Exploring Photosynthesis
Measuring Dissolved Oxygen from Aquatic Plants

Lesson Overview

Through this lesson, students will explore the process of photosynthesis by aquatic plants. Students will explore the role of plants in the conversion of light energy into chemical energy required to fix carbon dioxide into the simple sugar glucose and the subsequent release of oxygen into the environment. The process of photosynthesis is central to life on Earth, providing the basis for most food chains and food webs and resulting the release of oxygen as a byproduct. A series of stations will be used to help students understand the requirements and products of photosynthesis. As students move through the stations, they will measure the concentration of dissolved oxygen generated by the aquatic plant within an aquatic environment.

There are many factors to be considered in terms of water quality. One of the most critical factors for both plants and animals is the concentration of dissolved oxygen. It is important to note that aquatic and terrestrial plants and animals as well as many species of microorganisms require oxygen for cellular respiration to generate the energy necessary for carrying out life processes.

Next Generation Science Standards:

MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

Science & Engineering Practices	Crosscutting Concepts	Disciplinary Core Ideas
Construct a scientific explanation based on valid and reliable evidence obtained from sources [including students' own experiments].	Within a natural system, the transfer of energy drives the motion and/or cycling of matter.	Plants, algae, and many microorganisms use energy from light to make simple sugars [a food source] from carbon dioxide [absorbed from the atmosphere] and water. The process is photosynthesis and also releases oxygen as a byproduct.

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy

Science & Engineering Practices	Crosscutting Concepts	Disciplinary Core Ideas
Use a model based on evidence to illustrate the relationships between systems or between components of a system.	Changes of energy and matter in a system can be described in terms of energy and matter flowing into, out of, and within that system.	The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.

Missouri Learning Standards:
6-8-LS1-7. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

9-12-LS1-6. Use a model to demonstrate how photosynthesis transforms light energy into stored chemical energy.

Learning Objectives:
Upon the completion of this lesson, students should be able to:

- Use the Vernier dissolved oxygen sensor to accurately measure the concentration of dissolved oxygen within several samples of aquatic plants [*Elodea*] exposed to varying intensities of light.
- Equate the concentration of dissolved oxygen within the water sample to the photosynthetic activity of the *Elodea* aquatic plant.
- Develop a model explaining the role of light during photosynthesis.
- Correlate atmospheric CO_2 with the plant growth resulting from photosynthetic activity within aquatic and terrestrial plants.

Teacher Background Information:
The process of photosynthesis is carried out most commonly by plants. Even single celled organisms can be capable of carrying out photosynthesis. It is important to note that the process of photosynthesis is critical to life on Earth. To better understand that statement, stop to think about the end products of photosynthesis.

- First, the process of photosynthesis is actually generating food for the plant. Plant food is in the form of six-carbon sugars called glucose. The plants use glucose as the basic compound for generating all plant cells, tissues, and/or organs. This means that plants have the potential to convert the 6-carbon molecule, glucose, into lipids [fats], amino acids, and amino acids can be sequenced into large protein molecules. Plants, like animals, also use glucose to provide the cellular energy necessary to carry out all life functions.

- Second, the process of photosynthesis creates by products that are released into the atmosphere. Oxygen is actually a waste product of photosynthesis and released into the atmosphere. Of course, many forms of life on Earth are aerobic and, therefore, require oxygen for life.

It is safe to say that everything animals eat is either a plant or an organism that used plants as a food source.

There are many factors which can influence the rate of photosynthesis. One of those factors is light intensity. It is important to keep in mind that there two sets of reactions included within the process of photosynthesis. The **light dependent reactions** occur only in the presence of light. Light energy drives this process which converts light energy into chemical energy [Adenosine Triphosphate – **ATP** and **NADPH**]. ATP and NADPH provide the chemical energy to power the **light independent reactions [the Calvin-Benson Cycle].** During the light-independent reactions, CO_2 is taken up to form the simple sugar glucose [$C_6H_{12}O_6$]. The simple sugar serves as the basis for the formation of complex organic molecules including lipids, carbohydrates, nucleotides [to form DNA and RNA], an amino acids [sequenced into proteins].

Light intensity is one of the factors that influence the rate of photosynthesis. During this investigation we will explore the rate of photosynthesis under varying light intensities. Light is a limiting factor in that when the light intensity becomes too low, the light dependent reactions of photosynthesis will slow.

Light Intensity:
The light intensity to which the plant is exposed is inversely proportional to the square of the distance between the light source and the plant. This means that the distance from the light source is very important in terms of light intensity.

Materials:

- 500 ml beakers [1 beaker per station]
- 140 ml beakers [1-beaker per station]
- Aquatic plant
- Baking soda [$NaHCO_3$]
- Distilled water
- LabQuest 2
- Optical dissolved oxygen sensor
- Thermocouple sensor
- Light sources

Lesson Format:

Engage:
Distribute the photosynthesis probe (Beattie, 2012) to the students. The probe was taken from the Probe Booklet created by teachers from Lincoln-Way East High School. Instruct students to follow the directions by identifying the choice that they think is most directly responsible for the increase of mass as the acorn germinates and ultimately grows into a mature oak tree. Remind students to provide an explanation for their choice and their reasoning for not selecting other choices. Upon completion of the probe, collect students' work and keep the probe for reference at the close of the lessons comprising this unit.

Discuss the probe with the students and ask them to explain their thinking regarding the selection of what they believed to be the most accurate choice. Questions to ask during this discussion include:

- What is the role of light in the process of photosynthesis?
- Can photosynthesis take place in the dark? How do you know?
- When a plant grows, where do the materials [cells, tissues, etc.] come from to support plant life and growth?
- Living organisms require nucleic acid, amino acids, proteins and lipids for cellular, tissue, and/or organ function. You and I must consume many of the amino acids required for making proteins in our daily diet [essential amino acids] because our bodies are not capable of manufacturing these amino acids. How do plants get the amino acids and ultimately the proteins, the lipids, as well as the nucleic acids required for cell, tissue, and/or organ function?
- The probe asked about carbon dioxide, CO_2 alone cannot sustain life due to the need for oxygen by most organisms on Earth. Is CO_2 a requirement for photosynthesis? What evidence do you have to support your answer?

Explore:
Before you begin to develop a model for photosynthesis, you should first conduct a series of investigations to determine the correlation between light intensity and the rate of photosynthesis of an aquatic plant [*Elodea*]. The rate of photosynthesis can be determined by measuring the concentration of dissolved oxygen as the plant undergoes photosynthesis. There are multiple methods for measuring the rate of photosynthesis including:

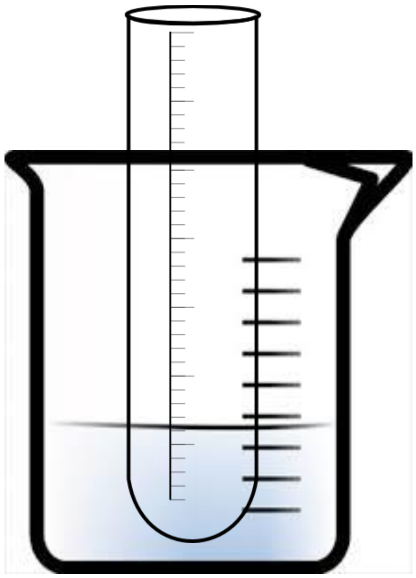
- The uptake of CO_2
- The production and release of O_2
- The production of carbohydrates
- The increase in the dry mass of a plant or plants

In this investigation we will measure the rate of photosynthesis through the production of oxygen. Remember that oxygen is a byproduct of the light reactions of photosynthesis. The optical dissolved oxygen sensor will be used to determine the concentration of dissolved oxygen under specific environmental conditions [varying light intensities] at five stations. The stations have been set up that will allow for students to investigate the concentration of dissolved oxygen as an indication of the rate of photosynthetic activity within the cells of the aquatic plant *Elodea*.

Station 1:

At this station, students will use the Vernier optical dissolved oxygen sensor to measure the concentration of dissolved oxygen within a beaker of water after adding sodium bicarbonate or baking soda to the water. It is important to note that sodium bicarbonate is soluble in water and upon going into solution, carbon dioxide is released and dissolves in the water as well, increasing the useable amount of CO_2 available for photosynthesis. Sprigs of *Elodea* will not be used in Station 1. The amount of baking soda has been pre-measured for you.

Collecting Data: Data collection will be accomplished with the Vernier optical DO sensor. Remember to use the thermocouple to measure temperature as well. Set the Lab Quest 2 so that the dissolved oxygen sensor is taking a reading of dissolved oxygen concentration once every 10 seconds for three minutes.



In Figure 1, the test tube contains water and has been placed in a beaker containing water as well. Sodium bicarbonate has been added to the water in the test tube. The concentration of dissolved oxygen can then be measured. Station 1 provides a baseline measurement for the concentration of dissolved oxygen in water in which the sodium bicarbonate has been added, but the *Elodea* has not been added. Instruct students to use the Vernier optical DO sensor to measure the concentration of dissolved oxygen within the test tube when the aquatic plant has not been included. It is important to note that the beaker serves as a heat sink to maintain a consistent water temperature within the test tube.

Figure 1: Equipment set up for Station 1

Station 2:

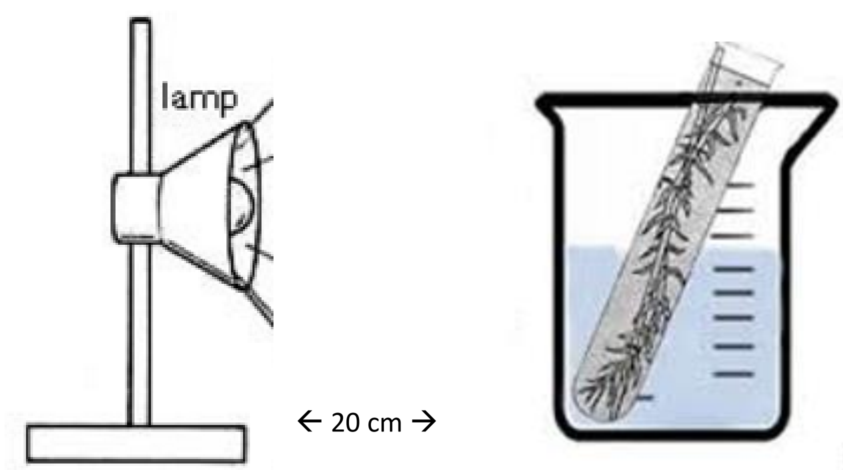
At Station 2, students will use the Vernier optical dissolved oxygen sensor to measure the concentration of dissolved oxygen within a beaker of water containing the aquatic plant, *Elodea*, when the beaker is exposed only to ambient light within the room. Sodium bicarbonate [baking soda] has been added to the water in which the plant has been placed. You and your partner will use the Vernier optical DO sensor to measure the concentration of dissolved oxygen in the water within the beaker over time. Set the Lab Quest 2 so that the dissolved oxygen sensor is taking a reading of dissolved oxygen concentration once every 10 seconds for three minutes. Add the sodium bicarbonate to the beaker containing water and the aquatic plant.

The diagram in Figure 2 is the basic set up for Stations 2 through 4. In figure 2, only ambient light is powering the light reactions of photosynthesis. Instruct your students to use the Vernier optical DO sensor to measure the level of dissolved oxygen in the test tube. Keep in mind that the test tube containing water and *Elodea* is placed in a beaker of water to create a heat sink [as indicated earlier]. This simply means that the water in the beaker will absorb the heat energy generated by the light bulb. We will use the same set up at all stations to reduce sources of error. This approach allows the water temperature within the test tube to remain constant.

Figure 2: Station 2 equipment set up

Station 3:

At this station, students will use the Vernier optical dissolved oxygen sensor to measure the concentration of dissolved oxygen within a beaker of water containing the aquatic plant, *Elodea*, when the beaker is exposed only to a bright light. You and your partner will use the Vernier optical DO sensor to measure the concentration of dissolved oxygen in the water within the beaker over time. Set the Lab Quest 2 so that the dissolved oxygen sensor is taking a reading of dissolved oxygen concentration once every 10 seconds for three minutes. Add the sodium bicarbonate to the beaker containing water and the aquatic plant prior to recording data.

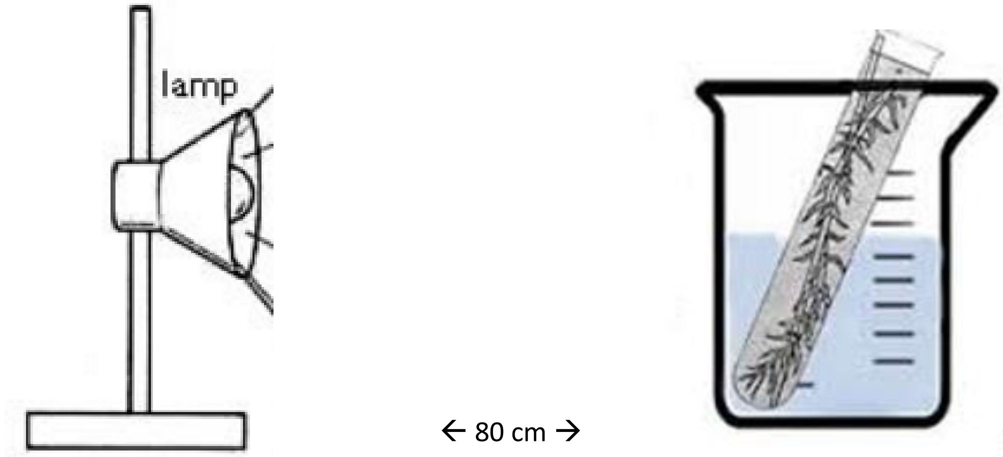


The equipment in Station 3 should be placed approximately 20 centimeters away from the light source. Once again, students should use the Vernier optical DO sensor to measure the concentration of dissolved oxygen when the *Elodea* is exposed to a bright light source.

Figure 3: Station 3 equipment set-up

Station 4:

At this station, students will use the Vernier optical dissolved oxygen sensor to measure the concentration of dissolved oxygen within a beaker of water containing the aquatic plant, *Elodea*, when the beaker is exposed to bright light and also contains the same quantity of sodium bicarbonate used in the other stations. Prior to recording data be sure to add the sodium bicarbonate to the beaker containing water and the aquatic plant. You and your partner will use the Vernier optical DO sensor to measure the concentration of dissolved oxygen in the water within the beaker over time. Set the Lab Quest 2 so that the dissolved oxygen sensor is taking a reading of dissolved oxygen concentration once every 10 seconds for three minutes.



The equipment in Station 4 should be placed approximately 80 centimeters away from the light source. Once again, students should use the Vernier optical DO sensor to measure the concentration of dissolved oxygen when the *Elodea* is exposed to a bright light source.

Figure 4: Station 4 equipment set up

<u>Station 5:</u>

At Station 5, students will repeat Stations 3 and 4 with one change, no sodium bicarbonate will be added to the test tube containing the *Elodea*. The goal is to explore the impact of adding carbon dioxide to the solution through the addition of sodium bicarbonate to the water in the test tube. Throughout these stations, students are measuring the role of light intensity with and without the addition of carbon dioxide.

Figure 5: Station 5 equipment set up

Food for Thought:

Light Intensity and Photosynthesis

At low light intensities, one would expect the rate of photosynthesis to be low due to the level of available light energy. However, as light intensity increases, the rate of the light-dependent reaction of photosynthesis would increase. So the question is, would this be a J-shaped curve with the rate of photosynthetic activity continuing to increase at an increasingly rapid rate. This is an important question, the more photons of light that fall upon a leaf, the greater the number of chlorophyll complexes stimulated resulting in an increase in the formation of chemical energy [ATP and NADPH] generated during the light reactions of photosynthesis. The light dependent reactions rely upon light as an energy source and to some degree are not affected by changes in temperature. There is a limit, however, and continually increasing the light energy has the potential to damage the chlorophyll within the photosystems. This damage has the potential to inhibit the light reactions resulting in a plateau within the rate of photosynthetic activity.

Carbon Dioxide and Photosynthesis

Carbon dioxide concentration is one of the limiting factors of photosynthesis. Keep in mind that during the light dependent reactions, light is converted into chemical energy [ATP and NADPH] which drives the light independent reactions during which the chemical energy generated during the light dependent reactions drives the Calvin-Benson Cycle [light independent reactions] to fix carbon [CO_2] and form simple sugars used to provide the chemical energy necessary to drive the functions of life and to serve as a basis for the formation of key organic polymers [lipids, proteins, nucleic acids, carbohydrates, etc.]. So what does the concentration of CO_2 have to do with the rate of photosynthesis? As the concentration of CO_2 increases, the energy storing molecules [ATP and NADPH] are used and returned to their lower energy states ready once again to be used during the light reactions. This rapid turnover allows these critical energy storage molecules to be reused, enabling process of photosynthesis to occur at a more rapid rate. The increase in CO_2 results in an increase in the rate of photosynthesis. There is a limit which is reached when the maximum rate of carbon fixation during the light independent reactions is reached.

Extend:

Once your team has completed all of the stations as well as collected and analyzed the data, prepare a chart that shows the following:

The Guiding Question for your argument:	
Your Claim:	
Evidence Supporting Your Claim:	**Rationale or Justification for the Evidence:**

Sampson, V., Enderele, P., Gleim, L., Grooms, J., Hester, M., Southerland, S., & Wilson, K. (2013). *Argument-Driven Inquiry in Biology: Lab I*nvestigations, *Grades 9-12.* Arlington, VA: NSTA Press.

Once your chart has been completed, you will have an opportunity to share your ideas with other teams. The class will use the Round-Robin format. This means that one member of your team will stay with the chart to explain your thinking to the other teams. The other members of your team will move from chart to chart and listen to the explanation provided by one team member for their argument. Visiting teams are encouraged to make written comments using the note cards provided. After the Round-Robin sharing, each team will have time to reflect upon their argument, consider the feedback from the other teams, and make changes in their argument. At this time, your team may determine that additional data is required or you might want to reconsider the supporting evidence cited in your argument and/or revise the rationale for using that evidence. The goal is for each team to develop the most valid response to the Guiding Question.

Evaluation:
Evaluation is ongoing, however, there are specific points during this lesson when formative evaluations can be assessed.

- Visiting with each team during the investigation and determining the most accurate data.
- Listening to the argument of each team: guiding question, claim, evidence, and rationale.
- Reviewing the final argument provided by each student.

Teacher Resources

Background Information
http://www.rsc.org/Education/Teachers/Resources/cfb/Photosynthesis.htm

- This site provides a detailed explanation for the process of photosynthesis.

http://www.life.illinois.edu/govindjee/encyc/encarta.htm

- This page is created by the University of Illinois and provides a detailed explanation for the process of photosynthesis.

http://photosynthesiseducation.com/photosynthesis-for-kids/

- This site provides a more basic explanation of photosynthesis for younger students who lack an in-depth understanding of the process and the chemistry behind the process.

https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookPS.html#Stages

- This site provides an in-depth explanation of the stages of photosynthesis.

Sampson, V., Enderele, P., Gleim, L., Grooms, J., Hester, M., Southerland, S., & Wilson, K. (2013). *Argument-Driven Inquiry in Biology: Lab I*nvestigations, *Grades 9-12.* Arlington, VA: NSTA Press.

http://brilliantbiologystudent.weebly.com/effect-of-light-intensity.html

- This site provides additional information about light intensity which may prove valuable as you adapt this lesson to your instruction.

Laboratory Activities
http://www.glencoe.com/sites/common_assets/science/virtual_labs/LS12/LS12.html

- This Glencoe site provides a virtual lab for photosynthesis and provides an opportunity for students to explore the process.

http://www.cathedral-irish.org/uploaded/faculty/abrooks/Biology_-_4/Photosynthesis_and_Respiration_Lab.pdf

- You will find a photosynthesis and respiration lab at this site that involves Elodea and snails. This is a simple lab and is nicely detailed for use in the classroom.

http://www.harcourtschool.com/activity/science_up_close/512/deploy/interface.html

- This video summarizes the process of photosynthesis and during the process identify key vocabulary terms.

http://www.vernier.com/experiments/bwv/7/photosynthesis/

- This photosynthesis investigation from Vernier will work nicely but only if you have spectrophotometer.

http://www.chicagobotanic.org/downloads/nasa/Unit_1_Grades_10-12_Activity_1.3_AreAllPlantsCreatedEqual.pdf

- This site provides a means of examining leaves for

YouTube Videos

https://www.youtube.com/watch?v=ZnY9_wMZZWI

- This is a Bozeman Science video that will move through a photosynthesis lab. Teachers can gain insight into a version of the photosynthesis lab.

https://www.youtube.com/watch?v=g78utcLQrJ4

- This is a Bozeman Science video that provides an introductory explanation for photosynthesis. This explanation is most appropriate for high school students.

https://www.youtube.com/watch?v=JJxZH_Y5D4shttps://www.youtube.com/watch?v=-rsYk4eCKnA

- This video provides a very brief overview of photosynthesis and has the potential to set the stage for a more in-depth discussion.

https://www.youtube.com/watch?v=wgqPv3rZ3zM

- This video provides an explanation for the light reactions only. The video is largely a PowerPoint but could serve as a review for teachers.

https://www.youtube.com/watch?v=VCqqq3XQJ18

- This video provides an explanation for the Calvin Cycle or the Dark Reactions.

https://www.youtube.com/watch?v=m8v7prlscM0

- This video provides a lecture format and reviews creation of glucose during the light independent reactions of photosynthesis.

https://www.youtube.com/watch?v=JUmT24R8CyA

- This video correlates the process of photosynthesis with cellular respiration.

https://www.youtube.com/watch?v=FfLLHQDgpjI

- This video provides teachers and students with a simple review of photosynthesis.

https://www.youtube.com/watch?v=YeD9idmcX0w

- Created by Pearson, this video provides an animation of the light reactions. This video is easy to follow and provides a clear explanation for the light reactions of photosynthesis. This video is best suited for high school students who have an understanding of photosynthesis.

The Mighty Oak

An acorn, the seed of an oak tree, has a dry mass of only a few grams. Under favorable conditions the acorn will sprout into a sapling and grow to be a mature oak tree with a dry mass 1 ton or more. Which of the following contributes most directly to this huge increase in mass?

A. The roots absorb minerals from the soil.

B. The leaves absorb CO_2 gas from the atmosphere.

C. The roots absorb water from the soil.

D. Light from the sun is absorbed into the leaves.

Please indicate the letter of the choice you think contributes most directly to the increase in mass as the acorn grows into a tree.

Explain your reasoning for selecting the choice you did and not selecting the other choices.

Suggestions for Instruction Following Analysis of the Probe:

Explicitly and reflectively discuss the need for light in creating glucose (food) for the plant and the importance of glucose as energy and building material for creating growth. Providing a description of van Helmont's experiment and sample data for students to analyze may help them understand the idea that plant biomass is derived from intake of carbon, not substances in the soil.

Explicitly discuss the role of light and pigments in the process of photosynthesis. Explain that pigments are molecules that can "capture" different wavelengths of light. Demonstrate that white light is composed of several wavelengths using a prism. Conduct a paper chromatography lab to illustrate the different types of pigments present in different types of leaves like spinach and red cabbage. Set up plants growing under different colors of light and white light over time to illustrate the relationship between wavelength of light, pigments, and plant growth.

Explicitly teach that in nature carbon dioxide is present in air and dissolved in water, and can enter a plant's cells via diffusion. The carbon is then used to synthesize other carbon containing structures – cellulose for structure, starch for food storage – or oxidized through cell respiration resulting in the formation of ATP. Water also diffuses into plant cells, where in the presence of light it dissociates to release oxygen which diffuses out of the plant cells. Explain to students that these biochemical processes can be measure by detecting the appearance of products (which is easier than attempting to detect the disappearance of reactants). Oxygen, a product of photosynthesis, is not very soluble in water and as a result appears as bubbles in water. Students can observe oxygen production by place sprigs of Elodea in test tubes under a lamp and counting the number of bubbles produced over time. The effect of carbon dioxide on oxygen production can be observed by placing one Elodea sprig in tap water, one in tap water with baking soda (carbon dioxide source) added, and one in boiled (to drive off carbon dioxide)and cooled water. Starch, another product of photosynthesis, can be detected using an iodine indicator that stains blue-black when starch is present. First microwave the leaves in a few milliliters of 95% ethanol for about 10 seconds (long enough for the ethanol to turn green). Using forceps remove the leaves from the ethanol and place them in a dish with iodine. Rinse the iodine from the leaves, if starch is present the leaves will appear blue-black.

Involve the students in a kinesthetic model to demonstrate the roles of photons, electrons, electron carriers, water, and protons during the light reactions. Review the products of light reactions and explicitly teach the Calvin cycle including the terms NADPH, RuBP, PGAL, ATP, Glucose, and Carbon Dioxide. Students could use manipulatives to create a model of the Calvin cycle that incorporates the products of the light reactions and traces the pathway of carbon from carbon dioxide through the cycle into glucose and then into storage organelles within cell.

Student: ______________________

Station 1:

1. Would you expect the temperature of the water to fluctuate will relying upon ambient light? ____ Explain your response.

2. Would you expect the concentration of dissolved oxygen to change? _____ What did you observe in the data gathered at Station 1?

Station 2:

3. Explain how the following equation will result in determining the rate of photosynthesis.

$$\textbf{Rate of Photosynthesis} = \frac{\textbf{Change in the } O_2 \textbf{ concentration}}{\textbf{Time}}$$

4. Did the data gathered at Station 2 indicate a change in the concentration of dissolved oxygen when compared to the data from Station 1? ____ Explain your response.

Station 3:

5. Using the equation below, determine the rate of photosynthesis and respond to the following:

Rate of Photosynthesis = $\frac{\textbf{Change in the } O_2 \textbf{ concentration}}{\textbf{Time}}$

a. How does the rate of photosynthesis vary from that calculated from Station 2 data?

b. Why did you place the beaker containing the Elodea sprig in a larger beaker of water?

6. Did the data gathered at Station 3 indicate a change in the concentration of dissolved oxygen? ____ Explain your response.

Station 4:

7. Using the equation below, determine the rate of photosynthesis and respond to the following:

Rate of Photosynthesis = $\frac{\textbf{Change in the } O_2 \textbf{ concentration}}{\textbf{Time}}$

a. Does the rate of photosynthesis vary from that calculated from Station 3 data? Explain the difference noted in the data.

8. Sodium bicarbonate was added to the equipment set up in stations 1 through 4.
   a. Why do you think that sodium bicarbonate was added?

   b. How could you determine if your explanation is accurate?