

SOLAR ENERGY: HOW IT IS HARVESTED BY THE LIVING THINGS

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.

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). While scientists use these 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). In the study of photosynthesis, such entities appear in the form of pigments, electron donor, electron flow, details of metabolic pathways, reducing power, and energy reactions, among others. Some laboratory experiences are means of relating these abstracts to the intuitive knowledge of the students. 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.

Obtaining Information About Students' Alternative Conceptions

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 make the discoveries potentially derivable from the experimental observations (Karplus & Thier, 1967). Science education researchers are looking to the day when they will be able to develop a good curriculum after having studied by direct means what students already know about a given discipline. An indirect way of doing this is to evaluate students' intuitive knowledge. Intuitive knowledge is contrary to what they are expected to learn, hence the name alternative conceptions. Evaluation of students' alternative conceptions relating to the plant nutrition can be done by:

1. conducting a pilot study with a large cross-section of students.
2. Thorough examination of the relevant literature dealing with the students' cognitive structures as they are documented in science education literature.

The findings obtained from the pilot study are matched with those documented in science education literature. A good curriculum can then drawn in an attempt to deal with these two sources of information. Teaching or instruction based on this approach turns out to be “undoing “ the intuitive concepts of the learner; hence the name, “conceptual change.”

Day One

Set the goals and objectives

1. Appreciate that all energy originate from the sun.
2. General understanding of photosynthesis, include brief details of the Calvin Cycle.
3. General understanding of respiration, include brief details of the Krebs Cycle.
4. Draw some Similarities between photosynthesis and respiration. Consider aspects of energy transfer.

Sun: The Source of All the Energy

Nuclear fusion Is a nuclear change in which two isotopes of light elements, such as hydrogen, are forced to unite together at an extremely high temperatures and pressure until they fuse to form a heavier nucleus. Temperatures of at least 100 million^o C are needed to force the positively charged nuclei (which strongly repel one another) to fuse. Fusion of hydrogen nuclei to form helium nuclei is the source of energy in the sun and other stars.

Laws of thermodynamics and interconversion of matter The vital and much celebrated equation

of Albert Einstein ($E=Mc^2$) comes into play when the fusion of elements at the sun takes place. Here, not all the mass (m) of hydrogen ($1.008 \times 4 = 4.032$) is converted into the mass of helium (4.026), but a small amount of this mass (0.006) is converted into some energy according to the equation of Albert Einstein $E=Mc^2$. The energy released is equivalent to

$E=0.006 \times (3 \times 10^8)^2$. This amount is enormous. Some of it proceed to the earth in the form of the electromagnetic radiation. About 0.1% of that hits the earth is trapped by the plants. Only plants have the ability to capture that energy in the form of the chemical energy. As these processes continue, the two laws of thermodynamics continue to operate in regard to the flow of that energy. At the sun, where hydrogen is being converted into helium, the first law operates just as it continues to operate when the electromagnetic radiation is reconverted into the chemical energy during the process of photosynthesis.

Only little of this electromagnetic radiation is converted into the chemical matter, thus obeying the second law of thermodynamics.

It is absolutely necessary for students to appreciate that solar energy can be used to do some work. Demonstrational experiments, like those done by Mr. Wizard can be used to illustrate this. One of them is shown below:

Effects of Different Colors on Reflection of Solar Energy.

Greater expansion of air in the black bag than that in the white bag. Some balloons were fitted in two different bags (see the diagram below). One of the bags was black, the other was white. The two bags were exposed to the blight sunlight for a while (half an hour is sufficient to bring about the required changes). Changes in the volume of the air in the bags was monitored by the changes of the volumes the balloons.

Observations The balloon fitted to the black bag was inflated but the one fitted to the white bag remained flaccid.

Explanations The black bag did not reflect light. Instead, it absorbed it and converted it into some heat energy. This heat energy increased the kinetic energy of the molecules of the air causing its expansion.

This forced the balloon to expand. It is worth noting that the principles involved, here, are the same that makes the hot air rise; the air in the black bag has fewer molecules, per given volume, than that of the surrounding air. As a result, the atmospheric air moves below the bag replacing the heated air in the black bag. It is necessary to note that the reverse is bound to happen if there is some very cold weather. The black bag will give away more heat energy to the surrounding air than the white bag would do.

(A class discussion; Energy as the force that moves matter and also required to maintain an order in any system. Any organism as being considered as a system and therefore being required for the processes that take place within it. This discussion can lead to the comparison of the black bag with the chloroplasts. An experiment to illustrate it can be set as follows.

Materials needed: fresh healthy springs of elodea plant (Anacharis, an aquarium plant); microscopes, slides and cover-slips.

Procedures Students may proceed to make slides as directed. Afterwards they compare what they see under the microscope with chloroplasts shown in a standard textbook of biology.

Guiding questions, such as, what are the green bodies that you can see under the microscope?

Expected response is that of identification, *chloroplasts*;

Guiding questions, what gives the green coloring to the chloroplasts:

Expected response is that of identification, chlorophyll.

Day Two

Separation of the Leaf Pigment by Paper Chromatography

A technique called Chromatography may be used to separate the chlorophyll pigments in a leaf. Explain to the students that chromatography has been known for many years and that it can be done in a variety of ways. Some of these ways can be technologically sophisticated. The one that they would perform then; paper chromatography was very basic. Paper chromatography work on the principle that different pigments, when dissolved in a solvent {such as water or ether), will move (travel) through a piece of paper at different rates of speed. The rate is determined by; 1. how soluble the pigment is in the solvent and, 2. The degree of adhesion of the pigment to the surface of the paper.

1. Obtain a piece of filter paper long and narrow enough to fit inside a test tube. *(A standard diagram of chromatography is essential).*

2. Crease the paper lengthwise to make it more rigid. Some extract has been prepared by macerating leaves in a small volume of acetone. This can be done either with a mortar and pestle or in an electric blender. By paper chromatography, you can separate the different pigments out of the leaf extract .
3. Get a test tube and add to it a small amount of solvent (about 1 cm or so in depth). The solvent is a mixture of 95 parts ether and 5 parts acetone. Plug the tube and set it aside.
4. Obtain a strip of paper long and narrow enough to fit inside a test tube(See the figure below) and crease it lengthwise.
5. With a medicine dropper, apply a few drops of the leaf extract to the filter paper strip about 2 to 3 cm from one end. Allow the spot to dry. Two or three repeated applications to the same spot may be needed. The spot must be dry before you proceed to step four.
6. Insert the paper in the test tube. Do not permit the extract on the paper to be directly wet by the solvent. Do not buckle the paper . Plug the tube and set it aside.
7. In a few minutes you will see the pigment begin to separate. As the solvent passes through the paper, the various pigments are dissolved in it move up the paper at different pace.

Examine the chromatography at frequent intervals because if pigment separation continues for too long, some of the pigments will be superimposed on each other at near the end of the strip.

The four pigments that separate out into their respective colors are:

1. Chlorophyll a: blue green color.
2. Chlorophyll b: olive green color.
3. Xanthophyll: pale yellow.
4. Carotene: orange yellow.

(*At this stage, the teacher may give details chloroplasts*).

PHOTOSYNTHESIS AN ANABOLIC REACTION

Anabolism is a general word for all the *building up process* that take place in an organisms. Photosynthesis is a general word for many anabolic processes that take place in plants. It is a form of nutrition, hence the synonym autotrophism, (auto=self, trophism= feeding) which literally means that plants feed themselves. What this means is that, plants organize low energy level inorganic nutrients into high energy level macromolecules (carbohydrates, proteins and lipids) from which they derive their food

a well as that of heterotrophs (hetero=different; implies feeding from elsewhere) which depend upon them for food.

Basic Understanding of Photosynthesis

Scientifically acceptable propositions. Shigo (1991) explained how a good 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 chemical 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. That is when solar energy is converted into chemical energy which is used in the carbon fixation (dark) phase. This phase occurs within the Calvin Cycle when CO₂ is reduced by a continuous supply of hydrogen ions [H⁺] and the electrons [e⁻] coming from water through NADPH as the O₂ is continuously released.

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. A Solution to this is to teach it in a broad framework before presenting the molecular details of photosynthesis.

Holistic Nature of a Plant

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).

- 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 plant 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. Shigo, (1991), explained that by relating the process of photosynthesis with its two phases, it is possible to see it as an emergent property of the intact chloroplast, which integrates the two stages of photosynthesis. Some factors prevents students from achieving the above propositions. Some of the major obstacles are understanding of the following: role of water, plant food, role of gases, and a tree as a single system.

Students' understanding of the process of photosynthesis is 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, among others.

Difficulty In Conceiving Gas as a Substance

As mentioned in earlier, students have some alternative conceptions or are not aware of basic facts about gases and how they relate to plant nutrition. I have chosen to deal with two of the familiar gases (O_2 & CO_2). Students mistake the process of photosynthesis for respiration of the plants or think that the process of respiration exists to restore the process of photosynthesis. As a result, they fail to relate the CO_2 taken in through the leaves with the water taken in through the roots. In a given reaction, gases are seen as possible source of other gases just as the liquids are a source of other liquids.

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 (Eisen & Stavy, 1987). 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 hold tenaciously to the alternative conception that CO_2 remains the same or is converted into another form of gas (mostly O_2). *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.*

Reactants and Products of Photosynthesis

Source of oxygen. Students' are required to appreciate that a gas can be formed from a liquid or from a solid the same way a solid can be formed from a gas. However most of the students hold to the alternative conception that O_2 originate from the CO_2 taken through the leaves (Eisen & Stavy, 1987). This 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. This problems may be caused by the summary equations of photosynthesis and respiration that are given in their textbooks indicating that photosynthesis is the opposite of respiration. The second one is based on intuitive reasoning that gases can only originate from other gases just as solids originate from other solids.

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 both the 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.

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. Understanding of the integration, complexity, dynamics, and the changes involved in all these processes required an

application of systems thinking (Shigo, 1991).

Day three

Students' Understanding of Plant Food

Students' understanding of plant food is 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" are treated as the main suppliers of this food. The absorbed food is supposed to supply the requirements of growth to the shoot. This conception confuses their understanding the role of autotrophism, a process that illustrates the plant's ability to manufacture its own food. Most people do not appreciate this as a system whereby parts of a plant and their processes are all involved in the process of photosynthesis (Shigo, 1991). Instead their textbooks explain many molecular level processes that are not familiar to them. Besides, they are not integrated with the macro- levels of the plant system. As a result, students are 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 lead them to relate plant nutrition to a form of heterotrophism, that is more familiar to them (Ausubel, 1963). The word "nutrients" influence them 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 students means the nutritional requirements of the tree. 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 reveal that students regard nutrients as more refined, prepared forms of plant food, probably as a result of excluding some unnecessary ingredients. Most students explain that plants absorb their food from the soil through the roots, and that it consists of water, nutrients and “other stuff” meaning the proportion of soil that is not in the nutrients.

Day four

The following is a brief account of photosynthesis: Photosynthesis is a two stage process; light phase and dark phase. In this context, the word *light* is correctly used, but it is important to realize that the word *dark* is somehow misleading since it implies that the phase takes place only in darkness, which is not the case.

Light Phase:

During the light phase solar energy is converted into two energy rich chemicals of; ATP (Adenosine triphosphate) and NADPH (hydrogenated nicotine-amide adenine di-nucleotide phosphate). The two are the only two chemicals compounds harvested during the light phase. The phase is in-turn organized into two sub-stages, namely; Photo-system one, and photo-system two. Since the two photo-systems are involved in the process of ATP synthesis, with the help of the sunlight, they are therefore called photo-phosphorylation (photo =sun; phosphorylation = making of ATP). Combined effects of the two phases generate ATP and NADH, both of which are highly energized. ATP synthesis occurs when excited electrons from *chloroplast a*, in the reaction center of photo-system two, are transferred from one carrier to another. As they do so, some energy is released in the course of these transfers. Meanwhile the energy levels of these electrons continue dropping as they progress to photo-systems one. (see the diagram below).

Primary

Acceptor

Energy----->

e⁻

Acceptor 1

(Plastoquinone)

Energy----->

e^-

Acceptor 2

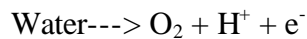
(Plastocyanin)

Energy----->

e^-

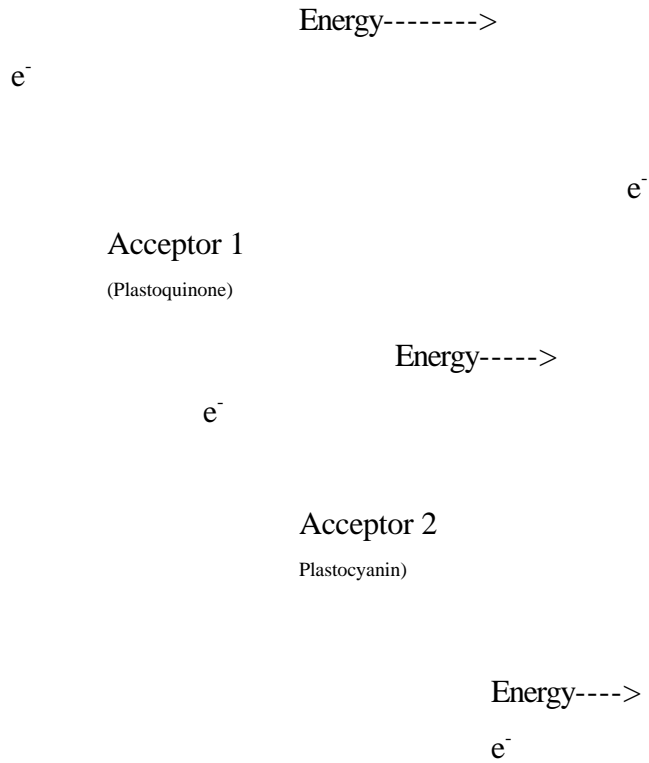
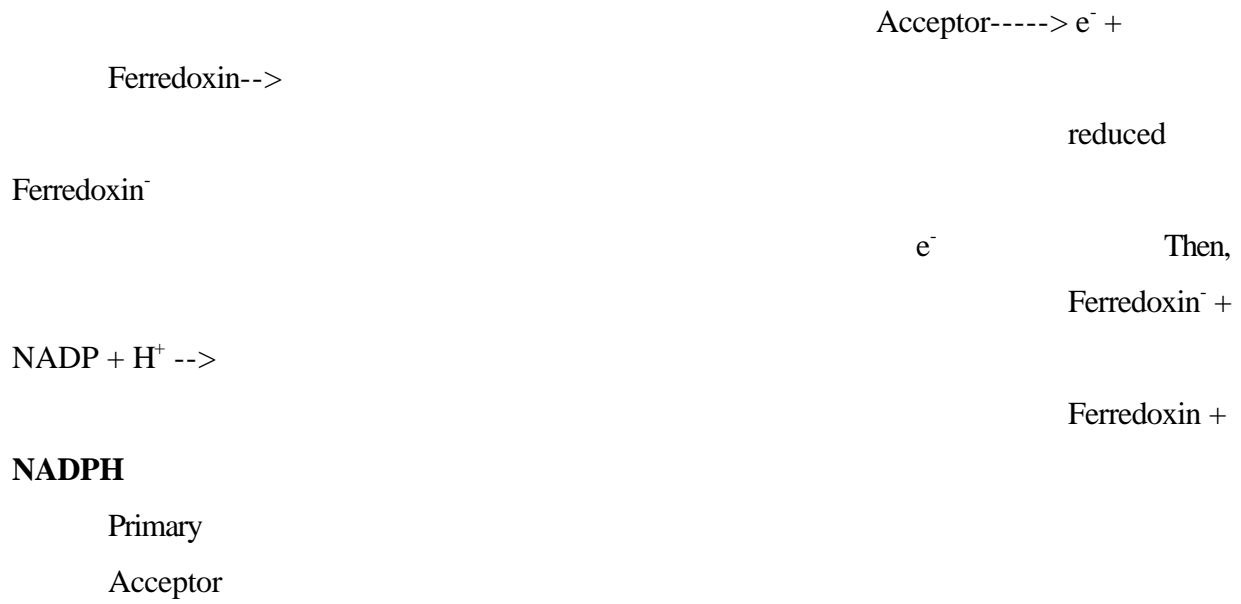
PHOTOSYSTEM I

PHOTOSYSTEM II



The released energy is used in transporting some protons [H^+] into the inner membrane of the chloroplast. As the protons accumulate therein, they build a concentration gradient. This gradient is reduced by a one way free flow of protons, along their concentration gradient (a form of osmosis called chemiosmosis). Meanwhile, the enzyme, ATP synthase complex, tap the energy from the free flow of protons by synthesizing some ATP (from ADP and some free phosphates). Once the electron has fallen to the lowest energy level, and has no more energy to give, then it is accepted in the slot of photo-system one. It is important to realize that electrons flowing from photo-system one do not return there, but, are instead, replaced by those flowing from water through photo-system two. Not only does the solar energy excite chlorophyll electrons but it also breaks water molecule into oxygen, which is released, as well as the proton ions, used at the end of photo-system one, and electrons. The electrons replace those lost by photo-systems one and two thereby creating un-interrupted flow of electrons. Meanwhile the solar energy will have activated the electrons in chlorophyll of photo system one. These excited electrons along with their energy are transferred into ferredoxin tht lead to the formation of *NADPH*. As mentioned earlier this *NADPH* is also used in the dark phase of photosynthesis.(see the chart below)

Primary



PHOTOSYSTEM I

Glucose

3 phospho
glycerates

ATP ADP

1, 3 Biphospho
glycerates

2ATP

2

ADP

[Low energy 3 C acid]

[High energy 3 C Acid]

Hexose

Biphos

hate

CALVIN

NADPH

Dihydroxy

CO₂

CYCLE

PO₄

3 phospho

acetone

glyceraldehyde

phosphate

Ribulose

3 phospho

Bi-phosphate

Regenerates some

glyceraldehyde

[5C]

----- ribulose biphosphate -----

[3 C Sugar]

1, 3

Biphos

pho

glycerates.

Hexose

Starch Glucose

2ATP 2ADP

Biphosphate

A

D

P

A

T

P

3 phospho

glycerate

DP

△

TP

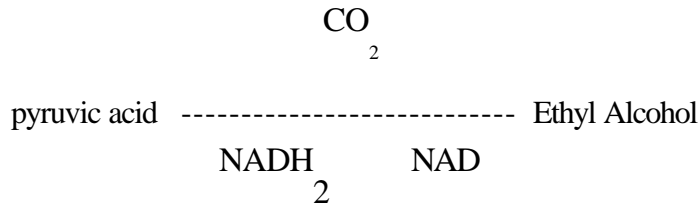
△

Pyruvic

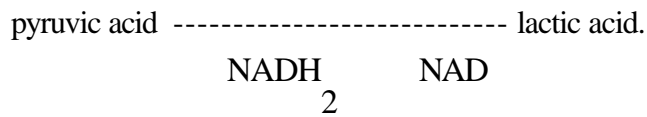
Acid

During the process of respiration, the stages beginning from glucose to the formation of pyruvic acid occurs in the cytoplasm, and are collectively called the process of GLYCOLYSIS. Glycolysis does not end up with the formation pyruvic acid as the final byproduct. Instead, pyruvic acid becomes the final acceptor of the hydrogens atoms released from the NADH_2 . The process of accepting them is different in plants from that of animals:

In plants, pyruvic acid is first of all decarboxylated before accepting these hydrogens. By doing this, it is converted into ethyl alcohol;

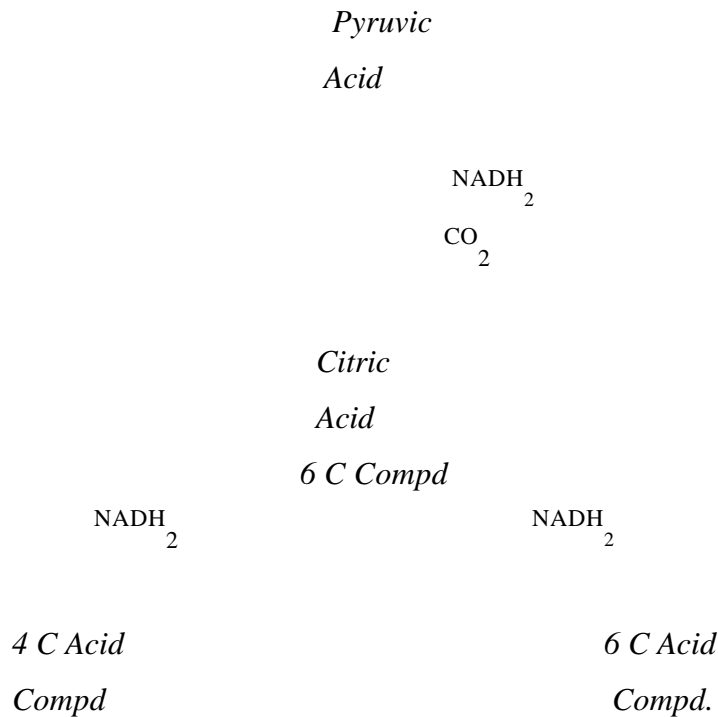


In animals, pyruvic acid accepts these hydrogens without having been decarboxylated. It is converted into lactic acid on accepting them;



Both methods are wasteful because only 8ATPs are harvested in those processes.

In presence of oxygen, the fate of pyruvic acid is the same for both plants and animals. It is decarboxylated and dehydrogenated, at the same time, into Acetyl Co-enzyme A, then ushered into Krebs Cycle where further dyhydrogenation and decarboxylation occurs as shown in the scheme below:





5 C Acid Compd

These NADH_2 are the source of most of the energy that is released during the process of respiration. Basically the process ATP synthesis in mitochondria is nearly the same as that of ATP synthesis in the chloroplast. The main difference is that the source of energy that generates the ATP is derived from the NADH_2 instead of being derived from the sunlight. A better way of relating the two is to recall the input of solar energy into generation of NADH_2 . It now comes the turn of the heterotrophs to generate energy from this NADH_2 . The NADH_2 molecule transfers e^- separately from **H**. These excited electrons are transferred from one carrier to another. As they pass along the carriers, energy is released in course of these transfers. Meanwhile their energy levels continue dropping in these processes. The released energy is used in transporting some protons [H^+] into the inner membrane of the mitochondria. As the protons accumulate therein, they build a concentration gradient. This gradient is reduced by free flow of protons, along their concentration gradient (a form of osmosis called chemiosmosis). Meanwhile, the enzyme, ATP synthase complex tap the energy, from this free flow of protons by synthesizing some ATP (from ADP and some free phosphates). Once the electron has fallen to the lowest energy level, and has no more energy to give, then it is accepted first by the (**H**) to become a hydrogen atom. These (H) atoms combine to form H_2 . The H_2 would become toxic if it were not for the oxygen that unite with them to form the non-toxic water molecule.

Harvested Energy

For each of the NADH_2 that goes through the electron transport pathway, 3ATP molecules are released. The FADH_2 enters through this pathway halfway through and so generate 2ATP molecules

instead of the three. Notice that after the hexoses molecule split into two parts we ended up with two identical pathways each of which generate the following:

$2 \text{ ATP} \times 2 \text{-----} > 4 \text{ ATP}$

$5 \text{ NADH}_2 \times 3 \text{ ATP} = 15 \times 2 \text{-----} > 30 \text{ ATP}$

$1 \text{ FADH}_2 \times 2 \text{ ATP} = 2 \times 2 \text{-----} > 4 \text{ ATP}$

Thus the total number of the ATPs is equal to 38 ATPs but since we had expended with two ATPs as we excited the Glucose to Fructose, then the net harvest becomes $38 - 2 = 36$ ATPs

Day six

ASSESSMENT

Obtaining Information About Students' Alternative Conceptions

The basic steps for developing diagnostic tests to evaluate students' alternative conceptions relating to the plant nutrition involves: 1. conducting a pilot study with a large cross-section of students. 2. Thorough examination of the relevant literature dealing with their cognitive structure. The findings obtained from the pilot study are matched with those documented in science education literature.

Construction of Test Items

For the identified alternative conceptions, several items are 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 are also used as a way of understanding students' alternative conceptions. Some of these alternative conceptions are deeply rooted in myths and stereotypes. . The development of these tests to date has shown that each item can be successfully refined to improve its diagnostic nature to identify alternative conceptions.

Source of plant food.

This concept is examined with the following task item that requires the students to identify the source of food used by the plant. This question is set because of the students' alternative conception (i.e., food comes from the soil). 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 diagram represents a tree 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).

Students alternative concept of nutrients as plants' food hinders, all the more, their understanding of the concept of plants' food. Most learners take nutrients to mean the same thing as humus, organic foods, and heterotrophically ingested material. The following task items are an attempt to investigate this:

.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.

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

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- (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 concept of fertilizers. The following task item tests students' understanding of the role and application of the fertilizer to trees. Fertilizers are nutrients. These 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. . 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 mineral elements.
- 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).

Role of the non-woody roots in absorbing nutrients. Task item 36 probes students' understanding of the exchanges that take place between the root and rhizosphere. Most students have not heard the word, rhizosphere, a familiar system boundary of the roots. Also, the task item investigates about the nutrients..

.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).

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

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

Understanding of Photosynthesis

The level of understanding the students have of the connections between the root system and the process of photosynthesis is investigated by the concepts of solar energy, gaseous exchange and the phenomena of autotrophism as system properties:

Solar Energy

Understanding of several aspects of the concept of solar energy were probed by means of the following task items

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 is 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.

Concept of interconversion of energy. Task item 13 probes students' understanding of the conversion of energy from solar to chemical. Most students do not appreciate that energy, when it is converted to another form fails to exist in the previous form.

.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.

Light Absorption Against Starch Synthesis

Percent of
light energy
reflected

The kind of colored light

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

The Concept of Gaseous Exchange and Transpirational Pull Few students know that the final effect of wilting is to cut off the CO₂ supply to the leaves.

.This concept was tested by task item 30 of the root probe. 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.

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

Role of gases. Most students hold some conceptions that: either that trees carry out the process of photosynthesis all the time, or that trees release O₂ all the time in exchange of CO₂. Many students regard photosynthesis as the respiration of the plant (Eisen & Stavy 1988). The following task

item investigates 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 are 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.
- c. roots absorb oxygen continually.
- d. leaves absorb carbon dioxide continually.

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

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.

Allocation of Photosynthates.

The following task item may be one of the most difficult task probe items to the students.

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. The following task item probes participants' understanding of the dynamics of reactants and products that are involved in the process of photosynthesis. The task item requires 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.

.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.

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