentage of Total *n=64*
to trap/absorb/capture light	9%	16%	13%
(to help in) photosynthesis	34%	34%	34%
to give plants color (make plants green)	41%	31%	36%
other	9%	9%	9%
no response	9%	6%	8%

In response to this question, only three students in the control group (9%) and five in the experimental group (16%) responded "to trap (or absorb) light." Eleven students in the control group (34%) said that chlorophyll was involved in photosynthesis, as did eleven students in the experimental group (34%). So 34% of students knew that chlorophyll was involved in photosynthesis, but did not indicate chlorophyll's specific function. Forty-one percent of the control group and thirty-one percent of the experimental group responded that chlorophyll's function is to "make plants green" or "give plants their color." While it is possible that these students' responses may be related to their not understanding the difference between a property and a function, it is more likely that their responses indicated all the students knew about chlorophyll.

Item 7, "Would animals be able to live in a world without plants?" was included to gather information about whether students not only understood the importance of plants in cycling carbon dioxide and oxygen, but also their importance as producers of the food on which all organisms ultimately rely. Nineteen students in the control group (59%) and twenty students in the experimental group (63%) gave responses that focused on the importance of plants in producing oxygen and/or helping maintain the level of carbon dioxide in the atmosphere. Some typical responses are below.

> No. There would be too much CO_2 and not enough O_2.
>
> No, plants provide oxygen that is vital to animals.
>
> No they need oxygen plants put off.
>
> No, because there would be no oxygen.
>
> No, plants give off oxygen for animals to live. Without oxygen, animals die because they don't have energy.

Many students were obviously aware of the importance of plants in the cycling of oxygen. Fewer students mentioned the importance of plants as producers of food, however. Nine students in the control group (28%) and four in the experimental group (13%) gave plants as sources of food as their reason that animals cannot survive in a world without plants, though some of their answers revealed that they did not fully understand that all of our food originates as food produced by plants. Several such responses are given below.

> No, because some animals eat plants to survive and some animals eat plants when they get sick.
>
> No, some insects (bees) get their food from plants and can't live off anything. Some insects live on and under plants.
>
> No, because some animals survive on plants.
>
> No. Some animals only eat plants.

Other students' responses reveal their understanding of plants as producers of food.

> No. Not all animals are carnivorous, even those that are rely on plant-eating animals to get their needed nutrients.
>
> No, the plants are producers and they start the food chain. If you don't have plants then the herbivores die, and if they die the carnivores won't have anything to eat so they die.

While most students mentioned either the cycling of oxygen and/or carbon dioxide or production of food as reasons animals cannot survive without plants, few mentioned both gases and food in their responses. Three students in the control group (9%) and six in the experimental group (19%) included both reasons in their answers.

> No, because plants do a lot. Plants give off O_2 and animals eat plants.
>
> No. Plants provide oxygen and food.
>
> No because of oxygen and carbon dioxide and also as food.
>
> No, because plants produce oxygen, and food for plant-eating animals, who provide food for carnivorous animals.

It is interesting to consider if the question had directed students to give all reasons they could think of to justify their answer, whether more students would have mentioned both food and gases in their responses. Regardless, the results of this pretest item indicated that students did have at least some understanding of the importance of plants.

Item 8 on the pretest was designed to determine whether the student knew the overall equation for photosynthesis. Would students be able to distinguish between raw materials, necessary conditions, and products? The choices and student responses are summarized in Table 9.

Table 9 *Student Responses to Item 8 "Which of the following equations best summarizes the process called photosynthesis?"*

Responses	Percentage of control group *(n = 32)*	Percentage of experimental group *(n = 32)*	Total *(n = 64)*
(A) glucose + oxygen $\xrightarrow[\text{chlorophyll}]{\text{light}}$ carbon dioxide + water	13	19	16
(B) carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{light}}$ glucose + oxygen	56	28	42
(C) light +chlorophyll + carbon dioxide + water $\Longrightarrow$ glucose + oxygen	28	34	31
(D) light + chlorophyll $\Longrightarrow$ glucose + oxygen	0	13	13
No Response	3	6	5

Fifty-six percent of the control group (18 of 32 students) and twenty-eight percent of the experimental group (9 of 32 students) selected choice B, the desired response. Of those students in the control group who answered correctly, five out of eighteen gave explanations that indicated that they understood, at least in part, why choice B was the best choice. Of those students in the experimental group who answered correctly, one out of nine gave an explanation that showed that he clearly distinguished between choice B and the closely-related choice C. To distinguish between these two choices, students had to realize that light and chlorophyll and necessary for the process of photosynthesis, but that they are not reactants. Samples of these explanations include:

> Plants use sunlight and their chlorophyll to change the CO_2 we exhale and the water collected by their roots into glucose for food and oxygen as a waste product.
>
> I know plants release oxygen as a waste product, and glucose is plants' source of energy. And CO_2 and water with help of light and chlorophyll might yield these products.
>
> Carbon dioxide and water with the help of light and chlorophyll give us glucose and oxygen.
>
> When carbon dioxide and water are taken into the plant, with the sun providing energy the plant produces glucose and oxygen.
>
> Plants get CO_2 from us then their waste is oxygen using light and chlorophyll in the process.

While it is possible that other students, if questioned further, may have known why choice B was the best choice, they did not communicate this understanding in their explanations. Five students who answered correctly gave no explanations, and others gave explanations that could apply to choice C as well as choice B, for example: "It was the only choice that included the things I think cause photosynthesis. I know it involves light and carbon dioxide and water. This looks like a logical equation." Looking at data for all students combined, the second most frequent response chosen was (C) with 31% of students selecting this answer. This choice differs from (B) in that in choice (C), light and chlorophyll are included as reactants along with carbon dioxide and water. Students' explanations included:

> Plants need light and water in order to grow and they produce oxygen.
>
> Because the plants need the light, chlorophyll, CO_2, and H_2O to create the food, glucose and the waste product, oxygen.
>
> Plants use light, chlorophyll, CO_2, and water to carry out photosynthesis. Photosynthesis gives off energy (in the form of glucose) and oxygen.

It is evident that some students who chose choice (C) have more knowledge of photosynthesis than some who chose choice (B), even though they may not distinguish between reactants, energy source, and light-trapping pigment.

Item 9 is a multiple choice question that uses graphs to address the same question as the open-ended question, that is, what raw material(s) taken in by a plant account(s) for most of its dry mass? Results are summarized in Table 10.

Table 10 *Student Responses to Item 9, "Select the graph below that best represents the amounts of materials used by the ash tree to produce this wood.*

Responses	Percentage of control group *(n = 32)*	Percentage of experimental group *(n = 32)*	Total *(n = 64)*
(A)Graph shows equal amounts of carbon dioxide, water, minerals, and other	38%	25%	31%
(B)Graph shows mostly carbon dioxide, with small amounts of water and minerals	19%	44%	31%
(C)Graph shows about 3/4 water, 1/4 minerals	0%	0%	0%
(D)Graph shows equal amounts of water and carbon dioxide occupying about 90% of the graph, with small amounts of minerals and other.	28%	25%	27%
No response	16%	6%	11%

Looking at the entire sample group, responses are fairly evenly distributed among choices A, B, and D. Comparing the experimental and control groups' responses, the experimental group had 44% correct responses (choice B), while the control group had 19% correct responses. However, this question did not necessarily measure what was intended. Some students arrived at the correct answer using the reasoning illustrated in the students' explanations below:

> Since the question said that the wood was dry, this was the only answer that had most of the wood dry.

> Because it has lost all the water and minerals since its gotten so old.
>
> The wood has no water left because it was dried out.
>
> Because the H_2O is gone and if that happens then the minerals will leave too. It would be left with other materials.
>
> I think B because it won't that much water dealing with B than it was with the rest.

Clearly, a student could arrive at the correct answer by reasoning that if the wood was dry, then the best answer is the one with the least water! No student who answered correctly in either group gave an explanation that indicated an understanding of the use of carbon dioxide in the production of cellulose. The majority of students who answered correctly either gave no explanation or wrote, "I guessed."

Summary of Pretest Results

The pretest results provided interesting data concerning the sample group and their knowledge of photosynthesis. The multiple-choice/short answer component of the pretest yielded much information. For example, item one revealed that most students are aware that plants use carbon dioxide and release oxygen to the environment, but very few demonstrated that they knew that plants use oxygen and produce some carbon dioxide as well. And very few students realized that plants make 100% of their food and absorb no food through their roots, as evidenced by responses to items 2 and 3. In response to item 4, ninety-one percent of students thought that plants obtain energy from sources other than light. Very few students identified a carbohydrate as food for a plant; most considered soil, water, and other things in a plant's environment as food in response to item 5. Before the unit, students clearly had a number of wrong ideas concerning what is the ultimate energy source for plants as well as what is food for plants. In their answers to question 6, a surprising number of students stated that chlorophyll has a role in photosynthesis--though very few knew chlorophyll's function, with many stating, in effect, that chlorophyll's function is to "give plants their green color." When asked in item 7 if animals could survive in a world without plants, more students communicated an awareness of the importance of plants in the cycling of oxygen than of their importance as producers of food. In identifying the overall equation for photosynthesis in item 8, the control group outperformed the experimental group, but looking at overall results, the majority of students did choose one of the two responses that showed carbon dioxide and water on the left side of the equation. Some of this success may be attributed to the students' having completed a short unit on respiration just before the pretest was administered, and thus being exposed to the overall equation for aerobic cellular respiration. Perhaps during discussion of the respiration equation there was some mention of the products of respiration being the raw materials for photosynthesis, but this was not an objective of the respiration unit. Students' responses to item 9, which was intended to reveal whether students realized that carbon dioxide was the primary substance a plant takes from its environment that adds to its final, dry mass, revealed that students could arrive at the right answer without really understanding the desired concept. A number of students reasoned their way to the right answer by choosing the graph with the least water, since the question indicated that the wood was dry!

Comparing pretest results for the control and experimental groups, there do appear to be some slight differences between the two groups on individual items; however, when all responses are considered, the groups are very similar. For example, the control group performed better than the experimental group (41% correct responses compared to 13%) on item 2 about the percent of a plant's food that is made by the plant. But of those 13 students answering correctly, only three students also answered question 3 correctly (that plants absorb 0% of their food through their roots.) A correct answer on either item 2 or item 3, paired with an incorrect response on the other indicates a discrepancy that points to a misconception. On item 8, identifying the overall equation for photosynthesis, 56% of the control group and 28% of the experimental group selected choice B, the desired response. Does this indicate a significant difference in terms of prior knowledge between the two groups? Most likely this suggests that the control group, as a whole, may have some slight advantage compared to the experimental group in terms of prior knowledge going into the photosynthesis unit. However, when the results of the open-ended question are considered, there does not appear to be a significant difference between the two groups at the comprehension level.

Based on pretest results for the open-ended question, 27% of the sample group either did not answer, or did not address the question in their answers. Sixty-four percent of students held the misconception that plants obtain their material for growth through their roots, from the soil, water, minerals, or some combination of these. Only 9% of students mentioned photosynthesis or food-making in their answer, and several of these students mentioned photosynthesis along with getting food through the roots or from the soil. No student in the sample group communicated an understanding that most of a plant's dry mass is due to the carbon dioxide taken in and used in photosynthesis in the production of carbohydrates—namely, cellulose.

<u>Open-ended Question Posttest Results</u>

After completion of the photosynthesis unit, students were again asked to respond to the open-ended question. Results are shown in Table 11, with pretest results included for comparison.

Table 11 *Percentage of Students Receiving Score on the Open-ended Question*

Score	Students in control group (*n*=32) pretest/posttest		Students in experimental group (*n*=32) pretest/posttest		Total (*n*=64) pretest/posttest	
0	25%	13%	28%	3%	27%	8%
1	66%	25%	63%	3%	64%	14%
2	9%	44%	9%	69%	9%	57%
3	0%	19%	0%	25%	0%	22%

Both the control and experimental groups showed overall improvement in their responses to the open-ended question. Considerably fewer students scored a zero on the posttest than on the pretest. The majority of students' scores shifted from a score of one to a score of two, as on the pretest 64% of all students tested scored a one while on the posttest the most frequent score for all students, at 57%, was two. The experimental group showed more improvement, with only 9% of students scoring a two (and 0% scoring a three) on the pretest, improving to 74% of students scoring a 2 or 3 on the posttest. In the control group 9% of students scored a two (and 0% scored a three) on the pretest compared to 63% scoring a two or three on the posttest. A t test analysis indicated no significant difference in pretest scores ($p<0.05$) between the control group (M=0.843; SD=0.574) and the experimental group (M=0.813; SD=0.592). Analysis of posttest gains scores did indicate a significant difference in posttest gains scores for the two groups, however, with the control group (M=0.844; SD=0.88) and experimental group (M=1.344; SD=0.90). While both groups made significant gains, the experimental group's gains were greater than the control group's. In all, 66% of students in the control group improved their score on the open-ended question compared to 84% of students in the experimental group. Below is a response from a student who scored a one on the pretest.

> The oak tree produces acorns, which are the seeds of the tree. These acorns will eventually drop off the tree and may be carried away by some phenomena, be it wind/water/or animal, and eventually buried in the ground, perhaps a squirrel will store it for food. The acorn contains a small plant inside that eventually grows into an oak tree. The plant that grow from the acorn (which contains atoms/molecules from its tree, and that tree's acorn, and so forth) will grow and develop, given enough sunlight, water, and nutrients to be nurtured and maintain homeostasis.

Compare his pretest response to his posttest response below, score 3.

> The tiny acorn is the seed of another massive oak tree. The acorn was planted in the ground, and eventually became a small seedling. Through its leaves (composed of many cells, which have tiny organelles called chloroplasts) it carried out photosynthesis by trapping light in the chloroplast. Photosynthesis formed glucose for the plant, which gave energy to the plant for growth. It also used glucose to form chains of carbohydrates called starch and cellulose. Cellulose is what forms cells walls, and eventually the plant developed bark, which gave it protection and support. The tree, after many years of photosynthesizing, now provides you and your family with warmth.

This student did not mention photosynthesis in his pretest response. In his posttest response, not only does he mention photosynthesis, but also describes compounds that are made from glucose. He does seem to have some confusion about bark; however, the instructional unit did not include a discussion of woody stems beyond that wood is primarily composed of cell walls, which in turn are made mostly of cellulose. Clearly, this student has grasped the major objectives of the unit. Below is another example of a pretest response with a score of one.

> I think all the building material came from the soil. The minerals and nutrients provided the material necessary for growing that large tree. The acorn has all the genetic material needed to shape its growth. The dead wood in the fire is left over cell walls from the dead tree.

Compare the same student's posttest response, which received a score of 3.

> A small acorn fell from a giant oak tree. This acorn fell in a mud puddle which covered it with wet soil. Slowly, the small acorn began to germinate in the soil until finally it burst forth from the soil. The energy needed for the seed to germinate was stored in the acorn in the form of starch. Eventually the tiny tree sprouts leaves. It is now able to carry out photosynthesis, from now on the tree makes its own food. The tree does not take its food from the soil though, it gets its food from the CO_2 in the air. Water brought in from the roots and CO_2 from the air are both (together) photosynthesized to make glucose and oxygen. The oxygen is a waste product but glucose is used to make energy and cellulose (the main structure of plants.) Eventually the tree will grow large and produce acorns of its own.

This student shows evidence of having recognized his own misconception. In his pretest response he states that he believes that "all the building material comes from the soil." But in his posttest response, he makes a point of saying that ". . .the tree does not take its food from the soil. . ." This is a student who has clearly changed his way of thinking about the source of a plant's food—who has formed a new conceptual framework. One more example of a student who made such progress is given below. First, the score 1 pretest response.

> The tree fed off the nutrients in the soil and the rainfall. It kept getting bigger just like people do, except they keep growing longer.

Compare the pretest response to the student's posttest response, score 3.

> Most people believe that plants get their food from the soil, but that is not true. Humans exhale carbon dioxide into the air when they breathe, and plants take that carbon dioxide in through their leaves, through little "lips" called stomata in the lower epidermis. The gas then flows through the air space in the layers of the leaf. Along with light and other enzyme, these plants carry out photosynthesis. A product of photosynthesis is glucose, which is the main source of food for a plant. With this food the plant, in this case an oak tree, grows and grows.

This student's responses bring up several questions. Does this student think that only humans add carbon dioxide to the atmosphere? Or that stomata are only found on the lower epidermis of leaves? Probably not, but if so, these are ideas that can be easily addressed. The student does seem very clear, however, about where a plant does and does not get food. And like the student in the previous sample, this student directly addresses the common misconception that is the focus of this study.

The student responses in the previous three samples are the types of responses that the instructor would like all students to make after this unit of study. Yet, when data was analyzed, only 22% of students taking part in this study showed evidence of this desired level of understanding in their posttest responses. Many students did, however, improve from scores of 0 or 1 to scores of 2, indicating that they had made at least some improvement in their understanding of where plants get their food. Several samples of students' responses that show an improvement in their level of understanding follow.

The first is from a student in the control group who improved from score 1 to score 2. First, the student's pretest response.

> The acorn starts out all by itself. It needs water to grow. Then it grows taller and taller just like any other living thing grows. The material comes from water, and is made up of dirt. Maybe the acorns grow roots that come from part of other roots or made from dirt.

The same student's posttest response shows much improvement.

> I would explain this by saying it came from photosynthesis. The acorn grows then it uses water, sunlight, and carbon dioxide to grow just as we use food. As it grows, it throws off oxygen."

The student whose responses are given above may not have achieved as much as the instructor would like, but has definitely made progress in his understanding of plant growth, as has the control group student in the next sample, who scored a 0 on the pretest response below.

> Every acorn has the ability to grow into a tree. It has enough seeds to produce a tree. Just like a human is born as a tiny baby and grows into an adult. It has cells in it to make it grow.

In the pretest response, the student makes no mention of photosynthesis or any substances taken in by the plant. Compare this to the student's posttest response below.

> The tiny acorn got to be a big massive oak tree because of photosynthesis. Producers use photosynthesis to make their own food. Sunlight also helped the acorn grow, because you need sunlight for photosynthesis. And, you need water.

The student in the sample above did not mention carbon dioxide, but showed definite progress in her awareness that photosynthesis is the process that makes growth of the tree possible, as did the experimental group student in the next sample, a pretest response that was scored a zero.

> When the acorn sprouts its roots grow all around making sturdy feet for the tree to start growing on. The roots grow larger every time the tree gets bigger.

This same student's posttest response, given below, received a score of two.

> What started as an acorn fell from a tree, having roots from it grow into the ground, as it is covered by dirt and roots, it slowly begins to grow out of the ground as a little plant getting sunlight and water, taking in all the carbon dioxide and forming oxygen. As it keeps on doing the same process called photosynthesis it grows bigger and bigger making an oak tree.

This student did not mention glucose, but did make definite gains from the pretest. His posttest included all raw materials needed for photosynthesis, and he appeared to understand that it is because of photosynthesis that the tree grew.

While the instructor would like to see every student score a 3 on the posttest, this expectation is not realistic. However, based on the posttest responses to the open-ended question, a number of students did appear to have achieved accommodation, while many others made progress as evidenced by their abandoning their "plants get food from the soil" concept in favor of "plants make food by photosynthesis."

Multiple Choice/Short Answer Posttest Results

Results on item 1 are summarized in Table 12. There was very little difference in pretest and posttest responses on item 1. This is likely due to two factors. One, choice B, though not the "best" choice, is not entirely inaccurate if one considers the net effects of plants and animals on the cycling of oxygen and carbon dioxide. So a student who chooses choice B is probably selecting the answer he or she has learned since elementary school—that plants give off oxygen that animals need. To choose the more sophisticated and desired response, the student likely would need to see very similar diagrams during

Table 12 *Student Responses to Item 1 about the Cycling of CO_2 and O_2*

Responses	Percentage of control group *(n = 32)*		Percentage of experimental group *(n = 32)*		Total *(n = 64)*	
	pretest	posttest	pretest	posttest	pretest	posttest
Desired response (A) Animals and plants both produce CO_2. Plants take in CO_2 and release O_2, which is used by animals and plants.	9%	19%	19%	25%	19%	22%
Response (B) Animals give off CO_2 which is taken in by plants. Plants give off O_2 which is taken in by animals.	63%	78%	66%	66%	4%	72%
Response (C) Plants take in CO_2 and release O_2 which is taken in by animals and plants. Animals and plants take in CO_2.	9%	3%	6%	3%	8%	3%
Response (D) CO_2 is taken in by plants and by animals. Plants give off O_2 which is taken in by animals.	9%	0%	9%	19%	9%	9%

instruction and have opportunity to compare and contrast the two. Not wanting to show the specific test items to students during instruction, the instructor did not point out the differences in these diagrams during the unit. Students did complete a laboratory activity during the instructional unit in which they observed firsthand evidence that plants do produce carbon dioxide, as the bromothymol blue solution turned yellow in test tubes in which plants were not exposed to light. (This could, unfortunately, foster the misconception that plants respire only in the dark.) The results on item one support the idea that students will cling to their old ideas unless they are carefully questioned in such a way that they are compelled to compare their old ideas with better alternatives. And, these results also support the idea that that most students need the instructor to help them make the connections between their observations and the desired concepts the instructor seeks for them to develop.

Results on item two are summarized in Table 13.

Table 13 *Student Responses to Question 2 "What percent of their food do plants get by making it themselves?*

Responses	Percentage of control group *(n = 32)*		Percentage of experimental group *(n = 32)*		Total *(n = 64)*	
	pretest	posttest	pretest	posttest	pretest	posttest
(A) 0%	9%	0%	13%	0%	11%	0%
(B) 50%	34%	0%	66%	9%	50%	5%
(C) 75%	13%	6%	9%	6%	11%	6%
(D) 100% (desired response)	41%	94%	13%	84%	27%	89%
no response	3%	0%	0%	0%	2%	0%

Based on the results for item 2, all students are now convinced that plants make at least some of their food. And 89% of students in the study indicated that plants make 100% of their food. Forty-one percent of the control group answered this question correctly on the pretest, compared to only 13% of the experimental group. Whatever the reason for the difference in the pretest results, both groups showed a significant increase in correct responses on this posttest item.

Item 3 is the partner question to item 2. If the majority of students now believe that plants make 100% of their food, will their responses on item 3 correlate with their item 2 responses, and indicate that plants take in 0% of their food through their roots? Results are summarized in Table 14.

Table 14 *Student Responses to Question 3 "What percent of their food do plants get by absorbing it through their roots?"*

Responses	Percentage of control group *(n = 32)*		Percentage of experimental group *(n = 32)*		Total *(n = 64)*	
	pretest	posttest	pretest	posttest	pretest	posttest
(A) 0%	13%	75%	3%	91%	8%	83%
(B) 50%	41%	13%	60%	6%	50%	9%
(C) 75%	16%	6%	25%	3%	20%	5%
(D) 100%	22%	3%	6%	0%	14%	2%
no response	3%	3%	2%	0%	8%	0%

The experimental group, improving from 3% to 91%, scored better than the control group on this posttest item, with the control group improving from 13% to 75% of students answering correctly. Interestingly, this item is the one most directly addressed in the PowerPoint presentation viewed by the experimental group. In the form of the presentation viewed by the experimental group, there are a series of slides that focus on the misconception that plants get food through their roots. The text of these slides is as follows.

(First slide) When asked "where do plants get their food," many people respond

(Second slide) "through their roots!" But this is a major MISCONCEPTION!

(Third slide) If you thought plants get food through their roots, don't feel bad . . . some Harvard graduates held this misconception, too!

(Fourth slide) (According to Webster's New World Dictionary, a misconception is "a misconceiving; wrong interpretation; misunderstanding.")

Could viewing these slides before the photosynthesis unit help students to overcome their misconceptions about where plants get food? If the student is not holding on to this misconception, both questions 2 and 3 should be answered correctly. In the control group, 72% of students answered both questions correctly compared to 84% of the experimental group. So the experimental group performed somewhat better on these two items, but considering the small sample size this is not necessarily meaningful. Of course, both groups received similar instruction in all ways with the exception of the PowerPoint presentation. And, this instruction was planned with a focus on misconceptions—particularly the misconception about where plants get food. Thus, it was expected that both groups would show improvement on their posttest scores, and particularly on items 2 and 3.

The goal of item 4 was to determine if students realized that plants obtain energy from sunlight, and not from other substances taken from the environment. Results are given in Table 15.

Table 15 *Student Responses to "Which of the following may be an energy source for plants?"*

Responses	Percentage of control group *(n = 32)*		Percentage of experimental group *(n = 32)*		Total *(n = 64)*	
	pretest	posttest	pretest	posttest	pretest	posttest
sunlight only (desired response)	13%	34%	6%	34%	9%	34%
sunlight plus other choices circled	87%	66%	94%	66%	91%	66%

Results on this item, like the results for item one, illustrate the difference in student performance when misconceptions are not directly targeted in instruction. While no student omitted sunlight as an energy source, far too many still think that other substances, and even organisms, can be energy sources for plants. In the course of instruction, sunlight was emphasized as the energy that was needed for photosynthesis, but the instructor did not emphasize that sunlight was the only source of energy that plants obtain from their environment. Students evidently needed further instruction about what energy is—and is not.

Results were somewhat better on item 5, identifying food for a plant as evidenced by the data in Table 16.

Table 16 *Summary of Student Responses to Item 5 "What is food for a plant?"*

Percent of Students Giving Response	Control Group *n=32*		Experimental Group *n=32*		Total *n=64*	
	pretest	posttest	pretest	posttest	pretest	posttest
Response						
Glucose/sugar/carbohydrate	6%	78%	6%	88%	6%	83%
Other responses	94%	22%	94%	12%	94%	17%

Students improved considerably on this item. At the beginning of the unit, when the overall equation for photosynthesis was discussed, glucose was identified as "food for the plant." We did not discuss what was *not* food for a plant, with the exception of pointing out that garden supply "plant food" is not plant food. But evidently the discussion about glucose *as* food for a plant, combined with the emphasis on plants making their food rather than taking it in through their roots was sufficient for most students to form the conclusion that glucose (or sugar) is the primary plant food.

Item 6 asked students to identify the function of chlorophyll. Recall that the function of chlorophyll was discussed in all classes as part of the discussion about the photosynthesis equation. The function of chlorophyll was also addressed as a followup question to the pigment chromatography lab. Table 17 show the results on the chlorophyll question.

Table 17 *Student Responses to Item 6 "What is the function of chlorophyll?"*

	Percentage of Control Group *n=32*		Percentage of Experimental Group *n=32*		Percentage of Total *n=64*	
Response	pretest	posttest	pretest	posttest	pretest	posttest
to trap/absorb/capture light	9%	25%	16%	69%	13%	47%
(to help in) photosynthesis	34%	44%	34%	9%	34%	27%
to give plants color (make plants green)	41%	25%	31%	13%	36%	13%
other	9%	0%	9%	6%	9%	3%
no response	9%	6%	6%	3%	8%	5%

While there was some improvement on this item, particularly in the experimental group, the instructor must reexamine how this particular concept was taught and possibly prepare an exercise which helps students distinguish between a function and a property or characteristic. Although an analogy was used in class, it evidently was not sufficient, as 13% of students still respond that chlorophyll's function is to "make plants green" or to "give plants color." Too, it could be helpful to reword the question in such a way that students must be more specific in their answers. For example, rather than asking "what is the function of chlorophyll" the question might read "what is the function of chlorophyll *in photosynthesis*?" Then perhaps some of those students who responded that chlorophyll's function was "to help in photosynthesis" might explain *how* chlorophyll helps in photosynthesis.

Item 7 posed the question "Could animals live in a world without plants?" Results of the pretest revealed that students tended to either focus on the role of plants in the oxygen cycle or the role of plants as producers of food, with only a few students mentioning both oxygen and food. Evidently, this unit on photosynthesis did little to improve students' performance on this item, as evidenced by the posttest results shown in Table 18. There was very little change in pretest and posttest responses on this item. Similar to items 1 and 4, there was no instruction that specifically targeted this idea. Certainly there was more in the instructional unit about photosynthesis and the cycling of gases than about plants as food for other organisms.

Table 18 *Student Responses to Item 7 "Would animals be able to live in a world without plants?*

Reasons given in responses	Percentage of control group *n=32*		Percentage of experimental group *n=32*		Percentage of total *n=64*	
	pretest	posttest	pretest	posttest	pretest	posttest
No, gas cycling and food	9%	22%	19%	16%	14%	19%
No, gas cycling	59%	63%	63%	75%	61%	69%
No, food	28%	16%	13%	6%	21%	11%
No, no explanation	3%	0%	6%	3%	5%	2%

Emphasis was placed on what is food for a plant, rather than on the importance of plants as producers of food for other organisms, an objective that might best be taught during an ecology unit. In addition, more students mentioned the importance of plants in the cycling of oxygen than in the cycling of carbon, although a major emphasis of the unit was on the idea that plants take carbon dioxide from the atmosphere, using it as their main raw material for growth. The instructor did not point out that in addition to plants' removal of carbon dioxide from the atmosphere for use in making food important, but that this taking in of carbon dioxide is also important in maintaining a fairly stable level of the gas in the atmosphere. But this concept could be explored in an ecology unit. In summary, most students' posttest responses indicate that they still focus on the importance of plants in the cycling of gases—particularly oxygen—with fewer students recognizing their absolute importance in the food chain.

Item 8 simply tested students' ability to recognize the summary equation for photosynthesis. Both groups were equally successful on item 8 on the posttest. Unlike the other items, this item was specifically targeted in instruction, as it would be impossible to effectively teach about photosynthesis without having students learn the overall equation. Results on this item are given in Table 19. In addition to students having this equation presented to them during a lecture/discussion period (and being told that, yes, they did have to write this down), students were also expected to be able to write this equation as part of a quiz during the unit. Ninety-four percent of students in both groups were able to identify the correct equation. In addition, 50% of the control group and 60% of the experimental group both selected the correct equation and gave very good explanations as to why their choice was correct.

Table 19 *Student Responses to Item 8 "Which of the following equations best summarizes the process called photosynthesis?"*

Responses	Percentage of control group (*n = 32*) pretest	posttest	Percentage of experimental group (*n = 32*) pretest	posttest	Total (*n = 64*) pretest	posttest
(A) glucose + oxygen $\xrightarrow[\text{chlorophyll}]{\text{light}}$ carbon dioxide + water	13	3	19	6	16	5
(B) carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{light}}$ glucose + oxygen	56	94	28	94	42	94
(C) light +chlorophyll + carbon dioxide + water $\Rightarrow$ glucose + oxygen	28	3	34	0	31	0
(D) light + chlorophyll $\Rightarrow$ glucose + oxygen	0	0	13	0	13	0
No Response	3	0	6	0	5	0

Representative samples of student explanations follow.

> Plants use CO_2 and water with energy from the sun to make glucose and the waste product oxygen. Water and CO_2 are the waste products of respiration. They're recycled for photosynthesis.
>
> Carbon dioxide and water are the raw materials needed for photosynthesis. Light and chlorophyll are needed, but are not 'used up' in the process. The end products of photosynthesis are glucose and oxygen.

> CO_2 and H_2O are raw materials for the process of photosynthesis. The light starts the process and chlorophyll traps the light. Glucose and oxygen are products of photosynthesis.

This student points out what is wrong with the other answers.

> In answer A, plants do not take in O_2. In C and D light and chlorophyll are needed but are not raw materials. In answer B carbon dioxide and water are raw materials needed.

Some students who did not give "good" explanations—for example, who wrote, "because this is the equation for photosynthesis," might be able to explain why if interviewed, or if given the paper back and told that they needed to give more specific reasons. Although the multiple choice component of item 8 requires that students only be able to recall, the ability to explain their choice tests their comprehension of the equation.

Item 9 was included to determine if students recognized that the main material plants take in that contributes to their dry mass is carbon dioxide. Unfortunately, as discussed in the pretest analysis, students could arrive at the correct multiple choice answer using perfectly good reasoning that was not related to the unit goals. Results are shown in Table 20. The control group showed more improvement on this item than did the experimental group. When explanations are analyzed, however, neither group was particularly strong on this item. In the control group, only three students out of 21 who chose B as their answer gave convincing explanations compared to only 2 out of 15 in the experimental group. The majority of students who answered correctly in both groups either gave no explanation, or explained their answer as the students did in these responses.

> B has the least amount of water. The bat had no moisture. This graph contains the least water.

B is the answer because you don't have as much water coming through as the other do.

B has the least amount of water. The bat had no moisture. The graph shows the least.

When a bat gets old it is usually lighter so that means the moisture is gone.

Moisture in a bat comes from water.

So the above students are typical of those who arrived at the right answer, but not by the desired means.

Table 20 *Student Responses to Item 9, "Select the graph below that best represents the amounts of materials used by the ash tree to produce this wood."*

Responses	Percentage of control group (n = 32)		Percentage of experimental group (n = 32)		Total (n = 64)	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
(A) Graph shows equal amounts of carbon dioxide, water, minerals, and "other"	38%	9%	25%	13%	31%	11%
(B) (Desired response) graph shows mostly carbon dioxide, with small amounts of water and minerals	19%	66%	44%	47%	31%	57%
(C) Graph shows about 3/4 water, 1/4 minerals	0%	3%	0%	0%	0%	2%
(D) Graph shows equal amounts of water and carbon dioxide occupying about 90% of the graph, with small amounts of minerals and other.	28%	0%	25%	0%	27%	0%

The next student response is an example of a very good explanation by a student who still arrived at the wrong answer.

Photosynthesis creates glucose which is turned into cellulose for wood. Carbon dioxide and water are the main sources of photosynthesis, thus giving my answer.

This student has the big picture, but does not understand that water supplies little of the final dry mass of the wood as compared to carbon dioxide.

The next three samples are from students who both chose B and who gave convincing explanations.

> Plants get water and minerals from the soil through their roots, but most of the mass of the tree is made by the CO_2 the tree takes from the air.
>
> Because the CO_2 that the tree took in while it was alive was used to make cellulose which makes up most of the mass of the tree itself.
> Because if we track back all the cellulose that is in that wood comes from the process of photosynthesis that uses CO_2 to make glucose and cellulose.

Given the students' responses on this item, this might be a good item to use *during* instruction in the future. It would promote good discussion and help to address some misunderstandings that might otherwise not surface. Since students learn that the overall equation for photosynthesis shows 6 molecules of CO_2 and 6 molecules of H_2O as raw materials, then it is understandable that they may be confused and think that if equal amounts of water and carbon dioxide are raw materials, then they might contribute equally to the dry mass of the plant. To help students to understand this item would require bringing out the periodic table and having students compare the atomic mass of carbon, hydrogen, and oxygen. Then, they would need to be reminded that the carbon and oxygen in the cellulose came from the carbon dioxide taken in by the plant, whereas the oxygen released came from the splitting of water. They should also notice that hydrogen has very little mass compared to carbon and oxygen. So while this item has proven to have some problems associated with it when used in assessment, it has great potential as a teaching tool.

Discussion and Conclusions

The purpose of this study was to evaluate the effectiveness of making students aware of a commonly held misconception about plant growth prior to instruction about photosynthesis. Would students who are made aware of misconceptions up front be more likely to abandon their misconceptions and form new, more scientifically-acceptable concepts, as compared to students who are not exposed to this information?

While the evidence is not overwhelming, the researcher concludes that the difference in progress made by the students in the experimental group as compared to the control group—particularly on the open-ended question--is sufficient to suggest that making students aware of misconceptions prior to instruction has some merit. This awareness of misconceptions may provide the "cognitive conflict" which Posner suggests is necessary as preparation for an "accommodation" (1989, p.224). Students who discover that they hold misconceptions about photosynthesis before classroom instruction begins may have greater intellectual curiosity as they begin the unit of study than those who discover their misconceptions during the unit. The experimental group may have been more likely to wonder, from the beginning, "Well if my idea is wrong, then what is the 'right' answer?"

A problem with this study is that the pretest itself was likely a source of cognitive conflict for students—particularly those who may be used to being very successful on tests. When these students realized that they really were not sure how to answer the open-ended question, as well as many of the multiple-choice and short answer questions, this was likely an unsettling experience for them.

This pretest experience alone could create a degree of dissatisfaction, especially in some students, that could facilitate accommodation. Had it been possible to conduct the study without using a pretest, perhaps there would have been a greater difference in results between the experimental and control groups in terms of their forming new concepts.

A second question addressed by this study was "how do students' conceptions change when instruction is planned with a focus on eliminating misconceptions?" While only the experimental group viewed the PowerPoint presentation that targeted the misconception that plants get food from the soil, both the experimental and control groups were taught using the same instructional strategies--strategies carefully planned to facilitate students' forming new concepts. And both groups made gains on certain items on the multiple-choice short answer test as well as on the open-ended question, indicating that these strategies were effective, at least to some degree. This careful attention to development of teaching strategies for helping students achieve accommodation is another component of the conceptual change theory. According to the conceptual change model, cognitive conflict will not lead to conceptual change unless students are presented with experiences that are intelligible and consistent with the desired conception. For example, the assignment about Van Helmont and the willow tree (see Appendix C) allowed students to analyze very simple data. These data should cause them cognitive conflict as they realize most of the mass of the tree could not have come from the soil, as the mass of the soil changed very little over the five-year period. The students must then consider other alternatives for what contributed most of the mass to the willow tree. The account of Van Helmont's experiment is certainly intelligible, and the observation that the mass gained by the tree does not correlate with the mass lost by the soil is consistent with the desired conception—that most of the material for plant growth does not come from the soil. Results for item 3 indicates progress in students' thinking about the source of a plant's food. On the pretest, only 8% of all students tested indicated that plants do not get any food through their roots. But on the posttest, 75% of the control group and 91% of the experimental group selected the correct response—that plants do not get any food from the soil.

Another example of an instructional strategy that was designed to facilitate conceptual change is the "Photosynthesis Makes Me Blue" laboratory activity (see Appendix D). In spite of the teacher's efforts to help students to understand that plants take in carbon dioxide and use it to produce glucose and other compounds, this was a difficult idea for students to grasp. Even though students cannot see a plant taking in carbon dioxide, this laboratory activity allowed them to see evidence that plants take in carbon dioxide. If students accepted that the bromothymol blue changed to yellow with the addition of carbon dioxide, then they can reason that removing carbon dioxide from the solution should cause a color change back to blue. This gives the students an experience consistent with the desired conception—that plants remove carbon dioxide from their environment. Lab follow-up questions then explore how plants use the carbon dioxide that is taken in. A lab question that could be an effective part of instruction is test question number 1, where students are asked to choose the diagram that best shows the cycling of carbon dioxide and oxygen in nature. This is in keeping with the conceptual change model implications for teachers—that we should "help students make sense of science content by representing content in multiple modes (e.g., verbal, mathematical, concrete-practical, pictorial), " and help students "translate from one mode of representation to another" (Posner et al, 1989, p. 226). Another example of a test question that can be used as an instructional tool is item 9, in which students must choose the best graphical representation for the material(s) taken in by the tree that account for most of the dry mass of the wood. This would be an excellent follow-up to the discussion of the overall photosynthesis equation in that students would be led to make connections between the carbon dioxide taken in and the cellulose that comprises most of the mass of the dry wood.

Posttest data analysis of the open-ended question indicated that both the control and experimental groups made significant gains, and that the experimental group's gains were significantly greater than the control group's gains. It is possible that this difference can be attributed to the instructional intervention that was designed to make the experimental group of students aware, prior to the instructional unit, of the major misconception that most plant growth is due to substances taken in from the soil. While this may not have been as effective for some students as it was for others, the researcher concludes that there is sufficient evidence to warrant similar interventions in the future.

Implications for Teachers In an age of content-driven standardized testing, the science teacher's role is too often reduced to that of "presenter of information," with pressure to "cover" an incredible amount of subject material. But if teachers are to assist students in going beyond memorizing a collection of facts--to forming scientifically accurate concepts--the teacher's role must change. Identifying the students' prior knowledge—and misconceptions—should be a planned part of instruction. There is much research available that identifies common misconceptions held by students in various areas of science. So a teacher would benefit by first becoming more informed about the misconceptions students are likely to hold. This anticipation would allow for the planning of the most effective instructional strategies. While time constraints may not allow for elaborate data-gathering and analysis, teachers can employ strategies that reveal their own students' misconceptions at the beginning of each new instructional unit. Rather than collecting and scoring essays, for example, a teacher might open the class with an open-ended question that students could answer in their journals, then quickly survey the class for their responses. Various types of responses could be written on the board and briefly discussed. Then, as the situation demands, the teacher could point out the students' misconceptions, either directly or by providing an experience that conflicts with the students' conceptions. For example, suppose the survey of the open-ended question responses reveals that many students believe that plants get most of their material for growth through their roots. Then the teacher could present students with the Van Helmont account in order to create the cognitive conflict necessary to initiate movement toward accommodation. The teacher might also summarize the "Private Universe" Harvard interviews so students can appreciate how far-reaching the misconception is. They might even be instructed to conduct interviews of their friends and family to see if they, too, hold this misconception. At the close of the unit, the teacher could assess students' success by having students critique their answers from the first day of the unit, and discuss, in written form, how their own way of thinking has changed.

Another observation that has implications for the classroom is that multiple choice questions alone may be very poor indicators of student achievement. Too many students were able to select correct answers on the posttest without being able to give sound explanations for their selections. While teachers may feel compelled to use multiple choice as the primary means of assessing student performance (in part due to the pressure to prepare students for a multiple-choice standardized test), we may be doing our students a great disservice. Students may, like the Harvard graduates in "A Private Universe," assimilate a great deal of information without forming the desired conceptions. Teachers must be aware of the pitfalls of multiple choice testing, and use other means of assessing student performance if conceptual change is a goal. This could be as simple as requiring students to give explanations for their selections on certain items on multiple choice tests. And maybe this would carry over into more success on multiple choice tests, as students develop the habit of analyzing the reasons behind their answer choices. Maybe this would help to eliminate the "I knew that" comments students make in frustration over an incorrect answer to a question that they later realize they had all the necessary knowledge to answer.

For a topic such as photosynthesis, the knowledge base that is required for conceptual change is very broad. When planning for instruction, teachers must consider all prerequisite concepts that students will need, and should anticipate that certain prerequisite knowledge will be lacking in many students. Then the teacher may be able to avoid pitfalls that would prevent students from achieving accommodation.

Should the teacher expect every student to achieve the same level of concept development? While maintaining high expectations is important, realistically, it is unlikely that all students will achieve as much as the instructor would like. For example, in this study, only 22% of students scored a 3 on the open-ended question posttest. Yet, this indicates gains as no student scored a 3 on the pretest. And 77% of students increased their score on the open-ended question one or more levels. So, if the teacher can provide experiences that cause students with misconceptions to be dissatisfied with their current concepts, she has started them on the path toward a new conception. And according to Galileo, a teacher cannot "teach a man anything," but can "only help him to find it for himself." Some students are certainly more motivated than others to find the "right" answers, and are thus more likely to achieve accommodation than those who, in spite of realizing that their ideas are not correct, are satisfied with their current conceptions—or lack of conceptions.

Further Research One potentially fruitful component missing in this study is the interview. While students did have the opportunity to respond to open-ended questions, the instructor did not have the opportunity to ask them sustaining questions—to try to get the students to explain their answers more fully. With written responses, it is not possible to know whether certain information was omitted because the student simply did not know it, or because he did not think to include it in his answer. Interviews conducted prior to and immediately after the unit may have provided some additional insight. And, it would be interesting to either interview or administer written tests to students several months after the unit, to see if those who made progress retain their new conceptions or revert to their old ways of thinking.

It would also be of interest to allow students to survey other people about where plants get their material for growth to explore whether including the students in data-gathering would have an impact on their own conceptual growth. Not only would the teacher be a "model of scientific thinking" as conceptual change research suggests (Posner et al., 1982, p. 226), but the students, too, would be involved in assessing the conceptions of others as they reflect more deeply on their own.

REFERENCES

Amir, R. & Tamir, P. (1994) In-depth analysis of misconceptions as a basis for developing research-based remedial instruction: the case of photosynthesis. *The American Biology Teacher 56* (2) 94-100.

Anderson, C.W., Sheldon, T.S., & Dubay, J. (1990) The effects of instruction on college majors' conceptions of respiration and photosynthesis. *Journal of Research in Science Teaching* 27, 761-776.

Barak, J., Gorodetsky, M., & Gurion, B. (1999) As process as it can get: students' understanding of biological processes. *International Journal of Science Education* 21, (12) 1281-1292.

Barass, R. (1984) Some misconceptions and misunderstandings perpetuated by teachers and textbooks of biology. *Journal of Biological Education*, 18 (3), 201-206.

Barker, M. & Carr, M. (1989) Photosynthesis: can our pupils see the wood for the trees? *Journal of Biological Education* 23 (1), 41-44.

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

Canal, P. (1999) Photosynthesis and 'inverse respiration' in plants: an inevitable misconception? *International Journal of Science Education* 21 (4), 363-371.

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

Eisen, Y. & Stavy, R. (1992). Material cycles in nature A new approach to teaching photosynthesis in junior high school. *The American Biology Teacher* 54 (6), 339-342.

Hazel, E. and Prosser, M. (1994) First-year university students' understanding of photosynthesis, their study strategies and learning context. *The American Biology Teacher* 56 (5), 274-279.

Lumpe, A. & Staver, J. (1995) Peer collaboration and concept development: learning about photosynthesis. *Journal of Research in Science Teaching* 32 (1) 71-98.

Posner, G.J., Strike, K., Hewson, P, & Gertzog, W. (1982) Accommodation of a Scientific Conception" Toward a Theory of Conceptual Change. *Science Education* 66 (2): 211-227.

Roth, K.J., Smith, E.L., & Anderson, C.W. (1983) Students' conceptions of photosynthesis and food for plants. A paper presented at the American Educational Research Association, Montreal, Canada.

Schneps, M.H., & Sadler, P.M. (1987) Harvard-Smithsonian Center for Astrophysics, Science Education Department, Science Media Group, *A Private Universe*. Video. Washington, D.C: Annenberg/CPB: Pyramid Film and Video, 18 mins.

Simpson, M., & Arnold, B. (1982b) Availability of Prerequisite concepts for learning biology at certificate level. *Journal of Biological Education* 16 (1), 65-72.

Smith, E.L., & Anderson, C.W. (1984). Plants as producers: a case study of elementary science teaching. *Journal of Research in Science Teaching*, 21, 685-698.

Treagust, D. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education* 10 (2) 159-169.

Waheed, T. & Lucas, A.M. (1992). Understanding interrelated topics: photosynthesis at age 14. *Journal of Biological Education* 26, (3) 193-205.

Weir, T. E. Botany: An Introduction to Plant Biology. New York: John Wiley and Sons, 1982.

Woolf, H.B. Webster's New Collegiate Dictionary. Massachussetts: G & C Merriam, 1981.

APPENDICES

Appendix A

Investigating Stomata

Purpose: to compare the number and structure of stomata in three different plant species.

Procedure: Prepare slides of lower epidermis from the three plants provided as demonstrated by your teacher.

View each slide at high power (400X), and for **each** slide:

- count the number of stomata seen in three fields of view. Record this in the data chart. Calculate the average number of stomata per field of view for each plant type.
- draw a stomate with several surrounding epidermal cells, labeling the pore and guard cells.

Data and Observations:

	Plant Type		
Number of Stomata	**lettuce**	**wandering jew**	**water hyacinth**
Field 1			
Field 2			
Field 3			
Average			

Make sketches here!

Questions/Discussion (respond on the back of this paper)

1. Compare the average number of stomata for each plant type and suggest reasons for any differences noted.
2. Describe the function of stomata.
3. Explain how stomata open and close. (use reference books provided.)
4. Suppose a plant kept its stomata closed for an extended period of time. How would this affect the plant?

Appendix B

Separating Pigments in Spinach Leaves by Paper Chromatography

Purpose: to use paper chromatography to separate and identify pigments in spinach leaves.

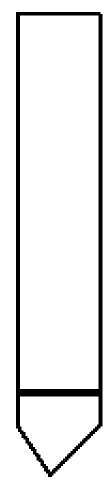
Materials: Chromatography paper   spinach leaf   dime or quarter   ruler
*Chromatography chamber (with chromatography solvent)

The chamber should be kept **tightly stoppered** at all times. If there should be a spill of chromatography solvent, notify your teacher immediately!

WEAR SAFETY GOGGLES DURING THIS LAB!

Procedure: Remember to handle chromatography paper by the edges only!

1. Make a pencil mark across the chromatography paper near the bottom, as shown on the diagram at the right.
2. Using a quarter or dime, roll the coin across the spinach leaf, with the leaf aligned such that a dark line of pigment is left on top, and covering, the pencil line.
3. Your teacher will put the strip of paper in the chromatography chamber. You should watch the solvent as it travels up the paper by capillary action. You should see bands of pigment separate as the solvent moves upward. When the solvent reaches the top of the strip, let your teacher know, so that she can remove the strip from the chamber.
4. Use your pencil to make a mark showing the furthest point each pigment reached.
5. Use color pencils and a ruler to duplicate your chromatogram on the diagram below.
6. Use the information provided by your teacher to the different pigments, labeling them on your diagram.



Questions 1. What is the function of chlorophyll in plants?

2. Suppose a plant was unable to produce chlorophyll. How do you think the plant would be affected? Explain.

Appendix C

The Willow Tree

Early in the seventeenth century, Jan van Helmont carried out an experiment that has become a classic. Here is what he wrote about it.

I took an earthen vessel, in which I put 200 pounds of earth that had been dried in a furnace, which I moistened with rainwater, and I implanted therein the trunk or stem of a willow tree, weighing 5 pounds, and at length, 5 years after being finished, the tree sprung from thence did weigh 169 pounds and about 3 ounces. When there was need, I always moistened the earthen vessel with rainwater or distilled water, and the vessel was large and implanted in the earth. Lest the dust that flew about should be co-mingled with the earth, I covered the lip or mouth of the vessel with an iron plate covered with tin and easily passable with many holes. I computed not the weight of the leaves that fell off in the four autumns. At length, I again dried the earth of the vessel, and there was found the same 200 pounds, wanting about 2 ounces. Therefore 164 pounds of wood, bark and roots arose out of water only.

From Leonard Nash, *Plants and the Atmosphere*, Case 5, Harvard Case Histories in Experimental Science, Harvard University Press, Cambridge Mass., 1952, p.15

Answer these questions:

1. How long did van Helmont continue his experiment?
2. What was he trying to find out?
3. Complete the data table, rounding data to the nearest pound.

	Initial Weight (to nearest pound)	**Weight after 5 Years**	**Change in Weight**
Willow Tree			
Earth (soil)			

4. Many people believe that plants grow by absorbing materials (not water) through their roots from the soil itself (a misconception that many people did, and still do, believe). If this were true, then by how much should the weight of the earth in which the willow tree was growing have decreased after five years?

   How does this compare to what really happened?

5. What did van Helmont (**wrongly**) conclude to be responsible for the weight gained by the tree?

6. If van Helmont had dried the willow tree, most of the remaining weight would be due to the compound **cellulose**, a polymer of **glucose**.

   What is the formula for **glucose**?

   What is the formula for **water**?

   What **element** found in glucose is not found in water?

7. In order to build cellulose, then, a plant must also obtain carbon from its environment. What carbon-containing compound does a plant obtain from its environment that ultimately may be used to make glucose and other carbohydrates, such as starch and cellulose?

8. How does this compound (your answer to #7) enter the plant?

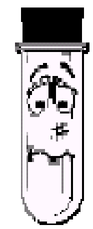
9. For what process do plants and certain other organisms use this compound?

10. What type of energy drives the process in number 9 above?

11. Explain how the intake of carbon dioxide, a gas, can result in a plant's gaining weight.

Appendix D

Photosynthesis Makes Me Blue



Purpose: to examine the effect of plants on the cycling of carbon in a pond community.

Materials (per group):
- four test tubes or vials
- parafilm
- bromothymol blue
- aluminum foil
- water
- aquatic plant
- straw

Procedure:

1. Label the test tubes 1, 2, 3, and 4. Label each tube with your group's initials.
2. Fill each test tube one half full with the bromothymol blue solution.
3. Add water to tube 1 to within 1 cm of the top. Cover tube 1 with parafilm.
4. Holding tube 2 over the plastic box, use the straw to gently blow into the solution in the tube until it turns a yellow color. Add water to tube 2 to within 1 cm of the top. Cover with parafilm.
5. Holding tube 3 over the plastic box, use the straw to gently blow into the solution in the tube until it turns a yellow color. Add a sprig of the aquatic plant provided. Add water to tube 3 to fill it to within 1 cm of the top. Cover with parafilm.
6. To tube 4 add a sprig of the aquatic plant. Fill tube 4 to within 1 cm of the top. Then cover tube 4 with aluminum foil to block all light.
7. Put all four tubes in the holder provided, then place them under the lights.
8. After 24 hours, check the tubes, recording your observations.

Data:

TUBE	DESCRIPTION	INITIAL COLOR	COLOR AFTER 24 HOURS
1			
2			
3			
4			

QUESTIONS

1. If you observe the plant in tube 3 several minutes after placing it under the light, you will notice bubbles released from the broken stem. What are these bubbles?

2. What was the purpose of tubes 1 and 2?

3. Compare the results seen in tubes 3 and 4. Explain your observations, using the terms photosynthesis **and** respiration **in your answer.**

4. What biological process adds carbon dioxide to the atmosphere?
What types of organisms carry out this process?

5. What biological process removes carbon dioxide from the atmosphere?
What types of organisms carry out this process?
What do these organisms produce from the carbon dioxide they take in?

6. Predict what would happen in each tube below. Each is set up with the contents below, placed under a light bank, and observed 24 hours later. Explain your answers.

Tube A—Bromothymol blue and a snail

Tube B—Bromothymol blue, a snail, and an aquatic plant

Tube C—Bromothymol blue and heterotrophic bacteria

Tube D—Bromothymol blue and yeasts

Tube E—Bromothymol blue and blue-green algae