

1999

How Does Undergraduate College Biology Students' Level of Understanding, in Regard to the Role of the Seed Plant Root System, Relate to Their Level of Understanding of Photosynthesis?

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HOW DOES UNDERGRADUATE COLLEGE BIOLOGY STUDENTS' LEVEL OF
UNDERSTANDING, IN REGARD TO THE ROLE OF THE SEED PLANT ROOT
SYSTEM, RELATE TO THEIR LEVEL OF UNDERSTANDING OF
PHOTOSYNTHESIS?

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

James Njeng'ere

B.Ed. University of Nairobi, June, 1977

May, 1999

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To my God Jesus Christ
and my beloved family

ACKNOWLEDGMENTS

As with any dissertation, many people have contributed to the completion of this project. I cannot list all their names, but I wish to acknowledge and thank them all.

I am indebted most to my major professor Dr. Jim Wandersee who has guided me since I registered for this program. His contribution has been invaluable. He helped me with warmth and respect as I sorted out a morass of data, providing me with insight at every moment of my need. I also want to thank the rest of the members of my committee all of whom brought a wide range of professional experience and wisdom to my work. Dr. Ron Good, Dr. Bill Pinar, and Dr. Catherine Cummins were always there to help me whenever I needed. I have appreciated their experience, as well as the understanding and respect which they accorded me.

I also want to thank arboriculture and other root experts who stimulated me to love trees. I owe a special thanks to Dr. Don Marx of Frogmore, South Carolina who sent me one piece of literature after another. I also want to thank Dr. Edward Gilman of the University of Florida, Dr. Kamran Abdollah of the Southern University, and Dr. Catalino Blamche who works with USAID, Booneville, Arkansas, all of whom were readily available to read and critique my work on roots.

I would like to thank Dr. Melinda Oliver for all the help she gave me and for allowing me sufficient time to do this work. I would also like to thank Debby Hernandez, the secretary at the LSU Center for Scientific and Mathematical Literacy for being so understanding as I worked under her. She organized the working atmosphere in the office very well. I would also like to thank the student workers for the respect they gave me during all the times we worked together.

I would also like to thank the teaching staff in LSU life sciences and horticulture programs, especially Dr. James Malone and Dr. Beth Schussler. They stimulated my professional interests when I took courses in botany. My committee was enhanced also by the presence of Dr. Gordon Holcomb, the Dean's representative who is from the department of Plant Pathology and Crop Physiology.

I would also like to thank the many students who came to assist me, and Dr. Peggy Rice, Barbara Holland and Lorna Holtman who helped me with editing. I am also fortunate to have had the assistance of exceptional friends from Kenya, and Africa at large, especially David Murungi who assisted me with a great deal of typing, and Dr Gathogo Mukuria and his family for linking me with the US. I would also like to thank John Rugutt for his cooperation, as well as Dennis Wissing and Phyllis Griffard who graciously extended invitations to me to visit their homes. My former roommates Jonah Njenga and Edmond Kabagambe deserve special thanks for being like biological brothers to me. Lately I have had close American Christian friends, especially the Armstrong and Rhodes families, as well as Charles Richardson. I am grateful to all of them for being close to me when I was away from my home and my family. Lastly, I want to thank my family, especially my dear wife Agnes, my three daughters Keziah, Ruth, and Eva, as well as my son Isaac, for being encouraging throughout my life with unwavering support.

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ABSTRACT

This research study investigated how undergraduate college biology students' level of understanding of the role of the seed plant root system relates to their level of understanding of photosynthesis. This research was conducted with 65 undergraduate non-majors biology who had completed 1 year of biology at Louisiana State University in Baton Rouge and Southeastern Louisiana University in Hammond.

A root probe instrument was developed from some scientifically acceptable propositional statements about the root system, the process of photosynthesis, as well as the holistic nature of the tree. These were derived from research reviews of the science education and the arboriculture literature. This was administered to 65 students selected randomly from class lists of the two institutions. Most of the root probe's items were based on the Live Oak tree. An in-depth, clinical interview-based analysis was conducted with 12 of those tested students. A team of root experts participated by designing, validating and answering the same questions that the students were asked.

A "systems" lens as defined by a team of college instructors, root experts (Shigo, 1991), and this researcher was used to interpret the results. A correlational coefficient determining students' level of understanding of the root system and their level of understanding of the process of photosynthesis was established by means of Pearson's r correlation ($r = 0.328$) using the SAS statistical analysis (SAS, 1987). From this a coefficient of determination ($r^2 = 0.104$) was determined. Students' level of understanding of the Live Oak root system (mean score 5.94) was not statistically different from their level of understanding of the process of photosynthesis (mean score

5.54) as assessed by the root probe, $t(129) = 0.137$, $p > 0.05$ one tailed- test. This suggests that, to some degree, level of the root system limits level of understanding of photosynthesis and vice versa. Analysis of quantitative and qualitative data revealed that students who applied principles of systems thinking performed better than those who did not. Students' understanding of the root system of the Live Oak tree was hindered by understanding of; plant food, the nonwoody roots, and the tree as a system.

CHAPTER 1

INTRODUCTION

Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at the human body or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design (AAAS, 1990, p. 165). These common themes are really ways of thinking rather than theories or discoveries. {AAAS, 1994, p. 261}.

As a result of the information explosion that is currently occurring in all areas of knowledge, course instructors may be tempted to add more material to their courses to keep them current (Garafalo & LoPresti, 1993). As a guide to the teaching of the science, the American Association for the Advancement of Science's *Benchmarks for Science Literacy* (AAAS, 1994) spells out some requirements for reforming the K-12 educational system. One of these requirements is that, if students are to learn science, mathematics, and technology well, the sheer amount of material now being covered must be radically reduced.

The common core of learning should center on attaining science literacy and not on understanding each of the separate disciplines. In agreement with this, Garafalo and LoPresti (1993) encouraged a teaching approach that points out the relationship between an instructor's own discipline and that of others. To do this, science educators need to adopt some conceptual and procedural schemes that will provide students with productive and insightful ways of thinking. These schemes should integrate a range of basic ideas that explain the natural and designed world (National Research Council [NRC] 1996). Three major documents of education reform (AAAS, 1990; AAAS,

1994; NRC, 1996) recognize systems thinking as one of these unifying schemes. The major perspective of this research project was to study how systems thinking (or the lack of it) influences students' understanding of photosynthesis.

Research Questions and an Overview of the Research Study

Research Questions

The primary research question that guided this study was:

How do undergraduate college biology students' levels of understanding of the roles of the seed plant root system relate to their understanding of photosynthesis?

Subquestions

The subquestions were:

1. What level of understanding do the students have of the root system of the common Live Oak tree?
2. What level of understanding do the students have of the connections between the root system and the process of photosynthesis in the Live Oak?
3. What are the implications of these findings for instruction?

A Gowin's Vee Diagram of the Research

A Gowin's Vee diagram (see Appendix A) illustrates the entire project in detail. The center of the Vee states the research questions; the far left side of the Vee indicates the mental framework behind the research, elucidated by identifying the concepts, principles, theories, and world views that support the validity of this research. The focus of this study was the objects and events which are located at the point of the Vee;

at the lower right side of the Vee are the objects and event records, as well as their transformations: Above them are some hypothetical knowledge and value claims that were eventually supported by the results of this study.

Flow Chart Diagram of the Research

A flow chart diagram of this study (see Appendix B) provided a time-line overview for this dissertation. The chart divided the research into the major phases, including: a literature search in science education (1994-1997); participation in course work where projects associated with roots were undertaken (1995-1997); pilot studies with middle and high school students on their understanding of the root systems (1995); participation in activities related to roots in horticulture and this researcher's involvement with arboriculture root experts (1995-1997); further refinement of the root probe instrument as suggested by the root experts (Summer, 1997-Fall 1997); synthesis of in-depth auxiliary instruments (Summer-Fall, 1997); administration of the root probe instrument to college students and to root experts (Fall 1997); final data collection (Fall, 1997-Spring, 1998); and data analysis (Spring and Summer, 1998). The researcher presented final results (Fall, 1998).

Support of Systems Thinking

General Historical Support

Does the history of science education point to some specific examples that support the relevance of this study for biology education? At the turn of this century classicists and scientists differed in their views of the nature of mind and the way in which mental development occurred. Classical educators argued for a generalized form

of a mental exercise that would, in an undetermined way, lead to improved mental power. DeBoer (1991) captured Youmans' (1867) summary of the scientists' view of how young children learn. He argued that children's early phase of science education would lead naturally into a more systematic observation of nature and, for older children, systematic development of both their inductive and deductive reasoning power.

This importance of understanding wholes is captured by Green (1982) in an essay entitled "Seeing Nature Whole." The author explained how the novelist John Fowles expressed a sense of sadness and loss in modern man's apparent inability to see nature or natural settings as rich and symbiotic systems, wild and interlocking wholes, without neatly defined boundaries. The philosophical aspects of general systems theory were taken up by Laszlo (1972), who advocated "seeing things whole" and seeing the world as an interconnected, interdependent field, continuous with itself. This synthetic stance is opposite to the intellectual fragmentation implied by compartmentalized research and piecemeal analysis. This and many other examples bear witness to historical support of systems thinking.

Historical Support in Science Educational Practice

DeBoer (1991) explained how science education replaced the classicists at the turn of this century. He emphasized how physical science was selected at the beginning because it dealt with systems of relationships that were the least complicated and most certain. Bertalanffy (1975) saw the implications of integration by the General System Theory (GST) for education, among other systems.

The following five principles were implied in his work:

1. There is a general tendency towards integration in the various sciences, natural and social.
2. Such integration seems to be centered in a general theory of systems.
3. Such theory may be an important means for aiming at exact theory in the nonphysical fields of science.
4. Developing unifying principles running "vertically" through the universe of individual sciences, this theory brings us nearer to the goal of the unity of science.
5. This can lead to much needed integration in science education. (p.37)

Matthews (1994) argued that systems thinking is like history, allowing seemingly unrelated topics within a science discipline to be connected. It also connects topics across science disciplines, for instance, the unraveling of the DNA code connected geology, crystallography, chemistry, and molecular biology. Science has always been seen as a means of arriving at truth through observation, experimentation, and reasoning.

Historical Support in the Learning of Photosynthesis

Systems thinking has played a role in many significant scientific discoveries and the process of photosynthesis was one of these. Nash (1964) recorded a historical achievement by de Saussure. By 1804 many experiments had been performed by Priestley, Ingen-Housz, and Senebier, among others that had contributed to the essential

aspects of photosynthesis. De Saussure applied Lavoiser's new system of chemical elements and finished the fundamental experimental work, then he supplied a convincing theoretical interpretation of the whole plant system's nutrition.

Nash does not explain the significance of the integration to what he calls whole.

It is Morton (1981) who explained it:

The great advance made by de Saussure was to exhibit the isolated facts, already known in outline, as a proof of a complex, but integrated interchange of matter between the plant and its surrounding (p. 338)It marked an advance of plant physiology from the simple exploration of facts to the status of science with its own basis of integrated theory. (p. 342)

Some key words and phrases (e.g., "integrated interchange of matter between the plant") imply that Morton was in support of systems thinking.

Urgent Need for Systems Thinking

Absence of Systems Thinking in Research

Has systems thinking continued to receive the research attention that it deserves? Chen and Stroup (1993) regretted that we had taken retrogressive steps in most areas of research. While Aristotle expressed the basic tenet of systems theory (the whole is more than the sum of the parts), this emphasis on synthesis was eventually displaced by an analytic approach. Galileo's mathematical conception of the world replaced Aristotle's descriptive-metaphysical approach and paved the way for what has become modern scientific analysis. Following Descartes, the scientific method involved analyzing complex phenomena into elementary particles and processes.

Green (1982) captured the weakness of this analytic method in the following:

Both artist and scientist are forced by the inheritance of their methods to examine only

the isolated entity, to place a frame or conceptual perimeter around it, to separate it neatly off from the rest of experience, and only then to begin to describe it. (p. 296)

This approach was (and is) phenomenally successful in helping to understand processes that can be readily decomposed into simple causal chains. However, multivariable systems have remained problematic within this framework. As many of the major problems facing science and society today involve complex multivariable systems, approaches that draw on the activity of synthesis recommend themselves (Chen & Stroup, 1993; Shigo, 1991).

explained that world environmental problems and genetic engineering are focal points for biology today. However systematic understanding of tree biology, which should play a major role in understanding environmental systems, has been left out. One of the goals of this study was to bring back to the school science curriculum the process of systems thinking.

Absence of Systems Thinking in Learning of Photosynthesis

Since research on tree nutrition indicates that a tree acts as a single system (Shigo, 1991, Waisel, Eshel, & Kafkafi, 1996), does the teaching of photosynthesis reflect this? Unfortunately, modern teaching and learning of photosynthesis in biology classrooms does not reflect it. A great many of the junior high school curricula in the US, for example, deal with the physiological aspects of photosynthesis, emphasizing equations and neglecting the macroscopic view of a plant (Garafalo & LoPresti, 1986). An average high school textbook (Wallace, Sanders, & Ferl, 1991) illustrates the process of photosynthesis with the phenomena of "How energy cycles" as:

- a. Photosynthesis and respiration form a continuous cycle. Products of one process are the starting materials for the other.
- b. Energy is stored in organic molecules made by linking carbon atoms together. Excess carbohydrates provide food for animals. (p.174)

One weakness of this approach is the linking of respiration to photosynthesis.

Eisen and Stavay (1988) recommended unlinking the two topics to avoid the common alternative conception that one is the reverse of the other. An additional weakness involves the emphasis given to carbon as the only carrier of high energy bonds. The role of the hydrogen contributed by the water from the roots is neglected. Besides, after they have learned the previous content in the eighth grade, a greater number of subtopics in greater depth are introduced at the eleventh grade. These new concepts and principles are meant to illustrate "How photosynthesis works". The subtopics given below (Wallace et al., 1991) can serve as a summary of them:

- a. In plants, photosynthesis occurs inside the chloroplast. These organelles contain the pigment chlorophyll, a light-absorbing compound.
- b. Light energy is packaged in photons. When a photon of light with the right amount of energy is absorbed by an atom, one of the atom's electrons is raised to a higher energy state.
- c. Chlorophyll and other photosynthetic pigments absorb photons. These pigments are arranged in molecule clusters, called photosystems. Two kinds of photosystems exist: photosystem I and photosystem II.
- d. Light energy is captured by a chemical in a series of reactions that is initiated when photons are absorbed by the two photosystems, which work in tandem.
- e. Excited electrons from photosystem II aid in the production of ATP while those of photosystem I aid in production of NADPH. Water molecules are split, releasing the electrons needed to replace those lost by photosystem II. Oxygen gas is produced as a result.
- f. ATP and NADPH are used to fix carbon in the Calvin cycle.
- g. Light, carbon dioxide concentration, temperature, and other environmental factors interact with one another to determine the optimum level of photosynthesis for a particular plant in its environment. (pp. 174-175)

The seven previous points indicate a range of phenomena such as formation of complex organic compounds from inorganic ones, interaction of environmental factors, and dynamic changes, among others. The systems approach would be useful for teaching such information, as explained in the section dealing with systems thinking.

Need for Research in Systems Thinking

Scarcity of Research on Practical Educational Applications

Before the turn of this century, science educators introduced the systematic teaching of physical science in schools. Biology was delayed because of its complexity and uncertainty (DeBoer, 1991). Since then, many people have recognized the need to introduce systems thinking into the learning of science (Eisen & Stavy, 1992; Garafalo & LoPresti, 1993; Senge, 1991). Such work has continued in areas of chemistry education (Garafalo & LoPresti, 1986), and even in professional fields such as arboriculture (Shigo, 1991), but has barely started in the area of biology education (Chen & Stroup, 1993). This study has made an additional appeal for such attention.

A Systems Attempt for Learning Photosynthesis

Has photosynthesis been taught as a systems process? As in most other topics in biology, educational theory calls for one approach, but teaching practices and textbook design often lead students in another direction (DeBoer, 1991). Teaching and learning of photosynthesis has not been an exception to this rule. The first attempt at learning the process of photosynthesis by relating it to the systems approach was made by Eisen and Stavy (1992). Earlier, a study (Stavy, Eisen, & Yaakobi, 1987) with students ages 13-15 had revealed that these students had a considerable number of

relevant factual details. However, they seemed to "lose their way" among the concepts and did not succeed in building the holistic picture that was expected.

In their second unit (Eisen & Stavy, 1988), the researchers omitted many details, but concentrated on the main ideas that are essential to understanding general principles of photosynthesis. They recommended that, when dealing with its process, the chemical composition of organisms be described only at the level of elements.

The problem with their systems approach was its breadth,-- covering plants, animals, and the environment. Their ideas were of an ecological nature, indicating how the material cycled from plants to animals and back to the atmosphere. This broad scope made it even more difficult for students to follow the process of photosynthesis in a single plant. Earlier on, Colletta and Bradley (1981) had devised a model for the teaching of ecology that may help more in the understanding of photosynthesis. Their model was based on the relationships derived from the principles of unity and interdependence that are so essential to the understanding of ecology. Unfortunately, as in the previous research discussed earlier, their work was not limited to the plant as a holistic system. The researcher hypothesizes that if biology is to remain within the fold of the sciences, it must be taught as the research findings suggest.

A Goal of This Researcher--Development of Systems Thinking for Understanding Photosynthesis.

The aim of this study was to uncover ways to move students from analytical thinking to systems thinking. Selection of the topic of photosynthesis was based on the general agreement that it is a difficult concept for most students (Finley, Stewart &

Yarroch, 1982; Johnston & Mahmoud, 1980). The Live Oak, a familiar tree to the participating students, was treated as the central object for which the holistic nature of understanding the process of photosynthesis was assessed. Contributions of the Live Oak's roots to the actual process of photosynthesis was investigated by means of test items. An in-depth analysis of students' conceptual frameworks was carried out by means of tree graphics and concept maps.

Definition of a System and Related Terms

Webster's New International Dictionary of the English Language (1988) gives us only a start in clarifying what a system is:

An aggregation or assemblage of objects united by some form of regular interaction or interdependence or assemblage of objects arranged in regular subordination after some distinct method, usually logical or scientific. (p. 2102)

Miller (1978) gave us a more relational interpretation of a system as a "set of interacting units with relationships among them." Shigo (1991) gave us a fine working definition of a system as "an orderly collection of parts and processes that produce a predetermined product or service." In support of all these views, Chen and Stroup (1993) summarized the core principles of systems theory:

- (a.) A "system" is an ensemble of interacting parts, the sum of which exhibits behavior not localized in its constituent parts. ("The whole is more than the sum of the parts.")
- (b.) A system can be physical, biological, social, or symbolic, or it can be comprised of one or more of these.
- (c.) Change is seen as a transformation of the system in time, which nevertheless conserves its identity. Growth, steady state, and decay are major types of change.
- (d.) Goal-directed behavior characterizes the changes observed in the state of the system. This means a system can be seen to be actively organized in terms of the goal and can be understood to exhibit "reverse causality."

- (e.) "Feedback" is the mechanism that mediates between the goal and system behavior.
- (f.) Time is a central variable in systems theory. It provides a referent for the very idea of dynamics.
- (g.) The "boundary" serves to delineate the system from the environment and any subsystems from the system as a whole.
- (h.) System-environment interactions can be defined as the input and output of matter, information, and energy. The system can be open, closed, or semipermeable to the environment. (pp. 448-449)

Systems Thinking

Hanson (1995) explained that the key word to understanding any system is interrelation. If parts that form a system (are interconnected), there is no such a thing as a single cause-and-effect relationship. Any action or inaction will reverberate throughout the entire system. In recognition of the time frame of attention it has received, Senge (1990) defined systems thinking as:

... a conceptual framework, a body of knowledge and tools that has been developed over the past fifty years, to make the full patterns clearer (p. 7).

The emphasis given by Trudgil (1988) is on ideas concerned with the state of matter and the factors that influence that state. He qualified this by explaining how systems thinking is concerned with the organization of matter, and the dynamics of the processes which lead to that organization. These seemingly different definitions can be summed up by looking at systems thinking as an abstraction of a holistic conceptual framework that attends to the overall interaction of parts, their processes and products.

Importance and Problems Associated with Learning of Photosynthesis

According to botanist Daniel Arnon (1982), photosynthesis merits its distinction as the most important biochemical process on earth. His view was supported by Finley,

Stewart, and Yarroch (1982), as well as Johnstone and Mahmoud (1980), who recognized not only its importance, but also pointed out the difficulty students had understanding it. Photosynthesis is studied by all high school students, even those who are not biology majors. The main reason for teaching it lies in its importance for a basic understanding of how the world biota interact. Looking at a large cross-section of studies on photosynthesis, Bell (1985) explained the causes of this difficulty. She emphasized that students lacked an understanding of the relationship between the process of photosynthesis and other physical, as well as chemical, processes which are carried out by plants. Few students appeared to integrate or interrelate their knowledge of the functioning of plants' internal processes such as respiration and photosynthesis with physical processes like osmosis, transport, and gas exchange, or appreciate the interdependence. This problem was retained at the 12th-grade level, where students lacked a coherent justification which would reflect a full understanding that both photosynthesis and the material absorbed from the soil contribute to the plant's life (Amir & Tamir, 1994). Even at the college level, students lacked knowledge of the exact mechanism by which oxygen is produced and an awareness of the role of ATP and NADPH in powering the Calvin cycle. Students did not understand that there is an absolute requirement for a hydrogen donor, and that water acts in this role (Hazel & Prosser, 1994). This researcher initially hypothesized that the approach of systems thinking to the teaching of the process of photosynthesis would solve most of these problems. Photosynthesis is a system product of the shoot and involves system boundaries of this shoot. Root system is a subsystem of the tree and has system

boundaries of its own. The goal of this research was to investigate how students relate the two subsystems of the tree and their activities.

Photosynthesis: A Systems View

Shigo (1991) emphasized how systems thinking would solve the problems that the students are currently facing as they learn the process of photosynthesis. He explained how the living network and the transport systems--xylem and phloem--maintain the connections between the shoot and the root systems. These views are supported by Chen and Stroup (1993) who gave the following four reasons as the major strengths of systems theory that recommend it as an approach to science education:

1. Toward integration. General System Theory (GST) provides a set of powerful ideas students can use to integrate and structure their understanding in the disciplines of life science. Systems thinking is a discipline for seeing wholes, and recognizing patterns and their relationships (Senge & Lannon-Kim, 1991).

Eisen and Stavy (1988) observed that students do not relate knowledge acquired in a chemistry lesson with that learned in biology. Their knowledge was compartmentalized according to the subject taught. Garafalo and LoPresti (1986) noted that the presentation of a more closely integrated natural science will enable students to maintain a broad perspective of natural science. Understanding the GST may enable them to learn photosynthesis, which involves connections between and among traditional scientific disciplines.

2. Engaging complexity. Complexity is the fundamental trait of the everyday environment in which the student lives. Harvey (1969) noted that there has been a

general change in emphasis from the study of simple situations of closed systems, in which the interactions are few, to situations in which there are interactions between large numbers of variables within open systems. The General System Theory provides the tools for actively engaging such a complexity.

Eisen and Stavy (1988) explained that, although students knew a lot of separate and detailed information related to photosynthesis, they lacked a coherent understanding. In support of this, Haslam and Treagust (1987) observed that students had little comprehension of the relationship between respiration and photosynthesis in plants. Elaborating on this, Amir and Tamir (1994) argued that the kind of gases exchanged in photosynthesis and respiration are well known to the students. However, many students perceive both processes solely as gas exchange events, without reference to the complex biochemical processes involved.

3. Understanding change. The world, as it is experienced, is dynamic. To ignore the centrality of change over time is to present a picture that is alienated from reality. Traditional science education has tended to focus on static and rote sequences. Systems thinking is concerned with the organization of matter and the dynamics of the processes that lead to that organization. The scientific construct of a system implies detailed attention to inputs and outputs, and to interaction among system components. Thinking and analyzing in terms of systems helps students keep track of mass, energy, organisms, and objects (NRC, 1996). Brook and Driver (1984) explained how children tend to think of the properties of a system as belonging to individual parts of it, rather than as arising from the interaction of its parts. Photosynthesis is a subsystem property

that utilizes inorganic substances continually withdrawn and released into the atmosphere and the soil. The parts of a plant involved, namely the root and the shoot, are not static but are functionally dynamic. Systems theory offers intellectual tools for learners to build understandings based on these dynamics.

4. Relating macro- and micro-levels. A sound scientific account requires facility in moving between the macro- and micro-levels. One of the essential components of higher order thinking is the ability to think about a whole in terms of its parts, and alternatively, about parts in terms of how they relate to one another and to the whole (AAAS, 1994). These levels work in concert. An understanding built on the two levels must be mediated. General System Theory offers the possibility of making explicit the complementary relationship between these levels of analysis. Harvey (1969) expounded on this by explaining how systems may themselves be embedded in systems. This implies that what we choose to regard as an element of a system at one level of analysis may itself constitute a system at a lower level of analysis. As a result of this, systems in nature will be subsystems of some larger systems (NRC, 1996).

Interaction of the Root System and Environment

The aerial portions of plants have received greater attention and study in biology, probably due to their visibility, while the subterranean portions have been neglected (Carson, 1974). This view is supported by Waisel, Eshel, and Kafkafi (1996), who recognized the importance of a tree's roots by calling them "The Hidden Half." In that text, Waisel and associates argued that, historically, most of the plant research has concentrated on shoot growth, development, and function. In line with

this realization, recently, greater attention has been focused on what effects human activities have had on urban forests, including a tree's roots (Dwyer, 1991). The environment is a mutually reactive system. It has been realized that changes in the urban infrastructure can displace trees, and the health of trees can be threatened by construction, maintenance, trenching, soil compaction, pollution, and pesticides (Day & Bassuk, 1994). This led Trudgil (1988) to caution against isolating and discussing specialized aspects of an environment in a simple way, without discussing every interaction and interrelationship which exists in that system.

The root system is an open system; it interacts with the soil components in which it grows. This study investigated students' understanding of how root-soil interactions influence the process of photosynthesis.

Roots and Alternative Conceptions

Many articles have been published by people dealing with urban forestry (Day & Bassuk, 1994; Gilman, 1989; Shigo, 1991) detailing the misconceptions that need to be addressed. A careful comparison of these misconceptions, or better, alternative conceptions, with those given by science educators (Arnold & Simpson, 1980; Barker & Carr, 1989a; Bell, 1985; Eisen & Stavy, 1988; Haslam & Treagust, 1987; Mintzes, Trowbridge, Arnaudin & Wandersee 1991; Smith & Anderson, 1984; Stavy, et al., 1987; Wandersee, 1983;) reveals a great deal of misunderstanding of the roots.

Wandersee (1986) noted that U.S. students' alternative conception that "soil is food" stubbornly persisted across grade levels from elementary through college. However, there was a gradual general decrease over grade levels (N=1,400) in the

percentage of those who retained this conception, although understanding was still quite unsophisticated.

Most of these alternative conceptions associate plant nutrition primarily with soil and roots. This study focused on ways systematic thinking can deal with this problem.

Importance of the Live Oak as the Object of Investigation

In order to investigate the status of systems thinking in college students as applied to an understanding of the relationship between plants' roots and photosynthesis, an examination of the relationship between science course content knowledge and understanding of the LSU campus's Live Oak trees was selected. This was based on the importance attached to this plant. In LSU today (1995), Burden called the Live Oak, "The most beautiful thing to come out of the ground." The same tree is also prominent on the campus of Southeastern Louisiana University. The root-associated problems that the plant is currently experiencing will also be considered. This is in line with Popadic's (1995) statement: "The root system is the most important part of a tree, but often the most neglected" (p. 1).

The Role of Graphics

The use of graphics can help organize conceptual information and draw students' eyes to the system or subsystem interaction. According to Tufte (1983), graphics are instruments for reasoning about quantitative information. Often the most effective way to describe, explore, and summarize a set of numbers, even a very large set, is to look at pictures of those numbers. Tree graphics adapted from biology textbooks were used in this study's tests and interviews.

Paivio's Dual Coding Theory (DCT) for Visual Learning

Psychologist A. Paivio (1971, 1975, 1983, 1991) has advanced a dual-coding theory (DCT) to explain how visual experiences enhance learning. This theory proposes that people can encode information as language-like propositions or picture-like mental representations. Information that is represented both visually and verbally is more likely to be remembered because it is stored and accessed in two places. Paivio's approach distinguished between nonverbal imagery and verbal symbolic processes, which are assumed to involve independent but partially interconnected systems for encoding, storage, organization, and retrieval of stimulus information. The imagery system is specialized for dealing with nonlinguistic information stored in the form of *images*, or memory representations corresponding to concrete things. The *verbal code* refers to stored representations corresponding most directly to linguistic units, namely text or words.

Independence implies that either one of the codes can be available and activated in varying degrees, depending on stimulus attributes and the experimental conditions involved in the task. It also implies that the two codes can have additive effects on recall. Interconnectedness of the codes implies that one code can be transformed into the other. The assumption simply means that pictures can be named, words can evoke nonverbal images, and similar transformations can occur entirely at the cognitive level. An object's name, covertly aroused, can arouse an image of such an object. Conversely, the name of the object presumably can be retrieved from its memory image. Research has shown that memory for pictorial information is superior to memory for corresponding printed words

which are in turn superior to abstract words. This accounted for Paivio and Csapo's (1973) explanation that pictures of familiar objects readily evoke a nonverbal image and a verbal code, but the availability of the latter is relatively lower because an extra transformation is involved. The verbal code is directly available in the case of concrete and abstract words, but the former are more likely to evoke images. Finally, verbal coding of pictures is assumed to be easier than image coding of concrete words. To summarize, image coding of pictures and verbal coding of printed words have the highest probability of being recalled; verbal coding of pictures, second; imaging to concrete words, third; and imaging to abstract words, fourth (Loftus & Kallman, 1979). The summative availability of both codes is accordingly highest for pictures, next for concrete words, and lowest for abstract words. This study dealt with pictures at the pencil-and-paper level with all students, and included an in-depth analysis with selected students.

Definition of Terms

For the purposes of this study, the following definitions apply:

Alternative conception: A small set of related concepts constructed by the student, that is not compatible with current scientific thought.

Concept: A perceived pattern or regularity in objects or events which is designated by a label.

Dripline: The distance to which the crown of a tree extends.

Meaningful learning: Learning that involves the deliberate, non-arbitrary, assimilation of new concepts and propositions into existing cognitive structures, thereby modifying those structures.

Mycorrhizae: A close physical association between a fungus and the roots of a plant, from which both fungus and plant appear to benefit; a mycorrhizal root takes up nutrients more efficiently than does an uninfected root. A wide range of plants can form mycorrhizae of one form or another and some plants (e.g., some orchids and some species of *Pinus*) appear incapable of normal development in the absence of their associated mycorrhizal fungi. Mycorrhizae are important to the Live Oak tree.

Photosynthesis: The process by which chlorophyll-containing cells in green plants convert light to chemical energy and synthesize organic compounds from inorganic compounds, especially carbohydrates from carbon dioxide and water (accompanied by the release of oxygen).

Rhizosphere: The area of soil immediately surrounding plant roots which is altered by their growth, respiration, and exchange of nutrients. Within this zone, a further zone called the rhizoplane or root surface is sometimes distinguished.

Root: The lower part of a seed plant, usually underground, by which the plant is anchored and through which water and mineral nutrients enter the plant.

Root-Shoot ratio: The ratio of the amount of plant tissues that have a supportive function to the amount of those that have growth functions. Plants with a higher proportion of roots can compete more effectively for soil nutrients, while those with a higher proportion of shoots can collect more light energy. Large proportions of shoot production are characteristic of vegetation in early successional phases, while high proportions of root production are characteristic of climax vegetational phases.

Symbiosis: A general term describing the situation in which dissimilar organisms live together in close association. The term is often restricted to mutually beneficial species interactions (i.e., mutualism).

Live Oak [and Its Roots]

The Live Oak (Genus and Species name --*Quercus virginiana* mill, Family name -- *Fagaceae*) was chosen as the representative seed plant for this study, because it is familiar to most of the target students. This researcher developed special interest with the Live Oak tree immediately after adopting it as the object of reference of this study. The many paper cuttings and various photographs of the trees that are in researcher's possession is a testimony to that. The following information is derived from the works of several people (Gilman, 1997; Popadic, 1995 & Thomas, 1995) most of who have had a special interest with this tree.

Live Oak has a gigantic size and evergreen canopy that make it very attractive, and it is the most popular oak in the Deep South, occurring from Virginia to Central Texas (Popadic, 1995). It is a large, sprawling, picturesque tree with a broad, spreading canopy that provides a large area of deep, inviting shade. It is an amazingly durable American native and can measure its lifetime in centuries if properly located and cared for in the landscape. Once established, a Live Oak will thrive in almost any location, since it is a tough, enduring tree which will respond with vigorous growth to plentiful moisture on well-drained soil (Gilman, 1997; Popadic, 1995).

The large crown of the Live Oak consists of leaves and branches. Its foliage is alternate, simple, elliptic or oblong, with 1.5 - 5 inch long, rounded ends. Margins of spring leaves are entire and occasionally revolute; those of summer growth are usually sparsely toothed, often hollylike (Popadic, 1995).

The trunk of the tree is the main stem running between the two processing structures -- the root and the canopy. It acts as the "lifeline" of the tree by transporting the food from the top to the bottom, and raw materials from the bottom up to the top. The bark is thick, nearly black, and divided by deep, narrow furrows into broad, heavy ridges (Popadic, 1995).

The Live Oak tree has a large root system extending horizontally, well beyond the shoot structure above the ground. Most of its roots do not grow deep into the soil, but are actually located in the upper 12 to 18 inches. They serve to absorb the maximum nutrients and oxygen. Besides these functions, the root system anchors the plant and stores excess food formed during the process of photosynthesis (Popadic, 1995).

The environmental contributions of the Live Oak are significant. The existence of a Live Oak tree in the microclimate has a stabilizing effect. The temperature is actually kept from fluctuating to extremes that would otherwise be reached as high points and low points in temperature. Also, the moisture content in the air is greatly increased by the Live Oak's presence in the ecosystem, constantly processing water in the form of absorption and the transpiration of water into the microclimate. The Live Oak can successfully shade large areas of land, making it a "master" in sun control, contributing to the success of other plant species which grow in its shade. The blockage of direct rainfall contributes to the easing of the impact that raindrops can have on the Live Oak itself, the soil, and other plants underneath it. In blocking wind, the Live Oak

tree is one of the best, and typically holds up against hurricane force winds with ease. It also forms a splendid canopy for the university students and faculty to enjoy. The height of the oaks is appropriate in relationship to the scale of the surrounding campus building structures. It conserves energy in the buildings by blocking direct sun rays. It also enhances the wildlife habitat, attracting birds, squirrels, and so forth (Popadic, 1995; Thomas, 1995).

The Live Oak is a hardy plant, and even construction-impacted trees take a long time to die, giving it a reputation for being a tough tree. However, with time, exposed surface roots may not be able to cope with the soil compaction created by people trafficking near them or by the cars parked close to them, or at football season, on them (Gilman, 1997; Popadic, 1995).

Urban sites are not ideal environments for these trees to flourish. Thomas (1995) said that, the constant demand for additions to and maintenance of buildings, streets, utilities, parking lots, and walks is a never-ending process that must be accomplished in order to properly carry out the mission of the university.

Unfortunately, for every small area allocated to this expansion, an equivalent loss of the root habitat occurs. All of these add to the stress of the trees.

Phil Thomas (1995) has explained the trees' needs and the steps that have been taken to bring about improvements and reduce stress on the Live Oaks at LSU. The campus arborist, Randy Harris, developed mulching techniques which reduce compaction, retain moisture, and help the trees' root systems to regain vigor and mass. Proper pruning techniques have been implemented.

Phil Thomas (1995) explained that, construction procedures have been developed which reduce the impact of concrete walks over existing root systems. There has been success in re-routing many pedestrian paths (away from root systems); foot traffic is a major cause of root compaction. Certain ground covers have been identified which should not be allowed to grow within 8-10 inches of the Live Oak trunks, because they accumulate moisture and cause bark decay. Excavation permits near Live Oaks are required for any type of digging or trenching. This has caused Thomas (1995) and his team to seek alternative routes for utility lines and other construction pathways, which reduces damage to root systems.

A Live Oak endowment fund is in place now through the LSU Foundation, which will eventually provide recurring funds for Live Oak maintenance, personnel, equipment, and planting. Public awareness of Live Oak problems has been heightened by articles in the Daily Reveille (1996a, 1996b, 1996c) and the university newsletters (LSU Today, 1995), along with low-level signage requesting that pedestrians not walk on the trees' root systems. The Athletic Department has placed fliers in ticket packages informing visitors to the campus of the harm that can be caused by parking on and depositing hot coals on the trees' roots (Thomas, 1995).

A new rule for new buildings requires a 15 foot buffer outside any Live Oak tree's drip-line. This limits space for construction but gives the Live Oak trees space to grow and develop. A tree policy has also been established which outlines procedures for any construction that may impact campus vegetation. In conjunction with these efforts, new

methods are constantly being developed to reduce Live Oak damage and deterioration (Thomas, 1995).

In the last 3 to 4 years, the Baton Rouge campus has lost Live Oaks at the rate of one every 2 months. Because of arborists' inability to address root damage as it occurs, and for a considerable time thereafter, this loss of Live Oaks will certainly escalate. A 1995 report (Thomas) showed that out of the 1,052 Live Oaks evaluated, 613 or 58% were in a strain or stress condition: Strain--151; Stress-- 462; and Healthy--439 (Thomas, 1995).

This means that 58% of the campus' Live Oaks currently require some form of stress reduction. It should also be noted that since this reporting started a few years ago, some additional trees have declined. The Live Oaks are in desperate need of a steady funding source. In addition to more manpower for maintenance, some means to strengthen the tree policy for contractors and employees is also required (Thomas, 1995)

The survey and evaluation of the campus Live Oaks was critical for several reasons. First, it provided a base-line for future evaluations of the Live Oaks. The University could also chart the trees' progress (or lack thereof), and determine the effectiveness of various stress reduction techniques, based on each tree's condition when evaluated (Thomas, 1995). Second, the report identified specific trees in danger of perishing (those in the strain condition) if restoration is not begun in the near future. This is particularly important because it permitted the staff to focus their extremely limited resources on trees which were in the poorest state of health. Finally, the sheer numbers of trees in the strain or stress condition (613 trees) provided a vivid indication

of the man-hours required to have a significant positive impact on the campus Live Oaks (Thomas, 1995).

The preceding information highlights the importance of the Live Oak trees to the campus community. The preventive and remedial measures being taken are based on some well-known behavioral characteristics of this tree. However, not enough is known about the students' knowledge of the Live Oak, especially of those who have taken a university biology course. It is not possible to gain standardized information from students by asking them everything about the Live Oak. If this were done, the knowledge gained from such an analysis would be vague, and difficult to specify and categorize. It is necessary to specify some key concepts and investigate those practical attributes that have paramount value to the Live Oak, hence the focus on Live Oak roots and photosynthesis. These concepts enabled the researcher to structure specific areas that can be quantified and the results gained could be used to promote knowledge of these trees to the whole campus community. This knowledge could also be used to structure a biology course syllabus that might consider the goal of understanding the need to preserve this valuable tree, as well as other trees. This research project is just a beginning. It points in a direction that others who will follow may expand upon, perhaps involving other stakeholders in their investigations.

There are many purple ribbons that decorate the campus Live Oak trees as a reminder to the campus campaign motto of "Save the Oak". These and other signs have been drawing the campus community's attention to the effect of compaction of soil

around the Live Oak root system. However, very few of the campus community could relate these activities to the decline of the shoot canopy.

Amir, Frankl, and Tamir (1987) observed that students did not mention the source of organic matter in the plant. Such an oversight originates from a teaching of photosynthesis that is based on chemical analysis of plant material, and air but ignores children's existing macroscopic views about plant nutrition (Barker & Carr, 1989).

Trees are the earth's largest plants and often typify the term "plant" to the layperson. They include the heaviest organisms ever to exist on earth, namely the giant Sequoia tree of California--weighing in at 6,000 tons. Biomes are named after the dominant vegetation in a region--often trees. Why? Consider the nearly 300 species of insects that live on mature oak trees. Many invertebrates depend on them, and so do vertebrates like us. After storms, when trees are toppled, or when excavation requires removal of a tree, their roots become visible for all who pass by them. They attract our eyes, even when they bulge out of the grass near the trunk. It seems logical, then, to use a tree, the Live Oak, as the common reference point to be used in probing students' knowledge of the root system and the connection they might make between it and photosynthesis.

CHAPTER 2

LITERATURE REVIEW

Theoretical Base of Research

Constructivism

Constructivist learning theory asserts that all worthwhile learning is an active process of constructing meaning. Constructivists quote the famous statement of Ausubel (1968):

If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him [sic] accordingly. (p. 163)

This statement was the beginning of deviation from the principles of behaviorists who maintained that a student is a blank slate and that the correct sequence of stimuli would produce the correct responses. Joseph Novak (1977), argued that, "... concepts are what we think with". If we cannot get our concepts clarified and organized, our thinking remains muddled. According to both Novak and David Ausubel, meaningful learning is a process by which new information is related in a non-arbitrary way to concepts the learner already understands. The opposite, rote learning, occurs when no conscious effort is made to associate new knowledge with the framework of concepts the learner has already constructed.

Systematic Nature of Science

Bruner (1960) explained that presentation of scientific ideas will require grasping the structure of a subject. He defined structure as a framework for understanding that permits many other things to be related to it meaningfully. In brief,

to learn structure is to learn how things are related. Karplus and Thier (1967) argued that if it is true that science has a structure, the teaching program should develop an idea in the context that reveals this structure adequately.

Yager (1988) explained that science is an exploration of the material universe in order to seek orderly explanations (generalizable knowledge) of the objects and events encountered. In an attempt to understand them, a careful observer quickly notices that, in some ways, all objects in our complex universe are continually interacting with each other (Karplus & Thier, 1967). Trudgil (1988) observed that the traditional reaction is to be dissective and to break down environmental processes into small defined compartments in a specialist manner. This approach focuses on selected items and ignores other specialist details.

Another approach is to look at systems in broad, main relationships and ignore subsidiary details. An alternative to either of these is to be more holistic and look at the whole system, both in general terms and the way in which specialist details fit into the whole scheme. In learning about nature, scientists and students can define small holistic portions for convenience of investigation. These units of investigations can be referred to as "systems." A word of caution is that nature may not know these boundaries, but they nevertheless represent a fundamental and important way of thinking about the environment. A holistic outlook enables us to see both how the individual parts relate to each other and how they relate to the whole. It also allows us to understand how the overall system is comprised of the detailed, specialist components. Such a holistic philosophy is central to systems thinking because it tends

to stress the study of the relationships between the individual components and the overall system. The idea of simple systems encompasses subsystems, as well as identifies the structure and function of systems, feedback and equilibrium, and the distinction between open and closed systems. This study sought ways by which systems thinking can enhance teaching and learning of the process of photosynthesis.

Understanding of Abstracted Terms in Learning of Photosynthesis

The dilemma of designing a good curriculum. A good curriculum is one that can be taught by ordinary teachers to ordinary students and that at the same time reflects clearly the basic or underlying principles of various fields of inquiry. Bruner (1960) explained that there are a number of problems that are encountered as we construct a curriculum of that kind. The major problem is to ensure that the pervading and powerful ideas and attitudes that are related to the underlying principles are given a central role. The most difficult decisions that have to be made in each unit have to do with the fact that some things can be discovered by children doing experiments, but some cannot (Karplus & Thier, 1967). The latter are the man-made constructs (higher order concepts), what is thought about natural phenomena. The creator of a unit must clearly have in mind what constructs are already available to the pupils and what constructs must be introduced to enable the pupils to make the discoveries potentially derivable from the experimental observations (Karplus & Thier, 1967).

Driver, Asoko, Leach, Mortimer and Scott (1994) argued that even in the relatively simple domains of science, the concepts used to describe and model the domain of science are not revealed in an obvious way. They are, rather, constructs that

have been invented and imposed on phenomena in attempts to interpret and explain them, often as a result of considerable intellectual struggles. Once such knowledge has been constructed and agreed on within the scientific community, it becomes part of the "taken-for-granted" way of seeing things within that community. As a result, the symbolic world of science is now populated with entities. These ontological entities, organizing constructs, and associated epistemology and practices of science are unlikely to be discovered by individuals through their own observations of the natural world (Driver, et al., 1994).

Relationship of Abstracted Terms to Scientists and Students

While scientists use terms to precisely communicate their findings to other scientists, they are taught as abstracted terms to students in order to understand important scientific concepts and principles, to become scientifically literate, or to lay a foundation for further learning in the sciences (Wandersee, 1988a).

Yager (1983) emphasized that the current crises in science education are an attempt to treat these many terminologies as bodies of facts which must be instilled in students. Most of these terms originate from an analytical approach to the learning of science. The contents "covered" on the topic of photosynthesis illustrate this. They lack coherence when a holistic approach is missing.

Wandersee (1983b) explained how a science educator can act as a biological membrane between science and society by regulating the flow of ideas and helping students decode the complex messages. This will not be possible without adopting a holistic view of observing these complex interactions.

For curricula of students in the primary grades, Project 2061 (AAAS, 1994) encouraged an emphasis on gaining experience with natural and social phenomena, and enjoying science. It strongly recommended that abstractions of all kinds be infused as students mature and develop an ability to handle explanations that are complex and higher order. This was supported by Youmans (1867):

When curiosity is freshest, and the perceptions keenest, and memory most impressible, before the maturity of the reflective powers, the opening mind should be led to the art of noticing the aspects, properties, and simple relations of the surrounding objects of Nature. (p. 26)

Alternative Conceptions

Student conceptions which were different from those generally accepted by the scientific community were formerly called 'misconceptions' (Helm, 1980). The term alternative conception is now preferred by many researchers over the previous term of misconception. Abimbola (1988), Gilbert and Swift (1985), and other researchers have built a strong case for using the term alternative conception. It refers to experience based explanations constructed by a learner to make a range of natural phenomena and objects intelligible. Similarly, it infers a conceptual framework (validly or invalidly) after one knows the "self-reported" alternative conceptions a student holds about a particular science topic. Amir and Tamir (1994) explained that descriptions of misconceptions are products of diagnostic studies usually based on interviewing a small number of students. Sometimes this is followed by a paper-and-pencil test with larger samples. Analysis of students' responses to such instruments yields the percentage of students selecting a particular distractor (on a multiple-choice item) or giving an answer

(in response to an open question) which can be identified as representing a particular misconception. Based on such data, conclusions about the frequency of different types of misconceptions can be drawn.

Many of these problematic concept sets become part of a larger conceptual framework by which the learner attempts to build a coherent scientific view of the world. As a result, the student tends to assimilate those concepts that meet his/her expectations and are consistent with his/her existing conceptual framework (Clough & Driver, 1986). Other contradictory concepts will not be assimilated unless the student is dissatisfied with his/her dysfunctional ideas (alternative conceptions) and can see some substantial benefits to making a change. If he/she embraces the scientific explanation, the student's alternative conceptions would have to change, as well as other elements of the framework which support it (Driver & Easley, 1978).

Alternative Explanations in Photosynthesis

In the last decade, a number of studies on student misconceptions have focused on photosynthesis. These studies contain detailed as well as comprehensive information about students' ideas regarding plant nutrition and photosynthesis (Arnold & Simpson, 1980; Bell, 1985; Barker & Carr, 1989a; Eisen & Stavy, 1988; Haslam & Treagust, 1988; Mintzes et al, 1991; Smith & Anderson, 1984; Stavy, Eisen & Yaakobi, 1987; Wandersee, 1983c, 1986). Research has uncovered five science concepts related to photosynthesis about which students tend to develop invalid conceptions: oxygen released (by plants), respiration, autotrophic feeding, food, and energy capture.

The Concept of Harnessing Solar Energy

Eisen and Stavy (1988) cautioned that one cannot understand the ecosystem without understanding that its energy flow originates in the sun. Roth, Smith and Anderson (1983) described how 11-year-old students gave non-functional roles for light in plant growth based on observations, such as plants need light to live and grow.

Students' understanding of the concept of solar energy is perhaps best illustrated by the summary of Bell (1985, p. 216) in the following interview:

Interviewer: You mentioned before that the sun also helped in terms of bringing some heat energy to the plant, and you're also saying that some of it comes up through the stalk. Could you explain that a bit more?

Student: Well, the sun . . . as the sun heats the plant, the energy - - all the parts of the plant, which the sun is able to get to, they receive energy from the sun, which helps them to grow, and the plant is able to get energy - - nitrogen from the soil, which also helps it to grow, from the roots. The roots are in the soil, and the sun will also shine down on to the soil, to give energy into the soil, so both those two energies will go up into the plant.

The students interviewed appeared to have little understanding of the function of minerals taken in through the roots or the function of the energy obtained from the sunlight. Few appeared to integrate or interrelate their knowledge of such internal processes as respiration, photosynthesis, osmosis, transport, and gas exchange to appreciate the interdependence. Both the interview and written responses suggested that the words "energy" and "food" were often used in an everyday sense of being energetic, and needing "to stay alive" and "be healthy," as previously described by Watts (1983). Other answers given illustrated some misunderstanding of the actual role of the plant.

Understanding the Concept of Respiration

Working with 12- to 16-year-old students, Simpson and Arnold (1982a) established that they confused respiration and breathing. Approximately half of the students thought respiration was the exchange of gases between the organism and the environment. This confusion arose from a lack of understanding of the net gas flow in and out of plants for photosynthesis and respiration, which differs between day and night in response to the process of photosynthesis. Haslam and Treagust (1988) noted that more than 10% of the total students (who were 8 to 10 years of age) selected respiration as taking place only in the roots. Working with the 11th and 12th grade, Amir and Tamir (1994) categorized their alternative conceptions into three types:

- a. Photosynthesis is the respiration of plants.
- b. Photosynthesis is the opposite of respiration.
- c. Photosynthesis and respiration are complementary processes.

They claimed that the kind of gases exchanged in photosynthesis and respiration were well known to the students. This led many students to perceive both processes solely as gas exchange events, without reference to the complex biochemical processes involved, thus mistaking photosynthesis for respiration.

Understanding the Concept of Food

According to Morton (1981), the idea that plants get their food from the soil is probably as old as agriculture itself, but Aristotle was one of the first to carefully examine it. Morton explained that Aristotle may have been influenced by Hippocratic writings when theorizing that plant food was elaborated in the earth itself under the

influence of heat. The elaborated food was then taken up in predigested form by the roots of a plant. Morton (1981) explained Aristotle's reasoning as: "Plants feed by the roots, and since plants feed by the roots, the root is functionally and morphologically equivalent to the mouth and head in animals" (p. 28). Thus, Gardner (1972) lists Aristotle (circa 335 B.C.) as the source of the notion that soil contains preformed food for plants. From ancient times onward the alternative conception, "soil is food" stubbornly persists across grade levels from elementary school through college (Wandersee, 1986).

Roth, Smith and Anderson (1983) gave the definition of food as materials that organisms can break down as sources of energy. However when Simpson and Arnold (1982a) interviewed 11-year-old students, they considered many things (such as fertilizer, water, sunlight, and even oxygen) to mean food. Thus, their answers were closely tied to the environment as sources of this food. The environment was given as either air (5%) or water (25%), but many of these students (80%) said that plants get their food from the soil via the roots.

Much later, Eisen and Stavy (1988) interviewed a number of high school and university students on the food. They noted that this meant either essential energy source, material for building the body, or both energy and building materials. Most of those interviewed answered water, but others gave answers such as minerals, fertilizer, or organic material. In addition, most students appeared to think that food is needed for growth, energy is obtained from food, and that energy is associated with movement or feats of strength.

There was a tendency to anthropomorphize when explaining how plants make and use food. There appeared to be little understanding that energy in the food is used for the plant's life processes. This led them to conclude that it could well be that the difficulties students have in learning the scientific concept of "photosynthesis" are due not so much to the abstract concept itself, as to the alternative conceptions held by the students relating the more basic concepts of "food", "living", "energy", and "gases". Systems thinking may minimize these alternative conceptions. It may bring science to the level of students' cognitions, since systems will build on familiar objects to students.

Understanding of Autotrophic Feeding

Bell and Brook (1984), as well as Barker (1985), found that students had difficulty in recognizing starch as a product of photosynthesis and in understanding the relationship between chlorophyll, starch, sugar, and proteins. Driver et al., (1984) followed a similar investigation with 15-year-old students. They realized that although 26% of them indicated an awareness that the tree takes material from the environment, only 8% of them related this with trees making their own tissue from the environmental materials.

As a result of realizing that 8th- and 9th-graders had considerable problems in conceiving a gas as a substance, Stavy and his associates (1987) made some recommendations. These included a prerequisite understanding that plants absorb carbon dioxide from the air and use it to build their own bodies.

In their second study, Eisen and Stavy (1992) explained how an understanding of photosynthesis required changing from a vitalistic conception, which differentiates

qualitatively between the living and non-living realities, to a naturalistic conception that does not make such a distinction. They based this on the realization that students had considerable difficulty treating the living body as a chemical entity, and describing biological phenomena in chemical terms.

Systems Thinking

Systems thinking is a conceptual framework, a body of ideas or knowledge concerned with the state of matter and the factors (like energy) that influence that state. It is concerned with the organization of matter and dynamics of the processes that lead to that organization (Trudgill, 1988). Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts (AAAS, 1994). Senge (1990) qualified this by explaining how it makes the full pattern clearer and helps us change them effectively.

A typical example involves our agricultural practices. Researchers (Waiser et al., 1996) explained that most agricultural investment (i.e., plowing, seed bed preparation, irrigation, and fertilization) is made to provide conducive conditions for the growth of roots of crop plants, but few students are able to associate the shoot with these agricultural practices. Failure to relate the roots to the shoot of the plant causes multiple confusions like that of Wendy, an eleventh-grader, interviewed by Mintzes working with other researchers (1983), who argued:

"the food has got to come from the soil or people wouldn't spend so much money on fertilizer". (p. 191)

The major strengths of systems thinking that recommend it as an approach to science education are as follows.

System Integration

A number of previous researchers of students' misconceptions in biology have revealed students' tendency to intellectually fragment the disciplines of science (Barker & Carr, 1989; Eisen & Stavy, 1992; Stavy, et al. 1987).

As noted earlier, General System Theory (GST) provides a set of powerful ideas students can use to integrate and structure their understanding in the disciplines of physical, life, and social science (Chen & Stroup, 1993). These ideas cut across subject boundaries (Hamm, 1992). The amount of factual information that students must assimilate in a modern science-based curriculum has risen to an overwhelming proportion (Holden, 1985; Lagowarski, 1985). A recent report by a special committee of the National Academy of Sciences, commenting in this instance on the amount of biological information states:

... we seem to be at a point in the history of biology where new generalizations are being approached, but may be obscured by the simple mass of data....(Holden, 1985, p. 1412).

This assimilation is complicated by the sheer weight of knowledge compiled by the collective cultures of a modern world that is becoming technologically more complex and compartmentalized, thrusting specialization upon our youth at an ever earlier age (Garafalo & LoPresti, 1986).

In each discipline of science, material is introduced from another discipline solely for the purpose of developing a specific topic. Such approaches leave students

with no other choice than to memorize definitions, terms, and details in order to pass examinations, since cursory coverage rarely allows for the development of solid, conceptual foundations. Besides this, students emerge with a highly fragmented picture of nature (Garafalo & LoPresti, 1986).

In order to avoid this compartmentalization of knowledge, Stavy and her associates (1987) suggested an integration between chemistry and biology. Garafalo and LoPresti (1986) explained that there are many areas of interdependence among chemistry, biology, and physics to which even the beginning student can have access in an integrated curriculum. When carefully planned, this approach provides students with an added advantage of seeing interrelationships between diverse disciplines.

Senge (1990) noted that without systems thinking there is neither the incentive nor the means to integrate the learning disciplines once people have come to practice. Many scientists have expressed the need for a commonly accepted language, systematic theories, and basic laws to organize the huge volume of research findings, bridge the gaps, and create order of our knowledge about living systems. The history of science is replete with instances of all the facts, but because of the lack of an interested and insightful theorist, the development of the unifying concept, law, or theory was retarded. Miller (1978) remarked that facts remain isolated until some synthesizing mind brings them together.

Science is an exploration of the material universe in order to seek orderly explanations and generalizable knowledge of the objects and events encountered (Yager, 1988). Senge and Lannon-Kim (1991) expounded on this and distinguished

viewing reality at three distinct levels: events, patterns of behavior, and systemic structure. All three levels of explanation are equally valid, but their usefulness is quite different. Event explanations, who did what to whom, doom their holders to continually reacting to change. Pattern-of-behavior explanations focus on identifying long-term trends and assessing their implications. They at least suggest how, over time, we can respond or adapt to shifting conditions. Structural explanations are the most powerful, because only they address the underlying causes of behavior and events, where real leverage lies for creating fundamental, long-lasting change.

The National Research Council (1996) set one of the goals of the National Science Education Standards as thinking and analyzing in terms of systems. Thinking and analyzing in terms of systems helps students develop an understanding of regularities in systems, and by extension, the universe. This enables them to develop an understanding of the basic laws, theories, and models that explain the world (NRC, 1996). Importance of this association was captured by Youman's (1867) words:

When a child associates the sight, weight and ring of a dollar, with the written word and verbal sound that represent it so firmly together in its mind that any one of these sensations will instantly bring up the others, it is said to "learn" it. (p. 14)

Systems thinking will enhance learning that relates the processes of the shoot with those of the root.

Engaging Complexity

Benchmarks (AAAS, 1994) identified a plant as one of the complex natural systems. In support of this, Bell (1985) identified some confusion that arises from a

lack of understanding of the net gas flow in and out of plants for photosynthesis and respiration, that differs between night and day in response to the process of photosynthesis. The AAAS (1994) explained the main goal of having students learn about systems is as a means to enhance their ability (and inclination) to attend to various aspects of particular systems in attempting to understand or deal with the whole system.

Miller (1978) supported this when he explained the importance of systems theory as a means of suggesting how to make new observations or to conduct experiments on a wide range of phenomena in order to extend our grasp of the basic principles underlying them. Without such theory, the scientist does not know how to decide which of an overwhelming number of possible observations are worth making.

Laszlo's (1972) version of systems theory uses two kinds of interaction hierarchies. Micro-hierarchies and macro-hierarchies are to be interwoven in modeling the natural world. Photosynthesis is a complex process where activities at the cellular level (micro) influence activities at the organ level (macro) and vice versa. A multiple number of environmental factors come into common interplay to determine the outcome of the whole process. The holistic approach suggested in this study matches the research findings and is likely to enhance students' understanding of photosynthesis.

Understanding Change/Dynamics

In studies on students' views of photosynthesis, it has been found that although most students appreciated that light was involved, few grasped the notion of energy transfer, the role of chemical energy produced, the role of water, or the idea of energy

storage (Bell 1985; Haslam & Treagust, 1987; Wandersee, 1983). Many students were unable to link photosynthesis with other physical and chemical processes such as water uptake and respiration (Hazel & Prosser, 1994). They regarded water as essential for plants, but rarely related it directly to plant growth (Barker, 1985). They also had ideas about the importance of fertilizers, plant growth, and plant products like wood, although the origin of wood was difficult for children to explain. Amir et al. (1987) explained that students lacked full understanding of the fact that both photosynthesis and the materials absorbed from the soil (mainly water) contributed to the added weight of the plant.

Over the last decade, research on students' learning has increasingly focused on the development of students' conceptual knowledge (West & Pines, 1985). Bruner (1963) suggested focusing on the underlying structure of the subject matter. Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully (i.e., to learn how things are related). Further, Bruner suggested that the most basic thing that can be said about human memory is that details are rapidly forgotten unless they are placed into a structured pattern.

System dynamics is a method for better understanding the underlying structure of a complex situation (Roberts, 1978). This view is supported by Miller (1978), who explained that what Mendeleyev's periodic table of the elements did for chemistry, the GST can also do-- supply a structure into which new discoveries can be fitted. This is in contrast with findings of LoPresti and Garafalo (1994) who noted that students had a tendency to emphasize the stasis rather than the dynamics. The education standards

(NRC, 1996) supported this by explaining how thinking and analyzing in terms of systems would help students keep track of mass, energy, objects, organisms, and events referred to in the other content standards. The idea of simple systems encompasses subsystems, as well as identifying the structure and function of systems, feedback and equilibrium, and the distinction between open and closed systems.

Senge (1990) went further and noted that to begin to look at how systems of two or more interrelated parts steer themselves means moving away from a model of systems as passive entities, towards seeing the way phenomena -- be it organisms, species, machines, or climates -- push back or create in ways that are not explained by knowledge of input and output alone.

Relating Micro- and Macro-Levels

Karplus and Thier (1967) explained that alternate or concurrent use of a system gives the scientist great flexibility in applying the system concept to entire complex phenomena, and yet attend to fine details. Barker and his associates (1989) regretted that most textbook approaches to the teaching of photosynthesis are based on the microscopic level. Chemical analysis of matter, soil, air, and plant material are used for the teaching of photosynthesis. Students would need to test these materials for the presence of carbon, hydrogen, oxygen, and so forth; identify the relevant reactants and products; and relate them in equation form. While this element analysis strategy undoubtedly reflects an adequate scientific view of photosynthesis, it ignores children's existing macroscopic views about plant nutrition. Instead it has as its prerequisite a theory-laden body of teachers' knowledge with which students apparently have

considerable difficulty. This view is supported by Hazel and Prosser (1994), who researched Israeli college students' understanding of photosynthesis. They explained that photosynthesis was taught as a physiological process with relatively little reference to ecological and other implications. Extensive notes were provided, including a summary equation representing photosynthesis.

Most of the biochemical reactions of photosynthesis found in curricular science belong to the domain of symbolic knowledge, whereas notions such as plant food are part of a student's intuitive knowledge (West & Pines, 1985). Students' notions of plant food may be affected by packets seen on supermarket shelves and may not be compatible with scientists' views of photosynthesis (Hazel & Proser, 1994; Wandersee, 1983). Barass (1984) also noted the following common misconceptions: respiration occurs in animals and photosynthesis occurs in green plants; and, green plants photosynthesize in sunlight and respire at night. Students did not realize that respiration occurred in plants all of the time. Barass suggested that the use of summary equations may cause some students to think that respiration and photosynthesis are alternatives and cannot occur simultaneously.

As noted earlier, Eisen and Stavy, (1988) explained that an understanding of photosynthesis requires changing from a vitalistic conception, which differentiates qualitatively between the living and non-living realities, to a naturalistic conception that does not make such a distinction. LoPresti and Garafalo (1994) explained that the biological approach to studying biological problems is not the only one that can yield useful results. Both top-down and bottom-up approaches have something important to

contribute, and properties of wholes cannot be deduced solely from dissection and analysis of their parts. Systems thinking offers a solution to this.

Support for Systems Thinking in History of Science Education

If systems thinking is necessary for the understanding of the structure of science, is it supported by the history of science of education as regards the plant nutrition. The four reasons given earlier as the major strengths of systems theory are all supported by the history of science education. These are illustrated below:

1. Towards integration. All of the disciplines of science have grown together. Morton (1981) explained the distinctive features of science as a human activity in an attempt to find a structure of causal laws, a guiding theory in the relations between the particular phenomena involved. The search process has not distinguished the arbitrary disciplines of school science curricula. The growth of specifically botanical concepts has drawn strength from other sciences and contributed to them in return, and has, at various stages, reflected in its thought the philosophical currents of the time.

The earliest experiments concerned with fundamental and general principles of plant behavior were done for non-botanical reasons as an offshoot of an attempt to clarify the chemical theory of transmutation. One of these experiments was done by Johann van Helmont in 1648. He began by transplanting a 5- pound willow tree in a 200-pound weight of dry soil. After 5 years of growth, he extracted the 164 pound tree and found the soil weighed about the same except for a loss of two ounces. In 1648 he showed that the plant food does not come from the soil (Gardner, 1972). (See task item 2 of the root probe.) This resulted in being the first quantitative experiment conducted

that involved a living organism. In other words, it was the first biological experiment in which substances were weighed accurately, and the carefully noted changes in weights supplied the answer being sought (Asimov, 1968).

As noted earlier, General System Theory provides a set of powerful ideas, students can use to integrate and structure their understanding in the disciplines of physical, life, and social science (Chen & Stroup, 1993). These ideas cut across subject boundaries (Hamm, 1992). The unraveling of photosynthesis began almost fortuitously from experiments in chemistry and only assumed the character of an independent plant physiological problem, as the theory and methods of chemistry became adequate for its solution.

In the early 1940's Samuel Ruben and Martin Kamen made use of heavier isotopes of O_2 , whose presence in a water molecule could be detected by the use of a mass spectrophotometer. They discovered that the O_2 gas given off contained the heavy isotope of O_2 whereas the carbohydrate formed did not (See task item 32 of the root probe.). In a second experiment, ordinary water was used, but the $C^{18}O_2$ contained the heavy isotope of O_2 , which was subsequently found to be present in the carbohydrate product of photosynthesis (Asimov, 1968).

2. Engaging complexity. The history of science education explains to us how wrong authoritative concepts are propagated from one generation to another. Although Van Helmont realized the emission of gases in plant nutrition, and indeed invented the name gas, he ignored the role of these gases in the whole process that he was investigating. Omission of these gases led him to cling to the theory of transmutation

first proposed by Thales who lived in 600 B.C. In the year 1671, his successor, Robert Boyler, went one step further and grew the plant in water in an attempt to exclude the role of the soil. Both Van Helmont and Robert Boyler concluded that water was transmuted into the plants' structural components (Morton, 1981).

The AAAS (1994) explained that the main goal of having students learn about systems is a means to enhance their ability and inclination to attend to various aspects of particular systems in attempting to understand or deal with the whole system. The same document of education reform (AAAS, 1994) identifies a plant as one of the complex systems. The theory of transmutation never took into account these vapors, contrary to the caution of Ernest Mach (1883) who explained that historical investigations not only promote the current understanding that now is, but also brings new possibilities before us.

Stephen Hales is credited with improving some methods and principles of learning botany. Using quantitative observations, he developed ingenious procedures which have been used by generations of physiologists ever since. His experiments were planned logically to answer precise questions. He consistently used control experiments, an advance in the methodology of biological experimentation. (See task item 20 of the root probe.). He established the constant uptake of water by the plants and its loss by transpiration as a fundamental physiological process (Morton, 1981).

3. Understanding change/dynamics. The education standards (NRC, 1996), another document of education reform explained how thinking and analyzing in terms of systems would help students keep track of mass, energy, objects, organisms, and

events referred to in the other content standards. It encouraged them to understand the idea of how simple systems encompasses subsystems, as well as identifying the structure and function of systems, feedback and equilibrium, and the distinction between open and closed systems.

By the year 1779, Ingen-Housz had observed that respiration was conducted by every part of the plant. He had, also, established that O_2 evolution by the plants was absolutely dependent on light shining on green parts of the plant. A few years later (1782) Senebier established that the O_2 evolved by green plants in light was absolutely dependent on a supply of CO_2 by dissolving CO_2 in water and allowing it to be taken in roots. Thus, in relation to the gas exchange of the plants, the great advance by de Saussure was to exhibit the isolated facts already known in outline in the year 1804. Many quantitative experiments by de Saussure had convinced him that leaves respire continuously, but that their respiration is concealed by the simultaneous assimilation of CO_2 in the light, (See task item 6) which resulted in release of O_2 (Morton, 1981).

4. Relating micro- and macro- levels. Both Morton (1981) and Nash (1964) explain how de Saussure who was a professional plant specialist completed the understanding of plant nutrition. The last of his experiments involved analysis of salts absorbed by the roots. He noted that plants did not absorb all substances present in solution in proportion, but selectively. In addition he established that the elements in a plant were related to those in the soil in which it was grown. His findings emphasize the system-boundary interaction whose understanding enables the learner to relate the micro- and macro- levels.

Barker et al. (1989) regretted that most textbook approaches to the teaching of photosynthesis are based on the microscopic level. Chemical analyses of matter, soil, air and plant material are used for the teaching of photosynthesis. Students would need to test these materials for the presence of carbon, hydrogen, oxygen, and so forth; identify the relevant reactants and products; and relate them in equation form. While this element analysis undoubtedly reflects an adequate scientific view of photosynthesis, it ignores children's existing macroscopic views about plant nutrition.

Van Helmont realized the emission of gases in plant nutrition, and indeed invented the name gas, however, he ignored the role of these gases in the whole process that he was investigating. These gases were investigated by Hales. After a long series of investigations, Hales concluded that one great role of leaves was to absorb some air which may be important for nutrition in plants. As Van Helmont left behind him a hint that gases may have been useful in plant nutrition, Hales did the same with sunlight. He was emphatic as he wrote:

And may not light also, by freely entering the expanded surface of leaves and flowers, contribute much to ennobling the principles of vegetables. (Nash, 1964)

Basis of modern plant physiology. Morton (1981) noted that the experiments of Van Helmont, Hales, and others showed how difficult it was to make progress in plant nutrition with the existing state of chemical knowledge. The true nature of plant nutrition could scarcely be investigated or understood except in the light of modern chemistry, effectively founded as a new science between 1767 and 1786. This is the period when chemists solved the mystery of the different kinds of gases. Prior to this

period, O_2 was dephlogisticated air or pure air, N_2 was phlogisticated air, CO_2 was fixable air, and NO_2 was nitrous oxide. The unraveling of photosynthesis began almost fortuitously from experiments in chemistry and only assumed the character of an independent plant physiological problem as the theory and methods of chemistry became adequate for its solution.

Both Van Helmont and Stephen Hales had some ideas on plant nutrition. However, neither of them had the notion of the whole process of photosynthesis. Nevertheless they laid the foundation on which Priestley, Lavoisier, and others who came after them had as a basis on which to build the understanding that was finally passed on to de Saussure. The major advance made by de Saussure was to exhibit the isolated facts already known in outline form as proof of the complex, but integrated interchange of matter between the plant and its surroundings, essential for its life and growth (Morton, 1981).

The history of science education indicates that, analytic approach to understanding of plant nutrition led early researchers to cling to outdated theories about plant nutrition. On the other hand when a holistic approach like that of Stephen Hales and de Saussure were adopted, great advances to understanding of plant nutrition were made. This convinced this researcher the need to adopt a holistic approach.

Holistic Solution

From the previously mentioned research it is possible to understand possible sources of the students' problem. Stavy et al. (1987) explained that students had an information overload related to photosynthesis, but their many separate bits of

information lacked a meaningful overall view. As in any other discipline, the teaching of photosynthesis should begin with information that matches the intuitive knowledge of students (Osborne & Freyberg, 1985) and then build logically on that knowledge. Teaching of photosynthesis has not followed this trend. Nearly all of the 188 students interviewed knew that plants absorb water from the soil (Stavy et al., 1987). This number exceeded those (74%) who knew that plants absorb carbon dioxide from the air. Barker (1985) noted that the traditional attention given to the starch test highlighted a material about which learners possess little prior knowledge, and what they know about plant materials is not adequately addressed. Their problems were compounded by learning many terms in biology, most of which can be excluded and be replaced by some more familiar terms (Storey, 1989; Wandersee, 1985).

Trudgil (1988) explained a method of learning based on an understanding of a systematic model. This is supported by Colletta and Bradley (1981) who saw models as a means of organizing concepts. A simpler way of looking at a system in this case is viewing it as an orderly collection of parts and processes that produce a predetermined product (Shigo, 1991). Model building seeks to build up a series of relationships in order to achieve sufficient explanatory power. It operates by initial isolation of one or two components (i.e., parts or processes) of the system under investigation, followed by the study of their interrelationships. Once the significance of these relationships has been specified, further attributes can be built into the model until it achieves a level of explanatory power that is sufficient for understanding the working of a system (Trudgil, 1988).

Model approach. Eisen and Stavy (1988) were the first to recommend a model approach by dealing with photosynthesis via the material cycles in nature. However, in this researcher's opinion their explanation was ecological, brief, and overgeneralized. Colletta and Bradley (1981) appear to have invented a better method than that of Eisen and Stavy (1992). Theirs involved a series of models. One of their models, (see Appendix C) highlighted the importance of the roots and soil to the understanding of the biogeochemical cycles such as the carbon cycle. It is worth noting that there are two major points, labeled A and B, where the four spheres contact one another in the circuitous flow of all materials in the Earth's ecosystem.

A - represents the plant. It is also part of the biosphere and is linked to the other spheres. Its use of carbon dioxide and its production of oxygen link it to the atmosphere. Its root system links it to the hydrosphere and lithosphere.

B - represents the soil.. Soil encompasses all four spheres. The living organism and organic debris in soil represent the biosphere, water, minerals, while soil gases represent the fourth sphere.

Notice the unique central position of the water cycle in the model. Water is the unifying agent within the system. Water, the almost universal solvent, is the only medium capable of carrying the raw materials necessary for life from the soil to life and back again. Water circulates through all four systems, uniting them by intermingling materials.

Shigo's (1991) model (see Appendix D) is even more specific, for it deals only with a single tree as a system. It emphasizes that the most important aspect to

remember is that trees grow to become like large oscillating pumps with the top trapping energy and pumping it downward, the bottom absorbing water and elements and pumping them upwards. The trees' "pumps" have developed over time to work on the basis of many synergistic associations that maximize benefits for all connected members and minimizes waste.

Many of life's essentials for the bottom associates come from the top of the tree, but the top works only because the bottom works. Energy is required to move things, while elements and water are required to build them. When the energy flow from the top of the pump is blocked, the bottom does not get enough energy for growth and defense. As in all other living things, plants require food and water for growth and maintenance. Via the sun by the process of photosynthesis, leaves provide the energy from the top of the pump. The non-woody roots and the rhizosphere provide water and elements from the bottom. Photosynthesis will not work without water and elements, and the absorption processes will not work without an energy source. Shigo's model is clear, holistic, and easy to follow. The process of photosynthesis can be related to the parts and material coming from the shoot or the roots.

This researcher has read good works by many authors on root biology. Among these, that of Shigo (1991) who is an arboriculturalist, is outstanding. It relates best to this researcher's study. This researcher has extracted a few terms that may help the reader follow the rest of the study. Work by other people has been inserted to help clarify the meaning.

Nature of Roots

The roots of a tree can be considered as the hidden half of the plant (Waisel et al., 1996). Roots are either woody or non-woody. Some characteristics of woody roots, like those of the Live Oak tree are:

- (1) They do not absorb water.
- (2) They have no pith.
- (3) Their conducting elements are usually wider than those in the trunk.
- (4) They have a greater proportion of parenchyma cells than is usual for trunks.

The living parenchyma cells store energy reserves, usually as starch.

Non-Woody Roots

Shigo (1996) explained that non-woody tree roots are organs of two basic types that absorb water and certain elements dissolved in it. These are discussed in the following section.

(1) Root hairs: Root hairs are extensions of single epidermal cells. They are found more on seedlings than on mature trees. They form when soil conditions are optimal for the absorption of water and elements. Root hairs and epidermal cells of small non-woody roots, the soil, water and microorganisms surrounding them, make up what is called the rhizosphere. The root hairs function for a few weeks, then begin to die.

(2) Mycorrhizae: Mycorrhizae are the other type of non-woody roots. Mycorrhizae are organs made up of a network of tree and fungus tissues that facilitates the absorption of phosphorous-containing ions and other essentials for growth. The

three basic functions of mycorrhizae are:

- (a) They connect with other fungal hyphae on other trees. In this way, they serve to connect trees of the same or, sometimes, of different species.
- (b) They provide some resistance against some root pathogens.
- (c) They provide a boundary for absorbing water and nutrient elements.

The Rhizosphere as a System Boundary

Russel (1977) defined the rhizosphere as the zone of the soil in which the environment for microbial activity, in general, is influenced by the root of any species. This distinguished it from the "bulk" or the non-rhizosphere soil which is not directly influenced by the root except by the withdrawal of water and nutrients. The diameter of the rhizosphere equals that of the cylinder of the soil that root hairs explore and into which they may release exudates. The term exudate refers to all organic substances which pass into the surrounding soil from living roots that have not been significantly damaged by pathogens or other agents. The additional term "rhizoplane" is used to describe the absorbing, non-woody root boundary, as opposed to the adjacent rhizosphere soil. Ions pass into and out of the tree by way of the rhizoplane.

The Tree as a Holistic System

Shigo (1996), highlighted the importance of rhizosphere as:

The more you know about the rhizosphere, the better the chances are that your treatment will lead to benefit rather than harm your plants. (p. 6)

From 5% to 40% of the total dry matter production of organic carbon from

photosynthesis may be released as exudates. When trees begin to decline, the amount of organic carbon released as exudate increases. Mineral deficiencies, low amounts of soil and air, and severe wounding are major causes for the increase. Another way to say this is that an increase in exudates could be caused by over-pruning, construction injury, planting too deeply, overwatering, soil compaction, or planting trees in soils that have a pH too high or too low for their optimal growth (Shigo, 1996).

Shigo (1996) explained further the systematic relationship of the shoot and the root by elaborating on the effect of pruning as one that injured the top first. When it is injured, the top fails to serve the energy requirements of the bottom. Soon root diseases start and are blamed for the decline or death of the tree. Where over-pruning is common, so are root diseases. Other common problems were noted as compacted soils and overwatering. Compacted soils block air and water to the bottom and crush all the micro-cavities where the microorganism live. In nature, such outcomes are controlled by decomposing wood and leaves which keep conditions optimal for the rhizosphere inhabitants.

When too much water is added to soil, the oxygen content is decreased. This stalls the respiration process in the roots, which in turn stops carbonic acid formation. When carbonic acid is not formed, ions necessary for the absorption process do not form. Reduced absorption within the roots leads to a troubled tree system. An equally important consideration is fertilizer, which can be of great benefit to trees growing in soils low in or lacking elements essential for growth. Nitrate is usually the ion that is absorbed by non-woody roots. When nitrogen enters a root as nitrate anion, an anion of

bicarbonate from carbonic acid exits. The bicarbonate ion is probably the second most important compound in nature, next to water, because it drives the absorption process. For one nitrate ion to enter the non-woody root, an anion must exit. When the bicarbonate anion concentration is low, nitrate anions entering the non-woody root will be few. When a bicarbonate anion exits into the rhizosphere, the pH of the rhizosphere increases.

Trees use energy in five basic ways: growth; maintenance of all cell processes; reproduction; production of exudates; and storage (mainly for new growth and defense). Growth and maintenance are linked, in that growth increases the mass of an organism while maintenance keeps the cellular bodies orderly and active. Reproduction, which increases the number of organisms, takes a great amount of energy from the system.

Technical Factors that Initiate Positive Correlation Between Graphics and Comprehension

Graphic Comprehension and Verbal Ability

Flow diagrams. The process of photosynthesis involves movements of material from one subsystem to the other that may pose a problem to the students for several reasons. Each of these systems involves loss and gain at the same time,.... phenomena identified to be major source of problems for students (Gargliano, 1975). Driver, Guesne and Tiberghien (1985) explained that concentrating on the inputs and outputs of a system often requires a different, time - independent view, which students may not take to be an explanation. This movement can be illustrated by means of flow diagrams. A flow diagram presents a scientific pathway or cyclic schema by

condensing a sequential chain of verbal labels described in the text into a more "manageable," coherent display. They provide a framework from which verbal labels contained within a chain are more fully explained in the text.

Holliday, Bruner, and Donais (1975) worked with flow diagrams. They studied the effect of flow diagrams on high school biology students' learning. They developed two types of flow diagrams: (a) picture-word diagram in color; and, (b) a black-and-white, blocked-word diagram. Both diagrams included all 37 concepts, and each diagram was accompanied by the same list of 22 instructive questions. Students were presented either the picture-word or blocked-word diagram instructional module with the accompanying 22 instructive questions in writing. Following that they were given a 30- question, multiple-choice posttest and a questionnaire. They were then divided into low- and high-verbal-ability students. The low-verbal-ability students did significantly better on the posttest after using the block-word diagram sequence. High-verbal-ability students did about the same with either learning approach. Low-verbal-ability, picture-word diagram-trained students did almost as well as the high-verbal-ability, picture-word diagram-trained students on the post-test.

Visual Explanation

Dilemma posed by information explosion. Garafalo and LoPresti (1993) have expressed concern about the information explosion that is currently forcing its way into school and college curricula in the form of images and texts. As these texts and images result in continually expanding curricula every year, there is a temptation to dequantify it. A warning against this is given by Tufte (1997) who cautioned:

When scientific images become dequantified the language of analysis may drift towards credulous descriptions of form, pattern and configuration, rather than answers to the questions "How many? "How often? "Where?" "How much? "At what rate?" (p.23)

These questions are central to all forms of science research, yet we cannot ignore the warning against overfeeding students with information and undernourishing them with concepts central to the understanding of science (AAAS, 1994). From the aforementioned, it is apparent that a problem is facing science educators: How do they communicate a basic body of scientific knowledge to students without a compromising loss of current and useful scientific views?

Graphical Solution

The graphic representation of scientific concepts and principles may help science educators deal with this dilemma (Wandersee, 1990). Tufte (1997) explained that graphical elegance, which is a form of illustration, is often found in simplicity of design and complexity of data. A graphic is knowledge on a two dimensional space by means of some either writing or marking or ink or pictorial or semi-pictorial form with an objective of communicating a meaningful learning beyond speech or linear text. Graphics are designed to convey information or knowledge in a powerful visual message. One type of graphic shows promise in illustrating the system analysis. Macro- and micro-readings are forms of graphics that can show specific levels of details and also a broader context (Tufte, 1992). At a micro-level, their importance is to show the significance of a digit. At a macro-level they can illustrate a holistic nature of

science. This compares to a system embedded within a system which can go on to infinity (Harvey, 1969).

While probing students' understanding of the process of photosynthesis, this researcher made use of many types of graphics. Most of these depicted a macro nature of a seed plant. This is in line with systems thinking that exposes, to the enquirer, the immediate environment surrounding the object being analyzed. A few graphics that showed micro-details of the tree were also used.

Role Of Graphics in Structuring the Test Items

Early negative correlation of pictures and comprehension. Before applying graphics to this study this researcher investigated their history and the effective procedures of application. Smith and Elifson (1986) reported that college students prefer material which includes pictures rather than those that do not. Knowing this, textbook publishers have increased the length of biology textbooks. This increase is due to additional illustrations rather than additional text (Blystone, & Bernard, 1988). Prior to 1975, the relation between pictures and reading comprehension seemed to indicate that pictures had a negative effect on reading comprehension (Braun, 1969; Concannon, 1975; Samuels, 1967). However, most of these studies were conducted with first graders. After 1975, the research conducted with more advanced students confirmed a positive relationship between pictures and comprehension although the illustrations were of a technical nature (Blystone & Dettling, 1990). This study used effective graphics to investigate how college students' understanding of the root system influenced their understanding of the process of photosynthesis.

Cognitive role of flow diagrams. The cognitive hypothesis that can explain the preceding variation is that the line drawings of the concrete concepts (e.g., car) in the picture-word diagram would generally facilitate verbal recall. On the other hand, the lack of line drawings in the block-word diagram would require a learner to identify (i.e., encode and remember) the same concrete concepts without a picture. This rationale is consistent with the work done in imagery (Paivio, 1973). Holliday et al. (1975) explained that imagery is viewed as a metaphorical model of coding and remembering, and in terms of dynamic perceptual images of things and events accompanied by verbal labels. By 1977, Holliday and his associates had totally disagreed with the negative correlation which previous work on illustration had revealed and urged research and development people to stop relying on intuition and explore techniques which coincided more closely with theoretical requirements of learning. Therefore, in the late 70's, a better method for evaluating the effective use of illustrations was gradually developed.

The root probe instrument used by this researcher made use of picture word diagrams similar to those explained in the integrated text (see more on this below). Such an instrument did not place into a disadvantage those students of low-verbal ability. Holliday (1976) asserted that a single flow diagram constitutes a more effective presentation than a textual description alone, and that it is also more effective than a combination of diagram and text.

Concept Maps

Structure of a concept map. A concept map is a metacognitive technique developed by learning theorist, Novak, (1977) to help students learn science

meaningfully. It is a visual representation of cognitive structure. It has four major components: concepts; relationships (propositional linkages), hierarchy, and cross links. Concepts are descriptions of some regularity or relationship within a group of facts and are designed by some sign or symbol (Novak, 1977). Concepts are linked with lines and linking words to make propositions (e.g., concept ... linking word ... concept). For example, the concept "root " would be linked to the concept "underground" by the words "is found." The full meaning of any science concept for a given person would be represented by all of the propositions that the person could construct using that concept. Each person constructs a concept map for the type of cognitive propositions that one has in regard to that particular concept. However, common cultural experiences and mapping conventions ensure that concept maps are somewhat similar and can be compared. Concept maps (like cognitive structures) are hierarchical. The relations between the terms are inclusive, with general terms (also called superordinate concepts) standing above more specific ones that are less inclusive (also called subordinate concepts). The hierarchical order of the concept map forces students to think about the relative importance of the subordinate concepts used in the map, relative to the superordinate concept (Heinz-Fry, Crovello, & Novak, 1984). Novak (1977) states that students have to struggle with the meaning of each concept before they really assume ownership of that concept. Ausubel (1963) recommends that learning is facilitated when broad, hence more general, information precedes and encompasses subsequent, more specific information. Cross-links are relationships that are made between concepts in different branches of a concept map. They are particularly significant

because they point out interrelationships which might not be obvious when the material is first learned. These integrative relationships become clearer with increased experience and more differentiated knowledge.

Diagnostic role of concept maps. Novak (1977) maintains that concepts are what we think with. Sanchez (1991) explained how progressive differentiation and integrative reconciliation can be better understood through examples of concept learning. To enhance meaningful learning more general and abstract concepts should be presented to the student first, followed by progressively differentiated or less abstract content. In this way a concept is acquired progressively through greater refinement and particularization of the content presented. If we learn the concept of a root, we first learn its definition (e.g., the hidden half of the plant). This is an abstract concept, but, we further explain how its two main components (woody and non-woody) can be recognized. This is what Sanchez (1991) explains as first presenting the more abstract concept.

CHAPTER 3

METHODS

Basis of the Research

Since this researcher enrolled in his biological education doctoral program at LSU, the researcher has used a variety of methods to gather knowledge of students' understanding of roots. While working as a graduate assistant in the department of Curriculum and Instruction with Dr. Sheila Pirkle, and thereafter with Dr. Melinda Oliver, in projects funded by the National Science Foundation, this researcher was able to visit many middle and high schools in South Louisiana. With permission from school authorities, the researcher conducted pilot studies on the understanding of roots within the schools visited. (See Appendix G.) As a result the researcher hypothesized that similar alternative conceptions might exist in college students, although probably to a lesser extent (Wandersee, 1985).

For the last 3 years of researcher's doctoral studies, the researcher associated most of the course projects with the concept of plant roots. This called for extensive readings that gave the researcher an opportunity to review current research literature. In the course of these consultations, the researcher was directed to some key personalities or root experts who had spent most of their lives researching roots. This researcher has had an opportunity to be mentored by some of them, besides the regular advice that the researcher got from departmental committee members. These experts advised the researcher on which textbooks to buy, which persons to consult, which professional meetings to attend, and so forth. The researcher established a working network through

which some information about students' understanding of the role of roots in plants was gathered. A list of names in this network is given in Appendix I of this document.

Interaction with members of this network exposed the researcher to arboriculturists who are dealing with tree nursing care. This researcher discovered that, for a long time, these experts have been dealing with problems similar to those science educators have been dealing with as they teach the concept of photosynthesis, but they seldom interacted.

Subjects

A great deal of research has been done with high school students on their understanding of photosynthesis. This topic has been isolated as one with high perceived difficulty even for twelfth-graders (Tamir, 1994). This researcher, who lectures on botany and education at Egerton University, Kenya, followed up the topic with college non-majors biology who had completed 1 year of biology at the university level. Students from Louisiana State University (LSU) in Baton Rouge, Louisiana were selected because of their proximity and their association with the Live Oak, which carries great importance to the campus community. Students from Southeastern Louisiana University (SLU) in Hammond, Louisiana, were also selected to increase diversity that may justify generalization from this study. Their campus is also situated in an urban setting, but enjoys a beautiful surrounding of many trees including Live Oaks. Initially 48 students were selected from the two universities, 24 from each institution, all of whom were non-biology majors. More students were later involved for reasons given in another part of this study.

Out of the 65 participants, 12 were chosen for in-depth clinical interviews. Students drawn from low, medium, and high performing science categories were selected, two from each level. This was done at both universities to yield a total of 12 such participants. Classification of students was based on teacher recommendations, and self-reported present and past science grades. All the participants were first year non biology majors who had completed 1 year of college biology.

This researcher read the non majors introductory course biology syllabi of the two universities. Their approach of the topic of photosynthesis was not different from that of the high schools referred to earlier in a section of this study. The common factors shared by the two syllabi are the excessive micro-details covered about the process of photosynthesis and the importance attached to the role played by carbon dioxide. As a result, the most basic features which are extremely fundamental to the understanding of a plant as an autotrophic organism have been left out. From one whole chapter in which the processes of photosynthesis was covered, this researcher noted that there was no reference to roots, neither the soil. Water was said to be supplied by vascular bundles or veins which also carried the sugar manufactured by the leaves.

Instrument Development Tests [The Root Probe]

The goal of this research study was to develop diagnostic instruments that would investigate students' levels of understanding. The first level was in regard to the role of the Live Oak tree's root as a subsystem. The second level was in regard to their level of

understanding of holistic nature of the tree. The third level was in regard to its process of photosynthesis as a subsystem product. The goal was achieved by presenting visual representations of some parts of the root, trunk and shoot of Live Oak to the participants. Some task items that called for a systems thinking were then presented to the participants. Understanding of the tree was assessed by means of the root-probe or oral interviews.

Visual Explanation

Separation of graphic from the text. The cognitive hypothesis used in setting up the root probe items was based on the work of Tufte (1983) and Paivio (1971) which is addressed in another section of this study. One of their recommendations is a separation of a graphic from a text. This is supported in a 1976 report by Holliday and Harvey (1969) who showed how such drawings could significantly improve middle-school students' comprehension of such physical concepts as density, pressure, and Archimedes' Principle. Their work was confirmed by Roller (1980) working with 13-year-old students. She found that students read a graph better when the graph is isolated and not embedded in the text. She agreed with the hypothesis that text and graph information are not commonly merged in the mind of the reader (Paivio, 1973).

In line with research findings, this researcher used some test items in which graphics were separated from the text. Whenever this was not possible, the test items were organized in a way that was favored by other factors as given below:

Prose graphics and comprehension. This researcher developed the root probe instrument after having read a number of high school biology textbooks. All the

textbooks consulted used various illustrations to explain the process of photosynthesis. The researcher hypothesized that students' alternative conceptions about photosynthesis are influenced by these illustrations. The key factors are given by Blystone and Dettling (1990), who identified three factors that may complicate comprehension when an illustration is included. The first one was where the text and the illustration do not coincide. Such a text-illustration conflict could lead to confusion on the part of the student. The second example of an illustration problem in textbooks considered the variation in illustration content dealing with the same topic. Textbook editors are careful to keep the prose on grade level throughout the book, but the same is not true for illustrations. For most publishers, content-ambitious illustrations exceed the level of content presentation in the text prose. The third kind of problem was identified as the complexity of an illustration. A seemingly simple illustration is not like a simple prose, since it will require a great deal of time investment to probe the content of it.

This researcher developed a pool of test items, each consisting of the prose and the graphics. A jury of educators, including at least one biology educator at the university level and some root experts, evaluated test items and then made suggestions for improvements. The evaluation criteria were brevity, clarity, vocabulary scope, content validity, matching of the text and the illustration, and the complexity of the illustration. The revised text was sent to some professional arboriculturalists who have been studying roots (i.e., root experts) for further refinement.

Effect of Questioning on Selected Items on Understanding

Since interviews involved what Holliday (1981) called interrogating, it was necessary to know the effect of it on students' understanding. In 1981, Holliday investigated this. As in his previous work, he used picture word diagrams illustrating biogeochemical cycles. The effect of four learning protocols was studied on tenth-grade biology students that were carefully matched but randomly grouped: (a) picture-word diagram accompanied by 20 textbook study questions (students were interrogated on all concepts); (b) the same picture-word diagram accompanied by five sample questions (students were interrogated on a few selected concepts); (c) the same picture-word diagram with no study questions (students were interrogated on no concepts); and (d) a prose passage describing biogeochemical cycles in question. A suitable study time was given. All four groups were given a thirty-question, multiple-choice exam. On the post-test, students with the twenty-question protocol and no-question protocol outperformed the five-question and prose-protocol groups.

Anderson (1970) accounted for these results with the following explanations; Students who were interrogated on all information focused their attention on all aspects of this material. On the other hand, students who were interrogated on a sample were only partially cued to the subject matter by these few questions. They did not focus on other material not covered by the five questions. The "no question" students had to devise their own study scheme which apparently worked. The "prose-only" group served as "controls." The conclusion to be drawn here by textbook developers is that

picture-word diagrams should be either supported completely, or not at all. Providing partial text support encourages the student to do poorly on illustration-based text.

In line with these research findings, the root probe instrument was based on identified root and photosynthesis propositions (see Appendix F). These items cover identified areas on the topics of photosynthesis, respiration, and Live Oak roots. Areas in which students have had some trouble have been identified (Abrams, 1994; Haslam & Treagust 1988; Johnstone & Mahmoud, 1980;). A great deal of emphasis had been on the questions that render an understanding of the role of the roots and its relationship to the process of photosynthesis. The process of respiration had been included because most students regard it as the opposite of photosynthesis (Haslam & Treagust, 1987.) As a result, the root probe items included several respiratory distractors. The oral interview probed the spots identified as "trouble areas" after exposing students to a narrower section of the root and photosynthesis. The relationship of this with Holliday's (1981) work is that it reverses the approach that the group which dealt with five sample questions experienced. They started with the large picture of the plant, as covered by the entire root probe, and then narrowed their perspective to more specified areas. A concept map was used along with other forms of integrated texts (see more on this below).

System Thinking and Integrated Text.

Moline (1995) described an integrated text as one in which texts and visual elements are combined in a way that its parts support, explain, or give context to one another. The drawing is integral to the meaning of the written text, just as the written

text is to the drawing. This study utilized mainly the concept map and the graphic design as the integrated text.

Moline (1995) explained that graphic design combines visual and verbal texts. A graphic design has several features. One of the most important is the layout or positioning of verbal and visual elements on the page. It serves to direct the reader from one part of the text to the other. In the classroom, graphic design can be an important part of the writing process, and also involve thinking as well as visualizing. This researcher used elements of graphic design in the root probe and during the oral interviews.

The instrument used was based on the modified works of Haslam and Treagust (1988). Broadly, the development of diagnostic tests for identifying students' alternative conceptions in specific areas comprised seven stages involving three broad areas as given below.

Defining the Content

Step 1: Identifying Propositional Knowledge Statements

The importance of identifying propositional knowledge statements has been described by Finley and Stewart (1982). Of particular importance to this research is the position that information is stored in long term memory in a propositional format (Norman and Rumelhart, 1975). Finley and Stewart (1982) outlined the advantages of this approach in curriculum development and teaching. Using educational literature review, the researcher has identified some key propositional statements regarding the roots, and the processes of photosynthesis and respiration. A number of these

propositional statements include those derived from horticulture and arboriculture (Gilman, 1989; Shigo, 1991; Waisel et al. 1996, see Appendix F).

Step 2: Validating the Content

The propositional statements were content-validated by science educators, secondary science teachers, and arboricultural specialists who have a thorough knowledge of the subject matter. Any discrepancies or irregularities were removed and the list of propositional statements were corrected and modified accordingly. In this way, the knowledge being examined was thoroughly documented so that no questions were developed which did not relate clearly to the concepts being researched. An essential feature of this development is that the content and concepts to be investigated are scientifically accurate, as far as the particular level of study being pursued. The final revised list of propositions reflected the input from persons with considerable knowledge in these content areas (see Appendix F).

Obtaining Information About Students' Alternative Conceptions

The second broad area for developing diagnostic tests to evaluate students' alternative conceptions involved a thorough examination of the relevant literature dealing with cognitive structure.

Step 3. Examining Related Literature

As mentioned earlier, this researcher conducted a pilot study with a large cross-section of students from middle and junior high schools. The findings obtained there were cross-matched with those documented in science education literature. A similar

cross-matching had been done with the review of those conducted in arboriculture and horticulture. The two were merged. A summary of these is given in Appendix G. Gilman (1989) and Shigo (1991), among others, have identified some alternative conceptions within this area. In most of their research, arboriculturalists have referred to alternative conceptions as misperceptions (Gilman, 1981). Regardless of the differences in terms, the concepts were similar to those identified in science education. This researcher also had an opportunity to attend two seminars organized by the Louisiana Arboriculture Association. One of these meetings was held at Southern University (1996) and the other one was at the Burden Research Center (1997), both in Baton Rouge, Louisiana. Dr. Don Marx, a well-known root specialist, was the guest speaker in both meetings. The theme of both meetings was "Take care of the roots, the shoot will come". The care for the tree has suffered from a lack of understanding of the role of the roots. However, to the best of this researcher's knowledge, students' understanding of the role of roots in photosynthesis has not been a focus of research in the field of science education. This research study addressed that need.

Developing a Diagnostic Test

This is the third broad area for the test item development.

Step 4: Designing a Specification Grid

A thorough specification grid was designed. This ensured that the diagnostic test formulated covered the propositional knowledge statements and their related alternative conceptions.

Step 5. Construction of Test Items

For the identified alternative conceptions, several items were included in the test. These items differed in format (multiple-choice, multiple-choice plus justification, or two-tier, open-ended, proposition-forming.) The items also differed in the cognitive level required of the student. The use of various formats is desirable since alternative conceptions are sometimes revealed in one situation but not in another (Eylon et al. 1987).

Multiple-Choice

The work by Tamir (1971) on an alternative approach to the construction of multiple-choice test items was innovative in that the distractors for the multiple-choice items were based on students' answers to essay questions and other open-ended questions and addressed underlying conceptual knowledge related to a limited content area. He explained as follows:

In constructing the set of four or five alternative answers for a multiple-choice item, one or two rules are usefully kept in mind. First, it is necessary that the individual item be clear and definite in its meaning. Second, it is important that wrong alternatives have different degree of obviousness in their 'wrongness'. No more than one member of the set of alternatives should be transparently irrelevant to the question put. The others should be possible or plausible. (p. 36)

As Tamir (1971) states

These alternative [responses] being representative of typical conceptions and misconceptions of students have a distinctive advantage as compared to regular test items for which professional test writers provide the alternatives (p 306).

Two-Tier

The first tier of each item relates to content based on propositional knowledge statements. In the proposition-forming task, students are given a proposition relating to

a concept or one that connects two concepts. The proposition should reflect the nature of the relationship between the referred concept or the two concepts that are connected. Additional concepts that would help to clarify the relationship may be added. Novak (1978) explained that such propositions can give evidence of idiosyncratic concept-meaning possessed by the student. The second part consists of justifications to multiple-choice items that have been shown useful in uncovering students' ideas and alternative conceptions (Amir, Frankl & Tamir, 1987; Tamir, 1989).

Free responses were also used as a way of understanding students' alternative conceptions. Some of these alternative conceptions are deeply rooted in myths and stereotypes. An example of the latter is how most textbook writers, as well as teachers, illustrate the concept of diameter by drawing it in a horizontal position. As a result, the irrelevant feature of location obscures the essence of the definition. It is suggested that such confusion may be with the team of root experts and researcher's committee was continued. The development of these tests to date had shown that each item can be successfully refined to improve its diagnostic nature to identify alternative conceptions.

Step 6: Final Instrument

Subsequently all of the above steps provided a focus for the development and refinement of the test items. The items on the final instrument were content-validated against the propositional knowledge statement using a specification grid indicated in Appendix F. Some parameters of the items, such as their reliability, was determined by

means of the Cronbach coefficient alpha. The ranges of difficulty indices and discrimination index were also determined.

How to Answer the Research Question

The cited research review illustrated the history, constancy, and the widespread nature of alternative conceptions relating to the understanding of the process of photosynthesis. In line with these findings, features of the social environment retain a high degree of constancy across time and space (Gall, Borg, & Gall, 1996). The major research question was introduced by the phrase "How are" which calls for qualitative interpretation. However, the strength of the research is carried by the repeated phrases "What are" which are linked to statements that call for quantitative interpretation. Besides that, the former (How are) refers to the root in general while the latter (What is) refers to the Live Oak in particular, which is the object of research questioning.

General Set up of the Root Probe Task Items

Levels of understanding. The answer to the main research question was answered after establishing three other levels of understanding. Each of these three levels was enhanced by a good understanding of scientifically acceptable conceptions (as well as being unaware of them) but was negatively influenced by the alternative conceptions. How each of these three levels were enhanced by a good understanding of scientifically acceptable conceptions was investigated by means of the root probe (as well as being unaware of them). Performance of the students was assessed at three levels: The level of understanding that the students had of the root systems of the common Live Oak tree; the level of understanding that the students had of the Live Oak

tree as one system and the level of understanding that the students had of the process of photosynthesis. Each of these levels was probed with 13 task probe items.

Correlational Research

The purpose of the study was to identify a correlational relationship between students' level of understanding of the root system of the common Live Oak tree and their level of understanding the process of photosynthesis. To achieve this goal, the researcher developed some propositional statements. The propositional statements were divided into three areas that addressed the ; (a) root system, (b) the holistic nature of the tree, as well as (c) the process of photosynthesis. Each of these three areas was assigned 13 propositional statements that were tested with 13 task probes items. Each of these probes assessed an understanding of the propositional statements along with their associated concepts. As a result, the students' responses to the root probe task items associated with a given section was taken as a level of understanding of that particular section. Each correct response to a root probe task item was awarded a score of one. That of student's score on the parts relating to the root system was categorized as a variable score on understanding of the roots, and that of the process of photosynthesis was categorized as a variable of understanding photosynthesis.

There is need to perceive the root system and the shoot as subsystems of the bigger tree system. As a result some measures of students' level of understanding of the holistic nature of the tree were also included. The latter were included as a means of investigating established alternative concepts that could not be attributed to either root or shoot systems alone. The section was particularly useful as a means of

investigating the general understanding of systems thinking that results from the processes that are influenced by dynamic interaction of the shoot-root activities. A correlational coefficient that indicates both the direction and the extent of relationship of each of the pairs of these variables was calculated by use of the SAS statistical analysis (Dilorio, 1991). In this case the correlation coefficient was determined by means of Pearson's r correlation, which is a measure of the degree and direction of relationship between the level of understanding of the root system and the level of understanding of photosynthesis.

In this case, the Pearson correlation was identified by the letter r , given in the last section of this study. The coefficient of determination (r^2) was also determined thus indicating the proportion of variability in the variables of students' understanding of the root system and the variables of their understanding the process of photosynthesis.

t-Test

A t-test was performed to determine the differences between the level of understanding of the root system and the level of understanding of photosynthesis.

Interviews and Concept Maps

After all the 65 students had taken the root probe instrument, the 12 students selected on the basis of performing science categories were probed further. Two types of probing procedures were used. In addition, concept maps and interviews were used.

Diagnostic role of concept maps. A method previously used by Abrams (1994) was adopted for this study. This researcher and the student both participated in drawing the concept map. The student was given a concept that was followed by a question

upon which he/she was expected to respond by providing subordinate concepts at various levels of the interviewer=student discussion. The student and the interviewer were able to restructure the map with minimum delay. After the interview, the student was asked to affirm that the map constructed during the interview actually reflects his/her actual understanding of the interview topics in some cases. A video camera recorded the student-interviewer interaction as the concept map was constructed. The videotape allowed this researcher to retrieve narratives that were not written. Their performance was low on this task and this researcher was forced to make less use of them (see Appendix L).

As in Cummins' (1992) study, videotaping was done with permission of the students under a Live Oak tree. This researcher mounted a clear mounting board whose inscriptions could be detected in a video film. Tags and other conspicuous labels were also used. The camera was placed in such a way that it captured all that was written, even the portions that were erased, during the course of the interviewer-student interaction.

To gauge the extent to which biologically meaningful knowledge, especially systems thinking, is revealed by the students' concept maps, a panel of two biology educators were asked to review the videos and to develop their own concept maps. An analysis of these maps produced a set of critical concepts and propositions that served as benchmarks for the analysis of students' concept maps. The students' maps were categorized based on concept elaborations, using the experts' maps as the referent. Shigo's (1991) text "the systems' window" was used to clarify root shoot systems'

concepts. The students' responses were categorized as knowledge of photosynthesis or root systems. Correlational statistics transformed their responses.

Interview, Interviews with the 12 selected students were done 1 week after administering the root probe. The subjects and the interviewer sat under a selected spot of a Live Oak tree, so that the students could observe the Live Oak as a living specimen. A set up of that kind gave them an opportunity to interact with events that were central to the objects that the interviewer wanted to probe. This is what Erickson (1979) calls an experiential maneuver. This serves two purposes: it provides a rich, varied, and intensely personal matrix for constructing meaning; it focuses students' attention and arouses curiosity in the domain the interviewer has targeted.

The interview took two forms; the first one was a follow up of their root probe responses. The interviewer asked them some questions related to their root probe responses. A method very similar to that used by Mintzes and associates (1983) was applied. His approach was to follow student's responses about a concept with other nearly similar questions. Since each student's root probe response was different from the other, every interview was different from the other.

During the second part of the interview, each student was presented with a graphic. The interviewer then asked them specific questions that elicited a discussion that was meant to probe their systematic thinking. For some graphics, students responded in writing. These responses were then graded afterwards. For others, the interviewer required them to give free responses by way of explanation or by writing on a paper placed on a board. These were videotaped and graded after the interview.

Reliability

Reliability of a test is the consistency of that test. A reliability coefficient was calculated to determine the reliability as follows:

Coefficient of stability. The scores obtained after administering the root probe were treated as the first test score. The in-depth analysis of the 12 students yielded scores that were treated as the second scores.

Weakness

The weaknesses with this approach were that not all the students were covered by the in-depth analysis. The test-retest method would have been more useful for assessing the stability of the students' knowledge of the root system and how it influences their knowledge of the process of photosynthesis, and vice versa. However, due to the cost involved of replicating the procedure, this was not done.

Internal Reliability Coefficient

The root probe test items were split into two halves of even numbers and odd numbers. The correlation coefficient (r) between scores on the odd and even numbered items was calculated. To obtain an estimate of the reliability based on the full-length test, a correction based on the Spearman-Brown formula was used. This formula is used to predict the new reliability expected from increasing the length of a test of known reliability by adding items similar to the original items. The r value that was obtained is given on page 166 of this study.

Validity

Validity refers to the consistency (accuracy) with which the scores measure a particular cognitive ability of interest. The two aspects of validity are what is measured and how consistently it is measured. The Standard for Educational and Psychological Testing (American Psychological Association, 1985) associates the term with a set of test scores rather than the test used to produce them. Validity has to do with the meaning of the scores and the way we use scores to make decisions. Two types of validity were measured, content validity and criterion- related validity.

Content validity. This concerns the degree to which various items collectively cover the material that the instrument is supposed to cover. A team of root experts had been reading the root probe instrument and had consistently offered their advice on this. All of the propositional statements were drawn and adopted from reputable educational journals (e.g., Haslam & Treagust, 1988) and some arboriculture journals (e.g., Gilman, 1989).

Criterion-related validity. This assessed the degree to which scores obtained from the root probe instrument matched the scores from the in-depth analysis. Students' performance on each of the two tests allowed the researcher to correlate the two sets of scores. The resulting r was the validity coefficient.

Knowledge Claims (Hypothetical)

This was a research study of how the level of understanding of undergraduate college biology students for the roles of the seed plant root system related to their level of understanding of photosynthesis. The hypothetical knowledge claims were that:

1. Students with a high level of understanding of the Live Oak root system develop high level of understanding for the process of photosynthesis.

2. Students with systematic approach to learning develop a high level of understanding of the root system and process of photosynthesis.

3. The implications of these findings for instruction were that biology instructors could teach their students more by adopting systems thinking and by including the teaching of the root.

Value Claims (Hypothetical)

If these hypothetical knowledge claims were to be supported by the research, then the following value claims would have been made. The level of understanding of undergraduate college biology students of the role of the seed plant root system relates to their level of understanding of photosynthesis.

Method

This researcher used the root probe diagnostic instrument to test what level of understanding the college biology non-majors had of the root system of the common Live Oak tree. The list of the task items was gleaned from science education literature, college biology textbooks, and from professional root experts. This was administered to 65 college biology students who had taken 1 year of college biology. Quantitative analysis of the results of this diagnosis revealed areas which were probed by interviewing 12 selected students out of those who had taken the root probe. The qualitative results were analyzed and these results were compared with the quantitative results obtained earlier.

Strength of this Approach.

1. The integration of systems thinking enabled this researcher to diagnose students' understanding of the holistic nature of the tree. No education literature had done this before.

2. Systems approach allowed this researcher to organize the research findings from two fields (i.e. science education and arboriculture) and bridge the gap of our knowledge about the living things.

3. Notice that some questions that were not in the root probe could be introduced in the qualitative part and allow this researcher to investigate their propositions about any given concept. For every root probe task item, there were a set of corresponding test items. These ranged from the simplest to the hardest.

Interviewees were given the task items that matched their performance in the root probe. An example of this kind is given below;

The root probe had this as task item two:

Nutrients absorbed by the roots of a tree consist of mainly one of the following.

- (a) All the food and water absorbed by the roots.
- (b) Inorganic matter and water absorbed by the roots.
- (c) Organic matter and water absorbed by the roots.
- (d) Humus and water absorbed by the roots.

And in the qualitative part we had this test item that was of a category of a simple test:

The main source of food for the root of a tree is:

- (a) The nutrients absorbed from the ground.

- (b) The food absorbed by the roots.
- (c) Both nutrients and the food manufactured by the shoot.
- (d) Roots synthesize their own food before passing the nutrients to the shoot.

The following test item was among the category of the harder type that were used in connection with the root probe task item 27 on page 232 that probed participants' understanding of the role of water in plants;

Salt is known to kill a tree when placed at the base of it or close to the roots.

Salt kills the tree by

- (a) moving into the plant tissue.
- (b) inhibiting some important metabolic reactions.
- (c) blocking the upward movement of water in xylem tissue.
- (d) plasmolyzing the epidermal tissue of the roots.

Limitations of this Study

1. All of the 65 students were not interviewed. The qualitative results of the purposive sample may not have given the true nature of the group's qualitative understanding.

2. The scores of individual students were not analyzed in detail to reveal the patterns of thought possessed by each student.

3. The Live Oak tree, though a familiar specimen to the interviewees, has many peculiar features and another seed plant may have evoked different answers to the root probe.

4. Additional pre- and post-tests to follow on changes in students' levels of

understanding of the root system after teaching crucial concepts, and whether these changes were accompanied by an increase in level of understanding for the process of photosynthesis were not done. This would have provided another indication of the strength of the two relationships.

CHAPTER 4

RESULTS

Research Question and the Participants' Performance

The major research question that this study sought to answer was, "How do undergraduate college biology students' level of understanding of the roles of the seed plant root system relate to their understanding of photosynthesis?"

Levels of Understanding

The answer to the main research question was answered after establishing three other levels of understanding. These three levels were referred to earlier (See the Method section of this study, i.e., p.79). Each of these three levels was enhanced by a factor of understanding the scientifically acceptable conceptions but was negated by factors of being unaware of them as well as sets of corresponding alternative conceptions. These conceptions are established in science education and arboriculture literatures covered in chapters one and two of this study. The three levels were established by means of the root probe. The root probe (See Appendix H) was a set of task items that investigated the influence of these factors to understanding of the three levels of understanding.

The first of these three, (a) the students' level of understanding the root system was used to answer the research sub-question one given in the earlier part of this study (see page 2). The second, (b) the students' level of understanding the process of photosynthesis was used to answer research subquestion two (see page 2). The third level, (c) the students' level of understanding the holistic nature of the tree was used

to answer both research sub-questions one and two. This explains why understanding of this level was treated as a partial answer to the main research question. See Final Findings on page 144. Students' level of understanding the holistic nature of the tree was included as a means of investigating established alternative concepts that could not be attributed to either root or shoot systems alone. As given in another part of this study (See page 35), students tend to develop invalid conceptions about oxygen, respiration, autotrophism, food and energy capture. Investigations of some of these conceptions was done under the level of understanding of the holistic nature of the tree.

The main research question was answered by considering the mean scores of each of the three levels as well as the correlational statistics between the first (a) and the second (b) levels of understanding. See the Table 1 on page 91. The mean scores of the third (c) level of understanding was particularly essential because it addressed some aspects that assessed a combined effect of understanding the other two levels.

The research sub-question one read as follows: What level of understanding do the students have of the root system of the common Live Oak tree?

Understanding of the Live Oak Root System

Performance of students on understanding of the Live Oak root system was assessed with 13 (1, 4, 5, 14, 15, 16, 23, 28, 29, 35, 36, 37, & 38) root probe task items. The maximum score was 11 and the minimum score was 2. The mean score was 5.94. See Table 1 on page 91. Results of participants' performance per task item are shown in Table 2 on page 92 and the accompanying histogram indicated as Figure 1 on page 93 respectively. The mean score of 5.94 would have been even lower had it not been

Table 1. Correlational and t-Test Results

3 Variables: ROOT 1 HOLISTIC 2 PHOTO 3						
Simple Statistics						
Variable	N	Mean	Std. Dev.	Sum	Minimum	Maximum
(a) ROOT 1	65	5.9385	2.1204	386.0	2.0000	11.0000
(b) PHOTO 2	65	5.5385	1.9928	360.0	2.0000	10.0000
(c) HOLISC3	65	5.2769	1.8667	343.0	1.0000	10.0000

Mean score of Level of understanding the root system - Mean score of Level of understanding of photosynthesis was not statistically significant.
 $t(129) = 0.137, p > 0.05$.

Summary of Correlational Statistics

Variable	Students' Holistic Understanding of Root System	Students' Understanding of Holistic nature	Students' Understanding of Photosynthesis as a System
Students' Understanding of Root System	1.000	0.462	0.322
Students' Understanding of Holistic Nature	0.462	1.000	0.312
Students' Understanding of Photosynthesis as a System	0.322	0.312	1.000

Table 2. Descriptive Statistics of Students' Scores on Understanding of the Root System

Task Item Number	MC's Number and type of Responses (As %N)				Total # Of Responses (N)
	(A)	(B)	(C)	(D)	
Q4	00(00.00%)	12(18.5%)	31(47.7%)*	22(33.8%)	65
Q5	08(12.3%)	17(26.2%)	13(20.0%)	27(41.5%)*	65
Q15	17(26.6%)	23(35.9%)	06(9.4%)	18(28.1%)*	64
Q16	12(18.5%)	09(13.8%)	37(56.9%)*	07(10.8%)	65
Q23	12(18.8%)	13(20.3%)	25(39.1%)*	14(21.9%)	64
Q28	26(40.0%)	22(33.8%)*	09(13.8%)	08(12.3%)	65
Q29	22(33.8%)*	29(44.6%)	06(9.2%)	08(12.3%)	65
Q35	15(23.1%)	35(53.8%)	13(20.0%)*	02(3.1%)	65
Q36	26(40.0%)	21(32.3%)*	13(20.0%)	05(07.7%)	65
Q38	09(14.5%)	23(37.1%)*	19(30.6%)	11(17.7%)	62
Free Responses					
		Correct		Wrong	
Q1		62(96.9%)*		02(3.1%)	64
Q14		35(68.6%)*		16(31.4%)	51
Q37		47(87.0%)*		07(13.0%)	54

Where N = Total Number of respondents consisting of 45 females and 20 males,
(Letter)* or correct* response.

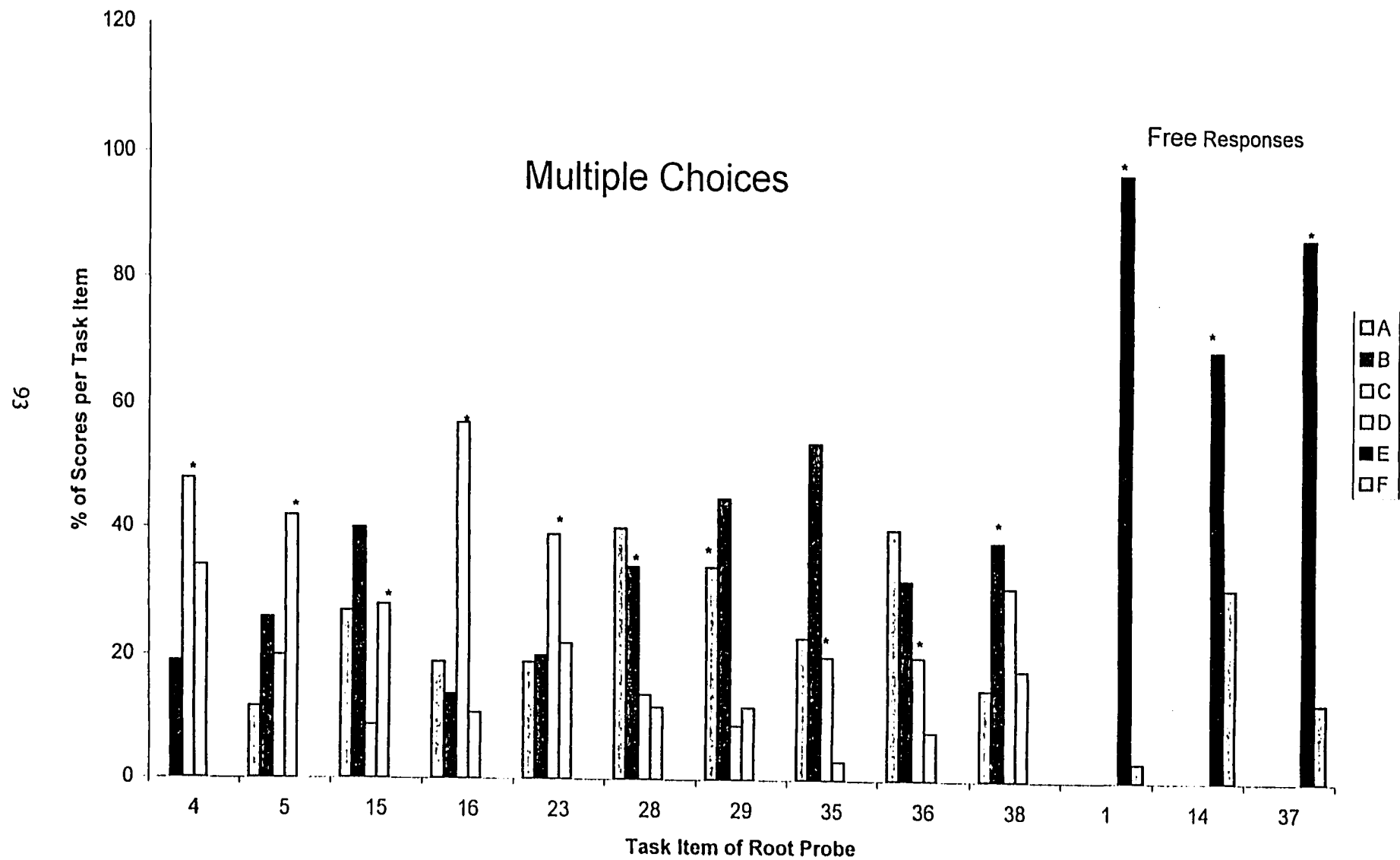


Figure 1- Students' Scores on Understanding of the Root System

for the high scores from the free responses of task items 1 (97%) and 37 (87%) that appears in Appendix H on pages 216 and 235 respectively.

The following students' responses to root probe task items were interpreted by the researcher in order to reveal students' understanding of the Live Oak root system. Not all task items were interpreted in this phase of the study. Selection of the task item was based on participants' low performance of selecting the correct choices and the items' specificity in answering the research question. The rest of the task items involved ideas most of which are interpreted in the interview section of this study (See page 102). In the following section understanding of the root as a sub system of the plant system and its interactions with the surrounding system boundary (i.e., soil) was investigated.

Plant Food

This concept falls under the second level (i.e., students' level of understanding of the process of photosynthesis). However, because of the influence that the factor of alternative conception (i.e., food comes from the soil) had on the participants, it was investigated under this level of understanding. The results of this task item appear along with those of the second level in Table 5 on page 108.

Source of plant food. This concept was examined with task item two:

The diagram on page 95 represents a Live Oak seedling.

.In order to continue to grow and become a large tree, the seedling will need to continually:

a. absorb its food from the soil.

- b. make its own food using its leaves.
- c. use its stored food reserve.
- d. use solar energy as its food.

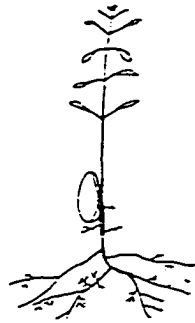


Figure 2. Seedling of a Live Oak (Adapted from Gilman, 1997).

The task item required the students to identify the source of food used by the plant. Only 22% made the correct choice (2b) that is, plants make their own food. The rest (76%) attributed the source of plant food to other sources. This includes 51% who took soil as the main source of that food. This is a common alternative conception documented in the work of Wandersee (1986). In that study, he found that the alternative conception that soil was the source of plant food stubbornly persisted across grade levels from elementary through college.

The researcher discovered that the concept of nutrients hindered their understanding of the concept of food. In an attempt to confirm whether participants believed that nutrients were plants' food, the interviewees were probed further using another probe item about their understanding of nutrients. The forced choices of this probe were as follows:

- .Nutrients absorbed by the roots of a tree consist of mainly one of the following:
- (a) All the food and water absorbed by the roots.

(b) Inorganic matter and water absorbed by the roots.

(c) Organic matter and water absorbed by the roots.

(d) Humus and water absorbed by the roots.

The correct choice (b) was selected least by the interviewees. Choice (a) was selected most frequently followed by choices (c) and (d). Comparisons of their understanding of this concept with the results of task item 36 was done. In that task item, the word “nutrients” was qualified by either “organic” or “inorganic”. Interviewees explained that organic nutrients carry some plant food. This confirmed that the participants took nutrients to mean the same thing as humus, organic foods, and heterotrophically ingested material.

The concept of fertilizers. Task item four tested students’ understanding of the role and application of the fertilizer to trees. Fertilizers are also part of the system boundaries because they are nutrients. Nutrients are part of elements that plants need that occur naturally in soils, but some are artificially made, hence the name fertilizer .

.As the seedlings grew into Live Oak trees, a farmer noticed that the seedlings which were treated with fertilizer grew faster than those which received none.

(See Figure 2 on the following page). The role of fertilizer was to:

- a. substitute for the water required by the plant.
- b. provide to the tree some metabolic requirements normally given by a close association of fungi and the roots (mycorrhizae).
- c. provide the tree with essential elements such as phosphorus.
- d. provide food in the soil close to the roots of the tree.

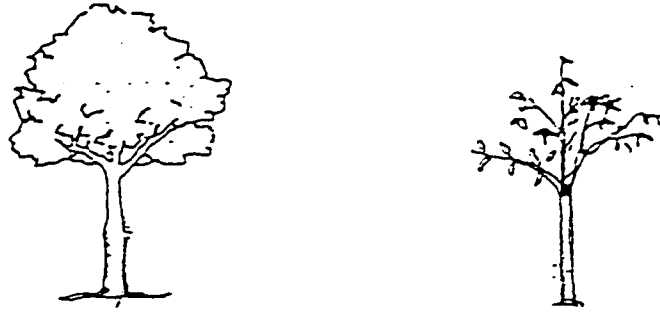


Figure 3. Fertilized and Unfertilized Live Oak Seedling (Adapted from Popadic, 1995).

Choice (4a) should not have been included as it sounded obviously wrong to all the students who took the root probe. In this task item, the word “phosphorous” was a guiding factor to the 48%, who made the correct choice (4c). All the students who were interviewed later knew that most fertilizers had either phosphorous or nitrogen or both of them. Distractor choice (4d) would probably have attracted more participants than the 34% had the words “phosphorous” or “nitrogen” been included in it as well.

Role of the non-woody roots in absorbing nutrients. Task item 36 probed students’ understanding of the exchanges that take place between the root and its system boundary (see Figure-4 on the next page). Also, the task item investigated whether the concept of nutrients was familiar to the participants.

.The rhizosphere is the area of soil immediately surrounding plant roots. In this region the

- a. Organic nutrients leave the soil region and enter into root hairs.
- b. The inorganic nutrients enter the root hairs from the soil as organic nutrients enter the soil from the roots.
- c. Unused inorganic nutrients enter the soil from the roots in exchange of useful organic nutrients.
- d. None of the above.

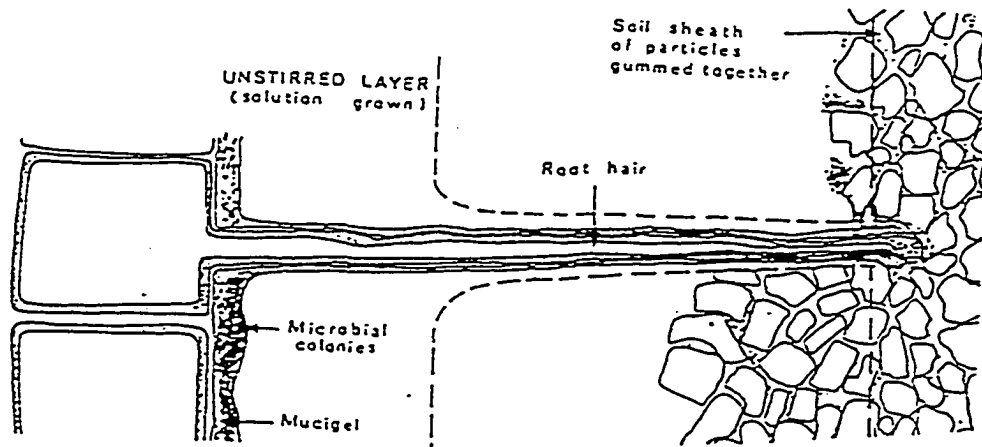


Figure 4. The Rhizosphere (Adapted from Waisel et al., 1996).

32% of the students selected the correct choice (36b). Since this choice attracted a significant fraction of participants, some comparison was done between those who selected the two correct choices of task items 2 and 36. Only 9 (14%) students selected both choices (2b & 36b), thus consistently avoiding the alternative conception that organic nutrients were the plant food that came from the soil. The distractor (36a) associated with “organic nutrients” was selected by the greater number of students 26 (40%). Later, all those who were interviewed in another part (see page 106) of this study revealed that they had not heard the word rhizosphere before. It could be that, the reasoning behind their choices for this question were like that of Question 2 had it not been for the influence the word, rhizosphere, had on this task item.

Root spread. The soil serves as the medium of the root spread. Task item 35 investigated participants’ understanding of the way the roots were spread in the soil.

This spread is in turn influenced by the interaction of the roots with its system boundaries. These boundaries provide a medium and the nutrients that are finally absorbed by the root system (Russell, 1977).

.The diagram on the following page represents the parts of a mature campus Live Oak. Each of three students interviewed indicated by means of circles how far they estimated the roots had extended from each side of the base of the tree. The first student indicated up to the edge of the canopy x , the second one indicated twice that distance, and the third one three times that distance. Which of the three students was correct or nearly correct?



Figure 5. The Root Spread of a Live Oak Tree (Adapted from Gilman, 1997)

- a. the first (x).
- b. the second ($2x$).
- c. the third ($3x$).
- d. None of the three.

Only 20% made the correct choice (35c). Choice (35a) was a distractor adopted

from the work of Gilman (1989) and Shigo (1991). It was selected by probably fewer students (23%) than would have been the case had it not been for the familiar protruding and far spread roots of the campus Live Oaks. However, even with this obvious evidence in sight all around them, a quarter of the participants selected it. Choice (35b) was an obvious attraction to most of them as a result of rejecting the obvious distractor. It fitted well within their mistaken estimate of the protruding roots, attracting a percentage of 54%. This is an indication of how poorly the spread of the Live Oak root system is understood.

Region of maximum interaction between non-woody roots and their system boundary. An established scientific conception is that non-woody parts of a tree absorb nutrients (Kozlowski & Pallardy, 1997; Waisel et al., 1996). This absorption takes place at the region of maximum interaction between non-woody roots and their system boundary (i.e., the soil). This concept was tested by task item 5, as follows:

.The diagrams on the following page is a birds' eye view of Live Oak trees with some of the circles indicating the edge of the canopy, (It is referred to as the dripline. How would you fertilize it? Indicate the right choice for the effective fertilizer from one of those shaded below:

The correct choice (5d) was selected by 41%. All the other choices were wrong since they encompassed mainly the woody parts of the root which are not effective in the absorption of nutrients. A significantly high number (26%) selected choice (5b). This item was adopted from the documented alternative conceptions by Gilman (1989).

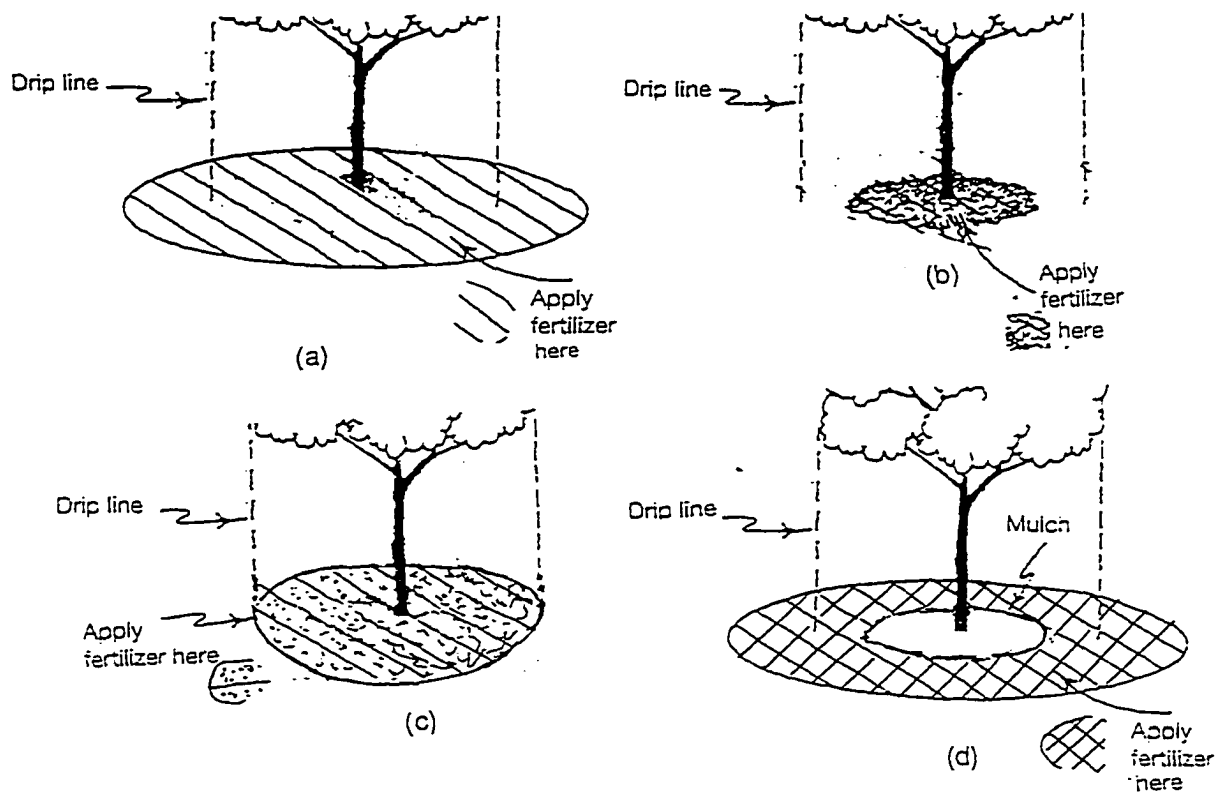


Figure 6. Region of an Effective Fertilizer (Adopted from Gilman, 1997)

Functions of Non Woody Roots

Understanding of functional differences between the woody and the non-woody parts of the roots was tested with task item 16.

.Root hairs are most important to a plant, because they

- anchor a plant into the soil.
- store starches.
- increase surface area for absorption.
- provide a habitat for nitrogen fixing bacteria.

The correct choice (16c) was selected by over half (57%) of participants. The word “absorption” appeared in only this choice. Students may have related this word to the more familiar heterotrophic nutrition, hence influencing the unexpectedly high percentage. Choice (16a) received a significant attraction (19%). This is an indication

of some confusion in terms of students' understanding of the role of the woody and non-woody roots.

Oral Interviews of Students' Understanding of Roots

Oral interviews were meant to clarify the students' responses to task items that related to root probe sub question one: What level of understanding do the students have of the root system of the common Live Oak?

Students' Understanding of Plant Food

During these interviews, the participants either used the word "food" interchangeably with "nutrients," or either said that nutrients were food and something else, or vice versa. More questions were posed to them about the meaning of organic nutrients and the humus. A summary of salient alternative conceptions and some concepts which students are unaware concerning the roots and plant food are given in Tables 3 and 4 on the next two pages. These summaries are about several alternative conceptions derived from common beliefs that have no scientific support. Students did not interrelate the root and the shoot systems, as a result of which they failed to master the acceptable scientific conceptions that were vital to their understanding of the plant nutrition. Below are examples that illustrate their responses: (Pseudonyms of students are shown next to their statements. This researcher's statements are delineated by Int.)

Int: What is the function of these big roots of the Live Oak?

Christy: They absorb food from the soil.

Table 3. (Verbal)

Lack of Awareness and Alternative Conceptions Associated with Roots	
<u>Root Features.</u>	<u>Description of Students' Ideas about Root Features.</u>
Live Oak roots.	Remain close to the surface to offer better support to the tree.
Root systems	Are mirror images of the tree's trunk and limbs.
Topping of shoot	Gives chance to the roots to establish themselves.
Root spread.	Influenced by tree's species but not the nature of the soil.
Width of roots	As wide as the canopy or spread up to the drip line.
Tap roots	Present in all trees for anchorage and feeding deep into the soil.
Roots and gases	Do not release CO ₂ nor absorb O ₂ because they need neither.
Tree transplanting	Insert its roots deep into the ground as you transplant.
Dependence of shoot	The shoot depends upon the roots for nutritional support.
Root-hairs	Always present in a mature Live Oak and are easy to see.
Natural habitat	Most suitable to a trees as it offers decomposed organic matter.
The woody roots	Involved in absorption of water and nutrients.
Live grass mulch	Best for the Live Oak tree. It does not harm the tree.
Over-watering	Always beneficial to the Live Oak.
Not aware of	The symbiotic interdependence of the roots and other organisms around them, for example, the concept of rhizosphere.
Not aware of	The harmful consequences associated with root compaction.
Passive absorption	Involves some medicine, mineral nutrients and water from the soil.

Table 4. (Verbal)

<u>Lack of Awareness and Alternative Conceptions Associated with Plant Food</u>	<u>Description of Students' Ideas about Plant Food</u>
Nutrients and food	Plant food is derived from some external source. Since nutrients are absorbed from the ground, they are therefore plants food.
Fertilizer as food	Fertilizer is a more concentrated form of plant- food.
Food absorption	Plants absorb their food from the soil by means of villi-like structures attached to the hair- roots.
Functions of food	Growth, storage and repair. It provides other things that plants need for their lives.
Food and Energy	Plant food was not associated with the supply of energy needed by the biochemical processes taking place within the plant. This food gave plants some nutrients.
Solar-energy	Low scoring participants treated solar energy as plant-food.
CO ₂ is food	Plants absorbed it from without to build themselves, especially the carbon part (after O ₂ is released).
Effects of topping	Has no affects on plant- food since their food come from the soil.
Autotrophic food	Plants do not use the food they make. This food is passed over to the animals. If by chance they do use it, that is when they are facing harsh conditions.
Glucose and starch	Participants failed to treat either of the two as forms of organic

(Continues--->)

<u>Plant Food</u>	Table 4. (Verbal) . . . <u>Description of Students' Ideas about Plant Food</u>
	matter for growth, storage and repair. As a result, they never considered them as plant- food.
Int:	Asha, what is the role of the hair roots in the plant?
Asha:	They have villi-like shapes that absorb nutrients from the soil.
Int:	Shalima, how does the tree absorb this food from the soil?
Shalima:	Their root hairs have ball-like things that absorb the food into the plant where it is used or stored.
Int:	Aimee, explain to me exactly how this food is taken into plant.
Aimee:	They just take it and pull it through the roots and then... I know it is more complicated than this... and then they carry it to other parts of the plant.

Concept of fertilizer as nutrients. The concept of nutrients as plant food was further complicated by fertilizers, which students regarded as either plant food or nutrients or both. Kalo said that fertilizer was something artificial which contained the exact nutrients that a plant needed to develop, which it could not get on its own when there was a deficit of it in the soil. In support of her, another student, Felicila, defined fertilizer as a more concentrated form of food for the plant which provided the necessary minerals and nutrients.

Further probing of their understanding of fertilizers is illustrated by the following interview with Felicila, Aimee and Katrina:

Int: (To Felicila) What is the role of fertilizers to the tree?

Felicila: It (fertilizer) provides the tree with minerals and nutrients.

Int: And what do you mean by nutrients?

Felicila: Nutrients are all the necessary substances it needs for living

Int: Such as?

Felicila: Such as minerals and salts.

Int: Now if minerals and salts are the nutrients... what is plant food?

Felicila: Plant's food is the nutrients... I'd say.

Int: (To Aimee) What is fertilizer?

Aimee: Fertilizer helps the plant grow.

Int: Tell me exactly how fertilizer helps the plant grow?

Aimee: Well, I guess it gives the plant nutrients or some kind of substances.

Int: (To Katrina) I want to revisit question 4 once again. What exactly does the word nutrient imply in the context of this question?

Katrina: That is everything that the tree gets from the soil or air such as the nitrogen, potassium, CO₂ and oxygen and, I don't think that it gets some amino acids. I know it obtains some acids, but I don't think they are amino acids.

Int: Are nutrients food?

Katrina: They are...what's food is made out of, so it is food... yes.

Understanding of Photosynthesis

The second research sub-question two, referred to earlier (see page 2) in this study: What level of understanding do the students have of the connections between the root system and the process of photosynthesis?, was answered by assessing; (b) students' level of understanding the process of photosynthesis and (c) students' level of understanding the holistic nature of the tree. The root probe task items 13 (2, 7, 8, 9, 10, 11, 12, 13, 17, 18, 30, 31 & 32) were used for assessing the second (b) level of understanding. Participants' maximum score was 10 and the minimum score was 2. Their mean score was 5.54. See Table 1 on page 91. Results of their performance per task item is shown in Table 5 on page 108 and the accompanying histogram as Figure 7 on page 109.

The following students' responses to root probe task items were interpreted in order to reveal students' understanding of the process of photosynthesis in the Live Oak tree. As in the previous interpretation of the first and the second levels of understanding, not all task items were interpreted in this phase of study for the same reason given earlier (see pages 94). Selection of the task item was based on participants' low performance of selecting the correct choices and the items' specificity in answering the research question.

Table 5. Descriptive Statistics of Students' Scores on Understanding of Photosynthesis

Task Item	MC's Number and type of Responses (As %N)				Total # Of
#	(A)	(B)	(C)	(D)	Responses (N)
Q2	32(50.8%)	14(22.2%)*	4(6.3%)	13(20.6%)	63
Q7	7(10.8%)	58(89.2%)*			65
Q8	6(9.2%)	39(60.0%)*	14(21.5%)	6(9.2%)	65
Q9	7(10.8%)	12(18.5%)	13(20.0%)	33(50.8%)*	65
Q10	7(10.9%)	23(35.9%)*	14(21.9%)	20(31.3%)	64
Q11	8(12.3%)	14(21.5%)	11(16.9%)	32(49.2%)*	65
Q12	36(57.1%)*	13(20.6%)	6(9.5%)	8(12.7%)	63
Q13	7(10.9%)	14(21.9%)	13(20.3%)	30(46.9%)*	64
Q17	12(18.5%)	20(30.8%)	6(9.2%)	27(41.5%)*	65
Q18	4(6.3%)	31(49.2%)	18(28.6%)*	10(15.9%)	63
Q30	9(13.8%)	21(32.3%)	25(38.5%)*	10(15.4%)	65
Q31	9(14.1%)	12(18.8%)	16(25.0%)*	27(42.2%)	64
Q32	24(36.9%)	5(7.7%)	19(29.2%)*	17(26.2%)	65

Where N = Total Number of respondents consisting of 45 females and 20 males,

(Letter)* or correct* response.

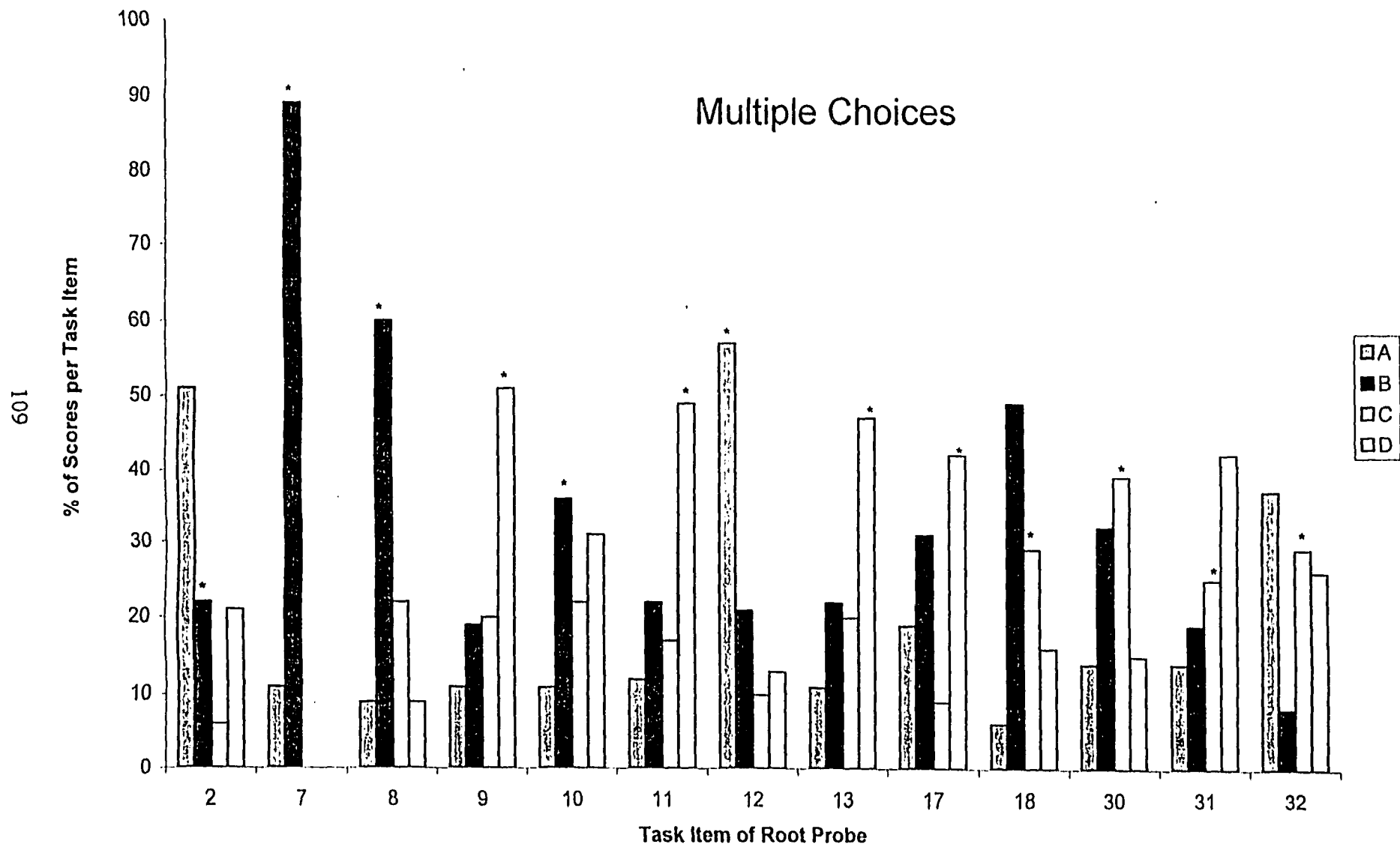


Figure- 7: Students' Understanding of the Process of Photosynthesis

In this phase of assessment, the concepts of solar energy, gaseous exchange and the phenomena of autotrophism as system properties were investigated.

Solar Energy

Understanding of several aspects of the concept of solar energy were probed by means of task items (8, 9 and 13).

Solar energy as the source of plant food. Solar energy drives the process of photosynthesis by synthesizing glucose from the ATP created in the light phase of photosynthesis. This concept was probed with task item 8

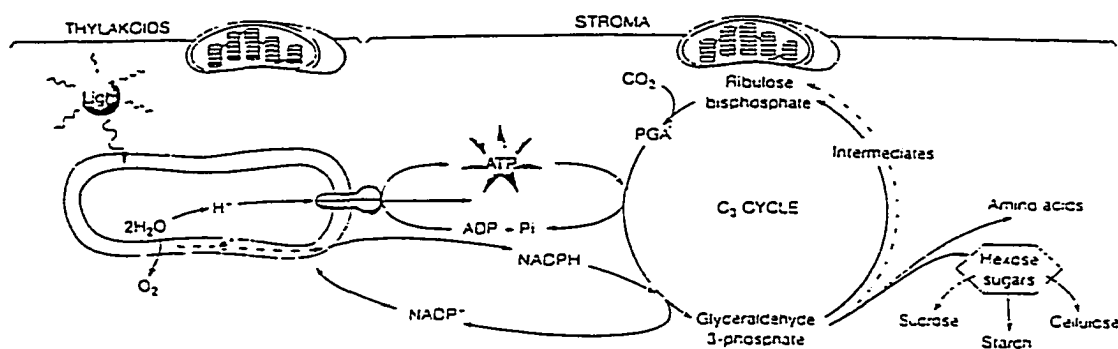


Figure 8. Inside of Stroma and Thylakoids (Adapted from BSCS, 1995)

.Which of the following statements is true about the light energy?

- (a) It is used by the leaves as food, so the leaves do not depend upon the roots for food.
- (b) It is used by the leaves to make food which is, translocated to the roots.
- (c) It is used by the leaves for growth and is not needed by roots since roots depend upon the food they absorbed from the soil.
- (d) It is used by the leaves for growth. Roots depend upon the translocated food.

Over half (69%) of the participants selected the correct choice (8b). That percentage was higher than would have been expected taking into consideration all of the difficulties participants had experienced when answering similar questions (e.g., question 2). Besides, not many students knew that food was translocated to the roots as had been established by their responses to other root probe task items (e.g., 14 & 18). They may have been influenced by the phrase “to make food” that appeared in only this choice. This phrase was familiar to most of the participants since it is an obvious statement in any biology textbook, attributing to this high percentage (69%). However, the alternative conception of prepared food in the phrase “food absorbed from the soil” influenced the 22% who selected choice (8c).

The other choice (8a), although closer to (8b), was selected by a very small percentage (10%) possibly, because it contradicted their intuitive knowledge.

Solar energy creates ATP and NADPH. Task item nine was more specific by

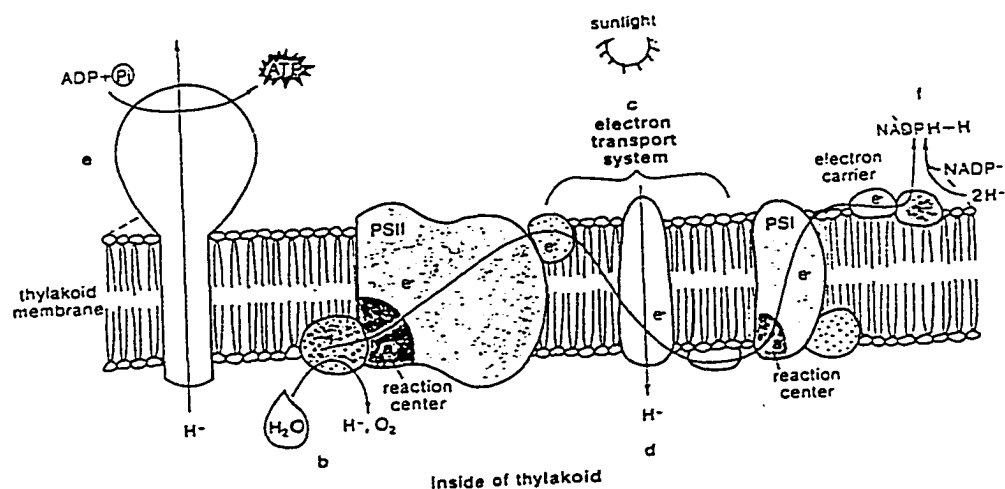


Figure 9. Relationship Between Light and Dark Phases (Adapted from BSCS, 1995)

.Using the figure 14 as a reference, choose the most appropriate answer concerning the role of light energy in photosynthesis:

- a. splits water into OH^- and H^+ ions.
- b. creates some ATP and H^+ ions.
- c. creates some sugar molecules.
- d creates some ATP and NADPH which fuel the Calvin cycle.

identifying the ATP and NADPH in relationship to the process of photosynthesis.

Most (51%) of the students could remember something about these molecules and were therefore quick to select choice (9d). In another part of this study the alternative conceptions which students had about ATP and NADPH as other forms of energy have been discussed. All the same, about half (49%) of them were attracted by the distractors distributed to the other three choices.

Concept of interconversion of energy. Task item 13 probed students' understanding of the conversion of energy from solar to chemical.

.A student took four similar plants and exposed each plant to a different colored light for 24 hours. She then measured the amount of starch present within each plant's leaves. In her experiment the student obtained the data shown in the following table:

<u>Plant</u>	<u>Color of Light</u>	<u>Starch in mg.</u>
A	Red	72 mg
B	Yellow	15 mg

C	Green	10 mg
D	Blue	68 mg

In another experiment, the same colored lights were used to investigate the percentage of light energy reflected by chlorophyll, and therefore not used in the synthesis of the starch. These colored lights were not in the same order as that given above. Results of the percentage of light energy reflected (as a result of chlorophyll absorption spectrum) are shown by the graph below.

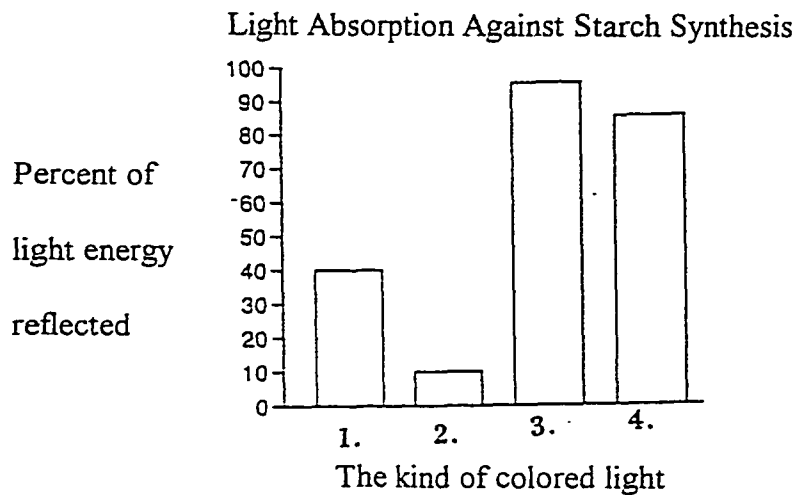


Figure 10. Starch Synthesis Against the Light Absorbed. (Adapted from BSCS, 1995)

The order that is an equivalent of the table above (starch synthesis) with the histogram below (the kind of colored light) is as follows;

- a. 1=blue; 2=red; 3=yellow
- b. 1=yellow; 3=green; 4=red
- c. 2=blue; 4=yellow; 3=green
- d. 1=blue; 3=green; 4=yellow

Over half of the participants failed to appreciate that energy, when it is converted to another form, fails to exist in the previous form. This alternative conception could possibly explain their lack of understanding of the relationship between the light and dark phases of the process of photosynthesis. An example of this are the students (11%) who selected choice (13a). The two other choices (13b) and (13c) that received over 42% selection had at least one of the types of lights that was said to be reflected in very high amounts even after being used in the synthesis of starch or vice versa. About 47% selected the right choice (13d). These are the students who related solar energy to a product of photosynthesis. The 47% who selected this choice compared well with those who selected choice (8b).

The Concept of Gaseous Exchange and Transpirational Pull

- .This concept was tested by task item 30 of the root probe. (See Figure 16 on the following page.) Photosynthesis begins to decline when leaves wilt because
- a. flaccid cells are incapable of photosynthesis.
 - b. there is insufficient water for photolysis during light reaction.
 - c. stomata close, preventing CO₂ entry into the leaf.
 - d. the chlorophyll of flaccid cells cannot absorb light.

Students who knew that the final effect of wilting was to cut off the CO₂ supply to the leaves were 39%. The rest (61%) attributed it to other distractors. About a third of them (32%) selected choice (30b). Almost equal number selected choices (30a) and (30d). Both choices implied that flaccid cells were incapable of doing photosynthesis.

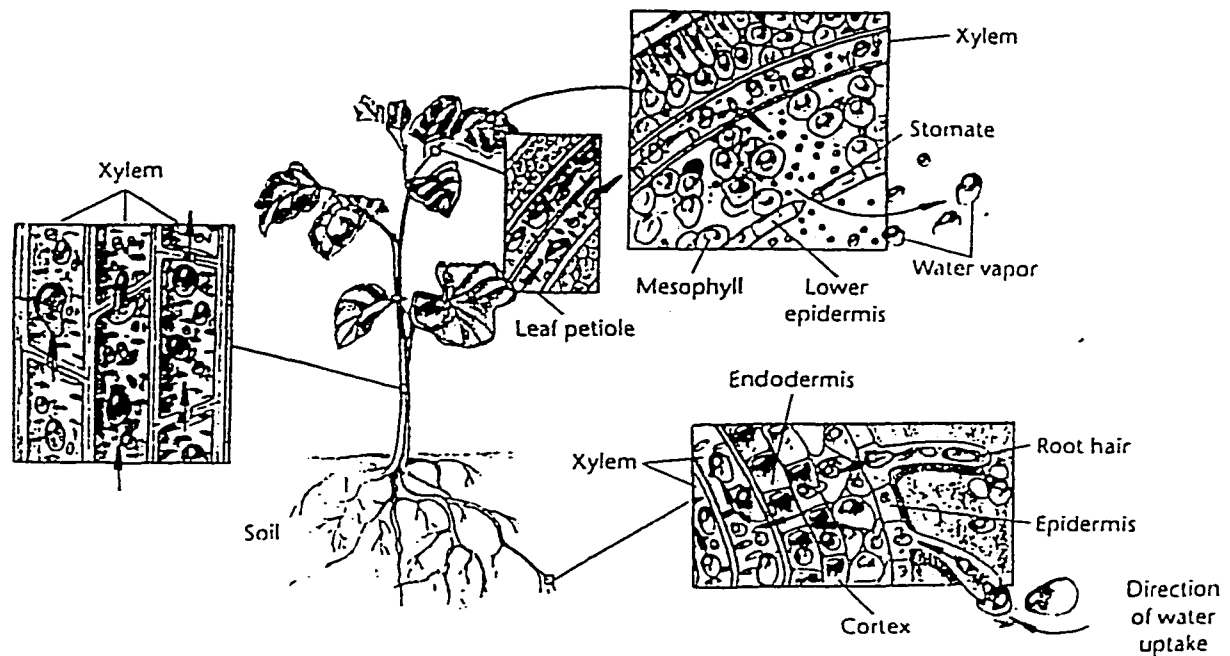


Figure 11. Effects of Wilting on Photosynthesis (Adopted from Essensfeld, Gontang & Moore, 1994)

Oral Interviews on the Concept of Autotrophism (Photosynthesis)

Oral interviews were a follow-up of students' responses to the task items relating to their answers to the second part of the sub-question two, which asked the following: What level of understanding do the college students have of the connections between the root system and the process of photosynthesis?

Two concepts that confused their understanding the phenomena of autotrophism most, were food and energy. A summary of each one of the two is given in Tables 6 and 7 that appear on the next three pages. Table 6 is a summary of the alternative conceptions that the students had about synthesis of plant food. As it had been established earlier on in another part of this study (see page 95), the influence of

the food coming from the soil can be inferred from a number of propositional statements listed in this Table. Some students attributed the increase in weight of the tree to the food absorbed by the plant including even those who knew that plants made their own food. Table 7 illustrates mainly the alternative conceptions held by most of the participants about the role of solar energy in synthesis of plant food. As a result of failing to master the three laws of thermodynamics, students had other alternative conceptions about energy. The concept of interconversion of energy as well as the location of this energy within the molecules was not familiar to them.

Plant Food and the Role of Photosynthesis

As mentioned earlier, many students knew that plants manufactured their own food, but still believed that they also needed other sources of food from external sources. Participants showed low levels of understanding the concept of autotrophism as the ultimate source of plants food, which was a union of nutrients from the air and soil, all of which were held together by the energy supplied by the sunlight. They found it difficult to relate the cyclic microscopic details given by their textbooks with the macroscopic specimen of the interviews. Interview results showed various forms of alternative conceptions in regard to the food made by plants:

Table 6. (Verbal)
Lack of Awareness and Alternative Conceptions Associated with Autotrophism
Food and Energy Descriptions of Students' Ideas about Food and Energy

Plant food	Found it hard to conceptualize plant food and its body as a composition of some chemical entities such as atoms, elements and molecules. They did not consider sugar as food.
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(Continues--->)

<u>Food and Energy</u>	Table 6. (Verbal) <u>Descriptions of Students' Ideas about Food and Energy</u>
Food and energy	Few of them realized that the food that plants made was their only source of energy released during the respiratory process.
Calvin Cycle	All interviewees failed to see the significance of the Calvin Cycle in bringing the $[H^+]$ to reduce the CO_2 into simple sugars ($C_6H_{12}O_6$) and found it hard to relate proteins or N_2 with the products of Calvin Cycle or with the plant as a whole.
Sugars and elements	Participants treated monosaccharide and disaccharides as elements that were continually being used to assemble some starch or other forms of carbohydrates.
Plant Nutrition	They could not relate the elemental nutritional requirements of the plant with the periodic table of elements.
Role of solar energy	Leaves absorb solar energy and convert it into useful substances or nutrients required by the plant. Plants grow by converting CO_2 into O_2 but their growth is not limited by the supply of CO_2 .
Radioisotopes	They never associated radioactive isotopes as a useful tool for investigating the source or end product of anything they learn in a biology lesson.
Relational processes	Participants failed to link up the process of photosynthesis with other chemical and physical processes such as diffusion and osmosis.

Table 7. (Verbal)

<u>Lack of Awareness and Alternative Conceptions Associated with Energy Plants' Energy</u>	<u>Descriptions of Students' Ideas about Plant and Energy</u>
Plants and energy	Plants do not need energy since they do not move.
Source of energy	All the energy that plants need is supplied directly by the sun.
ATP and energy	ATP is a form energy from solar energy that separates water into H^+ and OH^- . It transports electrons and high energy molecules.
NADPH and energy	Is a form of energy that carries some H^+ ions, electrons and makes some CO_2 .
ATP and NADPH	Solar energy makes some ATP and NADPH from which we get the carbohydrates.
Solar energy	After plants have absorbed solar energy this energy comes out in form of energized O_2 that is used by plants or either stored up or is converted in form of starch
Solar energy	Participants failed to relate the quantity of the chemical energy (glucose or starch) formed within the plant with the quality and quantity of wavelengths of light absorbed.
solar energy	All the solar energy is used once it hits the leaf surfaces. After it has been used up in the synthesis of organic compounds within the then it is released from the plant to the outside.
Molecules & energy	Solar energy activates the molecules that are stored within a plant some of in form of small pockets to make energy available

(Continues----->)

Table 7. (Verbal)	
<u>Plants' Energy</u>	<u>Descriptions of Students' Ideas about Plant and Energy to that plant.</u>
Thermodynamics	Participants were either not aware of the first or the second law of Thermodynamics or both of them as these laws related to transformation of solar to chemical energies
---- Calorific units	Calories were associated with burning of fats in human body.----
<p>Nearly all of the students who were interviewed and had selected choice 2a of the root probe, also, had alternative conceptions about the role of photosynthesis to the plants. The following three alternative conceptions are an illustrations of these views;</p> <p>Photosynthesis as a means of generating O_2 from CO_2; photosynthesis as a means of generating O_2 from energy rich molecules; photosynthesis as a means of generating energy rich molecules.</p>	

Photosynthesis as a means of generating O_2 from CO_2 . As a result of attributing the source of plant food to the soil, students had devised other conceptual models that accommodated the process of photosynthesis. Some saw photosynthesis as a means of generating O_2 for animals only while others saw it as essential for both plants and animals. In both of these cases O_2 was considered as an energy carrier. Aimee, a student who held some of these views, indicated that plants' phloem drew food while their xylem carried some water all of which was drawn from the soil. The sugar that was manufactured in the leaves was converted into some energy. This energy was carried by the oxygen that had been formed from CO_2 through one of the many cycles

and the Calvin Cycle was one of them. The remaining carbon was reconverted into some sugars or used to build the plant. It is also interesting to note that most of the students who held this view also selected choice 32 (c) of the root probe. This distractor was an alternative conception that the source of O_2 released during the process of photosynthesis was CO_2 . These propositions strengthened the alternative conceptions that photosynthesis was a predetermined means of generating some energy rich O_2 . Some participants held to the anthropomorphizing views that the energy was preformed especially for use by humans. The role of water in this was undetermined. Some students took the water as a catalyst for the process of photosynthesis. As the water played this role, it joined the CO_2 both of which went through series of different photosystems then ended up by giving out some O_2 . It was these different photosystems that enabled the H_2O and CO_2 to work together to release the vital O_2 .

Photosynthesis as a means of generating O_2 from energy rich molecules.

Students who selected choice (2a) and other distractor choices saw photosynthesis as a means of not only generating O_2 , but, some energy rich molecules such as the starch and sugars as well. They reasoned that the solar energy was converted into ATP and NADPH both of which were forms of energy. The ATP and NADPH were then used to generate some O_2 which was an energy carrier. The two molecules also supplied energy to the plant and the remaining ones were converted into sugars, starch, fatty acids and proteins which were also forms of energy. Some solar energy was also assumed to be supplied directly to the tree then utilized by the plant.

Photosynthesis as a Means of Generating Energy-Rich Molecules

Light phase activates ATP and NADP. Another group of students were of the opinion that ATP and NADPH pre-existed in the plant long before the light phase of the photosynthesis. Once these molecules were radiated by the solar energy, this energy was made available to the tree. Shalima was one of those students who held strongly to these views.

One area probed most was the location of the energy carrying factors within the energy rich molecules. Shalima attributed the source of energy to some little cells that were located in some energy store within their fruits. She admitted that a glucose molecule carried some energy and once it was drawn she indicated that the energy was carried in the protruding part of the molecule.

Int: In this molecule, where is the energy located?

Shalima: The energy is located in the part that is coming out.

It is interesting to note that the location of energy in synthesis of bonds was not indicated by any of the students who were interviewed. The reason for this may have been compartmentalization of knowledge. This topic is taught in chemistry, but it is limited to the synthesis of inorganic molecules such as H_2O , CO_2 etc. It appeared that students found it very difficult to apply the energy bonds taught in inorganic chemistry to a topic of organic chemistry taught in a biology lesson. This reason could probably explain why they found it difficult to identify the location of the energy rich molecules. Another factor that might have influenced them is the assumption that gases can only come from other gases.

Light phase creates the energy rich O₂ In an attempt to probe understanding of energy cycles, a question was asked about what a grasshopper living on a Live Oak gained from solar energy. Shalima explained that it obtained oxygen and food from the Live Oak. On probing her further on what each of the two provided to the organism, she gave oxygen's role as essentially that given earlier by Aimee of providing energy to the grasshopper. She then gave calories as the benefit that it derived from the food.

The views of both Shalima and Aimee about photosynthesis, respiration, food and energy may have been shared by most of the students (51% of the total) who selected choice 2(a) of the root probe. The concept of solar energy as the direct energy source of plants is well entrenched in their minds. In addition to this, some saw the O₂ produced during photosynthesis as another source of energy for both plants and animals. The last group believed that it was useful to the animals as a means of transferring the energy cycles from plants to the animal kingdom.

Although some students mentioned the burning of food, this was certainly not in line with the scientifically acceptable view of biochemical oxidation of food. Asha, for example, was not aware that what she called the burning of calories was equivalent to internal cellular oxidation.

Students' Understanding of Both the Root System and the Process of Photosynthesis

Holistic nature of the tree covered students' understanding of aspects of both the root system and the process of photosynthesis. This third level of understanding;

(c) students' level of understanding a tree as a single system (i.e., holistic nature of the tree) was used to answer both research subquestion one and two. Root probe task items (3, 6, 19, 20, 21, 22, 24, 25, 26, 27, 33, 34, & 39) were used for this. The maximum score was 10 and the minimum score was 1. The mean score was 5.28. See Table 1 on page 91. Results of their performance per task item are shown in Table 8 on page 124 and the accompanying histogram as Figure 12 on page 125 respectively.

The following students' responses to root probe task items were interpreted by the researcher in order to reveal students' level of understanding the holistic nature of the Live Oak tree. As in the previous interpretation of the first level of understanding, not all task items were interpreted in this phase of the study for the same reason given earlier (see pages 94 and 107 respectively). Some of them involved ideas that are interpreted in the interview section of this study (See page 115-117). Selection of the item was based on participants' low performance of selecting the correct choices and the items' specificity in answering the research question.

Role of gases. Task item 6 investigated whether the participants appreciated a tree as a system in which the gases released or absorbed during the processes of respiration, and photosynthesis depended upon the rates at which each of the two processes were progressing:

Which of the following statements is true about oxygen and carbon dioxide?

- a. oxygen always released by the leaves.
- b. carbon dioxide is never released by the roots.

Table 8. Descriptive Statistics of Students' Scores on Understanding of the Holistic Nature of Tree

Task Item #	MC's Number and type of Responses (As %N)				Total # Of Responses (N)
	(A)	(B)	(C)	(D)	
Q03	30(46.2%)	08(12.3%)	19(29.2%)*	08(12.3%)	65
Q06	22(33.8%)	05(7.7%)	10(15.4%)*	28(43.1%)	65
Q19	11(18.0%)	05(8.2%)	36(59.0%)*	09(14.8%)	61
Q20	17(26.6%)	22(34.4%)*	14(24.9%)	11(17.2%)	64
Q21	10(15.6%)	18(28.1%)	33(51.6%)*	03(4.7%)	64
Q22	15(23.8%)	19(30.2%)	22(34.4%)	07(11.1%)*	63
Q24	26(40.0%)	02(3.1%)	15(23.1%)	22(33.8%)*	65
Q25	16(24.6%)	05(7.7%)	02(3.1%)*	42(64.6%)	65
Q26	06(9.2%)	05(7.7%)	13(20.0%)	41(63.1%)*	65
Q27	06(9.4%)	45(70.3%)*	06(9.4%)	07(10.9%)	64
Q33	21(36.2%)	11(19.0%)	02(3.4%)	24(41.4%)*	58
Q34	21(32.3%)*	09(13.8%)	04(6.2%)	31(47.7%)	65
Free Responses					
	Correct response		Wrong response		
Q39	27(54.0%)*		23(46.0%)		50

Where N = Total Number of respondents consisting of 45 females and 20 males, (Letter)* or correct* response.

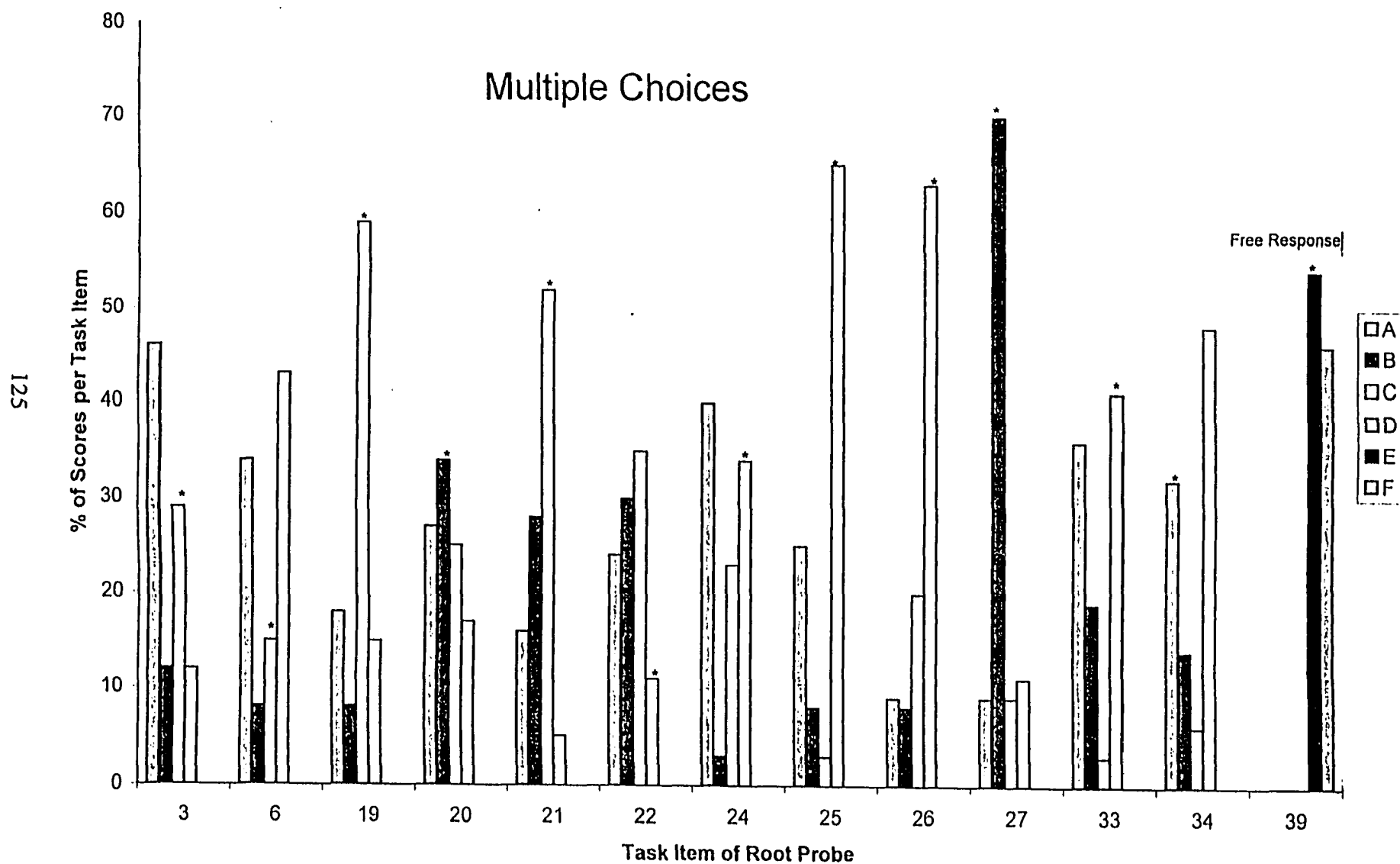


Figure 12. Students' Understanding of the Holistic Nature of the Tree

c. roots absorb oxygen continually.

d. leaves absorb carbon dioxide continually.

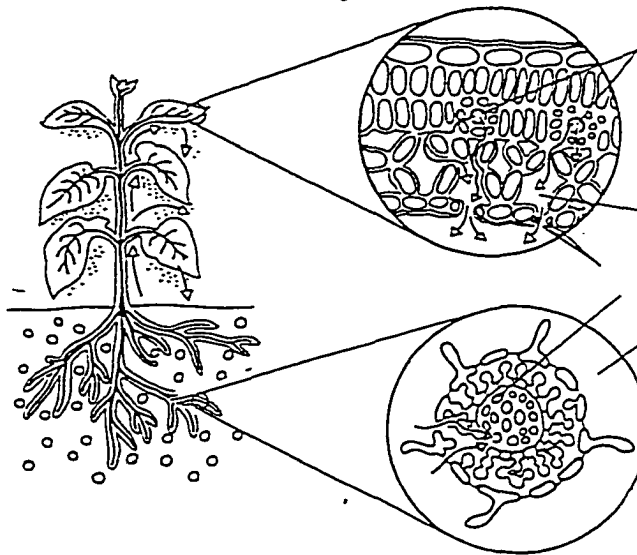


Figure 13. Gas Exchanging Parts (Adapted from Essensfeld, Gontang & Moore, 1994)

In the task item 6, only 15% selected the right choice (6c). When taken together, the alternative conceptions (6a) and (6d) were selected by 77%. These choices were influenced by two conceptions: either that trees carry out the process of photosynthesis all the time, or that trees release O_2 all the time in exchange of CO_2 . It is probably the latter choice that influenced them most because many students regard photosynthesis as the respiration of the plant (Eisen & Stavy 1988). Either of these suggestions indicated their lack of appreciation for the role played by both of these gases in plants.

Role of Water

Students' understanding of the role of water in plants was tested by means of several task items (20, 22, 24 & 25)

Fate of most of water taken by roots. Task items (20) probed their understanding of the fate of water that is continually taken up by the plant:

.The greatest proportion of the water taken up by plants is

- a. split during photosynthesis.
- b. lost through stomata during transpiration.
- c. returned to the soil by roots.
- d. held remaining in the xylem.

In this task, about 34% selected the correct choice (20b). About 27% attributed it to the process of photolysis that occurs during the light phase of photosynthesis. A similar percentage (22%) believed that the roots returned it to the soil. Finally, the 17% who assumed that it was held within the xylem vessels failed to appreciate the limitations of these vessels.

Mechanism of water uptake. The process of transpiration pull call for a system thinking illustrated by the principle of integrations. Movement of water through the plant allows integration of two system boundaries (i.e, soil and air). Task item 25 probed students' understanding about the mechanism by which water is taken by a tree

.Which of the following would be the best analogy for describing water movement in the xylem of a tree trunk?

- a. pumping blood with a heart.
- b. opening the flood gates of a dam.
- c. pushing water with an oar.

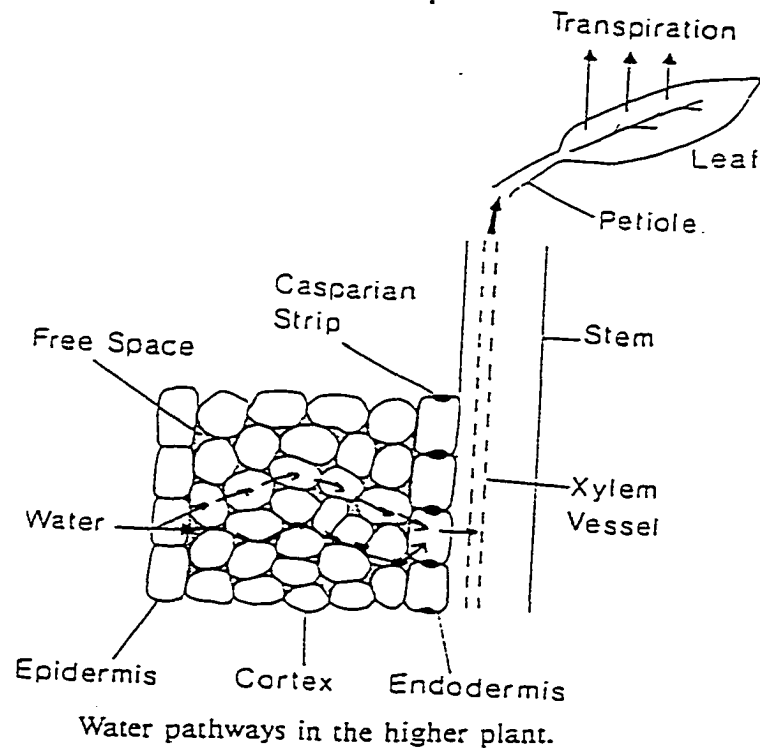


Figure 14. Movement of Water in a Plant (Adopted from Mengel & Kirby 1987)

d. drinking through a soda straw.

This item scored well since 65% selected (25d). They related the analogy of drinking through a soda straw, with the cohesion-tension theory. The only other choice that received a sizeable attraction (25%) was (25a). The implications of this choice were that the root system pumped water up the shoot.

Distribution of plant food. Task item 18 probed the participants understanding of the dynamics of food distribution in the plants.

.If plants are grown in an atmosphere of radioactive carbon dioxide, radioactive sugars will be detected:

- a. only in the veins of the leaves.
- b. throughout the entire plant xylem.

- c. throughout the phloem.
- d. moving towards the roots in xylem vessels.

Only 28% selected the correct choice (18c). The influence of the conception that food comes from the soil can be inferred from selection (18b), which was selected by nearly the same percentage (49%) that had earlier selected 2(a): 51%. Those who (16%) selected 18(d) may have had problems distinguishing some differences between the vascular vessels of phloem and xylem.

Allocation of Photosynthates.

Task item 22 may have been one of the most difficult task probe items to the students. However, principle reasoning behind its implications are crucial to the saving of the campus Live Oak. Students were presented with the following:

.The quantity of the manufactured food (photosynthate) distribution in a tree is governed by several factors. The following diagrams illustrate its possible distribution in a Live Oak under different shoot or root treatments.

Which of these choices indicate the correct sequence?

The shoot of a tree whose roots were pruned just before transplanting received____; while the tree whose canopy was topped (pruned) just before transplanting received____;

- a. normal; above normal.
- b. above normal; below normal.
- c. below normal; below normal.

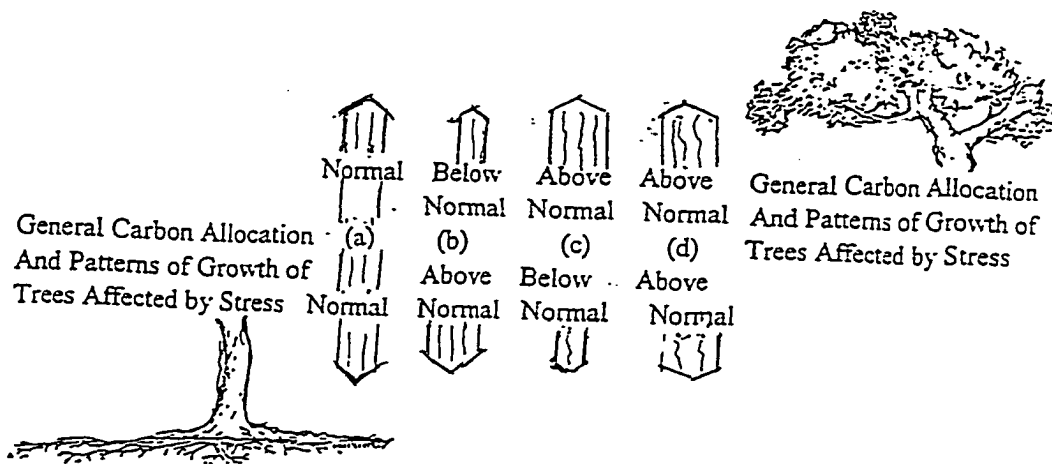


Figure 15. Distribution of Photosynthate (Adapted from Marx, 1995 & Popadic, 1995)

d. above normal; above normal

Only 11% knew that more food is allocated to the injured parts. The rest (89%) were not aware of this.

Reactants and Products of Photosynthesis

As a result of confusing photosynthesis for respiration, students confused role of gases involved. Oxygen's role is the one that is least understood.

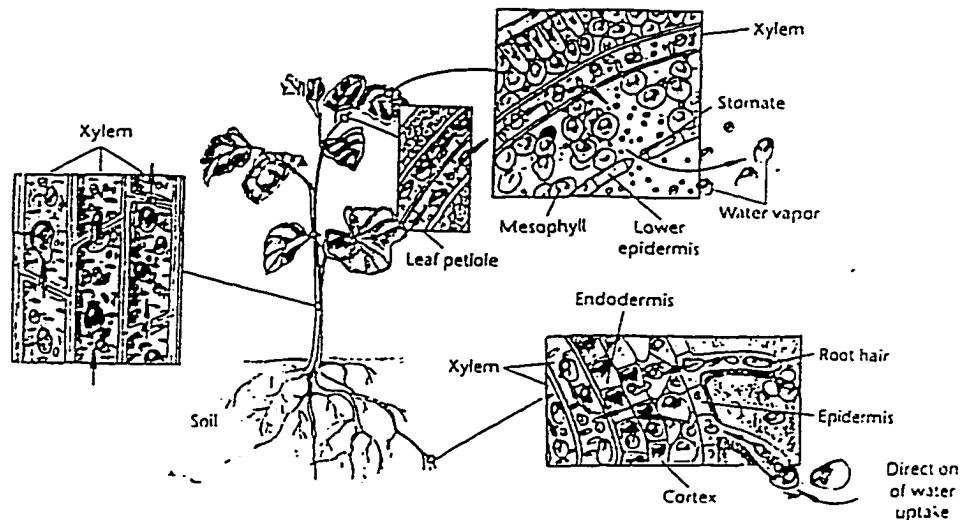


Figure 16-Source of Oxygen (Adapted from Essensfeld, Gontang & Moore, 1994)

Source of oxygen. Task item 32 probed participants' understanding of the dynamics of reactants and products that are involved in the process of photosynthesis

.The O₂ released by plants during the process of photosynthesis is derived from

- a. carbon dioxide taken through the leaves.
- b. excess water taken in through the stomata.
- c. water taken in through the roots.
- d. metabolic wastes of photosynthesis.

The task item required their appreciation that a gas can be formed from a liquid or from a solid the same way a solid can be formed from a gas. Only 29% knew that the O₂ originates from water taken in through the roots. About 37% held the alternative conception that O₂ originated from the CO₂ taken through the leaves.

Oral Interviews on the Holistic Nature of the Tree

Oral interviews were a follow-up of students' responses to the task items relating to their answers to the first and the second research sub-questions. As a result ,an understanding of the two levels reflected an understanding of the tree as one system. This explains why this level offered a partial answer to the main research question. The previous task items had probed their understanding of the holistic nature of the tree. These interviews revealed:

Compartmentalization of Knowledge

Absence of systems thinking is caused by compartmentalization of knowledge. Such compartmentalization dealt with gases (O_2 & CO_2). A summary of participants' ignorance and alternative conceptions about O_2 and CO_2 is given in Tables 6 and 7.

Across subjects. This is one topic that this study emphasized most, because in school curricula, biology, chemistry, and physics have traditionally been taught as separate disciplines, a practice that is contrary to the principle of integration. The following is an example of a student whose understanding was above average about the concepts of elements as they were taught in a chemistry lesson.

- Int: Did you learn about the elements of the periodic table?
- Felicila: Yes.
- Int: Name some elements which are common in fertilizer.
- Felicila: The elements? ... well some of the elements that appear in the fertilizer also appear in the periodic table, like may be
- Int: You say some? Can you give examples of some which do not appear in the periodic table of elements but are found in fertilizer?

Table 9. (Verbal)

<u>Lack of Awareness and Alternative Conceptions Associated with O_2 Oxygen in Plants</u>	<u>Descriptions of Students' Ideas about Oxygen in Plants</u>
Roots and O_2	Roots do not take in O_2 since they do not need it. Roots take in O_2 in the form of water.

(Continues--->)

Table 9. (Verbal)

<u>Oxygen in Plants</u>	<u>Descriptions of Students' Ideas about Oxygen in Plants</u>
Leaves and O ₂	Leaves do not need O ₂ but they take it by chance as they inhale air to extract the CO ₂
Origin of O ₂	The O ₂ released by the plants is derived from the CO ₂ or from both CO ₂ and Water.
O ₂ and energy	The energy required by the living things is derived/stored in the O ₂ . It performs specific functions in cells of the plant
Starch and O ₂	Starch and O ₂ to plants is like food and water to human beings or Oxygen does to a plant what a gas does to a moving vehicle.
O ₂ as a carrier	During photosynthesis plants will need O ₂ and water to carry the extra stuff synthesized by the leaves.
Calvin cycle and O ₂	Aerobic respiration use O ₂ that release some energy for the dark phase of Calvin cycle.
O ₂ and respiration	O ₂ used in respiration which occurs only in green plants when there is no light energy to photosynthesize.
O ₂ and air	N ₂ and O ₂ are both released by plants after the CO ₂ is removed from the inhaled air.
O ₂ and light	Plants stop photosynthesizing when there is no light energy but continue to respire and give off oxygen gas.

Table 10. (Verbal)
CO₂ in Plants Descriptions of Students' Ideas about the Role of CO₂

Inhaled CO ₂	In the plants CO ₂ is broken up into O ₂ that is released and Carbon that helps in formation of sugar or in building the plant.
Uses of CO ₂	Plants take in CO ₂ and water. CO ₂ is used for respiration where O ₂ and glucose are release as by-products of their respiration. Plants do not carry out the process of respiration during the day.
CO ₂ and O ₂	During the process of photosynthesis plants convert CO ₂ into O ₂ which serves as the energy source for the plant.
CO ₂ and energy	Plant's energy is stored in CO ₂ . As we need O ₂ , so do plants need some CO ₂ . CO ₂ takes the place of O ₂ in the plants
CO ₂ uptake	Leaves take in CO ₂ all the time for photosynthesis, however, they fail to get enough of it. When they are not making food, they store the CO ₂ for future use.
CO ₂ and minerals	CO ₂ acts as a catalyst that enables the plants' roots absorb minerals from the soil for use by the plants.
CO ₂ and roots	Roots take in CO ₂ that is used in photosynthesis.
CO ₂ and fertilizer	If CO ₂ supply to cut off, the plant would continue to grow as long as fertilizer supply is not cut off.
CO ₂ and sugars	The main function of CO ₂ is to assist chlorophyll molecule synthesize sugars or to generate other chlorophyll molecules
-----	phosphorous or carbon compounds.-----

Felicila: No, I do not know of any that do not appear.

Int: Would you therefore say that all the elements of fertilizer are all members of the periodic table?

Felicila: No, they are not.

The above is a case that illustrates the compartmentalization of knowledge. In a chemistry lesson students learn that all the matter on earth is made up of 109 naturally occurring elements. They are, also, taught in chemistry that compounds are formed from a union of these elements. Contrary to that, participants considered carbon compounds as elements which is also an alternative conception.

An attempt was made to probe their understanding of the role played by other macro- and micro-elements. Some participants explained that macro-elements were the big elements while micro-elements were the small ones, but most of them did not have any idea what they were. General cases of that nature are illustrated by the following two examples;

Int: Have you heard of macro-elements and micro-elements in connection with plant nutrition?

Aimee: No, I have not.

Int: Have you heard of macro-elements and micro-elements in connection with plant nutrition?

Felicila: Macro-elements are the big elements and micro-elements are the small elements.

Compartmentalization of knowledge within one discipline. This occurred within one subject at different topic levels. A case of this nature is illustrated by Sam. He is one of the few students who performed very well in the root probe. He held scientifically acceptable views in regard to most of the process of photosynthesis and also applied a systems approach to understanding how a tree operates. As a result he knew how the systems boundaries affected other physiological processes of the tree. . For example, he knew that all the O_2 released during the process of photosynthesis is derived from water. He, also, knew how the water molecule was split during the light phase and how the hydroxide (OH^-) ions regrouped to form H_2O and O_2 . He was aware that some O_2 was used during the process of aerobic respiration in animal cells.

However, Sam held alternative conceptions with regard to the process of respiration in the plants. He considered the process of photosynthesis to be a form of plants' respiration whereby the CO_2 served plants in the same way that O_2 served animals. This led him to consider photosynthesis as a form of respiration in terms of gaseous exchange. An interview with Sam took this trend:

Int: What happens to CO_2 once it is taken in by the plants?

Sam: It is broken up into carbon and oxygen.

Even when O_2 was clearly shown to originate from H_2O in the graphic accompanying the task item 9 of root probe, Sam continued to hold on to the old belief:

Int: I am referring to item number 9 on page 6, of your root probe where is this O_2 originating from?

Sam: The O₂ released by plant during photosynthesis is derived from CO₂ taken in by the leaves.

Katrina, also an A-student like Sam, held some alternative conceptions in regard to the relationship of photosynthesis and respiration. One of Her major problems was the assumption that the energy for the dark phase of photosynthesis is derived from the process of aerobic respiration. She was not clear as to the role played by CO₂ in plants. Below is a section of this researcher's interview with her:

Int: Is there another process going on hand in hand with photosynthesis?

Katrina: Yeah, respiration and that's what they need the oxygen for. They need the oxygen because even when it does not have sunlight it is still using oxygen and carbon and water to make food or starch, even without the sunlight and that's how the oxygen is used in that other process.

Int: Is this oxygen used in process of photosynthesis or in the process of aerobic respiration.

Katrina: I believe in process of respiration but photosynthesis will need it as well.

Katrina assumed that the dark phase of photosynthesis, in which the Calvin Cycle is located, benefitted from the energy generated in the process of aerobic respiration, thus respiration supplementing photosynthesis. In her opinion, this energy

was continually being passed over to the Calvin Cycle as the oxygen was continually being consumed.

As the interview progressed, her views on where this process took place were confirmed;

Int: Ok... I have question 6 with me, what is the role of oxygen in the roots?

Katrina: Well...I know plants, the roots need oxygen and I'm not really sure why.. I mean... but I know its one thing that they get from the soil that they need...they probably need it to live and to grow good.

Int: And do the roots carry out the process of respiration?

Katrina: Let me think... they probably do.

Int: They probably do?

Katrina: They build themselves...

Further probing on her understanding of energy indicated that she had some problems relating respiration with release of energy to the cells of the roots. This was brought out in the following probing:

Int: What process do all living things have in common that helps them generate some energy?

Katrina: They have water and oxygen... I guess that's what you mean about them getting these stuff because you get sunlight to the

plant, and then the plant gives food to everybody else.

Int: Tell me, when leaves fail to absorb carbon dioxide, is it a result of processes taking place within them not needing it or is it a result of its being unavailable to the plants?

Katrina: Ummm.... well they need it all the time, but they don't get it as good when leaves are closed from dehydration and uh... they can't exchange well, but they need it for photosynthesis and respiration.

Int: Now... let's clarify here. Do they need carbon dioxide when they are not carrying out the process of photosynthesis?

Katrina: I don't know... I believe they do.

Int: Why do they need it?

Katrina: For that other process that goes on ... the process that goes on without the sunlight... I know it is called respiration but... I forget the you know... exactly what goes on.

Katrina's understanding of some differences between the processes of respiration and photosynthesis, is an example of a general case. She maintained that CO₂ was necessary for respiration as well as for photosynthesis. Also, she saw respiration as a means of speeding up the process of photosynthesis. She related aerobic respiration which took place in the leaves with photosynthesis only by assuming that aerobic respiration existed to generate some ATP for the process of photosynthesis.

As a result, she had some considerable difficulties imagining aerobic respiration happening in the absence of the dark phase of photosynthesis. This is one reason why she could not confirm that the process of aerobic respiration was occurring in the roots. Her statement, “They build themselves,” can only make sense when interpreted in light of her earlier statements. At that point her explanation was how O₂ was used in aerobic respiration to generate energy which was used in propelling the Calvin Cycle. As this researcher probed her further on her understanding of energy, her subsequent responses indicated that she had some problems relating respiration with release of energy to the cells of the roots.

Participants’ conceptions of the role of food. Most of the students interviewed were in common agreement that plants needed food (nutrients) for generating new tissue and organs within themselves. For example, Eric explained that food was something taken by plants, then broken into components for generating other new materials like new roots and new leaves when old ones fell off.

Kalo saw food as something that helped the plant grow and produce fruits, and whatever else, it requires, for its own health. None of the students interviewed referred to nutrients as a means of converting the solar energy into chemical energy. Indeed none of them related nutrients with energy. The following section of this probe is included to illustrate cases of that nature:

Int: How does a plant benefit from these nutrients?

Felicila: Plants absorb nutrients and water from the soil. Nutrients are the

necessary things plants need for living. It supplies the plant with the necessary things.

Int: And how does this nutrient benefit the plant?

Felicila: Well, it sustains the plant...helps it grow.

Int: Apart from helping it grow what else does it do?

Felicila: Well, it feeds the plant... supplies it with the necessary things it needs.

Most students saw prepared food as the only means by which plants supported and maintained themselves. An extreme form of this misconception was apparent, when the participants assumed energy used in the process of photosynthesis came from this food as illustrated below:

Int: What is the role of this food?

Shalima: It requires that food to produce fruits or to grow or to produce ... like to grow I guess... produce fruits... and photosynthesis and all that it needs energy for.

Both the concept of what constitutes plant food and a lack of systems thinking proved to be a difficult barrier even for those who were familiar with the phenomena of autotrophism. This alternative conception is illustrated in the following interview with Katrina, referred to earlier as an A student that cited the textbook information about photosynthesis with ease.

Int: And from where do the roots get their food?

Katrina: From the ground.

Int: Have you heard of the word autotrophism?

Katrina: I think it means.. does it mean to make your own food?

Int: Yes it means self-feeding, but tell me whether when the plant makes its own food it makes the food only for the leaves or for the entire plant?

Katrina: It makes food for the entire plant..but I guess what you are saying..food in a .. plants is just chemical elements put together... you know and ... they don't eat food like we eat food... you know when you say autotrophism that means they grow and stuff by photosynthesis which they do themselves.. but what they do is get nutrients from the ground and from the energy of the sun and that's how it creates itself.

It is clear from this discussion that what most students referred to as food served the plant in growth and development only. As Kathy summed it up: "and that is how it creates itself."

Difficulty In Conceiving Gas as a Substance

Item 32 of the root probe tested their understanding of the process in which water, a chemical reactant of photosynthesis, is converted into O₂ (after photolysis).

The following discussion between the researcher and Kalo illustrates her problems:

Int: Why did you indicate that the O_2 released during the process of photosynthesis is derived from CO_2 ?

Kalo: I guessed that it is a waste gas from the plant.

Int: Do you think that plants ever take some O_2 ?

Kalo: Well, in carbon dioxide, but I have no idea if it just takes it in plainly.

Int: Do you think there comes a time when plants release some CO_2 ?

Kalo: I am not sure. I know it takes in CO_2 , but I do not know whether it ever releases it out. I think it just releases O_2 .

Similar interviews of this researcher and other participants who held the alternative conception that gases originate from other gases were as follows:

Int: And what are the metabolic wastes of photosynthesis?

Felicila: Oxygen is one of them.

Int: Are you sure that O_2 originates from CO_2 ?

Felicila: Actually I think it does.

Int: Where does the O_2 released by the plant during the process of photosynthesis come from?

Aimee: It is absorbed as carbon dioxide, and then it is converted into oxygen .

Int: And how does CO_2 form O_2 ?

Aimee: Through one of the cycles--- the Calvin Cycle.

Int: Once O₂ is released from the CO₂ what happens to the remaining carbon?

Aimee: It is changed into something else too.

Int: Into what?

Aimee: I don't remember--- either sugar or. . .
during the process of photosynthesis is derived from CO₂?

Final Findings.

Procedure: This researcher used the root probe diagnostic instrument to test what level of understanding the college biology non-majors had of the root system of the common Live Oak tree and the process of photosynthesis. The list of the task items was gleaned from science education literature, college biology textbooks, and from professional root experts. This was administered to 65 college biology students, who had taken one year of college biology. Quantitative analysis of the results of this diagnosis revealed areas which were probed by interviewing 12 selected students out of those who had taken the root probe. The qualitative results were analyzed and these results were compared with the quantitative results obtained earlier.

Reliability.

Coefficient of stability. The root probe scores matched those of the interview. A ratio of 0.78 (interview scores to the root probe scores) for those 12 students who were interviewed was obtained. The scores associated with further probes were not considered. An initial score was awarded for every first root probe task item

Consistency of coefficient. (R_c) was calculated by using;

Split half formula and this was established as $R_c=0.809$ and then by use of the

Spearman- Brown formula and this was established at 0.89

Statistical Analysis

Two types of analysis were performed; t-Test for mean differences between the levels of understanding, and the relational statistics based on the results shown in Table 1 on page 91. Special attention was given to the ways the systems approach to learning was applied and how its application influenced the conceptual change. These are discussed below:

1. t-Test There were no statistically significant differences between students' level of understanding of the Live Oak root system (mean score 5.94); and their level of understanding of the process of photosynthesis (mean score 5.54) as assessed by the root probe; Statistical analysis revealed that the sets of the two scores were not statistically different. $t(129) = 0.137$, $p > 0.05$ one tailed test. It was noted that the percentage scores of the root probe task items were uniformly low (i.e., 30-40%), and scores above 50%, were registered in only 3 task probe items. The mean score of students' understanding the holistic nature of tree matched that of understanding the first and the second levels.

2. Relational statistics. Results of the root probe task items were used to establish some relational statistics: the students' level of knowledge of the roots of a Live Oak; the students' level of knowledge of a Live Oak tree as a holistic system; and

the students' level of knowledge of photosynthesis. Correlational tests were performed to identify the pairs of variables of understanding. A correlational coefficient that indicated both the direction and the extent of relationship was obtained for all three variable pairs. From this a coefficient of correlation was derived at. See Table 1 on page 91.

(a). Correlational statistics A relational statistics of students' level of understanding the root system and their level of understanding the process of photosynthesis was measured by means of Pearson correlation ($r = 0.328$). This correlation was a modest level but statistically significant ($df=63$, $p < 0.05$). The other correlational coefficients were: between understanding of the root system and holistic nature of the tree, 0.462; the correlational coefficient between understanding of holistic nature of the tree and the process of photosynthesis, 0.312. The researcher decided to use the $P < 0.05$ level in advance of the analysis. All were statistically significant.

(b). Coefficient of correlation There existed a level of proportion of understanding of the process of photosynthesis that is explained by the level of understanding of the root system. This was inferred from the coefficient of correlation (hereby referred to as $r^2 = 0.104$) and determined from the Pearson correlation. This is an indicator of the proportion of variability in the students' level of understanding of the root system that was explained by the their level of understanding the process of photosynthesis which in this case was 10.4%.

3. Systems approach to learning Some task items were used to investigate their systems approach to learning . Analysis of these results indicated that: students who used systems approach to learning tend to develop a higher level of understanding the process of photosynthesis. This is supported by a few analyzes of individual scores of root probe. For example, most of the students who scored well on task item 2 are the same students who scored well in task item 32. Most of the students who attributed the source of plant food to autotrophism also knew that the O₂ released during photosynthesis originated from the water. During interviews students who applied principles of systems thinking answered well further probes that investigated applications of systems thinking. One notable example was the ability of those students to relate the changes in girth of a tree with changes in times of the day. Analysis of how students answered the root probe task item 20 and 30 that, also, tested their application of systems thinking revealed that these were the same students.

4. Effects of propositional statements on conceptual change. Further analysis of the way the students responded to the root probe task items as well as the interviews were used to investigate the factors that hindered the students from initiating the intended conceptual changes from their conceptually existing alternative conceptions to the scientifically acceptable conceptions. Results indicated that alternative conceptions are influenced by sets of propositions associated with that particular alternative conceptions. This was supported by the way students responded to the root probe task items as well as the interviews as illustrated by the examples given below: For

example, the students who knew that water was essential for a steady flow of CO_2 into the leaves also knew that a tree's diameter changed with the times of the day. The same students were also aware that organs (shoot or root) released a specified amount of gases depending on the physiological role that they were doing at that given time.(i.e., emission of a gas is a function of a physiological role.) Most of the sets of the documented alternative's propositions disappeared as a systems approach to understanding of the tree was adopted.

There were 22 (34%) students who selected 4d, the choice that indicated that the role of fertilizers was to provide food in the soil close to the roots of the tree. This was an alternative conception indicating lack of understanding the role of system boundaries of an open system (Russell, 1977). Eleven (50%) of these students also, selected choice 32d, an alternative conception that the O_2 released by the shoot originated from the CO_2 taken in by the leaves. This pattern of responses was different from that of the 31 (48% of the total) students who knew that fertilizers provided the tree with essential elements such as phosphorous (4c). Eleven (34%) of this second category of students, also, knew that this O_2 originated from the water taken by the roots. A much lower number 10 (27%) selected the alternative conception that O_2 originated from the CO_2 .

In regard to root probe task item 16, 12 (19% of the total) held to the alternative conception that roots hairs anchor a plant into the soil. 6 (50%) of these respondents also, held to the alternative conception that photosynthesis begins to decline when leaves wilt because of the insufficiency of water for photolysis during light reaction. In

regard to the 37 (57% of the total) who had made the correct choice (16c) that the functions of the root hairs was to absorb nutrients from the soil, only 7(19%) of these students held to the alternative conception that photosynthesis begins to decline when leaves wilt because of the insufficiency of water for photolysis during light reaction. 18 (51%), however, recognized the initial effect of wilting as that of the closing of the stomata, thus preventing CO₂ entry into the leaves.

Understanding of autotrophism requires systems thinking (Shigo, 1991). If we trace how the 14 (22% of the total) students who made the correct choice 2b of task item 2 responded to similar task items, we notice a high level of applying a systems thinking: 8(57%) of them selected the correct choice 20b of task items 20 and only 3(21%) of them went for the distractors 20c and 20d. These were alternative conception based on analytical thinking that water remained intact within the plant body. Similarly 7(50%) of these students selected the correct response of task item 30 and only 3(21%) of them selected the alternative conceptions (30c & 30d). The two alternative conceptions did not consider other contributory effects (e.g. turgidity of cells) of water during photosynthesis. A similar pattern of responses is obvious, when we analyze scores of other root probe task items that were made by these students. On the other hand there were 32 (i.e. 51% of the total) students who indicated that plant food came from the soil. This is how they responded to the other two root probe task items given above: Only 10 (31%) of them selected the correct choice 20b of task item 20. However 13 (41%) of them were influenced by the distractors 20c and 20d both of which implied

that either water remains intact within the plant body or was returned to the soil.

Similarly only 12 (37%) of the 32 students made the correct choice for task item 30,

but, 11 (34%) of these students were influenced by alternative conceptions (30a & 30d).

CHAPTER 5

DISCUSSION

Understanding of Roots

Students' understanding of the root system of the Live Oak tree was hindered by three main factors; understanding of plant food, understanding of the woody and the nonwoody roots, and understanding of the functional roles of the roots.

Students' Understanding of Plant Food

Students' understanding of plant food was in turn complicated by two other factors; the concept of nutrients and the concept of fertilizers.

Students' conception of nutrients. Most students attributed the source of plant food to an external source. As a result, "fertilizers" and "nutrients" were treated as the main suppliers of this food. The absorbed food was supposed to supply the requirements of growth to the shoot. This conception confused their understanding role of autotrophism, a process that illustrates the plant's ability to manufacture its own food. For most people, this is not appreciated as a system process of interaction of parts of a plant and their processes all of which are involved in the process of photosynthesis (Shigo, 1991). Instead their textbooks explain many molecular level processes that were not familiar to them. These were not integrated with the macro- levels of the plant system. As a result, they were unable to relate reactants, the processes and products of these molecular level processes, with the macro- parts of the whole tree and its phenomena of autotrophism (Barker & Carr, 1988).

Their failure to master these details as well as the textbooks' emphasis on the soil as the only source of most of the nutrients required by plants led them to relate plant nutrition to a form of heterotrophism, that was more familiar to them (Ausubel, 1963). The word "nutrients" influenced the participants to think of the soil as the main source of plants' prepared food. In contrast the current scientific conception is that soil is a substance that is made up of sands, silt, clays, decaying organic matter, air, water and an enormous number of living organisms (Shigo, 1996). However, trees depend upon the soil for water and mainly 14 elements, nearly all of which are absorbed in inorganic form and none in the form of organic molecules (Schmidt, 1986; Kozlowski, Kramer & Pallardy 1991). Shigo (1991) defined nutrients as the combination of an energy source with an essential element that does not yield energy.

Concept of Fertilizer as Nutrients.

The word, "food," as used by Katrina meant only the nutritional requirements of the tree. Most of the students interviewed shared Katrina's meaning of food. This conception is not in line with the current scientific conception of food. A scientific proposition for the word, "food," is something that provides both energy and nutrients that the organism needs (Hogan & Fisherkeller, 1996). Shigo (1991) explained that fertilizers do not add energy, neither do they feed trees, but they add elements essential for growth, metabolism, reproduction and defense.

Unlike these scientific conceptions, interviews revealed that the participants regarded nutrients as more refined, prepared forms of plant food, probably as a result of

excluding some unnecessary ingredients. For example, Kalo explained that plants absorbed their food from the soil through the roots, and that it consisted of water, nutrients and other stuff that is in the soil. Further probing revealed her meaning of “other stuff” as the proportion of soil that was not in the nutrients. However this “other stuff” was interpreted in different ways by each student depending on what they considered as their refined proportion. Richalo considered nitrogen as the “other stuff,” because, although it had not been absorbed from the soil, the plant finally got rid of it.

Scientific conception of non-woody roots The following are some important points about mycorrhizae of which students were not aware. Mycorrhizae are the non-woody structures composed of the root and the fungus tissue. The hyphae on mycorrhizae can be 100 times longer than some entire root systems. Mycorrhizae facilitate the absorption of elements, especially phosphorous, zinc, manganese, and copper. Most mycorrhizae form near the soil surface where leaf and twig litter is being formed (Shigo, 1996). The mycorrhizae population does not promote growth of hair roots (Shigo, 1991).

Participants’ understanding of the structure and the role of the roots as assessed by the qualitative interviews revealed some dramatic weaknesses. This was also supported by the results of the root probe.

Understanding of Photosynthesis

Students’ understanding of the process of photosynthesis was hindered by their understanding of the concept of gases, relationship between the process of respiration and the process of photosynthesis, and the concept of energy transfer.

Difficulty In Conceiving Gas as a Substance

An understanding of material aspects of photosynthesis requires the understanding that plants absorb gaseous CO_2 (and some H_2O) and utilize it to build their bodies. The two are then changed into another form of matter as a result of some chemical reactions within the leaves of a plant. However, most of the students held tenaciously to the alternative conception that CO_2 remains the same or is converted into another form of gas (mostly O_2). These problems may have been caused by the summary equations of photosynthesis and respiration that are given in their textbooks indicating that photosynthesis is the opposite of respiration. *Students' understanding of how gases can form other forms of matter and at the same time be formed from other forms of matter remains one of the greatest obstacles to their understanding the process of photosynthesis.* Item 32 of the root probe tested their understanding of the process in which water, a chemical reactant of photosynthesis, is converted into O_2 .

The concept of gaseous exchange and transpirational pull. There is a continuous gaseous exchange between the mesophyll cells of the leaf and the surrounding air. This gas passes through the stoma situated between the guard cells. The osmotic potential is in turn influenced by the metabolites within the cytoplasm as well as the transpirational pull. Wilting affects these processes and finally reduces the supply of CO_2 that is required in the dark phase of photosynthesis.

Difficulty of Relating Energy, Food, Photosynthesis and Respiration

Students experienced difficulty relating the sources of energy for the processes of photosynthesis and respiration. Few of them realized that the latter occurred in the plant. This was influenced by the alternative conception that plants did not use energy.

Role of Food

Participants' conception of the role of food. What most students referred to as food served the plant in growth and development only. As Kathy summarized it; "and that is how it creates itself." Interestingly, none of the participants associated what they called food with energy requiring biochemical processes that occurred within the plant. Shigo (1996) explained that trees use energy in five basic ways: growth, maintenance of all cell processes, reproduction, exudates and storage (mainly for new growth and defense).

Scientifically acceptable propositions. Shigo (1991) explained how a good systems understanding of the process of photosynthesis and respiration requires basic knowledge of the need by the plant for these two processes. Although they both occur in the same cells of a plant, and are the reverse of each other in terms of reactants and products, they are nevertheless two independent processes in terms of location and enzymatic demands. The three principal components of photosynthesis are light energy and sources of hydrogen and carbon. During photosynthesis, energy from the sun is changed into energy in the form of food. Food consists of material that organisms can break down as a source of energy. Photosynthesis occurs in two phases. The light

reaction occurs when solar energy generates ATP and NADPH. It is at that particular stage when solar energy is converted into chemical energy which is used in the dark phase. This phase occurs within the Calvin Cycle when CO_2 is reduced by a continuous supply of hydrogens coming from water through NADPH as the O_2 is released.

On the other hand, respiration is a catabolic reaction in which chemical energy stored in food is released in form of ATP. During this process, O_2 is used as the final acceptor of hydrogen and electrons released from the food resulting in formation of water. Respiration occurs in all cells at all times. In bright daylight photosynthesis occurs at a much faster rate releasing more O_2 than is used by the process of respiration. At night when there is no light energy at all, photosynthesis ceases while respiration continues. It is also necessary for students to realize that photosynthesis is a constructive process which may lead to an increase in weight while respiration is a catabolic phase that may lead to a decrease in weight. The root contributes all the hydrogen required despite its deficiency in organelles that perform the process of photosynthesis.

The Concept of Transfer of Energy

The major problem which educators face is to explain to students how the solar energy which is converted into chemical energy in the form of ATP is converted into a potential energy in sugar. An attempt to teach this concept to students as if they are scientists who can grasp all the details lead to loss of the fundamental concept in a morass of details. An example of how energy from ATP is passed over to the glucose is presented as follows in one of their textbooks. (Campbell, 1995 p. 196)

Figure 10.16 divides the Calvin cycle into three phases:

Phase 1: Carbon fixation. The Calvin cycle incorporates each CO_2 molecule by attaching it to a five-carbon sugar named ribulose biphosphate (abbreviated RuBP). The enzyme that catalyzes this first step is RuBP carboxylase, or rubisco. (It is the most abundant protein in chloroplast and probably the most abundant protein on Earth.) The product of the reaction is a six-carbon intermediate that is so unstable that it immediately splits in half to form two molecules of 3-phosphoglycerate.

Phase 2: Reduction. Each molecule of 3-phosphoglycerate receives an additional phosphate group. An enzyme transfers the phosphate group from ATP, forming 1,3-bisphosphoglycerate as a product. Next, a pair of electrons donated from NADPH reduces 1,3-bisphosphoglycerate to G3P. Specifically, the electrons from NADPH reduce the carboxyl group of 3-phosphoglycerate to the carbonyl group of G3P, which stores more potential energy. G3P is a sugar - the same three-carbon sugar formed in glycolysis by the splitting of glucose. Notice in FIGURE 10.16 that for every three molecules of CO_2 , there are six molecules of G3P. But only one molecule of this three-carbon sugar can be counted as a net gain of carbohydrate. The cycle began with 15 carbons' worth of carbohydrate in the form of three molecules of the five-carbon sugar RuBP. Now there are 18 carbons' worth of carbohydrate in the form of six molecules of G3P. One molecule exits the cycle to be used by the plant cell, but the other five molecules must be recycled to regenerate the three molecules of RuBP.

Phase 3: Regeneration of CO_2 acceptor (RuBP). In a complex series of reactions, the carbon skeletons of five molecules of G3P are rearranged by the last steps of the Calvin cycle into three molecules of RuBP. To accomplish this, the cycle spends three more molecules of ATP. The RuBP is now prepared to receive CO_2 again, and the cycle continues.

For the net synthesis of one G3P molecule, the Calvin cycle consumes a total of nine molecules of ATP and six molecules of NADPH. The light reactions regenerate the ATP and NADPH. The G3P spun off from the Calvin cycle becomes the starting material for metabolic pathways that synthesize other organic compounds, including glucose and other carbohydrates. Neither the light reactions nor the Calvin cycle alone can make sugar from CO_2 .

By relating the process of photosynthesis with its two phases (Shigo, 1991). Explained that it is an emergent property of the intact chloroplast, which integrates the two stages of photosynthesis.

In most of these illustrations the diagrams given do not coincide with the text. This causes what Blystone and Dettling (1990) called text-illustration conflict. This problem coupled with complexity and information denseness in an illustration (Blystone and Dettling) creates pedagogical problems. The students experienced some difficulty even answering the root probe.

Holistic Nature of a Plant

Understanding of a Tree as a System

Understanding of interconversion of matter. The scientifically acceptable propositions of the process of photosynthesis in relationship to plant food, energy and autotrophism are summarized by Lumpe and Staver (1995) and these views are supported by other plant physiologists (Kozłowski, Kramer, & Pallardy, 1991; Marx, Sung, Cunningham, Thompson, & White, 1995).

- 1a. Plants make their own food internally.
- 1b. The food that plants make internally is the plant's only source of food.
2. Food made by plants is matter that they can use as a source of energy.
3. Food supplies the energy that plants need for life processes.
4. Water and carbon dioxide are changed into another form of matter as a result of a chemical reaction.
- 5a. Water and carbon dioxide travel to leaves where they are involved in the making of food.
- 5b. Food travels from where it is made to all parts of the plant.

6. During photosynthesis, energy from the sun is changed into energy in the form of food (glucose, sugar, starch).
7. The food that plants make is their only source of energy.
8. Animals depend on plants for food and oxygen. Only green plants can make the energy containing food that all animals need.

Shigo (1991) described a system as an orderly collection of parts and processes that produce a predetermined product or service. A Live Oak is a living system in which the two major parts are the root and the shoot. Each of those parts interact with their immediate system boundaries from where they derive their requirements. They both have sub-processes all of which culminate with that of photosynthesis. This researcher discovered some factors that prevented the students from achieving the above propositions. Some of the major obstacles were understanding of the following: role of water, plant food, role of gases, and a tree as a single system.

Mechanism of water uptake. Shigo (1991) explained with an analogy of the “rope” the three factors that are involved in the process of movement of water. Its rise from the root (soil) to the shoot (air) involves: the cohesion of water molecules; its adhesion to the capillary vessels of xylem; and, the transpiration pull that raise water from the roots to the shoot. As the water leaves the stomata into the air it pulls the “rope” of water upwards. The “rope” of water is so strong that it remains intact within the capillaries for a distance of over 1500 feet. The smaller the diameter of the capillary the longer the “rope” can be. The analogy of “rope” by Shigo, calls for systems

thinking illustrated by the principles of integration and change. Movement of water through the plant allows integration of two system boundaries (i.e, soil and air). It also requires the understanding that water is changing its state from liquid to gas.

Plant Food Within the Tree System

Allocation of photoynthates. Energy from the sun is trapped in the chemical bonds that hold glucose together. Shigo (1991) explained that the glucose formed by the leaves is like a mobile battery (i.e., chemical energy in solution form). Sugar is soluble in water and it is the only fuel for the entire plant. As mentioned earlier, most of the students (51%) held to the alternative conception that plant food came from the soil. As a result, only a few reasoned that this food originated from the leaves and was carried in the phloem to all the parts of the plant.

Understanding of photosynthate allocation is based on the principles which some famous researchers (Marx et al., 1995) called dynamics of carbon allocation. The word carbon in this context refers to the end products of photosynthesis, which are formed as a result of sugar being changed chemically to a variety of other carbon compounds in the plant. A tree allocates its carbon where it is needed most. One factor that dictates this allocation is the injury inflicted onto any part of the plant. This explains why it is extremely necessary to educate the community of the two campuses about how soil compaction injures roots of a Live Oak tree. Compaction results in trees allocating most of the photosynthate to the injured parts at the expense of the shoot (Marx et al., 1995).

Reactants and Products of Photosynthesis

Source of oxygen. The task item 32 required students' appreciation that a gas can be formed from a liquid or from a solid the same way a solid can be formed from a gas. This is in line with Eisen and Stavy (1987) who argued that understanding the material aspect of photosynthesis required the understanding that plants absorb gaseous CO_2 from the air and utilize it to build their bodies. However most of the participants held to the alternative conception that O_2 originated from the CO_2 taken through the leaves (Eisen & Stavy). This is yet another illustration of lack of systems thinking.

The conception that O_2 originated from the CO_2 taken through the leaves contradicts the most basic principles of photosynthesis. There are two possible sources of thoughts that contributed to this. The first, assumes that photosynthesis is the respiration of plants. The second one is based on intuitive reasoning that gases can only originate from other gases just as solids originate from other solids. An almost equal number of students believed that O_2 originated from the metabolic wastes of photosynthesis which in this case were not specified. This is one distractor that may have confused even those who applied systems thinking. A better resetting of the distractor may have the percentages of those who selected choice 32d.

The products of photosynthesis (dissolved sugar and O_2 gas) resemble the reactants (water and CO_2 gas) only in physical forms. All the gas (CO_2) of reactants end up in the dissolved sugars which may later be converted into starch. Water, the liquid part of the reactant, contributes to the formation of both sugar and the gas (O_2). To the

sugar, water contributes by adding a hydrogen (H^+) ion (Asimov, 1968). It is worth noting that leaves do not absorb respiratory O_2 during the day. This is because of the continuous supply of O_2 that is generated during the photolysis associated with the light phase. Such a conception and a few related ones were tested by task items (6, 20, 22, 24, 25, 26, & 27). Understanding of the integration, complexity, dynamics, and the changes involved in all these processes required an application of systems thinking (Shigo, 1991).

Compartmentalization of Knowledge Across Subjects

School curricula. Traditionally biology, chemistry and physics have been taught as separate disciplines in schools. Teachers have promoted these boundaries by re-teaching the same concepts and principles over and over without pointing to the relationship between the disciplines, even when they are teaching more than one subject to the same class. As a result, transfer of learning skills from one subject area to another does not occur thus hindering the student's ability to function as effective problem solvers. What they had learned in chemistry is seen differently in the discipline of biology and vice versa (Garafalo & LoPresti, 1993).

As mentioned in earlier parts of this study, students had some alternative conceptions or were not aware of basic facts about gases and how they relate to plant nutrition. The researcher chose to deal with two of the familiar gases (O_2 & CO_2). A summary of participants' alternative conceptions about O_2 and what they are unaware of are given in Table 7 and those that relate to CO_2 are given in Table 8. The Table's

summary dealt with the compartmentalization of knowledge, so far, identified as a major source of problem in this study. Participants mistook the process of photosynthesis for respiration of the plants or thought that the process of respiration existed to restore the process of photosynthesis. As a result, they failed to relate the CO_2 taken in through the leaves with the water taken in through the roots. In a given reaction, gases were seen as possible source of other gases just as the liquids were a source of other liquids. It is this kind of reasoning that led most of them to think that the O_2 released by the leaves originated from the CO_2 taken in through the leaves.

Another major problem that the students experienced was understanding how plants used inorganic matter to make their own food. Such a conception called for a good knowledge of elements. A lesson on elements is normally taught as a topic in chemistry, but is essential for students to understand the process of photosynthesis as well. Although participants could write the summary equations on photosynthesis, they had a great deal of difficulty understanding the elements.

Problems of this nature originated from compartmentalization of knowledge. In a chemistry lesson students learn that all the matter on earth is made up of 109 naturally occurring elements. They are also taught in chemistry that compounds are formed from a union of these elements. Contrary to this, participants considered carbon compounds as elements which is an alternative conception. Understanding of photosynthesis requires a conceptual framework of chemical concepts such as elements, molecules, compounds and macromolecules. Bruner (1960) explained that an understanding of

fundamental principles and ideas appears to be the main road to adequate “transfer of training”. He emphasized how understanding something as a specific instance of a more general case is to have learned not only a specific thing but, also, a model for understanding other things like it that one may encounter.

During these interviews, serious gaps were found in the participants’ knowledge of chemical concepts required for their understanding of the basic processes of photosynthesis. These students experienced some difficulty in treating the products of photosynthesis as a chemical system, as they failed to relate the concepts taught in chemistry with those of biology. Whenever they referred to elements, it was in association with compounds of commercial fertilizers. In such a case, nitrogen, phosphorous, and their compounds were cited as the familiar elements. This will explain why students receiving correct scores for root probe task item 4, were significantly higher than those of task item 2. The word phosphorous appearing in task item (4c) influenced some of the students who had previously selected the distractor of task item (2a). Students had other alternative conceptions about elements besides these.

Confusion can arise from misunderstanding prefixes that have highly restricted meanings to a discipline. The following is a case that illustrates this: When participants were asked about the elements that formed carbohydrates during the process of photosynthesis, most of them said disaccharides and monosaccharide. Answers of this nature signify the emphasis biology teachers have given to sugars as the units from which carbohydrates are made without relating them to the elements from which these

compounds are formed. Systems thinking requires another top-down step of treating the elements of sugars. Failure to do this has influenced students to treat sugars as the equivalent of the elements of chemistry. Clear conception of this word can help them overcome other barriers occurring by its use in a restricted sense.

Compartmentalization of knowledge within one discipline. This occurred within one subject at different topic levels. As the questions became more general, their ability to understand the application of concepts became correspondingly vague.

Implications

The third sub question was:

“What are the implications of these findings for instruction?”

The following are the key factors drawn from this study;

Systems Approach

As indicated in the knowledge and the value claims (See pages 171 &172.), students who applied the systems learning scored higher than those who did not. One way of applying systems learning to teaching is by applying models.

Model approach.(See Appendix D on page 193.) Shigo (1991) explained that an understanding of trees as systems requires an appreciation that its parts act as large oscillating pumps. These tree pumps have developed over time to work on the basis of many synergetic associations that maximize benefits for all connected members. The shoot cannot function without the roots, and the roots cannot function without the shoot. One major factor that maintains this interdependence is the need for food and

water. All living organisms require food and water for growth. Leaves carry out the process of photosynthesis, providing energy at the top of this pump as well as the roots, thus enabling it to absorb minerals and water which are required to build the structures of the tree (Shigo 1996). Leaves benefit from the absorbed water as their cells remain turgid, forcing the stomata to open, and thereby allowing an inflow of CO₂ in air that is necessary for photosynthesis. The ability of the leaves to trap solar energy accrues from the vertical position of erect leaves.

For students to understand the above notions, information overload will need to be minimized and instead teach some key ideas that connect the systems being taught. Colleta and Bradley (1981) created such a teaching model that was later elaborated by Colleta (1993). The essence of their model was that an understanding of photosynthesis requires a teaching approach that emphasizes the interaction of biotic and abiotic (physical) components of the ecosystem. This approach will require conceptual change, which differentiates qualitatively between the living and non-living realities, to a naturalistic conception that does not make such a distinction (Eisen & Stavy, 1992).

In the Colleta and Bradley (1981) model, solar energy is irreversible and is continually coming to the earth in the form of electromagnetic radiation. (See Appendix C on page 192.) This energy affects the four domains of the earth and their most representative cycles, the biosphere (nutrient cycle), lithosphere (rock cycle), hydrosphere (water cycle), and the atmosphere (gaseous cycle). Within the interactions, we can identify some subsystems. Each of the ecological subsystems is identified with

a specific functional relationship to the ecological whole. Some of these ecological wholes that we can identify are some “power points”. Power points serve to link the greatest number of cycles and thus have the most control over the functioning of the system as a whole. Soil and life which are themselves part of the biosphere may be considered as excellent power points. All the four spheres given above contact one another in the circuitous flow of all material in the earth’s ecosystem through them.

A plant, which is a part of a biosphere, will use O_2 and produce CO_2 during respiration, both of which are part of the atmosphere. The water cycle (hydrosphere) flows through the plant carrying the nutrients (lithosphere). When the plant dies, its remains go back to the lithosphere for more recycling.

Systems thinking will guide students to see photosynthesis as a means by which plants evolved the ability to store the solar energy within the carbohydrates. The energy is held in their bonds, not in the other inorganic molecules, not even in the O_2 . This energy can be transferred to other life-forms through food chains. It is the only means of supplying energy to all the life on earth.

Photosynthesis releases O_2 as a by product and not as an energy carrier. Accumulation of O_2 could retard the process of photosynthesis by the principle of product inhibition. Nature evolved a solution to this in form of the process of respiration. Aerobic respiration utilizes the oxygen produced during the process of photosynthesis and in return produces some CO_2 that is required by the process of photosynthesis. Evolutionary studies suggest that the essentially reciprocal

photosynthesis respiration duality was formed through such interdependence (Colleta, 1992). The O_2 released by plants is not a source of energy, but a means of carrying the H^+ ions that have been released from the energy carrying C-H bonds of molecules synthesized during autotrophism. An accumulation of O_2 in the air is favored by two main factors. First, plants that produce it are numerous. Secondly, this gas is evolved whenever both processes of photosynthesis and respiration are going on simultaneously in the leaves. This is an indication that photosynthesis is an efficient process that is capable of supporting life. Besides, for any O_2 to be used through the process of respiration, the products of photosynthesis must be used (i.e. carbohydrates involved). When the students were shown models and were able to see this relationship, they answered well the questions of the interview.

Effects of the Neglect of Teaching the Root System

There has been some negligence of attending to the roots and their surrounding soil (Carson, 1974; Popadic, 1995; Russell, 1977 & Waisel et al., 1996). This negligence does not match the importance of the roots since the root systems are as important as their shoot counterparts, in functions (Shigo, 1991) and in size. Textbook examples of specific organs or tissue were all in reference to the shoot of the plant and not in reference to the root system (Campbell, 1995).

Failure to relate food allocation with the state of health of the tree led many students to select alternative conceptions of task item 22. Few students realized that food is allocated to the injured parts. Failure to teach about the root system as an

integral sub system of the tree has led to accepting wrong practices that have hampered the tree industry (Shigo, 1996). One of these practices has been pruning branches of the Live Oak tree around the campus. This has been done in an attempt to balance the shoot with their roots as a result of a reduction of root spaces for various reasons. When one part --top or bottom-- is threatened or made smaller, the other part will adjust. The part which most people cannot understand is that in nature, as the pump adjusts to a smaller mass, the energy in the parts that are shed are first transferred to the parts that will remain (Shigo, 1991). Tree topping does give time for this to happen.

Task item 23 (see page 228) related well to another major problem that campus Live Oaks are experiencing. This is as a result of the lawn planted on the surfaces of the Live Oak roots. This has been done to control the effects of soil compaction on roots. However those who plant such lawns fail to realize that the grass competes with the non-woody tree roots for water and nutrients. A reduced root space, accompanied by new growth from the additional lawn has created unfavorable conditions for the campus Live Oak. This problem is complicated by the high water table of Louisiana. It is no wonder that the trees that are growing at the sides of the South Road are very unhealthy.

Task items 37 and 38 illustrates conflict of common practices with scientifically acceptable conceptions. There is a common practice of fumigating the fresh-mulch that is lying on top of the Live Oak in an attempt to control the weeds and the pathogens. This illustrates a misunderstanding of the role these fungi play in root- fungi

interdependence. Some fungicides are detrimental to mycorrhizae formation. This practice not only kills undesirable organisms, but also reduces the non-target species such as the mycorrhizae forming fungi. As a result, the benefits of using a fungicide to control a particular plant pathogen will have to be weighed against its negative effects on mycorrhizal fungi (Medve, 1978).

If the root is given the attention it deserves during teaching, then perhaps these age-old practices would cease. It is possible to introduce mycorrhizae to a class by using them as good examples of symbiotic relationships with roots. The fungi receive carbohydrates from the plants and in return give some water and inorganic nutrients to the plant. Many times students are given unfamiliar distant examples of mutualism such as the termite bacteria at the expense of familiar ones whose introduction would reinforce the notion of autotrophism in plants.

Warnings against the practice of walking on roots are familiar to anybody who visits the LSU campus. (See task item 38 on page 236.) The reason is that the net effect of this practice has been the destruction of the rhizosphere; the area immediately adjacent to the non-woody roots contains a symbiotic relationship, forming a gel from which mycorrhizae can extract water and nutrients for the host plant. It is a fragile area and any soil compaction can easily destroy or diminish it, thus decreasing the amount of mycorrhizal activity and ultimately leading to restricted water and nutrient uptake by the tree (Shigo, 1996). If these warnings were accompanied by some graphics that illustrate the effects of the soil compaction, this would increase an awareness of the

harm caused by the soil compaction. Many under-tree footpaths continue to be used around the two campuses despite these warnings because few people regard trees as living and capable of experiencing death as a result of the physical injury affecting these symbiotic relationships.

Need for Teaching the History of Science Education

This researcher agrees with the ideas of other science educators that there can be no understanding separated from the history of a subject. Ernst Mayr (1982) proposed that the best way of acquiring an understanding of the concepts of a field is by learning its history. He asserted that only by studying the step-by-step process by which concepts were developed, and by learning all the earlier misconceptions that had to be refuted one by one, can one hope to acquire a thorough and sound understanding. In support of Mayr, Matthews (1994) explained that one learns not only from one's own mistakes in science, but, also, from the history of others' mistakes. Besides, the problems that the participants faced of distinguishing the alternatives conceptions from the scientific conceptions were the same problems faced by the pioneers who first set out investigated plant nutrition. Indeed most of the distractors given in the multiple choices were all drawn from the history of photosynthesis. (See task items 2, 6, 20 and 32).

Knowledge Claims

This research study investigated the relationship between the level of understanding of undergraduate college biology students of the roles of the seed

plant root system to their level of understanding of photosynthesis. The knowledge claims derived from the study are as follows:

1. There were no statistically significant differences between students' level of understanding of the Live Oak root system (mean score 5.94); and their level of understanding of the process of photosynthesis (mean score 5.54) as assessed by the root probe;(See Final Findings on page 145)
2. Relational statistics of students' level of understanding the root system and their level of understanding the process of photosynthesis indicated that there existed a low level of understanding of the process of photosynthesis that is explained by the level of understanding of the root system. This is an indicator of the proportion of variability in the students' level of understanding of the root system that was explained by their level of understanding the process of photosynthesis which in this case was 10.4%.(See Final Findings on page 145)
3. Students with a systems approach to learning tend to develop a higher level of understanding the process of photosynthesis. (See Final Findings on page 146)
4. Conceptual changes of alternative conceptions are influenced by sets of propositions associated with that particular alternative conceptions (See Final Findings on page 147).

Value Claims

Since these knowledge claims were supported by the research, the following value claim was made:

There exists a low level of relationship, that was nevertheless significant, between the following levels of understanding: The undergraduate college biology students' level understanding, in regard to the role of the seed plant's (Live Oak tree) root system, is related to their level of understanding the process of photosynthesis. Application of systems thinking enhanced the two levels of understanding.

Summary

The major research question that this study sought to answer was "How do undergraduate college biology students' level of understanding of the roles of the seed plant root system relate to their understanding of the process of photosynthesis?"

Results of the root probe task items were used to establish some relational statistics: the students' level of knowledge of the roots of a Live Oak; the students' level of knowledge of a Live Oak tree as a holistic system; and the students' level of knowledge of photosynthesis. Correlational tests were performed to identify the pairs of variables of understanding.

This study has been an eye opener and an opportunity for this researcher to survey a broad spectrum of thought which this thematic approach to learning advocates.

Systems thinking application spans through social studies (Senge, 1990) across living systems (Miller, 1978) to arboriculturists (Shigo, 1991).

Results of testing the 65 subjects indicated that low levels of understanding of the root system exist among the college students of both Louisiana State University in Baton Rouge, Louisiana and Southeastern Louisiana University in Hammond,

Louisiana. That such findings concerning Louisiana University students might be representative of other geographic locations should be considered. This is supported more by the documented results of arboriculture literature most of which was done outside Louisiana. This low level of understanding the root system impedes their understanding the process of photosynthesis.

Limitations of this Study

1. The scope of this study was very broad. As a result certain comparisons were not done in detail. Certain choices of the task items failed to yield the much needed comparative information either because the participants failed to answer those task items or those participants were not interviewed.

2. Scores of individual students on how they selected choices of specific task items were done on selected task items while making the knowledge and the value claims. However, all the scores of individual students were not analyzed in detail to reveal the patterns of thought possessed by each individual student.

3. The Live Oak tree, though a familiar specimen to the interviewees, has many peculiar features and another seed plant may have evoked different answers to the root probe. Neglect of teaching tree biology was evident in students' answers to very basic questions, especially during the interviews.

4. Certain methods set during the methods part of this study (e.g., the concept maps) were not familiar to the participants. This researcher attempted to familiarize all

the interview participants with such methods. Attempts to do so failed either because there wasn't enough time allocation for that or there wasn't the interest shown by them.

Recommendations

There exists a modest level of relationship between the students' level of understanding the root system and their level of understanding the process of photosynthesis. This relationship needs to be investigated further. This researcher suggests some ways of going about future investigations all of which should be accompanied by a systematic teaching of concepts central to understanding of plant nutrition:

1. Pre- and post test method. Since the topic of root biology has not been taught in the school curriculum, it is necessary to investigate effect of teaching it on the level of understanding the process of photosynthesis.

2. Use of a different type of a tree. As had been mentioned earlier on in this study, Live Oak has some peculiarities that are not shared by most of the other trees around this region. I suggest that a more non-familiar tree be used for a similar study.

3. Narrow the scope of the study. Certain concepts, such as, gases and water were very powerful at releasing some information about systems thinking of the participants. As the interviews progressed, this researcher was able to come up with powerful models and graphics that proved very effective. Greater depth and details will be available once this approach is adopted on a narrower scope of such a study.

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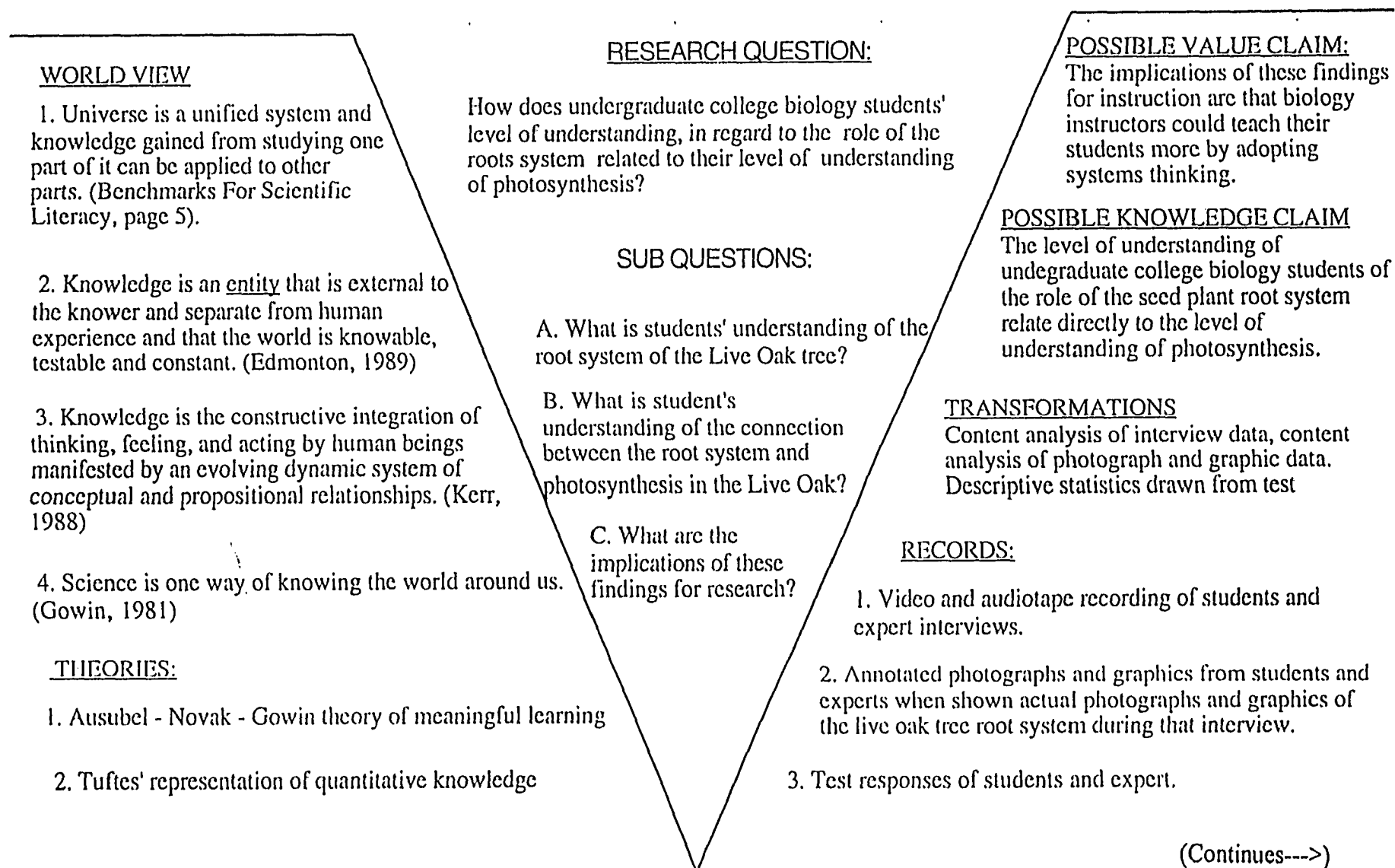
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APPENDIX A. GOWINS' VEE DIAGRAM OF RESEARCH



APPENDIX A. GOWINS' VEE DIAGRAM OF RESEARCH

Cont.

PRINCIPLES

- For healthy plant nutrition roots are as important as the leaves.
- Water and mineral salts are absorbed by the roots to the leaves.
- Roots absorb oxygen from their surrounding for their respiration.
- Soil compaction will harm roots of plant.
- Physical activities on surface of the roots will harm them.
- Roots extend far beyond the dripline and construction near them will destroy these roots.
- There are some factors that govern root/shoot ratio.
- Photosynthate is translocated from the leaves (source) to the roots (sink). There are factors governing root branching.

CONCEPTS

Root, root hairs, tap root, adventitious roots, dripline, fertilizer, manure, food, energy, root ball, mycorrhizae, symbiosis, clay soil, sandy soil, loamy soil, humus, air spaces, soil compaction, soil field capacity, rhizosphere.

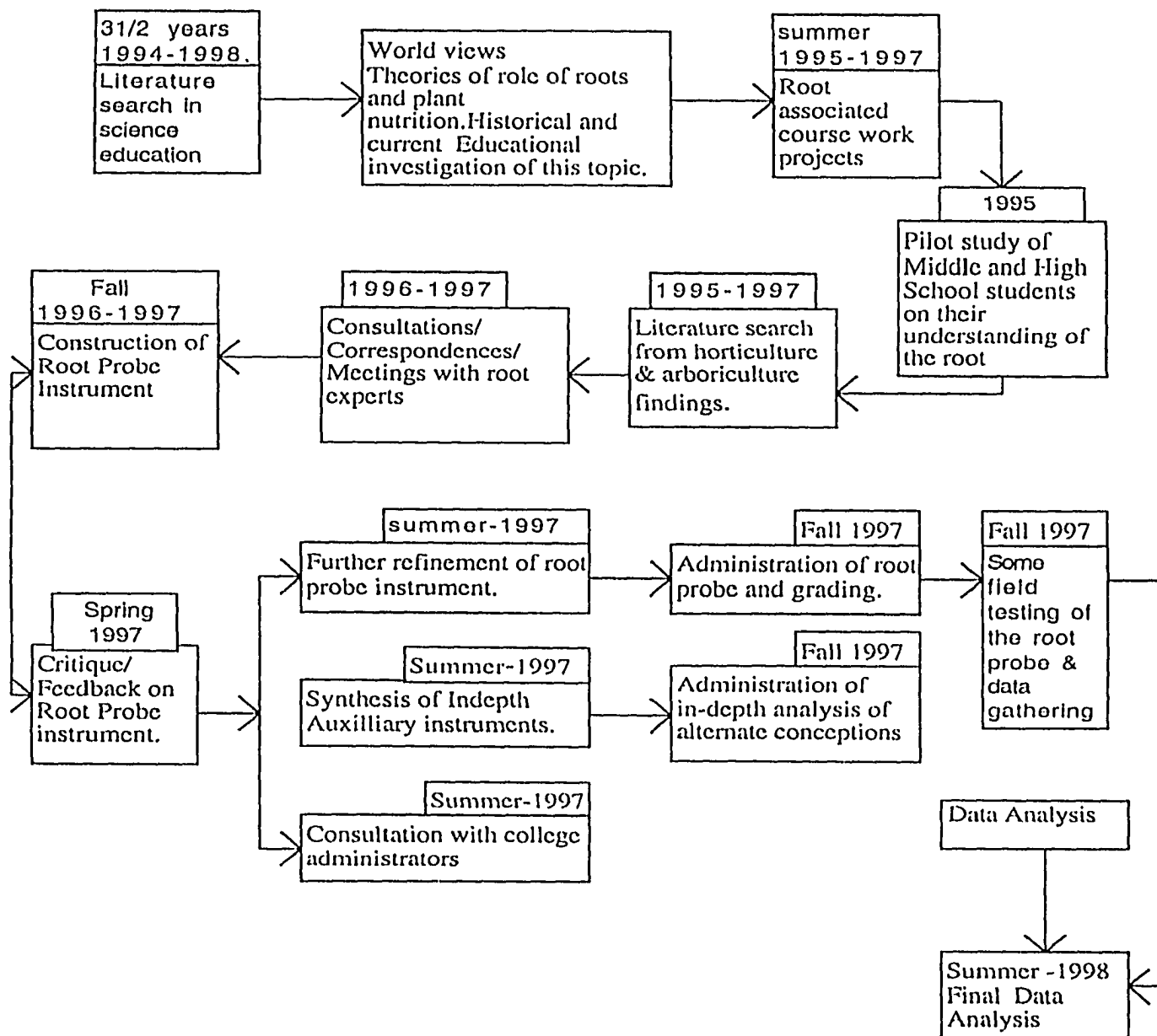
A. EVENTS

1. Students responding to questions about root architecture, gases, soil, and water when interviewed at the site of a Live Oak tree.
2. Students responding to questions about the relationship between the root and photosynthesis when shown actual photographs and graphics of the Live Oak tree root system during that interview.
3. Students' paper and pencil responses to diagnostic tests assessing students' understanding of the relationship between roots and photosynthesis.

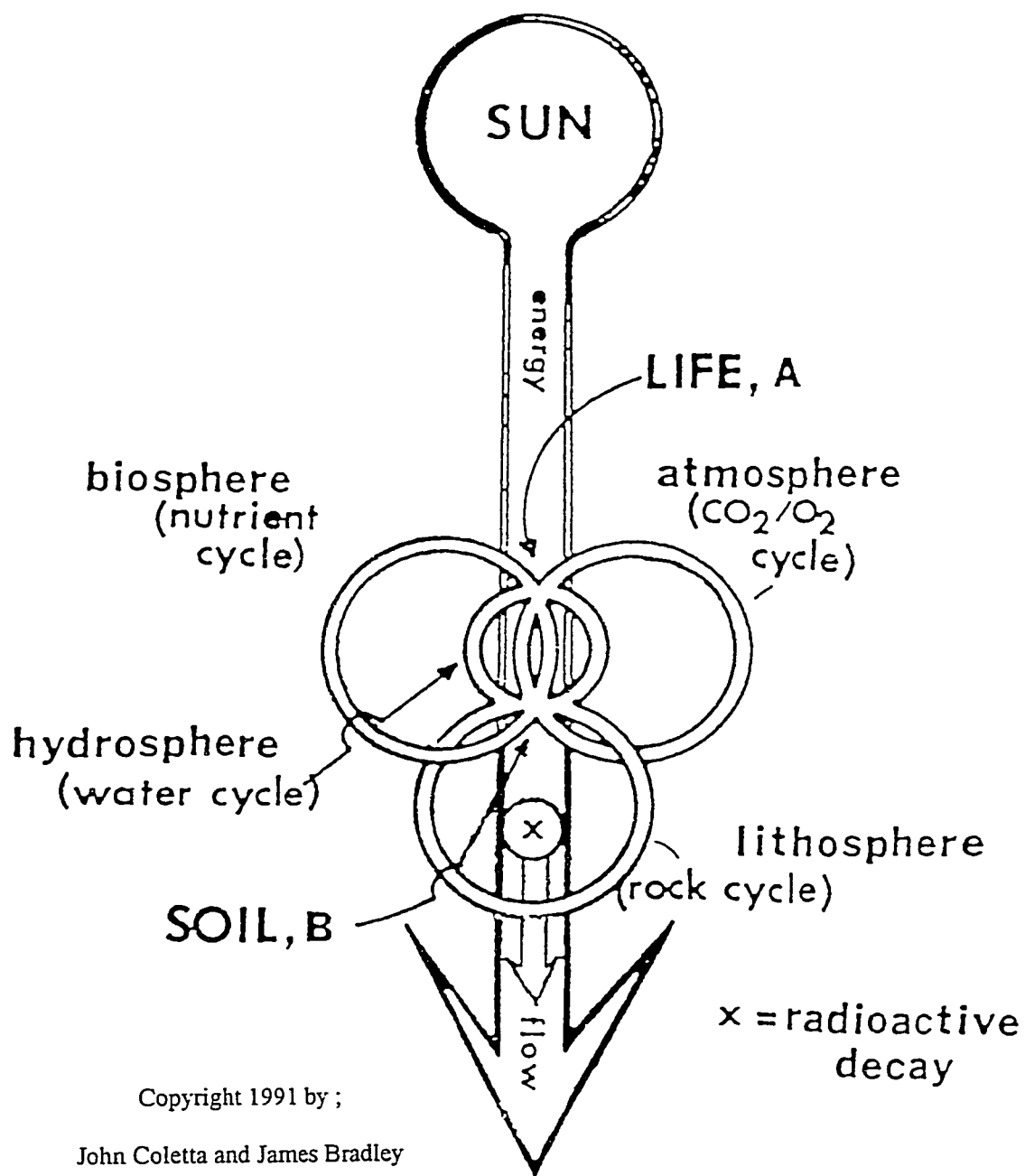
B. EVENTS

1. Experts (plant biology, plant pathology, arboriculture, forestry etc.) responding to questions about root architecture, gases, soil and water when interviewed at the site of a live oak tree.
2. Expert (plant biology, plant pathology, arboriculture, forestry etc.) responding to questions about the relationship between the root and photosynthesis when shown actual photographs and graphics of the Live Oak tree.
3. Experts; paper and pencil responses to diagnostic tests assessing students' understanding of relationship between roots and photosynthesis.

APPENDIX B. FLOW CHART DIAGRAM OF THE RESEARCH



APPENDIX C. A SYSTEMS MODEL BASED ON RESEARCH

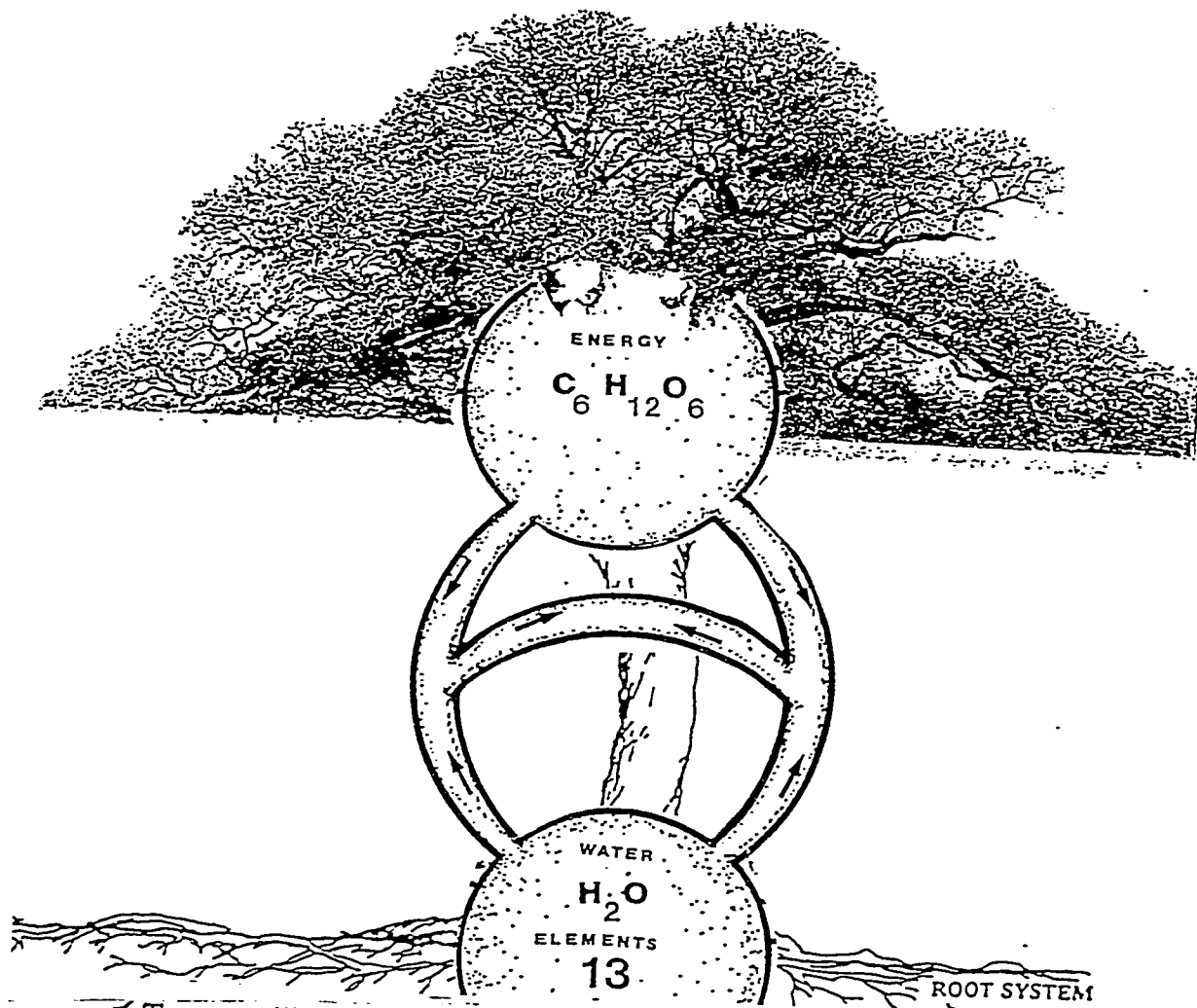


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THE AMERICAN BIOLOGY TEACHER, VOLUME 43, NO. 6, SEPTEMBER 1991

APPENDIX D. MODIFIED FORM OF SHIGOS' TREE SYSTEM MODEL



Trees are like large living pumps. A continuing supply of energy is required to maintain high order in the pumps. High order means health.

APPENDIX E. ALTERNATIVE CONCEPTIONS VS SCIENTIFIC CONCEPTIONS

Alternative Conceptions / Misconceptions/Misperceptions	Scientific Conceptions/Propositional Statements
1. Cultural/Myths: broad	Root functions: Support/ Anchor, absorb and transport water and essential elements, storage, produce growth regulators for the top
2. In order to begin to grow, a seed must absorb food from the ground. (Wandersee, 1986)	Food for seed germination and seedling growth are carbohydrates stored in cotyledons and endosperm.
3. Plants do not need oxygen, they only need carbon dioxide.	Almost all organisms need oxygen for respiration. Plants give off carbon dioxide and oxygen as well as use them.
4. Fertilizer is <u>plant food</u> . (Gilman, 1989)	Fertilizers provide mainly macroelements or microelements in small quantities. These are

used as parts of plant tissue
vitamins and support enzymes activity as
well as some structural compounds.

5. Fertilizers should be applied deep in the soil at the base of the trunk so that it can drip along the whole length of the tap root.

Apply it evenly out to about
1.5 times the canopy diameter
on the surface so it will leak
where feeder roots are located.

6. Photosynthesis is the reverse of respiration. One takes place in leaves, and the other in roots.
(Amir & Tamir, 1994)

Photosynthesis occurs in leaves only in the presence of sunlight.
Respiration occurs in both leaves and roots during growth.

7. Respiration & Photosynthesis occur at different times, in different compartments and neither uses the substrates of the other.
(Haslam & Treagust, 1987)

Respiration and photosynthesis occur in different organelles, but each of the two simultaneously utilize products of the other and are dependent on each other.

8. Light energy is changed directly to food. (Bell, 1985)

Light energy is converted into chemical energy which is utilized by the entire plant.

9. Students are unaware of the role of NADPH and ATP.

(Hazel & Proser, 1994)

ATP and NADPH help in fueling the Calvin Cycle and other metabolic functions. They are the gasoline supplying energy for this motor (Calvin cycle and other synthetic problems).

10. Carbon dioxide has no relation to roots.

(Shigo, 1996)

The carbon dioxide released by the roots forms a weak acid and promotes cation exchange and the uptake of essential elements like Mg^{++} .

11. The concept of a limiting factor is misunderstood.(i.e., fail to understand that a factor operates as limiting of the when the rate of the process in question does not increase even though the intensity or the amount of that factor is increasing. (Amir & Tamir, 1994)

A factor operates as a limiting factor when the rate of the process in question increases after the intensity of the amount of that factor is increased. Carbon dioxide is a limiting factor for most of the time.

12. All the rain that falls on the tree ends up in roots.

Only a small % of rain reaches the roots and this is influenced by the duration of

(Marx, 1996)

the rain, canopy interception, and absorption by the forest floor.

13/14. The concept of photosynthate distribution between the shoot and the root is not understood.

Photosynthate distribution is influenced by the relative vigor of the shoot and the root.

(Waisel et al. 1996).

14. Excessive watering will promote the health of a plant.

Excessive watering will deprive the roots of oxygen and directly cause the death of plant cells and contribute to root disease.

15/16. Wilting is caused only by lack of water in the soil.

Wilting may be caused by (drought) leading to plasmolysed cells or by lack of oxygen after overwatering (cells are turgid then).

(Tamir, 1971)

17. Concrete is the only physical barrier that limits root growth.

Preparing the ground to install concrete brings about soil compaction which in turn influences oxygen distribution

(Shigo, 1991)

(Smith, 1995), this limits gas movement in and out of soils.

17. Most tree roots (e.g. Live Oak roots) extend up to dripline and go deep into the soil.

(Gilman, 1989; Shigo, 1991)

18. Root growth extends up to the edge of the branches.

(Gilman, 1989; Shigo, 1991)

Roots of a Live Oak go 2-3 times beyond the dripline, and are mainly distributed in the upper 12" of soil.

Roots grow far beyond the edge of the branches.

19. The soil type has no effect on root distribution.

Clay soils restrict the root distribution more than sandy soils.

20/21/22. Root/Shoot ratio is not considered in explaining tree biology.

(Shigo, 1991; Waisel et al., 1996)

Root/shoot ratio exists and is influenced

23. Trafficking has no effect on root

by many factors.

systems.

(Day & Bassuk, 1994; LSU, 1996)

Trafficking by bulldozers/humans compacts soil, destroys soil structure and inhibits root growth.

24. Overwatering does not influence the physiological process of the root system.

Carbon dioxide released by the roots promote cation exchange.

25. Students unaware of the presence and role of mycorrhizae in root systems.(Marx 1996; Shigo, 1991)

Mycorrhizae serve as secondary root system and are indispensable for growth and development of most plants in natural soils and conditions.

26/27. Myths/culture

Free responses that require clear justifications.

APPENDIX F. PROPOSITIONAL STATEMENTS AND ASSOCIATED ROOT
PROBE ITEMS

	Roots	Photosynthesis	Respiration
1	<p><u>What is a root?</u></p> <p>A root is a large organ of a plant (the hidden half) usually found in the soil. Withing the root are many sub-organs and tissue.</p>	<p><u>What is photosynthesis?</u></p> <p>Is a process by which green plants containing chlorophyll, are able to trap light energy, and use it to combine carbon dioxide and water to make simple sugars (plant food) such as glucose and to produce oxygen gas.</p> <p style="text-align: center;">”</p>	<p><u>What is respiration?</u></p> <p>Is a chemical process in which chemical energy, stored in food (sugars and starch), is released using oxygen so that cells can use it in other ways.</p>
	Items # 18; 19		

2	<u>Relationship of roots with the two processes.</u> Roots do not carry out process of photosynthesis but supply the water (and the elements for that process. Respiration occurs all the times in roots during the lifetime of the plant. See Items # 13;14;24	<u>Requirements of photosynthesis.</u> Photosynthesis takes place only in the presence of light energy. The four essential factors for photosynthesis in plant cells are : light energy, chlorophyll, carbon dioxide and water. Respiration occurs all the time in the leaves in which the process of photosynthesis occurs during the lifetime of the plant ”	<u>Need for cellular respiration.</u> Every living cell respire. All organisms, plants and animals, respire continually. Respiration occurs all the time in both leaves and roots during the lifetime of the plant. ”
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3	<u>Role of roots.</u> Support/Anchor, absorb and transport water and essential elements, storage, produce growth regulators for the shoot. Items #1; 18; 19	<u>Role of photosynthesis.</u> Converts solar energy into chemical energy (starch and glucose). ”	<u>Role of respiration.</u> Release chemical energy stored in bonds of organic molecules (starch and glucose) into easily available energy (ATP= Adenosine Triphosphate). ”
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4	<p><u>Gaseous exchange</u></p> <p>Gaseous exchange is a method of taking atmospheric gas into- and out-of the body of a plant. Oxygen is taken into and carbon dioxide is given off from the plant during the process of respiration in roots (and in leaves of a plant).</p> <p>Items # 1; 18; 19.</p>	<p><u>Gaseous exchange</u></p> <p>During process of Photosynthesis gaseous exchange may be represented by these equations:</p> <p>Carbon dioxide + water $\xrightarrow{\text{light energy}}$ glucose + oxygen gas. or $6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{light energy}}$ $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$</p> <p>Items # 6; 7.</p>	<p>Gaseous exchange.</p> <p>Respiration take in oxygen and release carbon dioxide, and water.</p> <p>This process may be represented by the equation:</p> <p>Glucose +Oxygen ----> Energy + Carbon Dioxide + Water.</p> <p>Items # 3; 6; 7.</p>
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5	<p><u>Role of CO₂</u></p> <p>The carbon dioxide released by the roots promote cation exchange. The following occurs in the roots:</p> <p>(i) $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$</p> <p>(ii) $\text{H}_2\text{CO}_3 + \text{H}_2\text{O} \rightarrow 2\text{HCO}_3^-$</p> <p>(iii) The uptake of nutrients like Mg^{++}, NO_3, and NH_4 ions depends upon the exchange with this HCO_3.</p> <p>Items # 10, 24</p>	<p><u>Role of CO₂</u></p> <p>Carbon dioxide is taken in by the green leaf (or stem) during the process of photosynthesis.</p> <p>Some of this CO₂ may come from that formed by the process of respiration. The rest diffuse out through the stomata when the process of photosynthesis is not going on.</p> <p>Items 11; 24</p>	<p><u>Role of CO₂</u></p> <p>Both plants and animals release carbon dioxide during respiration.</p> <p>Items # 10; 24</p>
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6	<p><u>Role of Oxygen.</u></p> <p>Roots of plants obtain oxygen from the soil and air.</p> <p>The oxygen dissolved in soil water diffuses into the root cells.</p> <p>Items #3; 6; 7; 10.</p>	<p><u>Role of Oxygen.</u></p> <p>Oxygen gas is given off by the green leaves (or green stems) during the process of photosynthesis.</p> <p>Since process of photosynthesis depends solely on solar energy, it does not require any oxygen.</p> <p>Items # 6; 7.</p>	<p><u>Role of Oxygen.</u></p> <p>Oxygen gas is taken up by all the plant cells during the process of respiration.</p> <p>Oxygen required by the leaves enter through the stomata (pores).</p> <p>Items # 6, 7.</p>
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7	<p><u>Water.</u></p> <p>Water is absorbed through the roots of the plant and is essential for many functions. Lack of it causes plasmolysis.</p> <p>Excessive watering deprives the roots of Oxygen and causes the death of plant cells (wilting).</p> <p>This contribute to root disease. Only a small % of rain reaches the roots and this is influenced by the amount and duration of the rain.</p>	<p><u>Water.</u></p> <p>NADPH formed from water (and ATP from the solar energy) help in fueling the Calvin Cycle.</p> <p>The ultimate source of the hydrogen (NADH) is water taken in by the roots.</p> <p>Water helps maintain turgidity of the leaf-cells.</p> <p>This enables the plant to capture solar energy easily.</p>	<p><u>Water.</u></p> <p>Water is released continually by the process of respiration.</p> <p>The effect of this water on other metabolic processes is however negligible.</p>
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8	<p><u>Photosynthate.</u></p> <p>More photosynthate needed when the roots are injured.</p> <p>As the plant pump adjusts to a smaller mass, the energy in the parts that are shed (the shoot) is first transferred to the parts that will remain (the roots).</p> <p>Items # 13; 14</p>	<p><u>Photosynthate.</u></p> <p>Photosynthate is formed by the process of photosynthesis then distributed according to the energy needs and the sate of the shoot and the root.</p> <p>”</p>	<p><u>Photosynthate.</u></p> <p>Photosynthate help the process of respiration.</p> <p>”</p>
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9	<p><u>Energy</u></p> <p>Roots depend upon the shoot for all the energy.</p> <p>Glucose is converted into starch in the cells of the roots (or of the leaves).</p> <p>Items #13; 14</p>	<p><u>Energy</u></p> <p>Light energy is converted into chemical energy by the process of respiration. This is the source of all the energy of the plant system.</p> <p>Glucose <respiration==storage> starch</p> <p>Items # 8; 9; 13; 14.</p>	<p><u>Energy.</u></p> <p>Plants need energy to live and grow. During respiration plants derive energy from glucose. Glucose is therefore used up during respiration.</p> <p>When energy is limiting a system goes from order to disorder.</p> <p>Item # 13; 14</p>
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10	<u>Limiting Factor.</u> A root is an organ in which many processes are influenced by many factors. Besides the root processes of the root influence processes of the shoot	<u>Limiting Factor.</u> The rate of photosynthesis increases when light and Carbon dioxide intensity increases. Carbon dioxide is a limiting factor most of the time.	<u>Limiting Factor</u> A factor operates as a limiting factor when the rate of the process in question increases after the intensity of the amount of that factor is increased. Respiration is influenced by very many factors.
	Items # 11; 13; 14; 24	Items # 11, 24	Items #11; 24

11	<p><u>Fertilizers</u></p> <p>Fertilizers provide mainly macro-elements in small quantities. These are used as parts of plant tissue, vitamins, and support enzymes activity.</p> <p>Apply fertilizer evenly about 1.5 times the canopy diameter on the surface so it will leak where feeder roots are located.</p> <p>Items # 4; 5.</p>	<p><u>Fertilizers.</u></p> <p>Some enzymes and co-enzymes and co-enzymes required during the process of photosynthesis are derived from the nutrients absorbed by the roots.</p> <p>”</p>	<p><u>Fertilizers</u></p> <p>As in the process of photosynthesis, process of respiration requires many enzymes and co-enzymes.</p> <p>”</p>
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12	<p><u>Soil Compaction</u></p> <p>Trafficking by bulldozers/humans compacts soil, destroys soil structure and inhibits root growth. It destroys mycorrhizae which influence water and mineral uptake.</p> <p>Concrete brings about soil compaction which in turn influences oxygen distribution (Smith, 1995) and limits gas movement in and out of soils.</p> <p>Item #17; 23; 24.</p>	<p><u>Soil Compaction</u></p> <p>Reduced water uptake slows down the process of photosynthesis.</p> <p>Reduced mineral uptake exert a negative effect on secondary metabolic reactions that affect process of photosynthesis.</p> <p>”</p>	<p><u>Soil Compaction</u></p> <p>Reduced oxygen slows down all the processes.</p> <p>”</p>
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APPENDIX G. PILOT STUDIES

A pilot study of the proposed research was conducted in the Fall semester of 1995. Several middle and junior high school students participated. All the students were enrolled in sixth-to-tenth grades. The following are examples of the questions that covered that pilot study:

1. The main functions of a plant's roots are:

- (a) to absorb water
- (b) to absorb food particles from the soil.
- (c) to absorb mineral nutrients from the soil
- (d) to absorb water and mineral nutrients from the soil
- (e) to release waste products from the plant into the soil.

2. A student was investigating the source of food which plants use during their growth and development. She set up an experiment using a potted plant. She kept the plant outdoors and watered it frequently. The plant increased its weight from 1 to 20 pounds.

Now answer these questions.

(a) What role, if any, did the roots play in this weight gain?

----- (b)

Did the soil lose as much weight as that gained by the plant?

Give a brief and clear explanation of your answer.

3. A boy was amazed when he discovered that some of the corn seedlings had died. He knew that there had been a heavy rain storm a few days prior to his visiting this farm. He also knew that lowland soil on this farm had a tendency to get water-logged.

Give a brief explanation to the student suggesting why some of the seedlings died and why some had survived.

(1) Reason(s) why some seedlings died.

(2) Reason(s) why some seedlings survived.

Results of Pilot studies.

1. This is the way the students selected choices of the main functions of plants' roots :

Most students selected (d) (i.e., to absorb water and mineral nutrients from the soil) as the correct choice. This was followed by (a) (to absorb water) and then (b) (to absorb food particles from the soil).

This confirms that the notion that roots take preformed food from the soil still persists in these students' mind.

2. Most students failed to understand the role which the roots played in the weight gain.

However, a good number of them mentioned that some minerals added some weight even those who had not selected choice (d) of question 1.

(b) This is the section that revealed source of these alternative conceptions. Most students indicated that the soil lost as much weight as that gained by the plant. Their explanations for this varied from water, minerals, to the food absorbed by the roots.

3. The explanations given by the students as to why some of the seedlings died and some survived varied as follows:

(1) Reason(s) why some seedlings died.

Due to lack of warmth, water and air. However, most students left a blank in this section.

(2) Reason(s) why some seedlings survived.

Most students gave the opposite of choice #1 or avoided the question. This is enough evidence that the students had no clear understanding of the role of respiratory process related to the roots.

Participants showed a low level of understanding the functions of the root system and failed to relate these functions well with that of the shoot. The pattern of the scores outside of the United were similar to those of Louisiana schools. This researcher hypothesized that a similar trend existed at college level. As a result, the researcher set to carry out this study as a pattern other similar studies that will follow thereafter.

APPENDIX H. ROOT PROBE

AN INSTRUMENT FOR EVALUATING HOW UNDERGRADUATE COLLEGE STUDENTS UNDERSTAND THE ROLE OF THE ROOT SYSTEM IN RELATIONSHIP TO THEIR UNDERSTANDING OF PHOTOSYNTHESIS (WITH SPECIAL EMPHASIS ON THE LSU CAMPUS' LIVE OAK).

Instructions

- 1 For multiple choice questions select only one of the choices; a-d.
2. For all the other questions supply the answers in the spaces provided.



Figure 17. Live Oak Tree (Adopted from Orso, 1992)

1. What do you think are the main functions of the roots of a Live Oak tree?

- (i) _____
- (ii) _____
- (iii) _____

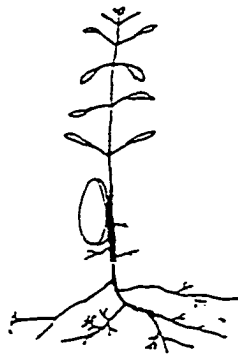


Figure 18. Seedling of a Live Oak tree. (Adopted from Gilman, 1997).

2. This diagram represent a Live Oak seedling. In order to continue to grow and become a large tree, the seedling will need to continually:

- a. absorb its food from the soil.
- b. make its own food using its leaves.
- c. use its stored food reserve.
- d use solar energy as its food.

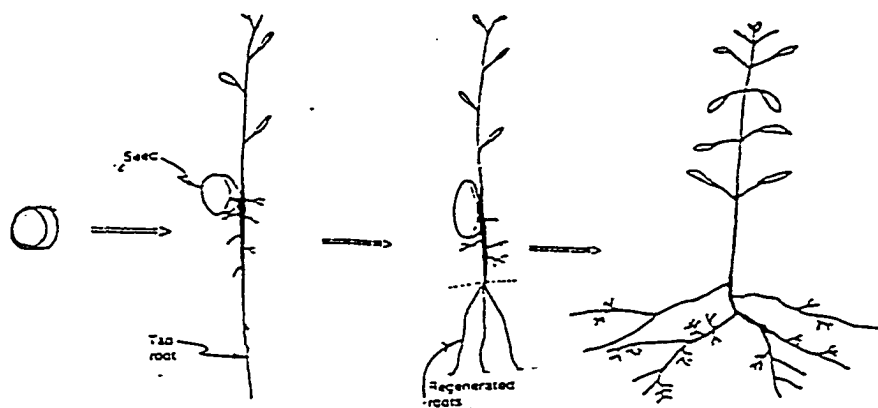


Figure 19. Stage of Growth of a Live Oak Seedling (Adopted from Gilman, 1997)

3. Which of the following is a prerequisite (a necessity) for the seed germination of a Live Oak?

- a. light and water.
- b. carbon dioxide.
- c. oxygen and water.
- d. chlorophyll and light.



Figure 20. Fertilized and Unfertilized Live Oak Seedling. (Adopted from Popadic, 1995)

4. As the seedlings grew into Live Oak trees, a farmer noticed that the seedlings which were treated with fertilizer grew faster than those which received none.

The role of fertilizer was to:

- a. substitute for the water required by the plant.
- b. provide to the tree some metabolic requirements normally given by
a close association of fungi and the roots (mycorrhizae).
- c. provide the tree with essential elements such as phosphorus.
- d. provide food in the soil close to the roots of the tree.

5 The diagram below is a birds' eye view of a Live Oak with the circle indicating the edge of the canopy (it is referred here as the dripline).

How would you fertilize it. Indicate the right choice of the effective fertilizer from one of these shaded below.

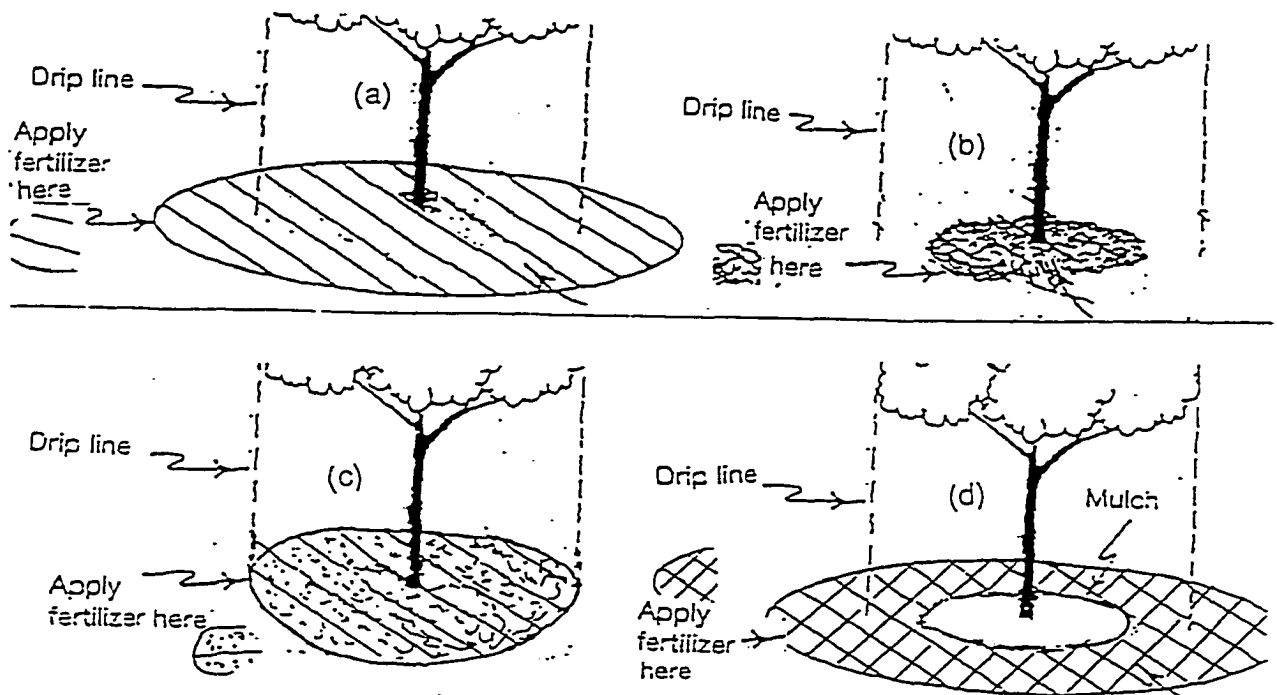


Figure 21. Region of an Effective Fertilizer (Adopted from Gilman, 1997)

The following diagram shows a Live Oak seedling with some of its parts

in gaseous exchange magnified. Use it to answer questions 6 and 7 below:

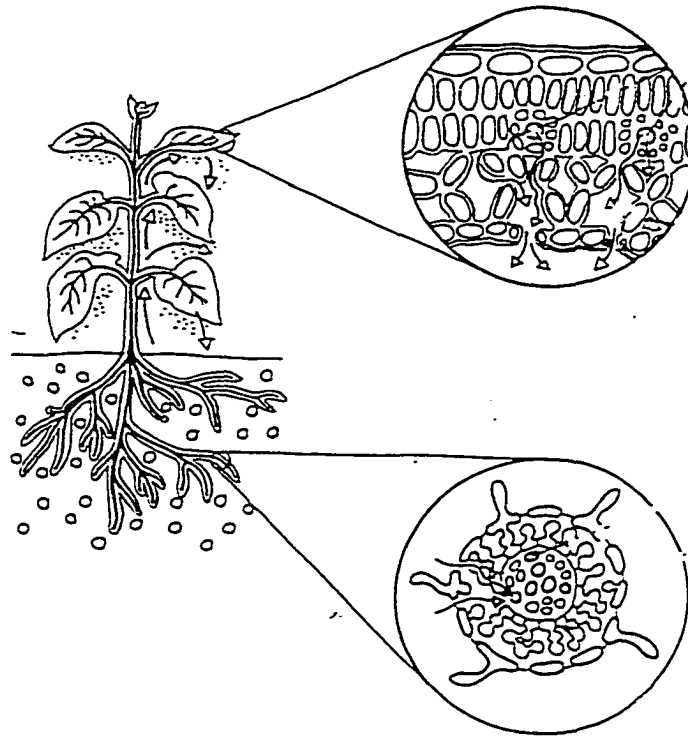


Figure 22. Gaseous Exchanging Parts of a Plant, (Adopted from Essenfeld, Gontang & Moore, 1994)

6. Which of the following statements is true about oxygen and carbon dioxide?
- a. oxygen is always released by the leaves.
 - b. carbon dioxide is never released by the roots.
 - c. roots absorb oxygen continually.
 - d. leaves absorb carbon dioxide continually.
7. The oxygen produced during the process of photosynthesis by a Live Oak tree is:
- a. absorbed in solution by leaves and is transported to the roots along with the manufactured food.

- b. released into the air when it exceeds that required by leaves for respiration.
- c. stored within some air spaces of the leaves.
- d. destroyed by enzymes involved in photosynthesis.

Use this diagram to answer question 8 and 9;

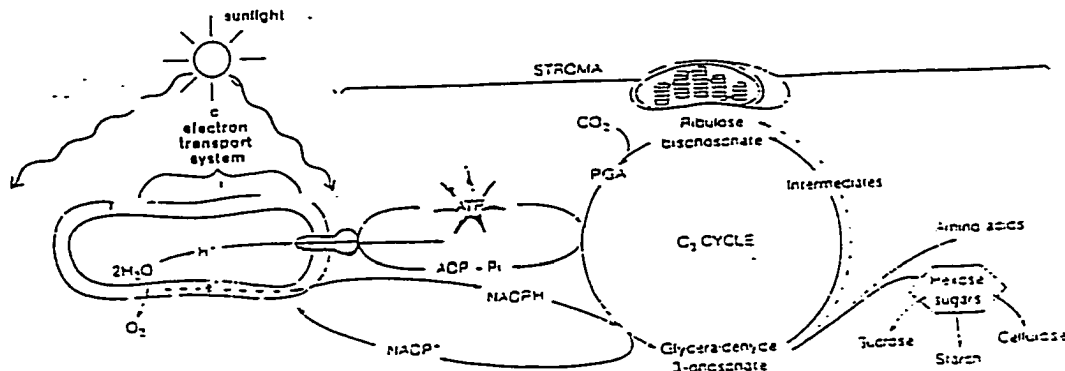


Figure 23. Inside of Stroma and Thylakoids (Adopted from BSCS, 1995)

8. Which of the following statements is true about the light energy?

- (a) It is used by the leaves as food so the leaves do not depend upon the roots for food.
- (b) It is used by the leaves to make food which is also translocated to the roots.
- (c) It is used by the leaves for growth and is not needed by roots since roots depend upon the food they absorb from the soil.
- (d) It is used by the leaves for growth since roots depend upon the translocated food.

9. Which of the following explains the role of light energy in process of photosynthesis?

- a..splits water into OH^- and H^+ ions.
- b. creates some ATP and some H^+ ions.
- c. creates some sugar molecules.
- d. creates some ATP and NADP which fuel the Calvin Cycle.

Use the following diagram and one on the previous page to answer questions

10.11, and 12:

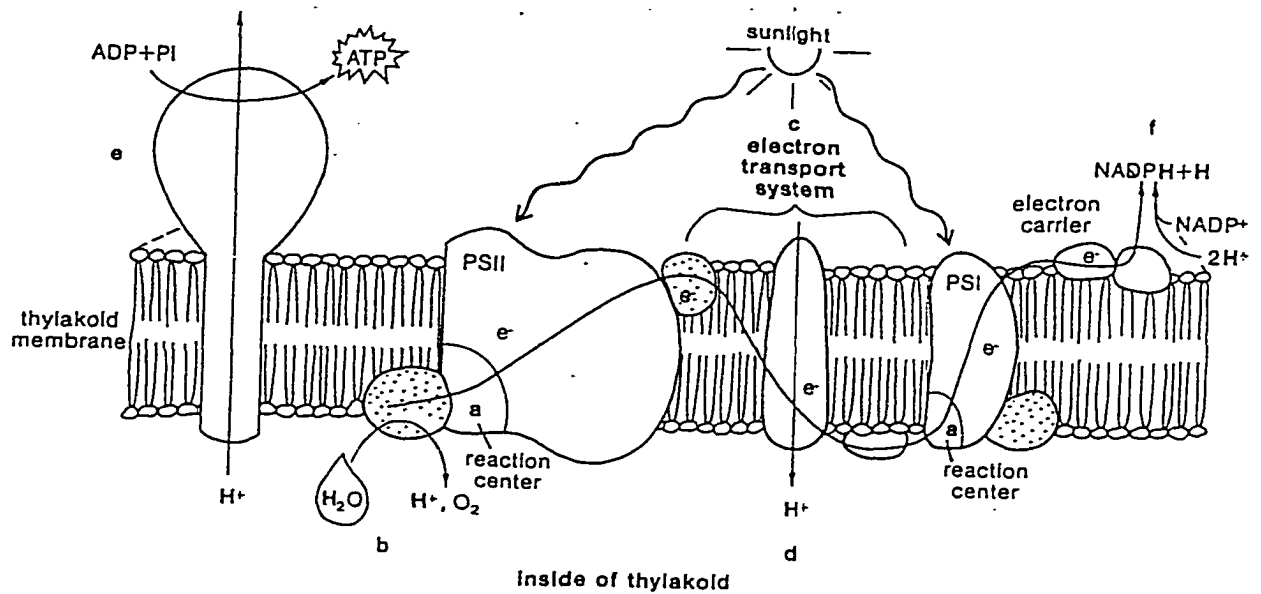


Figure 24. Light and Dark Phases of photosynthesis (Adopted from BSCS, 1995)

10. Which sequence correctly portrays the flow of electrons during photosynthesis?
- a. $\text{NADPH} \rightarrow \text{O}_2 \rightarrow \text{CO}_2$.
 - b. $\text{H}_2\text{O} \rightarrow \text{NADPH} \rightarrow \text{Calvin cycle}$.
 - c. $\text{H}_2\text{O} \rightarrow \text{photosystem I} \rightarrow \text{photosystem II}$.
 - d. $\text{NADPH} \rightarrow \text{Electron transport chain} \rightarrow \text{O}_2$

11. The stage of photosynthesis that actually produces sugar is;
- a. photosystem I (PSI).
 - b. photosystem II (PSII).
 - c. The light reaction.
 - d. The Calvin cycle.
12. In the light reaction, hydrogen ions cause the inside of photosynthetic membrane to;
- a. Become positively charged.
 - b. Become negatively charged.
 - c. Lose its charge.
 - d. "Leak" electrons.
13. A student took four similar plants and exposed each plant to a different colored light for 24 hours. She then measured the amount of starch present within each plant's leaves. In her experiment the student obtained the data shown in the following table:

<u>Plant</u>	<u>Color of Light</u>	<u>Starch in mg.</u>
A	Red	72 mg
B	Yellow	15 mg
C	Green	10 mg
D	Blue	68 mg

In another experiment the same colored lights were used to investigate the percentage of light energy reflected by chlorophyll and therefore not used in the

synthesis of the starch. These colored lights were not in the same order as that given above. Results of the percent of light energy reflected (as a result of chlorophyll absorption spectrum) is shown by the graph below.

Light Absorption Against Starch Synthesis

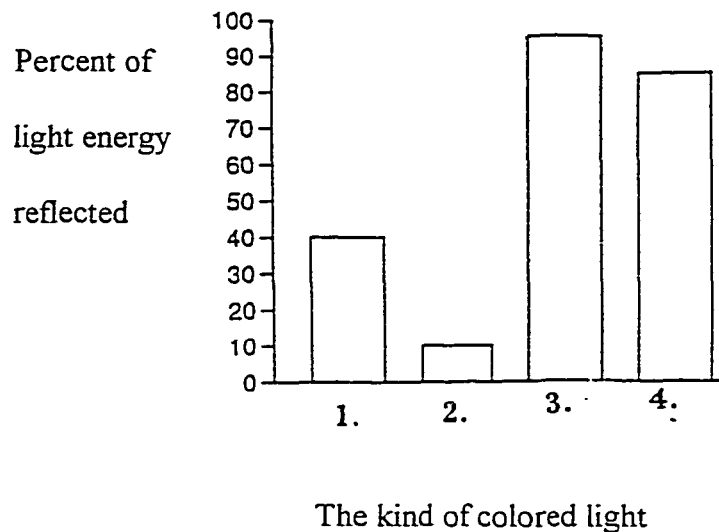


Figure 25. Starch Synthesis Against the Light Absorbed. (Adopted from BSCS, 1995)

The order that reflect the table above (starch synthesis) with the histogram below (the kind of colored light) is as follows;

- 1=blue; 2=red; 3=yellow
- 1=yellow; 3=green; 4=red
- 2=blue; 4=yellow; 3=green
- 1=blue; 3=green; 4=yellow

The diagrams below shows the exchanges that take place between the roots of a healthy Live Oak tree and its environment. Use it to answer questions 14 and 15;

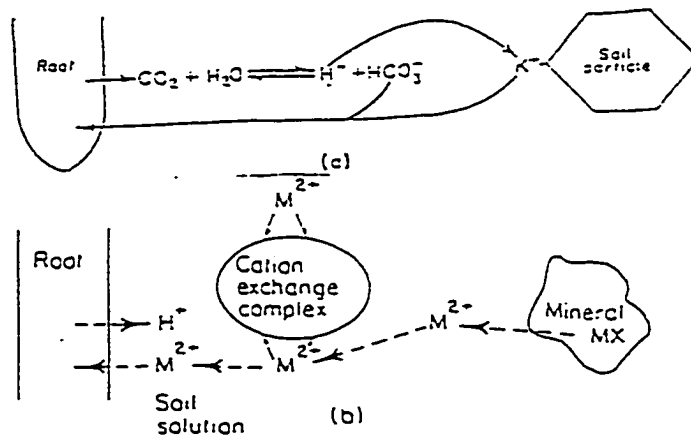
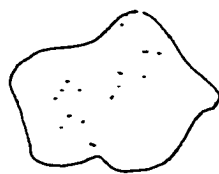


Figure 26. Exchanges Between the Roots and their System Boundaries (Adopted from Schmidt, 1986)

14. (a) Give a brief explanation of the exchange processes taking place between the Live Oak roots and their surroundings.



Clay micelle

Figure 27. Clay Micelle (Adopted from Schmidt, 1986)

15. Which soil mineral is most likely to be washed away due to a hard rain?

- | | |
|------------------|----------------------|
| (a) H^+ | (c) Ca^{++} |
| (b) K^+ | (d) NO_3^- |

16. Root hairs are most important to a plant because they;
- anchor a plant into the soil.
 - store starches.
 - increase surface area for absorption.
 - provide a habitat for nitrogen fixing bacteria.

Use the following diagram to answer questions 17 and 18;

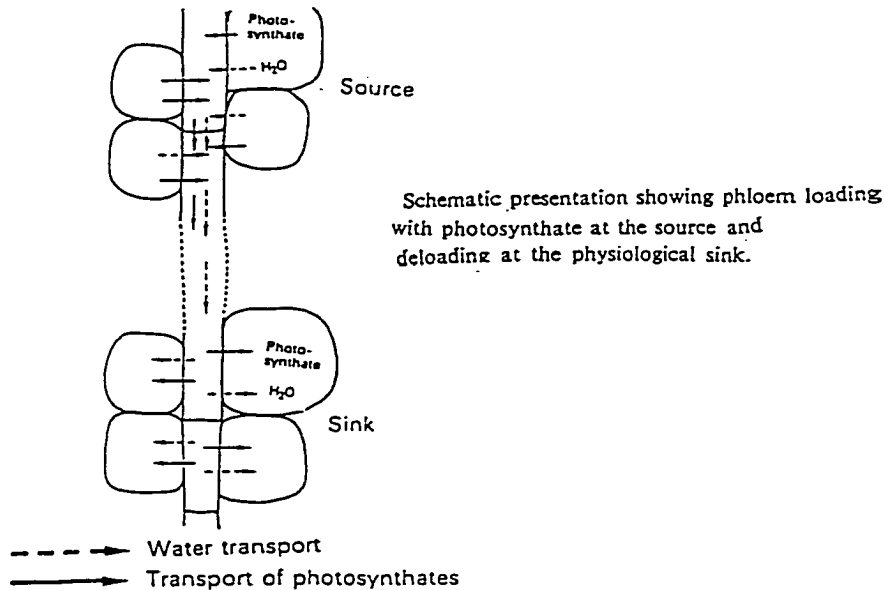


Figure 28. Translocation of Photosynthate (Adopted from Mengel & Kirby, 1987)

17. Arrange the following five events in an order that explains the mass flow of materials in the phloem.
1. water diffused into the sieve elements.
 2. leaf cells produce sugar by photosynthesis.
 3. solutes are actively transported into sieve elements.
 4. sugar is transported from cell to cell in the leaf.
 5. sugar moves down the stem.

The correct choice is;

a. 2,1,4,3, 5

b. 1,2,3,4,5

c. 4,2,1,3,5

d. 2,4,3,1,5

18. If plants are grown in an atmosphere of radioactive carbon dioxide, radioactive sugars will be detected.

a. only in the veins of the leaves.

c. throughout the phloem.

b. throughout the entire plant xylem.

d. moving towards the roots
in xylem vessels.



Figure 29. A Live Oak Tree (Adopted from Orso, 1987)

Use this diagrams to answer questions 19 , 20 and 21;

19. Which of the following accounts for the fact that only 25% of a 1 inch of slow rain reaches the roots under the Live Oak tree.

1. Evaporation

2. Adherence to foliage

3. Respiration

4. Trapping by the dead wood & mulch over the roots

a. 1, 2, & 3

b. 2, 3, & 4,

c. 1, 2, & 4

d. 1, 3, & 4

20. The greatest proportion of the water taken up by plants is

a. split during photosynthesis.

b. lost through stomata during transpiration.

c. returned to the soil by roots.

d. held remaining in the xylem.

21. Salt is known to kill a tree when placed at the base of it or close to the roots.

The cause of this death is because salt;

a. moves into plant tissue.

b. inhibit some important metabolic reactions.

c. block the upward movement of water in xylem tissue.

d. block the downward movement of food in phloem tissue.

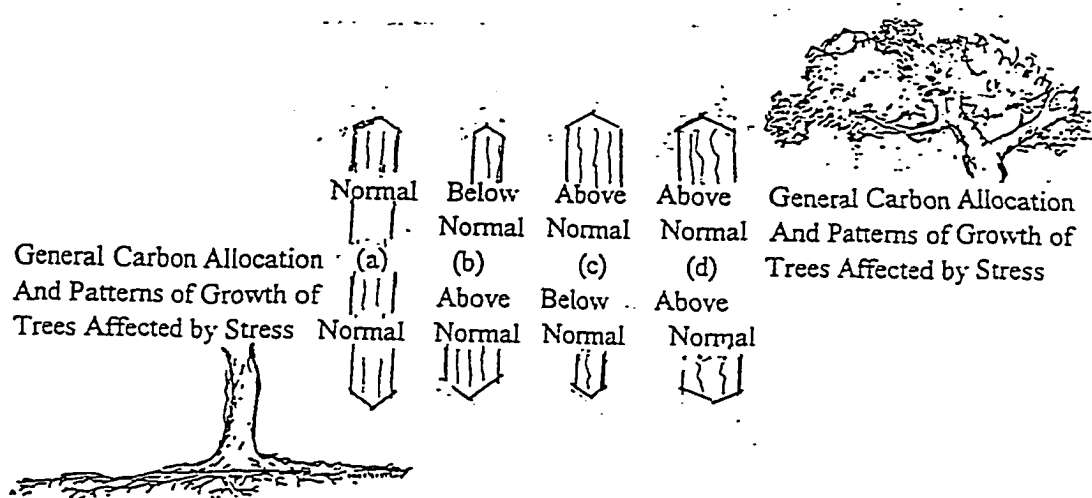


Figure 30. Distribution of Photosynthate (Adopted from Marx et al., 1995 & Popadic, 1995)

The diagrams on previous page illustrate the fixed carbon (photosynthate) distribution in a Live Oak. Use it to answer questions 22 and 23 below;

22. The quantity of the manufactured food (photosynthate) distribution in a tree is governed by several factors. The following diagrams illustrate its possible distribution in a Live Oak under different shoot or root treatments.

Which of these choices indicate the correct sequence:

The shoot of a tree whose roots were pruned just before transplanting received____; while the tree whose canopy was topped (pruned) just before transplanting received____;

- a. normal; above normal
- b. above normal; below normal
- c. below normal; below normal
- d. above normal; above normal

23. Some campus Live Oak trees have their surface up to dripline covered with a growing grass carpet while others have only leaf mulch. Each of the two affect the Live Oak differently. Which of the following indicate the best answer;

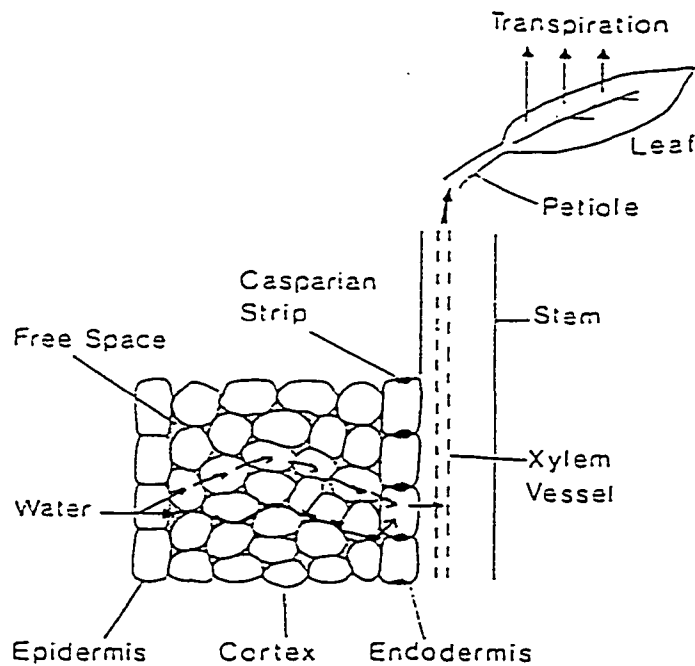
- a. Grass mulch is better than leaf mulch because it holds the soil strongly, stops soil erosion and supply some food to the roots of the Live Oak.
- b. Leaf mulch is better than grass mulch because it is more effective against soil compaction.

- c. Leaf mulch provide the plant with nutrients and at the same time stops competition that results from grass cover.
- d. Grass mulch substitutes for the leaf mulch well, and at the same time protects soil against erosion.

Use the diagrams on the following page to answer questions 24, 25 and 26:

24. A water molecule could move from soil to root to leaf to air and pass through a living cell only once. Where is the cell located ?

- a. In leaves
- b. In twigs
- c. In trunk
- d. In roots



Water pathways in the higher plant.

Figure 31. Movement of Water Through a Plant (Adopted from Mengel & Kirby, 1987)

25. Which of the following would be the best analogy for describing water movement in the xylem of a tree trunk?
- a. pumping blood with a heart

- b. opening the flood gates of a dam
- c. pushing water with an oar
- d. drinking through a soda straw

26. Which of the following has the lowest (most negative) water potential?

- a. soil
- b. root xylem
- c. trunk xylem
- d. leaf air spaces

Use these graphics to answer questions, 27, 28, and 29;

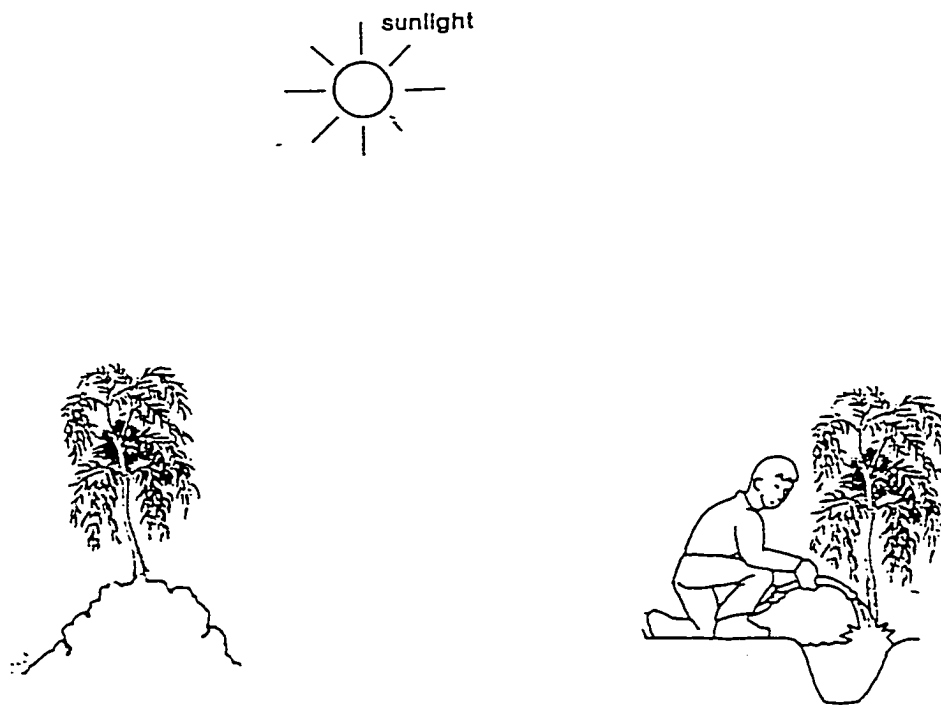


Figure 32. Cause of Wilting (Adopted from BSCS, 1990)

27. All trees suffering from excess water in the soil show symptoms quite similar to those which appear in trees which are suffering from drought. However structural nature of cells during the two processes of wilting differ in

their appearance. Cells that are affected by excess water are____; and cells that affected by drought are____;

Now choose the correct combination that would complete the last statement above:

- a. flaccid and normal c. turgid and normal
- b. turgid and flaccid d. flaccid and normal

28. You can kill house plant by over-watering them because excess water ;

- a. displace the nutrients from air spaces in soil.
- b. displace oxygen from air spaces in soil.
- c. enter the phloem tissue.
- d.cause some root burn.

29. Which of the following is one of the best sequence of events that may follow the process of over-watering:

- a Respiration stops -----> process that require some energy stops ---->essential nutrients not absorbed.
- b. Water suffocates the non woody roots ----> carbonic acid excessively formed----> Nitrate ions not absorbed.
- c. Root respiration increases ----> root micro-organisms lack food ----> the tree dies.
- d. Water suffocates the non-woody roots ----> Root micro-organisms lack energy ----> The affected roots bend to another direction.

Use the diagrams on the following page to answer questions 30, 31 and 32;

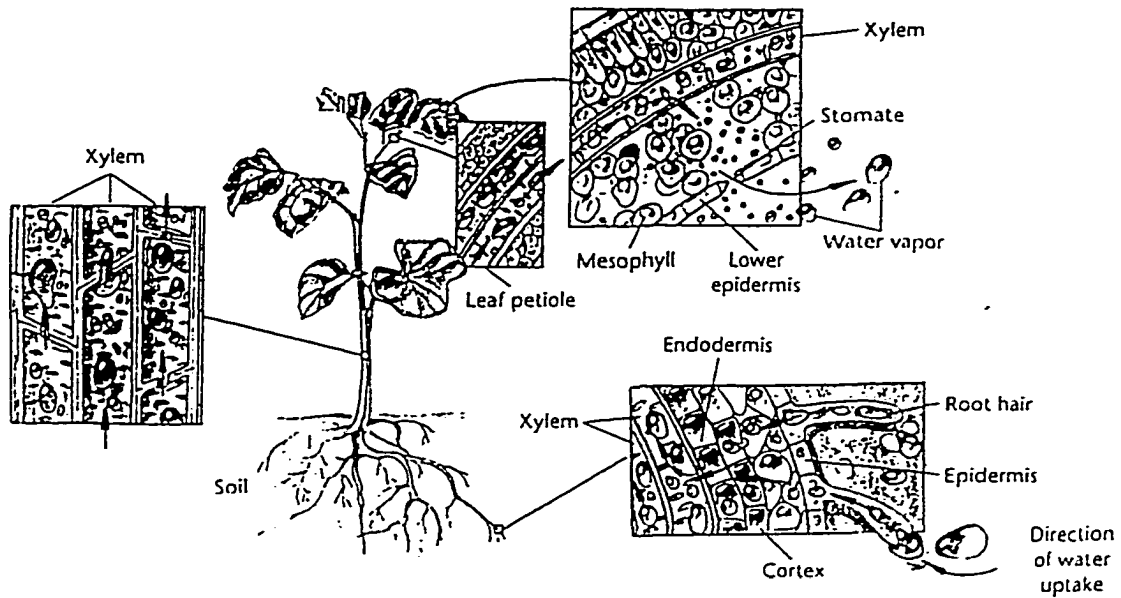


Figure 33. Effects of Wilting on Photosynthesis (Adopted from Essensfeld, Gontang & Moore, 1994)

30. Photosynthesis begins to decline when leaves wilt because
- flaccid cells are incapable of photosynthesis.
 - there is insufficient water for photolysis during light reaction.
 - stomata close, preventing CO_2 entry into the leaf.
 - the chlorophyll of flaccid cells cannot absorb light.
31. For a gas to enter cells of a leaf, the gas must;
- diffuse into the guard cells.
 - pass through several chloroplasts.
 - be dissolved in a thin film of water.
 - pass through its epidermal cells.
32. The O_2 released by plants during the process of photosynthesis is derived from;
- carbon dioxide taken through the leaves.
 - excess water taken in through the stomata.

- c. water taken in through the roots.
- d. metabolic wastes of photosynthesis.

33. Generally, the interdependence of roots and shoots can best be expressed as a functional equilibrium. Each compartment supplies essential materials for the growth of the other. As a result, there exists a specified shoot to root ratio. Which of the following diagrams represents an accurate pictorial representation of the shoot to root ratio of a Live Oak tree grown in a well aerated area?

34. During dry periods, the root shoot ratio of an oak tree will _____ while that of an oak that receives a regular amount of fertilizer mainly with fixed nitrogen will _____. The correct choice is;

- a. increase and decrease
- b. increase and increase
- c. decrease and decrease
- d. decrease and increase

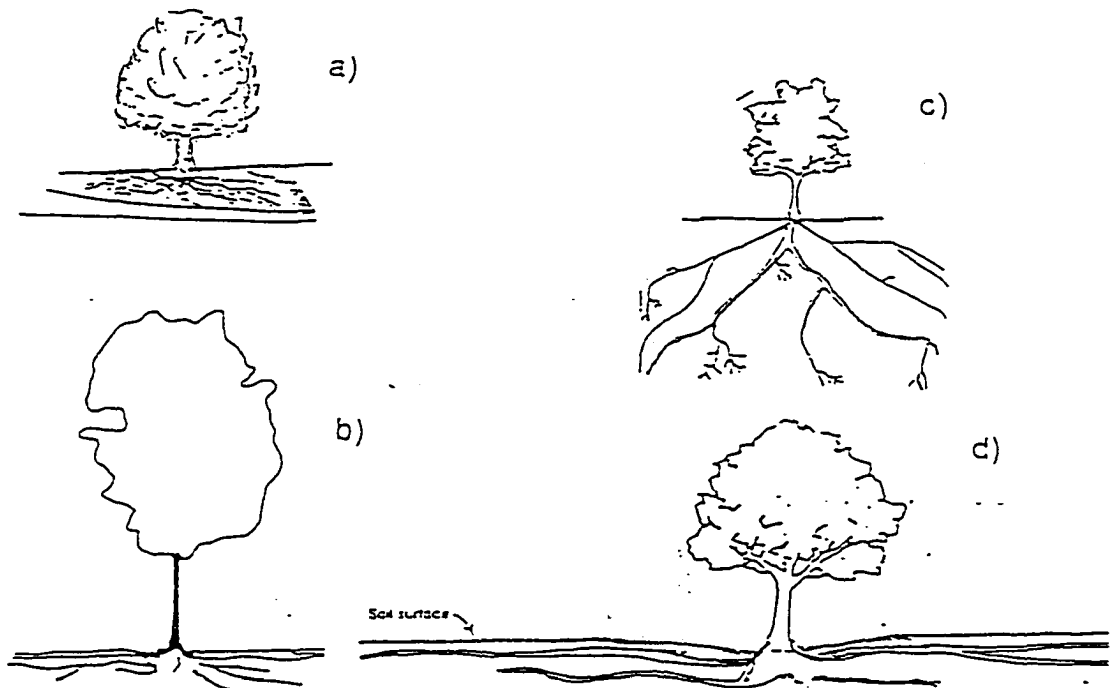


Figure 34. Factors that affect the Root Shoot Ratio (Adopted from Waisel et al., 1996)

35. The following diagram represents parts of a mature campus Live Oak.

Use the following diagram to answer question 36.

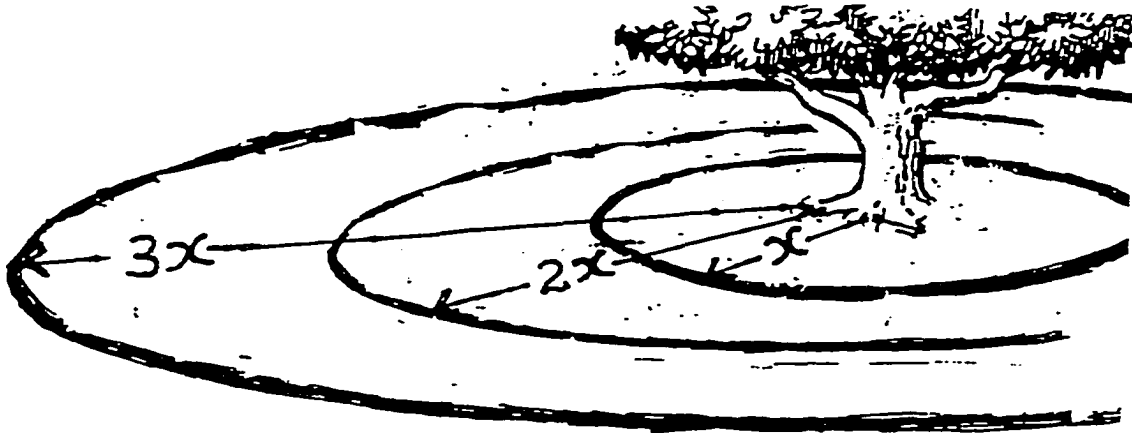


Figure 35. Spread of a Live Oak Roots (Adopted from Gilman, 1997)

Each of three students interviewed indicated by means circles how far they estimated the roots had extended from each side of the base of the tree. The first student indicated up to the edge of the canopy x , the second one indicated twice that distance and the third one three times that distance. Which of the three students was correct or nearly correct?

- a. the first (x).
- b. the second ($2x$).
- c. the third ($3x$).
- d. None of the three.

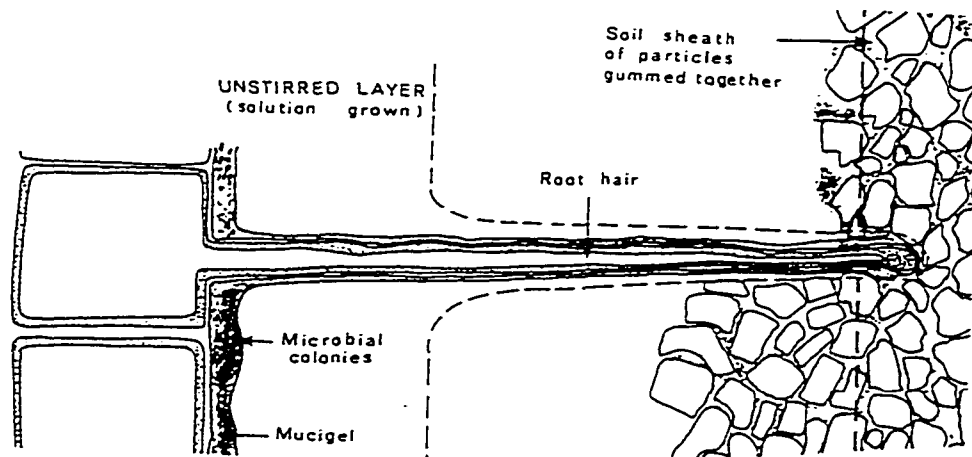


Figure 36. The Rhizosphere (Adopted from Waisel et al., 1996)

36. The rhizosphere is the area of soil immediately surrounding plant roots. In this region the;

- a. Organic nutrients leave the soil region and enter into root hairs.
- b. The inorganic nutrients enter the root hairs from the soil as organic nutrients enter the soil from the roots.
- c. Unused inorganic nutrients enter the soil from the roots in exchange of useful organic nutrients.
- d. None of the above.

37. (a) Give several reasons explaining how a Live Oak tree's ability to make food is affected by what happens in its root system such as the use of construction equipment near the Live Oak tree.

(i) _____

(ii) _____

(iii) _____

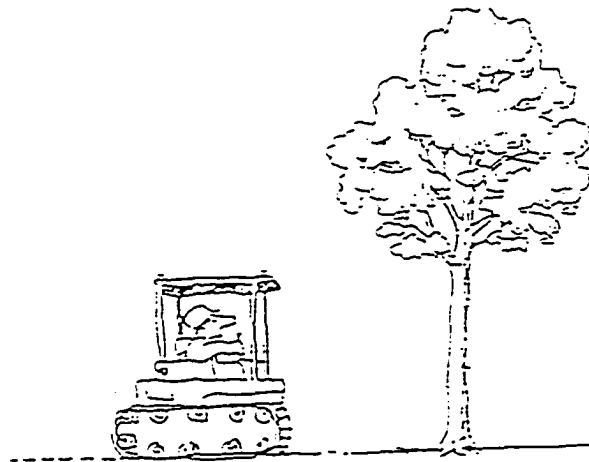


Figure 37. Effects of Root Compaction (Adopted from Popadic, 1995)
38. This diagram is an association of a Live oak tree's side root and some fungi.

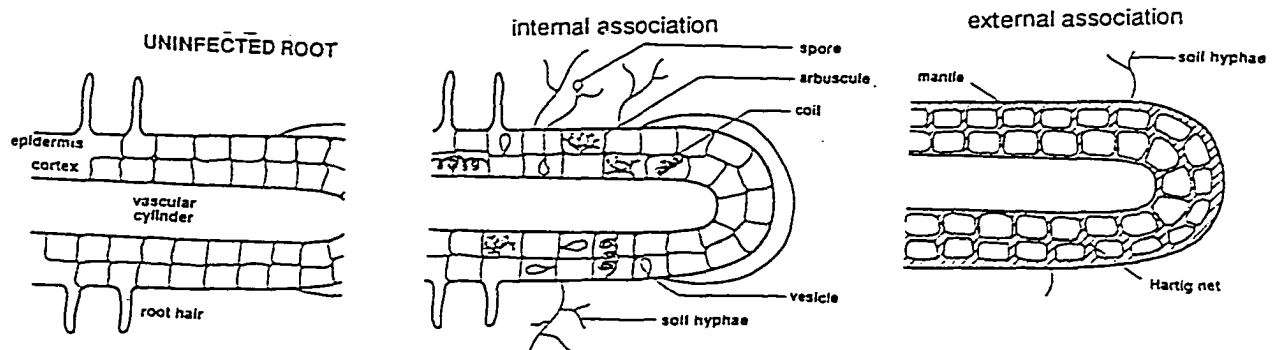


Figure 38. Non-woody Roots of a Live Oak (Adopted from Janerette, 1991)

Which one of the following statements is not true about this association?

- (a) it is part of the non-woody root system that absorbs water and the mineral elements dissolved.

- (b) it promotes formation of the root hairs of an oak tree.
- (c) it serves to connect trees of the same or different species.
- (d) it influences the plant to use more energy than other trees that do not have such an association.

39. How can a Live Oak tree support such a long side branch?

APPENDIX I: ROOT EXPERTS

Dr Donald H. Marx received his Bachelors of Science and Master of Science in Plant Pathology from the University of Georgia and has a Pd.D. in Plant Pathology from North Carolina State University, Raleigh, NC. He began his Forest Service career in 1958 as a technician. In 1975, he founded the Institute for Mycorrhizal Research and Development, Southeastern Forest Experiment Station, U.S. Department of Agriculture, Forest Service, Athens, GA. He later became its director. In 1990, he founded and was Director of the Institute of Tree Root Biology located in the same facilities. In 1994, Dr. Marx retired from the U.S. Forest Service after over 37 years of service. Since his retirement, he has presented several seminars and workshops on root and soil biology sponsored by various organizations in the tree care and horticultural industry. He has also published several articles in journals of various tree care organizations on commercial application of the mycorrhizal technology. Dr Marx is named in American Men and Women of Science, Who's Who in Frontier Science, Who's Who in America, Personalities of the South and Who's Who in the South. He authored over 230 scientific articles and has presented over 300 invitational lectures in Europe, South America, Asia, and Africa. He has received many awards, including the Marcus Wallenberg Prize, considered the equivalent of a Nobel Prize, by the King of Sweden in recognition of his research on tree mycorrhizae, his successful development of the pure culture inoculation technology, and the significance of this technology in reforestation and environmental restoration and stability. In 1993, he was awarded the U.S. Department of Agriculture Distinguished Science Award and was named Emeritus Scientist by the U.S. Forest Service.

Dr. Edward F. Gilman is an Associate Professor, Environmental Horticulture Department; University of Florida. He has worked with field arboriculturalists for a long time and has also written some educational material on trees for farmers as well as the middle schools. He authored a famous text book presenting the most comprehensive all-in-one-color tree guide for continental North America. This complete book includes the latest information on the cornerstones of tree management, selection, planting, establishment, and fertilization, while giving practical details on over 1000 species. More than 500 color photos make tree identification realistic and enables readers to easily select the right tree for the landscape. The book has a good guide about the tree selection process, *Trees for Urban and Suburban Landscapes* and is one of the most complete references on tree culture and management.

Dr. Blanche is currently working with USDA in Booneville, Arkansas. He is familiar with the Live Oak tree as a result of conducting some research on soil compaction at Louisiana State University while he was working at Southern University.

Each one of these scholars read the work on the root probe and gave very useful suggestions on changes that were necessary. The Louisiana arborist association invited me to their seminars from which I tremendously benefitted. I particularly want to thank its Chairman, Dr. Mark Guidry, for being very kind to me. Lastly, I would like to thank Randy Harris, the LSU landscape officer, for all the help he gave me. I particularly want to thank him for all the arrangements that he made for me to meet many root experts.

APPENDIX J: HUMAN SUBJECTS' STUDENTS CONSENT FORM.

Louisiana State University -- Department of Educ.
Institutional Review Board for Human Research.
CONSENT FORM:

Project Title:

How does undergraduate college biology students' level of understanding, with regard to the role of the seed plant root system, relate to their level of understanding of photosynthesis?

This consent form gives detailed information about the research study which you have been asked to participate in. You may decline participation or withdraw from this study at any time.

PURPOSE OF STUDY AND SELECTIONS OF SUBJECTS

1. You are invited to participate in a research study examining how you understand the parts and processes of a plant that influence its nutrition. You will answer some questions that will take about one hour.
2. This researcher hopes to learn how students best learn the seed plant as a system in an effort to improve instructional strategies in the teaching of botany.
3. You were selected as a possible participant in this study due to the biological course that you took.
4. If you choose to participate you may experience the following results:
 - a. Increased understanding of systematic thinking.
 - b. Improved understanding of plant nutrition in general and the process of photosynthesis in particular.
 - c. Improved study skills.

5. Participation in this study will not adversely influence your grade for any course in the biological sciences.

6. Some of you will be selected for the interview part of this study. This selection will not be based on the outcome of this first part only, but mainly on the outcome of random sampling.

7. The information that you will give will be treated confidentially and will be recorded in such manner that you cannot be identified, directly or through identification linked to you.

9. I have been fully informed of the above-described procedure with its possible benefits and the risk and I give my permission for participation (or participation of my child) in the study.

7. Questions or comments may be directed to the principal investigator:

Faculty advisor, Dr. Ron Good LSU ; EDCI Office Phone#

Home Phone#

Student James G. Njeng'ere, LSU; EDCI Office Phone# 504-388-6001

Home Phone

VITA

James Gicheha Njengere was born in Rift Valley Province, Kenya, where he received his elementary and high school education. He did a two year, post high school science program that led him to an early specialization in science. He joined the University of Nairobi where he graduated with a bachelor of science education degree with specialty in botany and zoology in 1977.

Mr Njengere has been a science educator for nearly 16 years. For 12 years he taught at ordinary level (K9-K12) and advanced level (Equivalent of Junior College) science in a number of high schools in Kenya. In 1990 he joined Egerton University as a member of teaching staff in the department of botany. For the last five years he has been a graduate assistant in the Center for Science and Mathematics Literacy, Louisiana State University, Baton Rouge, Louisiana. During that time James enrolled in the Department of Education and specialized in teaching of botany to college students. Currently he is a candidate for the degree of Doctor of Philosophy, which will be conferred in May, 1999.

Mr. Njengere is married to Agnes Njengere and is a father of three daughters (Keziah, Wambui, Ruth Nyambura and Eva Mwara) and one son (Isaac Njengere).

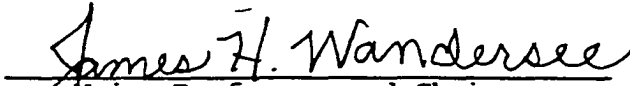
DOCTORAL EXAMINATION AND DISSERTATION REPORT

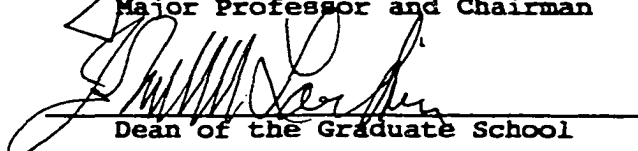
Candidate: James Njeng'ere

Major Field: Curriculum and Instruction

Title of Dissertation: How Does Undergraduate College Biology Students' Level of Understanding, in Regard to the Role of the Seed Plant Root System, Relate to Their Level of Understanding of Photosynthesis?


Approved:


Major Professor and Chairman

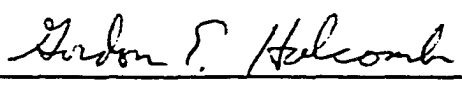

Dean of the Graduate School

EXAMINING COMMITTEE:





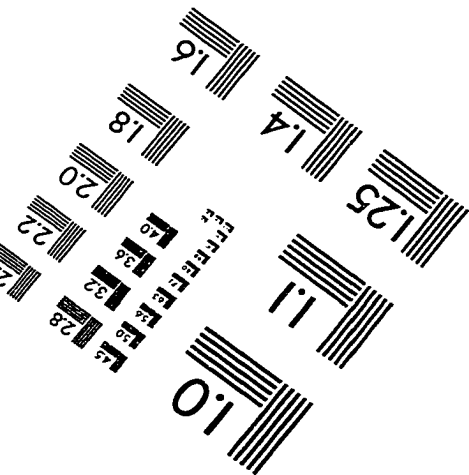
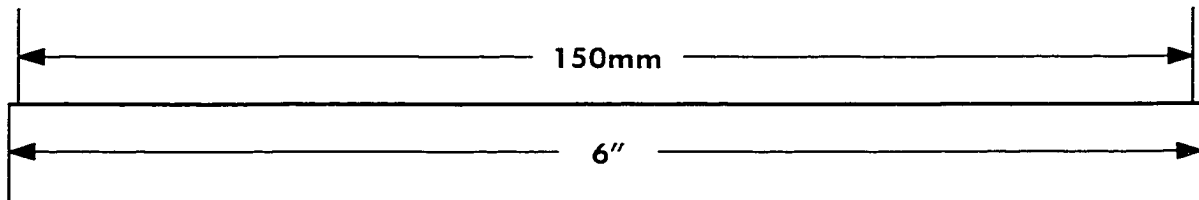
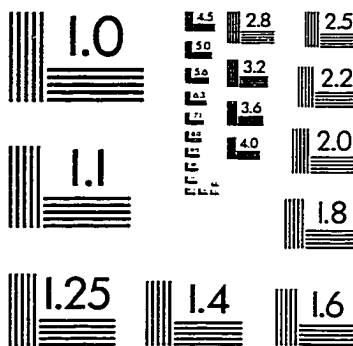
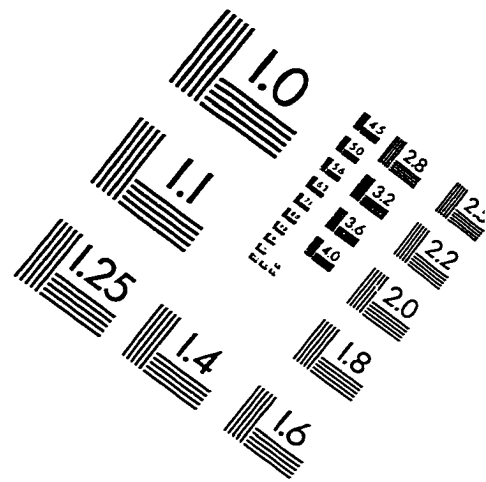
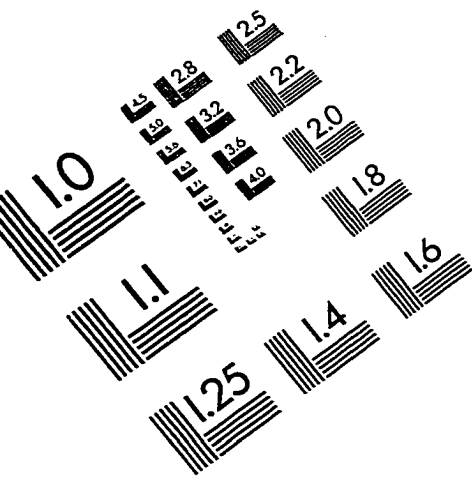




Date of Examination:

5 October 1998

IMAGE EVALUATION TEST TARGET (QA-3)



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