Modelling Photosynthesis and Cellular Respiration

GRADE LEVELS	5th – 10th
SUBJECTS	Life Sciences; Physical Sciences
DURATION	Preparation: 1 hour; Activity: 1 hour
SETTING	Classroom

Objectives

Through this kinesthetic model, students will learn:
1. that plants need carbon dioxide, water, and sunlight to carry out photosynthesis.
2. that photosynthesis produces sugar molecules that store energy.
3. that plants and animals can use that energy after breaking apart the sugar molecules through cellular respiration.
4. that plants exchange gasses through the stomata and land vertebrates exchange gasses through the lungs.

Materials

egg cartons (6 per group)
ping-pong balls (36 per group)
"energy tokens" (24 per group)
three signs, one that says "stomata", one that says "stem", and one that says "lungs"

Teacher Background

Photosynthesis is an essential process in plants. Through this process, energy from light is converted into a form that can be used by the plant. The energy is stored in sugar molecules. Animals (including humans) are not able to make this conversion, so we depend on plants to provide energy in a form that our bodies can use.

Plants take in water through the roots and carbon dioxide (CO_2) through the **stomata**. A pigment called chlorophyll, found in green parts of the plant such as leaves and green stems, captures energy from the sun. All three of these components—water, CO_2, and light—are required in order for photosynthesis to occur. Oxygen is produced as a waste product.

Cellular respiration is also an essential process, and takes place in all living things. Through this process, large molecules, such as the sugar molecules produced by photosynthesis, are broken down so that the energy stored within them can be used by the organism. Oxygen is required in order for this to occur, and CO_2 and water are produced as waste products.

Since both plants and animals do cellular respiration, they both need to take in oxygen from the air and release CO_2 and water into the air. In plants, this occurs through the stomata. In land vertebrates (like humans) this happens through the lungs. (Other animals have other methods, like gills, tracheoles, etc.)

In this activity, students will act out both processes (photosynthesis and cellular respiration), providing a tangible illustration of what components are needed for each process, as well as what the waste products are.

Preparation

Teacher Tip: *Gathering and preparing these materials will be time-consuming the first time you do the activity. However, all of the materials can easily be stored and reused year after year. See page 7 for pictures of the complete set-up!*

1. **Determine how many groups you will have.** Each group will need 4 – 6 students. (If you are short on supplies, groups as large as 8 students could work.) You will need 36 ping-pong balls, 24 energy tokens, and 6 egg cartons for each group.

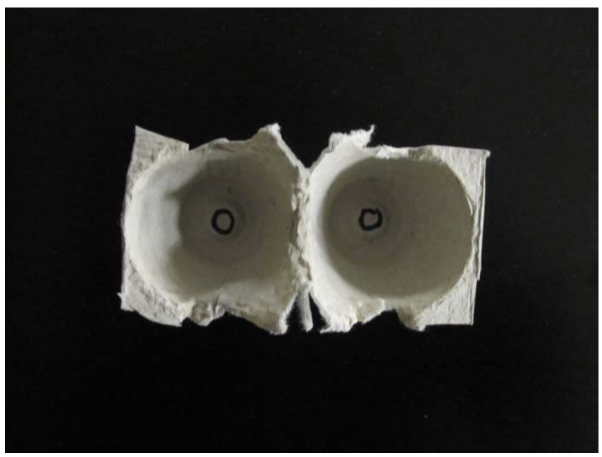
2. **Prepare ping-pong balls.** These will represent carbon, hydrogen, and oxygen atoms. Use a sharpie to label the ping-pong balls. For each group of students, you will need 6 balls labeled "C", 12 balls labeled "H", and 18 balls labeled "O."

3. **Collect egg cartons.** These will be used to structure the molecules that students will be constructing. (Ask students to bring in egg cartons from home for a few weeks before the activity to help collect enough.) You will need 6 egg cartons for each group.

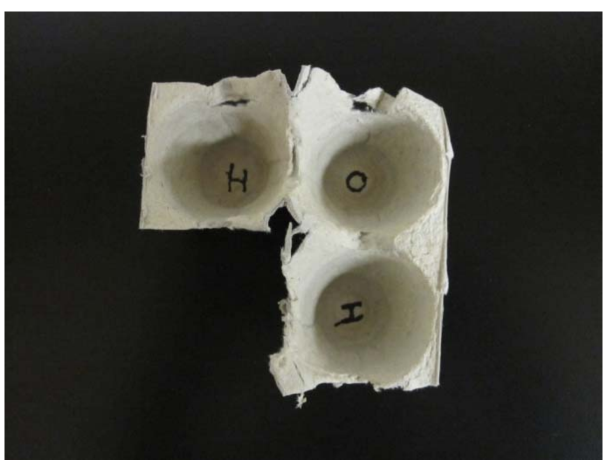
4. **Prepare the egg cartons.** Cut the egg cartons apart into the shapes shown. These shapes will "frame" the molecules that students will assemble. Label the inside of each compartment to show what atom should be placed in it. Note that the shapes of the O_2, CO_2 and H_2O frames are roughly accurate; however, the shape of the sugar molecule is greatly simplified.

Each group needs 6 CO_2 frames:

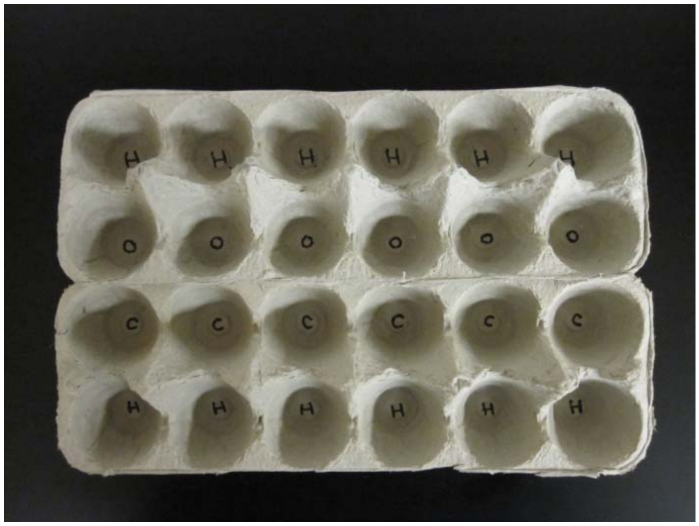
Oxygen in the atmosphere is normally found in the form of O_2 (two oxygen atoms bonded together). Each group needs 6 O_2 frames:



Each group needs 6 H_2O frames:



The sugar (glucose) produced by photosynthesis is made of 6 carbons, 12 hydrogens, and 6 oxygens. Each group needs one sugar frame:



5. **Prepare "energy tokens."** These should be small squares of paper or cardstock (about 2 inches by 2 inches is ideal). Each group of students will need at least 24 energy tokens. Prepare them for the simulation start by folding in half to represent "light energy."

6. **Post signs in the classroom.** These label areas for the simulation. The door will be the "STOMATA" and the sink (or a place of your choice) will be the "STEM".

7. **Prepare filled H_20 and $C0_2$ "molecules."** As you describe the simulation to your students, you'll place the water near the sink, the carbon dioxide in the hallway, and the empty oxygen frames in the hallway, too.

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Part One: Photosynthesis

Your Task: Build a sugar molecule in a leaf cell!

Review (or introduce) some necessary prior knowledge:

1. Review (or introduce) the term **photosynthesis**. This is the process that plants use to get energy (whereas humans and other animals get energy by eating food). Through photosynthesis, plants create sugar molecules that store energy for them to use later. Some of the sugar molecules become part of the structure of the plant in the form of cellulose.
2. Have students discuss with a partner what they think plants need in order to do photosynthesis. Let them brainstorm ideas, then tell them they will discover this through the activity.
3. Review (or introduce) the concept of **stomata**, which are small openings on the underside of the leaf. When the stomata are open, air can move in and out of the leaf. When they are closed, the inside of the leaf is sealed off from the outside air.
4. If appropriate for your students, review the difference between **atoms** and **molecules**. An atom is the smallest possible piece of a pure substance, like carbon or hydrogen. A molecule is made of two or more atoms bonded together.

Set the stage:

❖ Explain that the classroom will represent a leaf, and that each table within the classroom will represent a cell within the leaf. Students will be working in groups to build a sugar molecule in their cell.

Explain the materials and room layout:

1. Give each group an empty **sugar frame**. Look at labels in the frame. Review what atom each letter represents. *(C = carbon. H = hydrogen. O = oxygen.)*
2. Tell students the **carbon atoms** will be coming from carbon dioxide molecules (CO_2). Where is CO_2 found? *(In the air.)* How does CO_2 gets into the leaf? *(CO_2 in the air enters the leaf through the stomata.)* Tell students that the classroom represents the leaf and the area outside the room represents the air surrounding the leaf. Open the door and place filled CO_2 molecules just outside.
3. The **hydrogen atoms** will be coming from water molecules (H_2O). How does water get into the leaf? *(It is drawn from the soil into the roots, up the stem, and into the leaf.)* Place the filled H_2O molecules under the sign.
4. Some of the **oxygen atoms** will come from CO_2 molecules and some from H_2O molecules.
5. Show students the **energy tokens**. Explain that sugar molecules store energy. To represent this, students will have to pack an energy token under each atom in the sugar frame. Ask students where the leaves get this energy. *(From sunlight.)* However, the energy in light is not in a form that can be used by a plant. Show students the folded energy tokens. Folded in a rectangle, they represent "light energy" from the sun. Folded in a triangle, they represent "chemical energy" that they plant can use. (See photo on page 7 to clarify.)

Explain that plants convert energy from one form to another so that it can be stored in sugar molecules. Act as the sun and will sprinkle the "light energy" tokens around the room.

Explain roles and rules:

1. Students will have to work together within their groups to gather the things they need and put the sugar molecule together. ***Teacher Tip:*** *You can decide whether to assign a role to each student or to let the groups work out the process on their own.*
2. Actions:
   - **Sugar molecule must be completed.** As the materials are gathered, take atoms from the CO_2 and H_2O molecules and place them in the appropriate places in the sugar frame.
   - **Carbon dioxide molecules must be carried to the cell.** Bring CO_2 molecules from the outside area to the table.
   - **Water must also be carried to the cell.** Bring these molecules from the sink to the table.
   - **You have to get rid of empty frames**. Put them where they belong!
   - **Energy must be collected and converted into a usable form.** Gather energy tokens to the table and convert them from "light energy" into "chemical energy." Pack an energy token under each atom in the sugar molecule. This represents the energy stored in the bonds within a sugar molecule.
   - **Atoms cannot be wasted.** When you take apart a molecule, take all the atoms out of the frame. For example, you can't take the hydrogen out of the water frame and leave the oxygens in. Without the hydrogen, it's not a water molecule anymore.
   - **Leftover atoms go from the cell to the air.** At the end of the activity, the only thing students should have on their table is the completed sugar molecules. Any leftover materials need to be taken out of the leaf and expelled into the air.
   - **Only fetch one thing at a time.**
   - **You can split up the tasks**, but STILL only one thing at a time!

Procedure

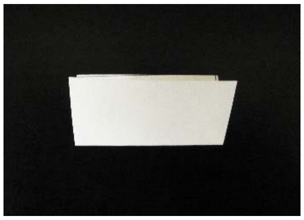
Once students are clear on what to do and where to find the materials, have them start building sugar molecules. **Teacher Tip:** *Now is a good time to put the empty 0_2 molecule containers in the hallway.*

Discussion

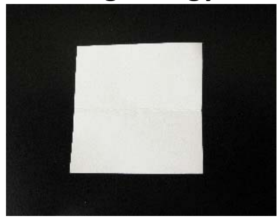
After the simulation, discuss some of these questions:

- What did the plant need to do photosynthesis? *(Carbon dioxide, water, and light energy)*
- Where did it get those things? *(Carbon dioxide from the air outside the leaf, water taken up from the soil, and light energy from the sun)*
- Where did the oxygen come from? Where do it go? *(Oxygen was leftover after the carbon and hydrogen had been used from the CO_2 and water; the oxygen went out through the stomata into the air)*
- Is the air outside the cell any different than it was before? *(After photosynthesis, the air contains less CO_2 and more oxygen)*

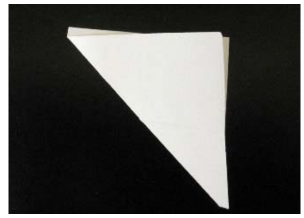
Converting energy tokens:



This token represents light energy.



To convert it, unfold...



...and refold. Now it represents chemical energy.

Summary of materials before photosynthesis:

The energy tokens (showing the "L.E." side) should be scattered around the classroom.

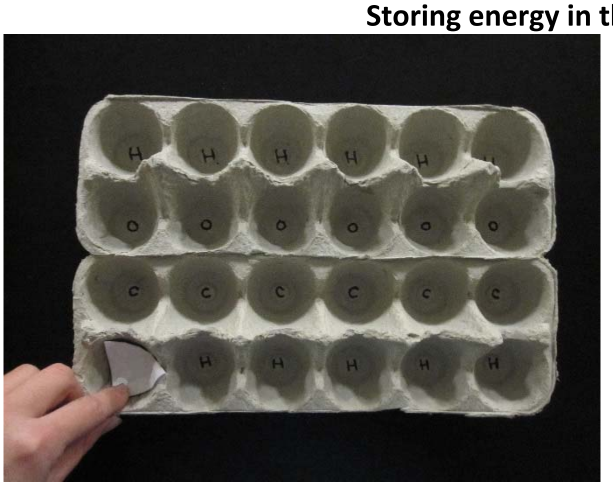
The water molecules should be located below a sign reading "stem."

The carbon dioxide molecules should be located outside of the door labeled "stomata."

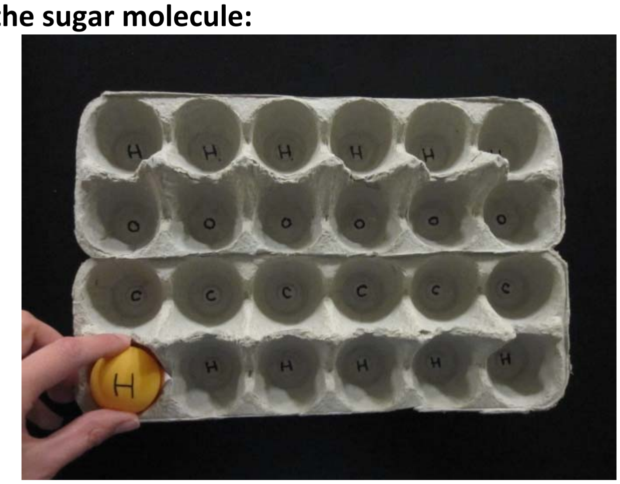
Empty oxygen frames should be located in the hallway, outside of the door labeled "stomata."

Each group of students should have an empty sugar frame at their table.

Storing energy in the sugar molecule:



Pack an energy token under each atom of the sugar molecule by placing the token in the spot...



...and then placing the appropriate ping-pong ball atom on top of it. Repeat until the tray is full.

Extension
If desired, you can emphasize the ingredients that are needed for photosynthesis by repeating the activity with limited access to the different components. This also highlights some ways that plants can be affected by the environment.

In each scenario, start by putting all materials back in their original starting places. Tell students the scenario, remove access to one resource, and let them try to produce a sugar molecule. They will soon realize they can't do it without light/ CO_2 / H_2O. Ask students why this is so.

Round 2: Take away all the energy tokens. Tell the students the sun has gone down and no light is available. They must try to produce a sugar molecule without light, while still following all the rules. Do they think it's possible? [Try → fail → discuss!]

Round 3: Close the door. Tell students the stomata have closed and no air is able to enter or exit the leaf. They must try to produce a sugar molecule with no air. [Try → fail → discuss!]

Round 4: Remove all the water molecules from the stem area. Tell students there is a drought and there is no water for the plant to take up from the soil. They must try to produce a sugar molecule without water. [Try → fail → discuss!]

Part Two: Cellular Respiration

Your Task: Find something cells need to break down sugar, so we can use energy from our sugar molecule!

Introduction
1. Let's **use** some of the energy that they stored in their sugar molecules.
2. Tell students that when cells break down sugar to access energy, they release CO_2 and water. However, there is a piece missing—they need to get something in addition to sugar to make this happen. Their task is to discover what that is and how to get it.
3. Give groups empty CO_2 and H_2O frames. Tell them success is achieved when these molecules are complete and released in to the air as byproducts.

Procedure
Round 1: plants
- ❖ Give them time to break apart the sugar molecule, remove the energy tokens, and try to make the CO_2 and H_2O molecules. Leave the door (stomata) open and the oxygen atoms from earlier outside.
- ❖ Students will find that they need oxygen in order to complete the molecules, and should figure out that they can get it from the "air" outside the leaf.
- ❖ The CO_2 and H_2O molecules should then be taken out the stomata (released into the air.)

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Round 2: animals

- Reassemble the sugar molecules for this round and put all materials back in their starting places.
- Explain that animal cells need energy, and also get it by breaking apart sugar molecules. BUT animal cells can't make their own sugars the way plant cells can. So where do animals get the sugar they need? *(By eating plants.)*
- Tell students that the leaf they are a part of is about to be swallowed by a hungry herbivore. The leaf is getting chewed up and digested. Then the sugar molecules that were contained within the leaf are passed to cells in the body.
- Take down the "stomata" sign and the "stem" sign. Tell students that the classroom now represents the animal's body. Each table is a cell within the animal. The cells need to break apart the sugars to release energy so the animal has can use it to keep moving around. Just like in plants, the process will release CO_2 and water. What are they missing to make this happen? *(Oxygen.)* Where will the animal get that oxygen? *(By breathing it in.)* Put a new sign over the door that says "lungs."
- Now go through the respiration process again. This will be the very same process as it was for plants—the only difference is that oxygen enters through the lungs instead of the stomata. Students should bring oxygen in through the lungs (door) and release the CO_2 and H_2O produced in the process out through the lungs.

Optional: Discuss vocabulary

- If desired, discuss the terms *respiration* and *cellular respiration*. This can be confusing since they refer to different but related processes.
- The task students were doing at the tables—breaking apart sugar to release energy—is called **cellular respiration**. It's a metabolic process—essentially a chemical reaction.
- The task of bringing O_2, CO_2, and H_2O molecules to and from the cell is called **respiration**. It's not a chemical reaction, it's simply the exchange of gasses (CO_2, H_2O, O_2, etc.) between cells and the environment.
- The process of **cellular respiration** is exactly the same in plants and in animals.
- The process of **respiration** differs between plants and animals. In plants, gas is exchanged passively through the stomata. In land-dwelling vertebrates (like humans), gas is exchanged actively through the lungs. (Other animals have other methods, like gills, tracheoles, etc.)

Next Generation Science Standards

Disciplinary Core Ideas

Grade Five

LS1.C: Organization for Matter and Energy Flow in Organisms

- Plants acquire their material for growth chiefly from air and water.

PS3.D: Energy in Chemical Processes and Everyday Life

- The energy released from food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water).

Middle School

LS1.C: Organization for 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.

PS3.D: Energy in Chemical Processes and Everyday Life

- The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.
- Cellular respiration in plants and animals involves chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials.

High School

LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.

Science and Engineering Practices

- Using Models

Crosscutting Concepts

- Systems and System Models
- Energy and Matter

Performance Expectations

Remember, performance expectations are not a set of instructional or assessment tasks. They are statements of what students should be able to do after instruction. This activity or unit is just one of many that could help prepare your students to perform the following hypothetical tasks that demonstrate their understanding:

5-PS3-1. Use models to describe that energy in animals' food (used for body repair, growth, motion, and to maintain body warmth) was once energy from the sun.
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.
HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.