Food and Energy for All

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Turning a Demonstration into an Inquiry Activity

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CONTENT AREA

Biology/life sciences

GRADE LEVEL

6–8

BIG IDEA/UNIT

Photosynthesis

ESSENTIAL PRE-EXISTING KNOWLEDGE

Food webs, chemical reaction basics (reactants and products), types of energy, and energy transformations

TIME REQUIRED

1–2 weeks

COST

$34.40 per infrared lamp and reflector (one-time cost)

$6 for a pack of ten 60 cc syringes (one-time cost)

$10 for spinach leaves and baking soda

When asked what plants need for photosynthesis, many students can correctly recall the reaction equation and state that plants require CO_2, H_2O, and light. Many students, however, do not understand that these reactants are the raw materials plants use to make sugars and instead believe that they are food for plants. Moreover, when questioned further, students often voice the idea that plants get their food from the soil (Kestler 2014). This is consistent with findings that fewer than half of current middle and high school students have a correct understanding of the process of photosynthesis (AAAS 2015). We developed this lesson to help students confront their misconceptions about photosynthesis and what constitutes food for plants. Photosynthesis is a complex process that requires a unit of instruction including multiple student experiences. Therefore, we use this lesson as an introduction to the unit on matter and energy in organisms and ecosystems so that students develop a better understanding of the reactants of photosynthesis.

We wanted students to investigate how different variables typically mistaken for plant food (e.g., CO_2, H_2O, light, soil) affect photosynthesis, with the goal of helping students develop an understanding that *photosynthesis* is a chemical process that produces food for plants. We modified a demonstration (Fox, Gaynor, and Shillcock 1999) that allows for an estimation of the rate of photosynthesis by timing how long it takes punched-out spinach-leaf disks to rise to the top of a solution due to the production of oxygen gas. In our modification, students perform the original demonstration in small groups and then develop their own follow-up investigations to explore the effects of other variables on the rate of photosynthesis, using the initial procedures as a model (see Online Supplemental Materials for a complete teacher guide).

Part 1: Initial investigation

To probe students' prior knowledge about where food comes from and how it is made, students answer the following questions in groups of three or four:

1. What is food?
2. Where do we get food?
3. How is our food made?

Students can typically answer questions 1 and 2, but they struggle with question 3, which leads to a class discussion (see Online Supplemental Materials for a teacher guide that provides typical student answers to these questions, as well as suggested facilitation tips for helping students expand upon their answers). In our experience, these discussions show that few students have a good understanding that matter (food) is broken down by organisms to provide them with usable energy that was captured by plants and ultimately came from the Sun.

Now that students have thought about the relationship between plants and food, in small groups, they conduct an investigation to answer the question, "What is the rate of photosynthesis in spinach leaves?" (A list of materials necessary for both days of this investigation can be found in Figure 1.) Although students are not able to design the procedure for this investigation, to help them think about what they are doing during the activity, we provide the steps on individual strips of paper and have students put the steps in order (see Online Supplemental Materials – Student Guide).

The only significant safety hazard in this activity is the possibility of getting bicarbonate solution in the eye, which may cause burning, so students should wear protective goggles throughout the experiment. To reduce student wait time and keep things organized, we provide baking soda, soap, scales, water, and spinach leaves at two or three different stations around the classroom. Students have a light, ring stand, syringe, cup, beaker, meter stick, timer, hole punch, and pipette at their tables.

Remind students to use the amounts indicated in the procedure so that data can be compared between groups. To conduct the experiment, students must use a single-hole punch to create 10 small disks from a spinach leaf, being sure to avoid the major veins. They also need to make a bicarbonate solution by adding 0.5 g of baking soda to 300 mL of water. Students then add the leaf disks to the syringe and draw up approximately 20 cc (mL) of bicarbonate solution. They then create a vacuum by placing their thumb over the end of the syringe and pulling back on the plunger with their other hand. It is important

FIGURE 1: Materials list

- 1 g sodium bicarbonate (baking soda)
- 1 drop of liquid soap (any brand)
- plastic syringe (60 cc)
- bag of spinach leaves (one per class)
- plastic cups (transparent)
- heat lamps (light source)
- timer
- 500 mL graduated cylinder
- timer
- hole punch
- 500 mL beaker
- plastic disposable pipette
- meter stick
- different-colored light bulbs (red and green; only for groups investigating this variable)
- safety goggles

FIGURE 2: Student sample data

Rate of photosynthesis as measured by # of disks floating

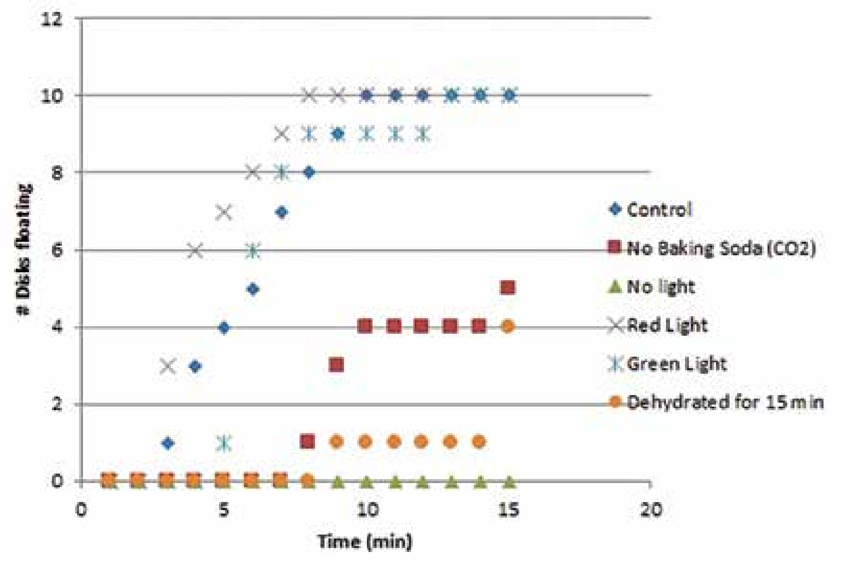

IMAGE COURTESY OF THE AUTHORS

to push on the plunger so that no air is in the syringe before creating the vacuum. When creating the vacuum, students should hold it for 10 seconds and release. This should cause the leaf disks to sink to the bottom; however, students may have to repeat this process two or three times before all the disks sink. After all of the disks sink, students remove the plunger and pour the solution containing the leaf disks into a clear plastic cup. They may need to add more bicarbonate solution until the cup is half full. Finally, students place the cup about 30 cm beneath a light and record the time it takes for all the disks to float (see Online Supplemental Materials for a full procedure outline with pictures). To further encourage students to think about the procedure, they are also asked to construct their own data table. If students need help with this, ask them to review their procedure and focus on identifying the independent and dependent variables, as well as the number of trials. We do not provide students with the data table because we want them to continue to think about what they are doing, what data are important, and how to organize them. If students continue to struggle, we use additional scaffolding questions such as (*desired student answer in italics*):

1. What will you be measuring in your experiment? (*The time it takes for the disks to float.*)
2. Do you think it is important to record just one time or should you record the time it takes for one disk, two disks, etc., to float? (*Record multiple times.*)
3. Based on what you have told me, what kind of column headings do you think you need in your table? (*Number of disks and time.*)

Data analysis requires students to determine which type of graph to generate, decide how to best summarize their numerical data (mean, median, range, or mode), and identify patterns in their data (see Figure 2 for a sample graph). We facilitate this process by having students share what they have done or are planning to do to analyze their data after 20 minutes of discussion in their groups. As a class, we discuss the types of graphs students think they should use and any patterns students have noticed in their data. Many students recognize that it is not a useful measure to wait for all 10 disks to float, as there can be outliers. Students typically suggest, sometimes with a little guidance, that the median (when half the disks are floating) works as the best representation.

Students reflect on their work by answering three follow-up questions:

1. What could be sources of error in your investigation?
2. If you did this investigation again, would you expect the same results?
3. What question would you like to investigate now?

The important outcomes of part 1 are that students understand the basic procedure for the investigation, think about the best way to analyze and interpret the data, have baseline data with which to compare their results from part 2, and identify some other variables that they think could affect the rate at

FIGURE 3: Facilitating the formulation of a testable question

Teacher: What did you investigate in the initial experiment?
Student: *Rate of photosynthesis*
Teacher: How can you relate your variable to this?
Student: *How does carbon dioxide affect the rate of photosynthesis?*
Teacher: Can you be more specific about what you will do to change the amount of carbon dioxide?
Student: *How does increasing the amount of carbon dioxide affect the rate of photosynthesis?*
Teacher: What provided the CO_2 in solution?
Student: *Baking soda*
Teacher: How much did you use in the initial procedure and how much are you going to use this time?
Student: *We used 0.5 grams initially and we will use 1 gram this time*

which the disks float, such as the amount of baking soda, intensity of light, or color of light.

Part 2: Designing an experiment: What factors are necessary for a plant to survive?

Part 2 allows students to plan, design, and conduct their own investigations and engage in argument through writing, while collecting data that support the need for carbon dioxide, water, and light in the process of photosynthesis. This step is important in providing students a concrete experience that they can remember and reflect on as they build their understanding of photosynthesis.

Students are challenged to answer the driving question: "What factors are necessary for a plant to survive?" Students refer back to the variables they came up with at the end of part 1 and share them with the class to formulate a list of variables that they believe will affect the rate of photosynthesis. Good candidates for variables that students can explore are CO_2, light intensity, light color, and H_2O. Some students may bring up ideas such as plant type. Although this is a good idea, it may not answer our driving question. To redirect students, you can probe with questions such as, "How would plant type affect photosynthesis?" Students often identify that although almost all plants conduct photosynthesis, the rate may vary between species. This provides an opportunity to discuss the importance of only modifying one variable at a time (see Online Supplemental Materials for a teacher guide that provides additional suggestions for facilitating students' variable choices).

After identifying variables as a class, students are placed in groups of three or four, based on the variable they are interested in investigating. The students' first task is to formulate a testable question. An example of how a teacher might facilitate this process with a student group is shown in Figure 3. Once students generate their question, they can plan their investigation using the procedure from part 1 as a model. Students are expected to modify the initial protocol to investigate their variable of interest. Generally, students are easily able to do this without any assistance. If they do struggle, you can ask them what they would have to change from their initial experimental procedure to be able to answer their new question. As students modify the initial procedure, you can point out that scientists often take procedures that they or others have used before and modify them to address their questions.

As in part 1, students construct a data table, collect data using their modified procedure, and then graph and analyze their data. Students compare the results from parts 1 and 2 to determine how their chosen variable affects the rate of photosynthesis. Students are also asked to compare their results with other groups that investigated the same variable and do some research, usually online, to see if they can explain why their variable affected the rate of photosynthesis the way it did. Initially we try not to provide too much guidance, as we want students to try to research on their own. We do, however, remind them that they should be using reliable websites (.edu. .uk, .ca, and .gov sites tend to be more reliable than many .com sites) and that if they can find the same information in multiple places, this suggests that it is more reliable. If students struggle with finding information, you may want to help them generate good search terms (e.g., factors affecting photosynthesis) or provide them with some sites (e.g., the Royal Society of Chemistry has a handout on the rate of photosynthesis, and Bitesize science has a site that discusses factors affecting the rate of photosynthesis [see Resources]). As students discuss their results with other groups, they are provided with questions to help guide them, including the following:

1. Why did you decide to focus on those data?
2. What did you do to analyze your data? Why did you decide to do it that way? Did you check your calculations?
3. Is that the only way to interpret the results of your analysis? How do you know that your interpretations of your analysis are appropriate?
4. Why did your group decide to present your evidence in that manner?
5. What other claims did your group discuss before you decided on that one? Why did your group abandon the alternative ideas?
6. How confident are you that your claim is valid? What could you do to increase your confidence?

After students have analyzed their data, they share with the class the variable they tested, how they changed the procedure, and how their variable affected the rate of photosynthesis. A sample of data from student experiments is presented in Figure 2. From these data, it is clear that students find that using red light increases the rate of photosynthesis, whereas removing bicarbonate solution (the source of CO_2), water (dehydrating), using green light, or removing light slows down the process.

To encourage students to make important connections between their investigations, photosynthesis, and the cycling of matter and energy, students write an explanation for the results of their experiment using the claim, evidence, and reasoning framework (CER) (McNeill and Krajcik 2012) and answer several follow-up questions. The claim should answer the focus question, the evidence should support the claim, and the reasoning should try to explain what they observed. Figure 4 shows an example of one student's CER conclusion. Students are not penalized for claims that do not match what science research says, as long as the claims are supported by data. Students often discover that there are issues when comparing their data with other groups' data or when researching the reasoning to explain their results. In this case, students are expected to write a claim based on their data but explain why they are not confident in their claim (e.g., other students got different results, the literature tells them that something else should happen) and what they could do differently to better test their variable.

FIGURE 4: A student CER conclusion

Claim: I claim that a green light makes photosynthesis go slower.
Evidence: The data that we collected was slower than with normal white light. The pattern I noticed was that it took about two minutes longer with the green light than the white light. It took five minutes for five disks to float up, and when we used the green light It took seven minutes for five disks to float up.
Reasoning: The knowledge I had already was I knew that plants need water and sunlight to grow because when I helped my parents grow plants, if we didn't water them they died and if they didn't get enough sun they died. We as a group are somewhat confident because we did only one trial but minimized error by keeping the amount of carbon dioxide, light distance, and amount of water the same. They only thing we changed was the color of the light bulb. We were unable to compare with another group in the class because we were the only ones that tested green light. We found from an outside source that green light slowed photosynthesis because the green wavelengths are reflected by the green leaves rather than absorbed (University of Arizona College of Agriculture 1998).

Student evaluation

We wrap the activity up with a whole-class conversation about the discussion questions students completed in their groups (shown in Figure 5) and follow that up by asking students to connect their knowledge of photosynthesis to the larger context of a food web. We create a food web with students labeled as dif-

FIGURE 5: Discussion questions used after the lab

Question	Rationale
Answer the following questions using the class data: 1. What factors seemed to speed up and slow down photosynthesis? 2. What does this tell you about what is necessary for photosynthesis to occur? 3. Look at the data for presences of light and note the light color. What can be said about the importance of light for photosynthesis? 4. Think about what we learned during the wave unit. Why does the color of the light affect photosynthesis?	These questions are designed to help students identify patterns in their data and make connections between the data and the reactants of photosynthesis. Question 4 is designed to help students make connections across concepts by making connections to a previous unit on waves.
Answer the following questions using the cK–12 Flexbook reading (see Resources) and prior knowledge from previous units: 1. Read through the Light Reactions of Photosynthesis cK–12 Flexbook. What is the chemical reaction of photosynthesis? Use the chemical formulas of the substances. Do the reactants for photosynthesis match what we found necessary in questions 1 and 2 above? 2. Where does the mass of the products in the reaction come from? How do you know? Supply evidence. 3. What is the purpose of food? 4. What substance in the reaction is food for plants? Think about what could be used as food for animals. 5. In which organelle does photosynthesis take place? Is this organelle found in both animal and plant cells? Can animals go through photosynthesis? Explain. 6. Where do the C, O, and H in sugar and oxygen (products) come from? 7. In most cases, how do sunlight, water, and carbon dioxide get into plants? 8. In what part of the plant does photosynthesis take place? 9. What energy transformation takes place in plants? Use the law of conservation of energy to explain. 10. Plants can store large amounts of food. What evidence is there that supports this? (Hint: What do we use plants for?)	These questions are used to help students delve deeper into the concept of photosynthesis. Question 1 aims to help students make connections between the reading and the data they collected. Questions 2 and 6 are designed to help students take knowledge from a previous chemistry unit and apply it to photosynthesis. Students should be able to recognize that the C, H, and O in glucose come from the C, H, and O in CO_2 and H_2O. Question 3 requires students to reflect on their definition of food to see whether they have revised their ideas from the prelab. Question 4 aims to guide students toward the understanding that sugar, not CO_2 and H_2O, is food for plants. Relating the source of food to animals helps focus them on the idea that plants make their own food and do not ingest it. Questions 5, 7, and 8 help students reflect on text reading and deepen their understanding of the process of photosynthesis. Question 9 helps students think about energy and matter and relate these topics to other lessons in previous school years. Question 10 is used to get students prepared for the extension activity and help them understand that photosynthesis is only necessary for plants.

ferent organisms such as mice, grass, owls, and deer. They hold up strings to show the connections (see Online Supplemental Materials for a sample web in the student guide). We start removing the organisms that conduct photosynthesis one at a time, and students find that removing plants causes the food chain to fall apart and organisms go extinct. This helps students understand the role of photosynthesis in the cycle of matter and energy. Scaffolding questions to help guide students to this understanding include:

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standard

MS-LS1: From Molecules to Organisms: Structure and Processes
www.nextgenscience.org/dci-arrangement/ms-ls1-molecules-organisms-structures-and-processes

Performance Expectation

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

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Planning and Carrying Out Investigations Engaging in Argument from Evidence	After all students conduct the same baseline experiment, they identify variables they believe will affect the rate of photosynthesis, then modify the original procedure to test the effects of one variable of their choice. Students make a claim about how their variable affects the rate of photosynthesis and support that claim with evidence from their investigation.
Disciplinary Core Idea	
LS1.C: Organization of Matter and Energy Flow in Organisms • Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.	Students explore the phenomenon of oxygen evolution during light reactions. They then use the rate of oxygen evolution as a proxy for the rate of photosynthesis. Students use this to investigate the effects of light, CO_2, and other factors on the rate of photosynthesis. Students answer several follow-up questions that require them to make connections between the data they collected and the process of photosynthesis.
Crosscutting Concept	
Energy and Matter	Students respond to discussion-scaffolding questions and answer questions using a reading about photosynthesis.

Connections to the *Common Core State Standards* (NGAC and CCSSO 2010)

ELA
WHST.6-8.9. Draw evidence from informational texts to support analysis, reflection, and research.

Mathematics
6.EE.C.9. Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express a quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate those to the equation.

1. What is the ultimate source of energy for all living things? (*The Sun.*)

2. What do plants do with that energy? Can animals do that? (*Plants absorb sunlight and use it in a chemical reaction to produce glucose [food] by converting it to chemical energy. Animals are not able to absorb and use the Sun's energy directly to make food.*)

3. How is the energy from the Sun used to create usable matter for plants? (*Energy from the Sun [light] is used to break apart water molecules and combine them with carbon dioxide to create glucose [chemical energy], which can be used by the plant immediately for growth or repair, or stored for later.*)

4. How do the initial consumers in the food web indirectly use sunlight? (*The initial consumers eat plants and use the glucose produced by photosynthesis as a source of food. During photosynthesis light energy is converted to chemical energy in the formation of glucose, so the consumers are indirectly using sunlight to live once it is transformed into usable chemical energy.*)

5. Without plants, what happens to the food web? Why? (*Without plants, the food web would collapse, because plants are the only organisms that undergo photosynthesis and convert light energy into usable chemical energy for all other organisms by rearranging water and carbon dioxide into glucose.*)

Conclusion

We believe that the key to the success of this lesson is providing students the opportunity to explore photosynthesis in a way that emulates how science is practiced. This lesson gives students experience manipulating variables and modifying procedures to investigate how different variables affect the rate of photosynthesis. Additionally, students act as scientists and engage in activities in which they are required to identify patterns and think about connections. They confront their misconceptions and build a deeper understanding of photosynthesis. ●

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RESOURCES

Bitesize Science: Photosynthesis and respiration—*http://bbc.in/2cqvs66*

cK–12 Flexbook—*http://bit.ly/2bRPKZs*

Complete student and teacher guides—*www.gvsu.edu/targetinquiry*

Royal Society of Chemistry: Rate of photosynthesis—*http://rsc.li/2cqwHCk*

ONLINE SUPPLEMENTAL MATERIALS

Experiment steps and teacher guide—*www.nsta.org/scope1612*.

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