Teacher Notes for "Using Models to Understand Photosynthesis"[1]

In this analysis and discussion activity, students develop their understanding of photosynthesis by answering questions about three different models of photosynthesis. These models are a chemical equation, a flowchart that shows changes in energy and matter, and a diagram that shows the basic processes in a chloroplast. Students learn about the role of scientific models by evaluating the advantages of each of these models for understanding the process of photosynthesis.

This activity is intended to be part of a series of related activities that foster student understanding of cellular respiration and photosynthesis (see "Cellular Respiration and Photosynthesis – Important Concepts, Common Misconceptions, and Learning Activities" (https://serendipstudio.org/exchange/bioactivities/cellrespiration).

Learning Goals

In accord with the Next Generation Science Standards[2]:

- Students prepare for the Performance Expectation:
  - HS-LS1-5. "Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy."
- Students learn the following Disciplinary Core Idea:
  - LS1.C: "The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen."
- Students engage in recommended Scientific Practices, especially:
  - Using Models, "Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations."
- This activity can be used to illustrate two Crosscutting Concepts:
  - Systems and system models, including
    - "Models can be used to represent systems and their interactions – such as inputs, processes and outputs – and energy, matter, and information flows within systems."
  - Energy and matter: Flows, cycles and conservation, including
    - "Matter is conserved because atoms are conserved in physical and chemical processes."
    - "Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion)."
    - "Energy cannot be created or destroyed – only moves between one place and another place, between objects and/or fields, or between systems."

Instructional Suggestions and Background Information

To maximize student learning, I recommend that you have your students work in pairs to complete groups of related questions. Student learning is increased when students discuss scientific concepts to develop answers to challenging questions; students who actively contribute to the development of conceptual understanding and question answers gain the most

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[1] By Dr. Ingrid Waldron, Dept. Biology, University of Pennsylvania, © 2021. These Teacher Notes and the Student Handout for this activity are available at https://serendipstudio.org/exchange/bioactivities/modelphoto

[2] Quotes from Next Generation Science Standards, available at https://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf

(https://education.asu.edu/sites/default/files/the_role_of_collaborative_interactions_versus_individual_construction_on_students_learning_of_engineering_concepts.pdf). After students have worked together to answer a group of related questions, I recommend having a class discussion that probes student thinking and helps students to develop a sound understanding of the concepts and information covered. To maximize student participation and learning, you can alternate between having student pairs work together to answer each group of related questions and class discussions of their answers and any related information you want to introduce.

If your students are learning online, we recommend that they use the Google Doc version of the Student Handout available at https://serendipstudio.org/exchange/bioactivities/modelphoto. To answer questions 1-2 and 5-7, students can either print the relevant pages, draw on those and send you pictures, or they will need to know how to modify a drawing online. They can double-click on the relevant drawing in the Google Doc, which will open a drawing window. Then, they can use the editing tools to add lines, shapes, and text boxes.[3] You may want to revise the GoogleDoc or Word document to prepare a version of the Student Handout that will be more suitable for your students; if you do this, please check the format by viewing the PDF.

A key is available upon request to Ingrid Waldron (iwaldron@sas.upenn.edu). Additional background information and instructional suggestions are included in the paragraphs below.

Question 1 is designed to get students thinking about what they already know about photosynthesis. Class discussion of student answers to this question will alert you to any misconceptions your students may have. If your students begin with a weak understanding of photosynthesis, you may want to include in your discussion of question 1 the NOVA brief video introduction to photosynthesis (https://whyy.pbslearningmedia.org/resource/2bdaf922-572b-4f5c-a801-1eb2fb31b101/photosynthesis-unctv-science/) or you may want to precede this activity with a sequence of introductory photosynthesis activities (https://carbontime.bscs.org/plants).

A model is a simplified representation of reality that highlights certain key aspects of a phenomenon and thus helps us to better understand and visualize the phenomenon. Many students tend to think of a model as a physical object and may not understand how a chemical equation or diagram can be a useful model. It may be helpful to introduce the idea of a conceptual model. As noted in *A Framework for K-12 Science Education*, "Conceptual models allow scientists… to better visualize and understand a phenomenon under investigation… Although they do not correspond exactly to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of their application and

[3] To draw a shape

1. At the top of the page, find and click Shape.
2. Choose the shape you want to use.
3. Click and drag on the canvas to draw your shape.

To insert text

1. At the top of the page, click Insert.
    - To place text inside a box or confined area, click Text Box and drag it to where you want it.
2. Type your text.
3. You can select, resize and format the word art or text box, or apply styles like bold or italics to the text.

When you are done, click Save and Close.

the precision of their predictive power, it is important to recognize their limitations."[4] If your students are not familiar with conceptual models, you may want to give examples of conceptual models that students may have used, e.g a map, an outline for a paper the student is writing, a concept map, or a diagram of a football play.

The Student Handout focuses on understanding the basic process of photosynthesis and includes multiple simplifications. For example, the equation for photosynthesis follows the common convention that photosynthesis produces glucose. The Calvin cycle of photosynthesis produces three-carbon molecules which are converted to glucose and fructose which can be combined to produce sucrose (which is transported throughout the plant). Also, the Student Handout only mentions photosynthesis in plants and omits mention of photosynthesis in cyanobacteria.

Another simplification is that the equations, flowchart and diagram in the Student Handout do not include the conversion of some of the energy to thermal energy. As shown in the key, discussion of question 5 provides the opportunity to introduce the general principle that all types of energy conversion result in some thermal energy. The conservation of energy applies to the equivalence between the energy in the light input and the increase in stored chemical energy and thermal energy (outputs).

After question 6, you may want to ask your students this question:

> A typical leaf is flat and thin, so each leaf cell is relatively near the surface of the leaf. How does this leaf shape help to maximize the rate of photosynthesis in leaves?

This question will provide the opportunity to discuss that, in order for chloroplasts to carry out photosynthesis, both CO_2 from the air and light must reach the chloroplasts. Both of these requirements will be more easily met for leaf cells that are near a surface of the leaf.

The chloroplast diagram on page 3 of the Student Handout introduces some additional information about how photosynthesis occurs.[5] This diagram is a more detailed model of photosynthesis than the chemical equation or energy and matter flowchart; however, the chloroplast diagram (like all models) is still a simplification of a more complex reality. More of the complexities of photosynthesis are explained at http://www.bozemanscience.com/photosynthesis/.

To help your students understand the chloroplast diagram in the Student Handout, you may want to ask them to identify which arrows represent:

- movement of molecules into and out of the chloroplast
- chemical reactions that use CO_2 molecules, H atoms and chemical energy to make sugar molecules.

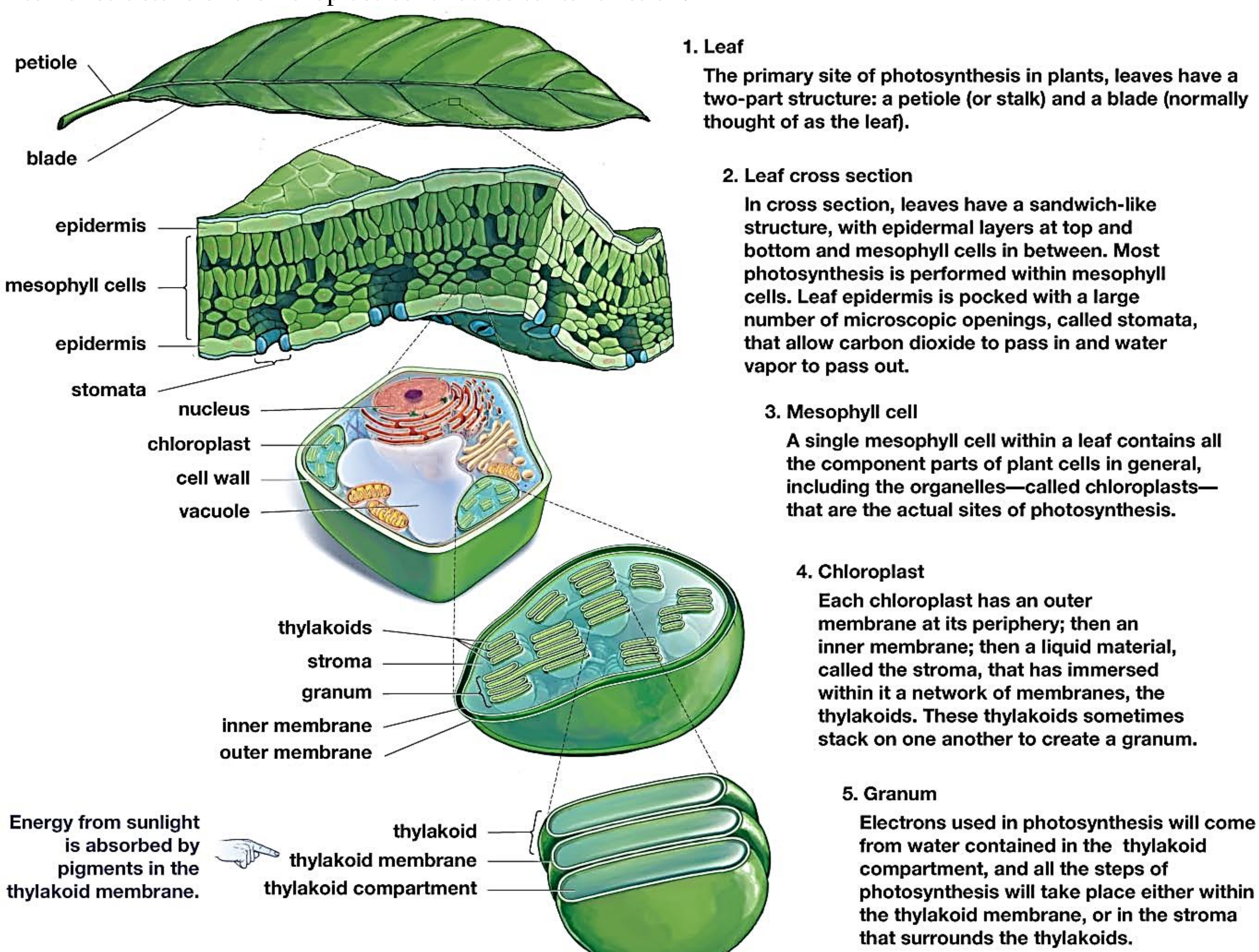
The other arrows in the chloroplast diagram indicate how ATP and NADPH transfer chemical energy and reducing power from the light-dependent reactions to the Calvin cycle. Students who habitually think about what different arrows represent will be better able to understand many types of diagrams and figures.

[4] Quotation from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (available at https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts).

[5] Although photosynthesis in plants occurs in chloroplasts, prokaryotes (e.g. cyanobacteria) carry out photosynthesis without chloroplasts.

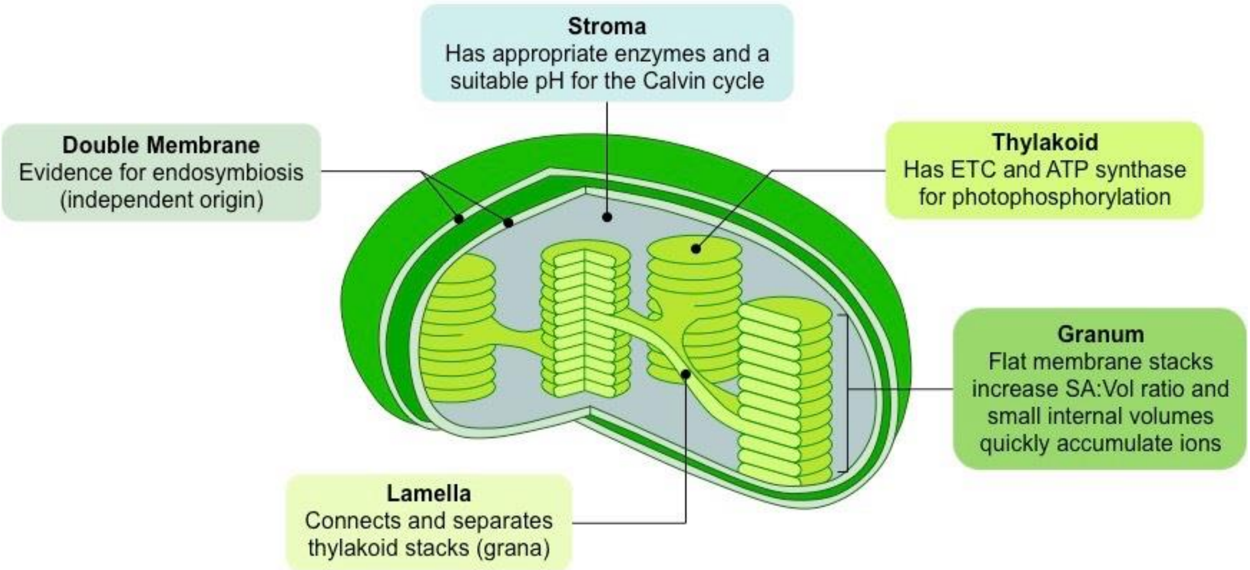
I recommend that you explain to your students that there are <u>many repeats</u> of each of the molecules and structures shown in the chloroplast diagram in the Student Handout. A typical leaf cell has about 40 chloroplasts, and a square millimeter of leaf typically has about 500,000 chloroplasts. You may want to mention that the <u>chlorophyll</u> molecules in chloroplasts give leaves their green color.[6] Or you may want to ask the questions, "Why are leaves green? Why aren't roots green?"

The figures and explanations below provide more detail about where and how photosynthesis occurs. The figure below shows the relationship of the microscopic chloroplasts to the macroscopic leaf. The figure on the next page provides additional information about how the internal structure of a chloroplast contributes to its function.



(from Krogh, 2011, Biology – A Guide to the Natural World)

[6] Obviously, leaves are not always green. Other pigments in leaves can assist chlorophyll by absorbing light at different wavelengths and passing the energy to chlorophyll. In some types of plant, the large quantity of these other pigments masks the green of the chlorophyll, but, even in these leaves, chlorophyll is needed for the light reactions that begin photosynthesis. In deciduous trees in the fall, leaves lose their chlorophyll so the colors of the other pigments are seen in fall foliage.



(https://ib.bioninja.com.au/higher-level/topic-8-metabolism-cell/untitled-2/chloroplast.html)

The thylakoid membrane in the chloroplasts plays several important roles in photosynthesis. Chlorophyll and proteins embedded in the thylakoid membrane absorb light and split water to produce O_2 plus H^+ and electrons. The electron transport chain proteins in the thylakoid membrane produce NADPH and a proton gradient between the thylakoid compartment and the stroma. This proton gradient powers the enzyme, ATP synthase, which is also embedded in the thylakoid membrane. Thus, the thylakoid membrane is crucial for the production of NADPH and ATP which play key roles in the Calvin cycle which produces sugars. (https://en.wikipedia.org/wiki/Thylakoid; https://bio.libretexts.org/Bookshelves/Microbiology/Book%3A_Microbiology_(Boundless)/5%3A_Microbial_Metabolism/5.12%3A_Biosynthesis/5.12C%3A_The_Calvin_Cycle)

As an introduction to questions 9 and 10 you may want to revisit your discussion of conceptual models (see page 2 of these Teacher Notes). Students should understand both the usefulness and the limitations of conceptual models. Question 10 highlights how the three different models of photosynthesis clarify different aspects of a complex biological phenomenon, so different models can be useful for different purposes.

Follow-up Activities
Photosynthesis and Cellular Respiration – Understanding the Basics of Bioenergetics and Biosynthesis
In this minds-on activity, students analyze how photosynthesis, cellular respiration, and the hydrolysis of ATP provide energy for biological processes. Students learn that sugar molecules produced by photosynthesis are used for cellular respiration and for the synthesis of other organic molecules. Thus, photosynthesis contributes to plant energy metabolism and plant growth. The optional final section challenges students to explain observed changes in biomass for plants growing in the light vs. dark. Student Handout and Teacher Preparation Notes are available at https://serendipstudio.org/exchange/bioactivities/photocellrespir.
or
Photosynthesis, Cellular Respiration and Plant Growth

This hands-on, minds-on activity begins with the question of how a tiny seed grows into a giant Sequoia tree. Students analyze data from research studies on plant mass and biomass, and they conduct a hands-on experiment to evaluate changes in CO2 concentration in the air around plants in the light vs. dark. Students interpret the data to understand how photosynthesis makes an essential contribution to increases in plant biomass, and cellular respiration can result in decreases in biomass. This activity counteracts several common misconceptions about plant growth, photosynthesis, and cellular respiration. Student Handout and Teacher Preparation Notes are available at https://serendipstudio.org/sci_edu/waldron/#photobiomass

Where does a plant's mass come from?
Students analyze evidence to evaluate four hypotheses about where a plant's mass comes from. For example, students analyze Helmont's classic experiment, and evaluate whether his interpretation was supported by his evidence. Thus, students engage in scientific practices as they learn that plants consist mainly of water and organic molecules and most of the mass of organic molecules consists of carbon and oxygen atoms originally contained in carbon dioxide molecules from the air. Student Handout and Teacher Notes are available at https://serendipstudio.org/exchange/bioactivities/plantmass

Additional activities for learning about photosynthesis and cellular respiration are available in "Cellular Respiration and Photosynthesis – Important Concepts, Common Misconceptions, and Learning Activities" (https://serendipstudio.org/exchange/bioactivities/cellrespiration).

Source for Figures in Student Handout

- Figure on top of page 1 and bottom of page 2 modified from https://i.pinimg.com/originals/f8/e1/10/f8e11021445a4c54417401d7f653279c.jpg
- Figure on page 3 modified from http://www.mhhe.com/biosci/esp/2001_gbio/folder_structure/ce/m6/s4/assets/images/cem6s4_1.jpg

The chemical equations figure on page 1 was constructed by the author.