**Teaching the Concept of Photosynthesis in 4U Biology**

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Background Information: Photosynthesis

Q: Can you think of one living thing that does not require oxygen for survival?

A: Aside from some forms of bacteria, nearly all living things need oxygen to survive. Photosynthesis is a very important process that is responsible for providing oxygen to the environment. By using energy from sunlight, water from soil and carbon dioxide from the atmosphere, plants produce oxygen and carbohydrates (i.e., glucose). This allows plants to feed themselves and become food sources for other organisms.

“Each year, trees and other plants of Canada’s boreal region convert about 12.5 million tones of carbon, as carbon dioxide from the atmosphere, into carbon compounds [glucose] that help sustain their own lives and those of billions of other organisms” (Carter-Edwards et al., 2011)

The **process** of photosynthesis is summarized in the following equation:

6 CO2 (g) + 6H2O (l) + energy 🡪 C6H12O6 (s) + 6O2 (g)

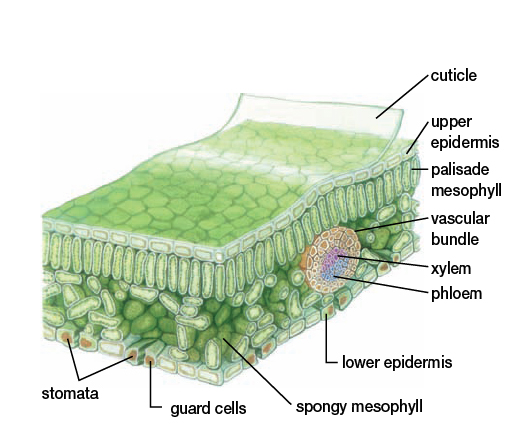
There are two types of reactions that take place during the process of photosynthesis:

1. **Light-dependent reactions:** *Photo*, meaning light, refers to the reactions that capture light energy from the sun. This light energy is used to create two high-energy compounds: ATP and NADPH.
2. **Light-independent reactions:** *Synthesis*, refers to all the reactions that produce carbohydrate. The energy of ATP and the reducing power of NADPH are used to make an organic molecule (i.e., glucose).

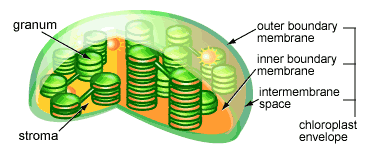
(Carter-Edwards et al., 2011)

**So, where does it all happen?**

**……..**



**Leaf Cross Section**



thylakoid

**Chloroplast**

Figure 1.1 (Pighin, 2003; Toronto Prep, 2012)

Refer to figure 1.1 above for a cross-sectional view of a plant leaf and a chloroplast. Photosynthesis takes place inside specialized cell organelles called **chloroplasts.** Water enters the leaf through leaf veins (**xylem**) and carbon dioxide enters through small openings called **stomata**. The carbon dioxide and water diffuse into the plant cells and enter the chloroplast, where photosynthesis will take place. A typical leaf has millions of chloroplasts per square millimeter! (Carter-Edwards et al., 2011)

Inside the chloroplast, there are interconnected disks called **thylakoids**. They look like flattened sacs, stacked one on top of the other to form structures called **grana** (singular = granum). Inside the thylakoids are tiny compounds called **photosynthetic pigments** that will absorb energy from the sun during the process of photosynthesis. The grana are surrounded by a fluid-filled interior, called the **stroma**. The stroma holds the enzymes that will be used to speed up the conversion of carbon dioxide and water into carbohydrates. (Carter-Edwards et al., 2011)

**So, how does it all happen?**

**……..**

Chloroplasts contain two types of photosynthetic pigments: **chlorophyll *a***and **chlorophyll *b***. These pigments absorb light energy, which initiates the light-dependent reactions (refer to figure 1.2). However, these pigments do not absorb light independently. They form clusters with other pigment molecules and are associated with a specific group of proteins. These pigment and protein clusters, called **photosystems,** are embedded in the thylakoid membranes. Plants and algae contain 2 types of photosystems that each absorb different wavelengths of light: photosystem I and photosystem II (Carter-Edwards et al., 2011).

These photosystems, as well as a **hydrogen ion pump (B6-f)**, work together to split a water molecule in order to convert NADP to NADPH, a high-energy compound. Finally, hydrogen ions build up inside the thylakoid space and can not diffuse back across the membrane into the stroma. An **ATP Synthase** enzyme provides the only pathway for hydrogen ions to move to an area of lower concentration in the stroma. As hydrogen ions move through the ATP synthase enzyme and back into the chloroplast stroma, ATP molecules (high energy compounds) are generated (Carter-Edwards et al., 2011).

Figure 1.2 (Wikipedia, 2012)

Are we done yet?

The NADPH and ATP produced in the light-dependent reactions, as well as certain enzymes in the stroma of the chloroplast, are used to convert carbon dioxide into carbohydrates (i.e., glucose). This process can occur in the absence or presence of light. Therefore it is known as a **light independent reaction**. The conversion of inorganic carbon, in the form of carbon dioxide from the atmosphere, to organic carbon, in the form of a carbohydrate (G3P), occurs through a process known as the **Calvin Cycle** (see figure 1.3)**.** The product of the Calvin Cycle, G3P, can be used to create other sugars, such as glucose.

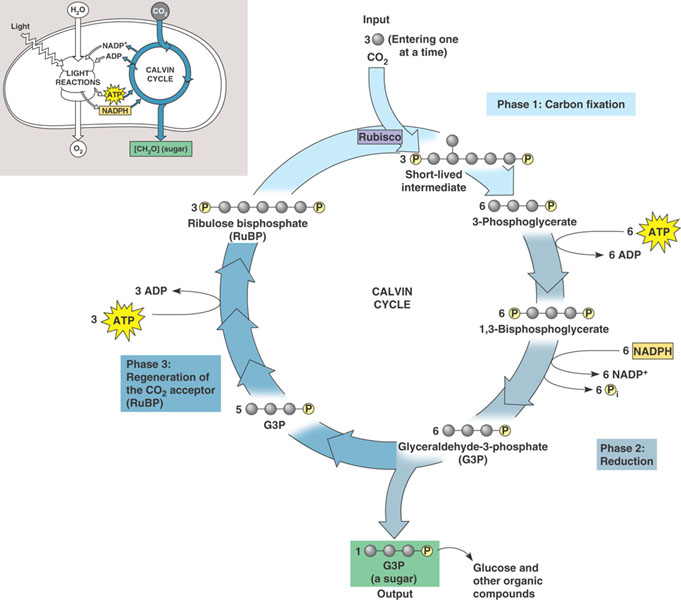


Figure 1.3 (Google Images, No source)

In summary, photosynthesis involves a combination of separate reactions in order to use light energy to convert water and carbon dioxide into oxygen and glucose. Refer to figure 1.4 for a general summary of the entire process of photosynthesis.

Advance Preparation/Teaching Strategies

Prior to this unit on photosynthesis, students should have been taught about cellular respiration. As well, students should have a general understanding of plant cell anatomy and function. To introduce the topic of photosynthesis and diagnose student background knowledge, begin with **discussion/oral investigation** on where our energy comes from. Ask the question: Where does all of the energy on the planet come from? Have students backtrack the process to arrive at sunlight.

After discussion, show students the first introductory video that emphasizes the importance of photosynthesis for the survival of life (see link below). Then, show students the second introductory video, which will help students visualize the “big picture” of the process of photosynthesis and key physiology (see link below). The teacher should be sure the videos are set up in an appropriate file for viewing on the SmartBoard.

During the videos, students will be asked to add notes to a personal **KWL Chart** (see attached). After the video, students will be asked to share their ideas so that the class can create a master KWL chart. The teacher should be prepared with chart paper and markers to complete this interactive KWL chart (interactive writing) activity. This chart will be used through out the unit as a reference for students to set goals, monitor learning and track progress. Students will be asked to hand in their individual KWL charts completed during the video presentation.

After the discussion on photosynthesis using the KWL chart, students will assemble in the computer lab. Prior to this activity, the teacher should be sure to sign out the computer lab for that class period and give students clear instructions on accessing necessary files. Students will access a link within their class folder that will open a **Virtual Gizmo Lab activity** on Photosynthesis (see link below). Through this lab, students will explore and manipulate variables that affect the rate of oxygen production through photosynthesis (i.e., light intensity, carbon dioxide, temperature, wavelength of light). From this lab, students will gain a better understanding of the process of photosynthesis and the ideal conditions necessary for photosynthesis to occur. They will demonstrate this knowledge by completing the online Student Exploration Sheet affiliated with this lab activity.

After the virtual lab activity, students will return to the classroom where they will take part in a **photosynthesis game board activity**. The teacher should be prepared with a game board template, as well as pre-made game cards. Each group of students (collaborative learning) will be given game cards that will have hold the name of part of a step in the process of photosynthesis (i.e., carbon dioxide, oxygen, chloroplast, glucose, etc.). Students will work together to place their game card in the correct location on the game board in order to display the overall photosynthetic process. As students progress through the unit of photosynthesis, the class will re-visit the game board to add more game cards (i.e., number of ATP, Hydrogen ions, photosystems). By the end of the unit, the class will have complete game board that shows all the detailed steps in photosynthesis. Using dice, students can make their way around the game board by answering a trivia question about the game card that they land on. As an enrichment activity, students can add challenges to the game board and create new trivia questions.

Other teaching strategies and resources to supplement subsequent lessons:

* PowerPoint presentation of concept highlighting the structure of chloroplasts, the thylakoid membrane, light-dependent/independent stages, and the Calvin cycle. Lots of diagrams and figures should be used to visualize the process as well as worksheets for the students to summarize/draw the processes.
* Online photosynthesis quiz can be used as diagnostic or formative assessment.

<http://www.biologycorner.com/quiz/qz_photosynthesis.html>

* Class role play that acts out the process along the thylakoid membrane. Have students act as proteins, hydrogen, oxygen, ATP, NADPH, etc. and use basket balls as electrons. As the electrons are passed down the thylakoid membrane, each student carries out their function by: breaking away from other students (e.g. 3 students making up a water molecule brake down into hydrogen and oxygen), adding another student to a group (NADP forms NADPH by adding a hydrogen), etc. If there are not enough students have single students act out transformations such as ADP becoming ATP, water breaking down, etc.
* Online interactive activity simplifying the reactants, products, and process of photosynthesis in fun way.

<http://www.pbs.org/wgbh/nova/nature/photosynthesis.html>

* Photosynthesis lab experiment in which students design and carry out an experiment to test how different light sources can affect the rate of photosynthesis on spinach leaves. Full written lab report can be assessed for this activity.

<http://serc.carleton.edu/sp/mnstep/activities/26481.html>

* Chromatography Lab: This lab activity allows students to see the pigments inside of the chloroplast. Students discover that green is not the only pigment in plant cells.

<http://www.phschool.com/science/biology_place/labbench/lab4/intro.html>

* Photosynthesis Jeopardy: Using Jeopardy Software, students can review key concepts from the photosynthesis unit.
* Also, see the references section for more activities to support this unit.

Curriculum Expectations

**C2.1** use appropriate terminology related to metabolism, including, but not limited to: *energy carriers, glycolysis, Krebs cycle, electron transport chain, ATP synthase, oxidative phosphorylation, chemiosmosis, proton pump, photolysis, Calvin cycle, light and dark reactions,* and *cyclic and noncyclic phosphorylation* [C]

**C2.3** conduct a laboratory investigation of the process of photosynthesis to identify the products of the process, interpret the qualitative observations, and display them in an appropriate format [PR, AI, C]

**C3.2** explain the chemical changes and energy conversions associated with the process of photosynthesis (e.g., carbon dioxide and water react with sunlight to produce oxygen and glucose)

**C3.3** use the laws of thermodynamics to explain energy transfer in the cell during the processes of cellular respiration and photosynthesis

**C3.4** describe, compare, and illustrate (e.g., using flow charts) the matter and energy transformations that occur during the processes of cellular respiration (aerobic and anaerobic) and photosynthesis, including the roles of oxygen and organelles such as mitochondria and chloroplasts

Lesson Sequence:

LESSON 1: **Introduction to photosynthesis: An overview**

* Importance, Photosynthetic Organisms, Physiology, The Photosynthetic Process: Big Picture

LESSON 2: **The Absorption of Light Energy**

* Photons and Wavelength, Pigment/Chlorophyll, Photosystems

LESSON 3: **Light-Dependent Reactions: Photosystems and ATP Synthesis**

- Z diagram, B6-f Complex (Hydrogen Pump), Making ATP by Chemiosmosis

LESSON 4: **Light Dependent Reactions: Making ATP by Chemiosmosis**

- ATP Synthase Enzyme, Phosphorylation

LESSON 5: **Cyclic versus Non-Cyclic Photophosphorylation**

- Two methods for ATP production by chloroplast

LESSON 6: **Light-Independent Reactions: Calvin Cycle**

- Carbon dioxide fixation, Reduction, Regenerating RuBP

LESSON 7: **The Energy Cycle**

- Compare Aerobic Respiration with Photosynthesis

Potential Student Difficulties and Possible Solutions

* Photosynthesis consists of **light-dependent and light-independent reactions**. Students tend to think of photosynthesis as one large reaction that uses only sunlight as a reactant, when in fact, it is a series of many reactions and light is only required in the first stage.
* Plants respire just like humans. Photosynthesis is used to create energy, which is stored in the form glucose, starch, etc. However students must understand that this energy must be broken down through respiration so that it can be used at the cellular level by the plant. Thus, plants must respire both in the day and at night. To help students see the **relationship between stored energy and useable energy**, teachers can use a carrot demonstration. Carrot plants store energy in the orange tap root (the part of the carrot that you eat) but when it comes time to flower, the plant will use this stored energy to reproduce and thereby shrivel up the tap root by using its stored sugars/starch. Also, to help students see the **relationship between respiration and photosynthesis**, students can conduct an experiment where an aquatic plant is placed in a test tube filled with water and sealed with no air bubbles. The test tube is covered with aluminum foil so light is unable to enter. The plant over night for a day or two. Little air bubbles appear inside the test tube, but they are not oxygen as a result of photosynthesis because there was no light. Instead, they are carbon dioxide bubbles as the plant still respires in the absence of light.
* The **electron transport chain** along the thylakoid membrane and the **Calvin cycle** are both fairly complicated processes. Students often find these topics daunting or overwhelming. Teachers should use many visual strategies for teaching these topics, such as diagrams, online simulations, role-play, mnemonics, color-coding, etc.

Differentiated Assessment and Evaluation

**Assessment for Learning:**

* Class Discussion: Where does energy come from? (K, T/I)
* KWL Chart (K, T/I)

**Assessment as Learning:**

* Classroom Lab activities (i.e., photosynthesis Lab with spinach leaves) (K, T/I)
* Case Studies (T/I, C, A)
* Exit Slips (i.e., One thing I learned today…) (K)
* Quizzes (K, T/I, C, A)
* Photosynthesis Board Game (K, T/I, C)
* Virtual Labs: Lab Exploration sheet (K, T/I, C, A)
* Class Role-play (K, C)
* Re-visiting KWL Chart (K, T/I)
* Photosynthesis Jeopardy (K)

**Assessment of Learning:**

* Unit Test (K, T/I, C, A)
* Culminating Task: RAFT activity - Students will take on the role of a scientist in working in a field related to one of the three “hot topics” associated with photosynthesis (artificial photosynthesis, deforestation or global warming). They will research their topic and design a brochure, newspaper article, poem, or other written format of their choice, to educate the community on their topic. Students will be assessed based on the four categories of achievement: Knowledge, Thinking/Investigation, Communication and Application.

**Special needs/ELL students**: consider simplifying diagrams by not including the names of the proteins in the thylakoid membrane or the structures of the molecules at the different stages of the Calvin cycle. As well, scaffold student learning by having students fill in the blanks on assignments such as labs, diagrams, etc. Use songs (i.e., <http://www.youtube.com/watch?v=Q_1mxZdF2TY>), rhymes and poems to help these students retain important information. Also, students could use molecular model kits to visually represent reactions in the photosynthesis process.

**Enrichment:** Allow opportunities for students to create their own laboratory activities using materials provided by the teacher. Students can investigate variables that can affect photosynthesis, based on student interest (i.e., water stress, drought, chemicals, type of plant, etc.). The teacher could provide a **“Challenge Box”,** where students could draw out index cards that would present questions for students to answer through investigation and inquiry.

Applications and Societal Issues (STSE)

* Fuel Production through Artificial Photosynthesis: Students will learn how scientists are using solar energy to generate hydrogen through a process called **artificial photosynthesis**. Hydrogen can be used a fuel source. Through artificial photosynthesis, solar energy can be used to split water into hydrogen and oxygen in a laboratory. Students can debate the pros and cons of artificial photosynthesis through reports, T Charts and class discussions. This can also bring up ethical concerns regarding the topic of “humans mimicking nature”! (Carter-Edwards, 2011).
* **Global Warming** and its affects on photosynthesis. Students can explore the global warming debate and how plant productivity is related. It is shown the rising CO2 levels increase the rate of photosynthesis and plant productivity. As a result, scientists should see that over time, a there would be a positive affect on the current CO2 levels. Is this a solution to global warming? Students can take on the role of a scientist and conduct research to present their opinions in the form of a RAFT activity (see links below).
* **Deforestation:** Plants removes the carbon dioxide that humans pump into the atmosphere. Deforestation due to agriculture, logging, and other activities, will negatively impact the level of carbon dioxide in the atmosphere (see links below)

Annotated Internet Addresses

**Importance of Plants and Photosynthesis**

Gregorio Educational Production. 2009. Introduction to Photosynthesis. *You Tube.* Retrieved July 16, 2012, from <http://www.youtube.com/watch?v=zEgIO9Kq2_Y>

This link takes you to a video that emphasizes the importance of plants and photosynthesis. Use this as the first introductory video.

**Overview of the Process of Photosynthesis**

Alberts, et al. 2004. Essential Cell Biology*,* Second Edition. [*Garland Science Publishing*](http://www.garlandscience.com/) *Inc.* Retrieved July 16, 2012, from

<http://www.sumanasinc.com/webcontent/animations/content/harvestinglight.html>

This link takes you to a video that gives an overview of the process of photosynthesis. It is used as the second introductory video to introduce the concept of photosynthesis to students.

**KWL Chart**

Sarzinski, P. n.d. Planning, Assessing, Evaluation. *School of Education: University of Michigan.* Retrieved July 16, 2012, from

<http://sitemaker.umich.edu/pamsarzynski/planning__assessing__evaluating>

There are many resources for KWL charts on google images. The link above is just one example of a KWL chart taken from google images. This chart is also attached below for your convenience.

**Photosynthesis Gizmo**

Explore Learning. 2012. Photosynthesis Lab. *Gizmos.* Retrieved July 15, 2012, from

<http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=395>

This link takes you to the online Gizmo Lab on Photosynthesis.

**Photosynthesis Game Board Activity**

Anselmi, K. 2011. Photosynthesis Board. *The NSTA Learning Centre.* Retrieved July 16, 2012, from

<http://learningcenter.nsta.org/discuss/default.aspx?tid=6yyVQG5vNMI_E>

This link will give a template for the Photosynthesis Game Board activity noted within the Teaching Strategies and Advance Preparation section of this summary.

**Deforestation**

Global Greenhouse Warming. n.d. Deforestation. *Google.* Retrieved July 17, 2012, from

<http://www.global-greenhouse-warming.com/deforestation.html>

**Rising Carbon Dioxide is Great for Plants**

Wittwer, S. 1992. Rising Carbon Dioxide is Great for Plants. *Policy Review.* Retrieved, July 16, 2012, from

<http://www.geocraft.com/WVFossils/Reference_Docs/CO2_good_for_plants.pdf>

This link gives insight into the global warming debate and how it relates to plants and photosynthesis. It introduces the argument over global warming and proposes that even though rising CO2 levels are dangerous for many reasons, they also increase plant productivity.

**RAFT Activities**

Saskatoon Public Schools. 2004-2009. What is Raft. *Instructional Strategies Online.* Retrieved July 17, 2012, from

<http://olc.spsd.sk.ca/de/pd/instr/strats/raft/>

This link explains the RAFT technique.

**The Calvin Cycle**

Kent, G. 2004. Carbon Fixation in Photosynthesis. *Biology 203 Cell Biology Laboratory, Smith Edu.* Retrieved July 17, 2012, from

<http://www.science.smith.edu/departments/Biology/Bio231/calvin.html>

This link provides an interactive video on the Calvin Cycle. Students can observe the 3 stages of this cycle.

**Photosynthesis Leaf Lab (online simulation)**

Science Courseware.org. 2005-2008. Leaf Lab. *Virtual Courseware Project.* Retrieved July 15, 2012, from

<http://www.sciencecourseware.com/BLOL/screenshots/leaflab.html>

**Process of Light Reactions (online simulation)**

Kyrk, J. 2012. Light Reactions. *Cell Biology Animation.* Retrieved July 16, 2012, from

<http://www.johnkyrk.com/photosynthesis.html>

This link provides a simulation of the light reactions in photosynthesis. You can also access a simulation of dark reactions from this website.

**How Light Affects Photosynthesis**

<http://www.mhhe.com/biosci/genbio/biolink/j_explorations/ch09expl.htm>

In this activity, students can manipulate light and see the effects on photosynthesis.

**Lessons, Overviews, Videos and simulations of photosynthesis**

Muskopf, S. 2012. Cellular. *AP Biology.* Retrieved July 16, 2012, from

<http://www.biologycorner.com/APbiology/cellular.html>

**Photosynthesis Diagrams**

Wikipedia. 2012. Photosynthesis. *Wikipedia Foundation Inc.* Retrieved July 17, 2012, from

<http://en.wikipedia.org/wiki/Photosynthesis>

Toronto Prep School Biology. 2012. Plants – Anatomy, Growth and Function. *Tangient LLC.* Retrieved July 16, 2012, from

<http://tpsbiology11student.wikispaces.com/Plants+-+Anatomy,+Growth,+and+Function>

Pighin, J. 2003. Capturing the Sun: An explanation in the World of Plant Science. *The Science Creative Quarterly.* Retrieved July 16, 2012, from

<http://www.scq.ubc.ca/capturing-the-sun-an-exploration-into-the-world-of-plant-science/>

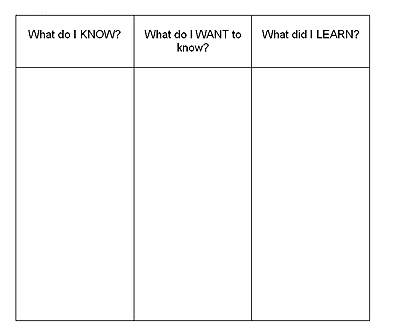
All diagrams, aside from the photosynthesis summary, were found using Google images.

Annotated References

Carter-Edwards, Trent et al. 2011. *Biology 12*. Canada: Mc Graw-Hill Ryerson Limited.

This textbook is a great source of background information for the process of photosynthesis.

**KWL Chart – Unit on Photosynthesis**



(Google Images)