

Follow the Atoms, Follow the Energy: A Sealed-Jar Model

Investigation question: Inside a sealed jar holding a water plant, water, air and a snail in sunlight, where does every atom go, where does the energy go, and what crosses the boundary in each direction?

Collaborative systems modeling

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-LS1-6 · assesses

MS-LS2-3 · practice

Scientific purpose

Students draw a boundary around a sealed jar and use paper atom tokens and energy cards to run photosynthesis, storage, eating and energy use as a sequence of rearrangements. At every stage they count carbon, hydrogen and oxygen tokens inside the boundary and track where the energy cards are. They discover that the atom counts never change, that light energy enters the system and ends up leaving as heat, and that the plant's biomass is made from atoms that were in the air and water a few minutes earlier. The lab makes conservation of matter and the one-way flow of energy concrete before students meet whole-ecosystem cycles in Lessons 6 and 7.

Why this helps students with this chapter

Students readily say 'matter is conserved' and 'energy flows' without knowing what either sentence rules out. Having to put every oxygen token somewhere, and finding that there is nowhere for a light card to hide inside a sugar except as stored chemical energy, forces the two ideas apart. The snail step shows that a consumer's body is built from the same tokens the plant pulled out of the air, and the final count shows that the jar still holds every atom it started with while all the energy has left as heat.

Standards connections

MS-LS1-6 (assesses, the explanation of matter entering a producer and energy flowing into and out of it): Students use their token record to write an explanation of how carbon dioxide and water become a producer's body and how light energy becomes stored chemical energy and then heat. The explanation traces matter and energy without any biochemical mechanism, which matches the PE and its assessment boundary.

MS-LS2-3 (practice, developing a bounded model of matter cycling and energy flow among living and nonliving parts): The jar is a tiny ecosystem with a drawn boundary, a producer, a consumer, air and water. Students show matter cycling inside the boundary and energy flowing through it. The chemical equation is used only to count atoms, not to describe the process, and the full ecosystem model with decomposers and reservoirs comes in Lessons 6 and 7, so the role is practice.

Roles (rotate each session)

- **Boundary keeper:** Draws and labels the jar boundary and its zones (air, water, plant, snail), and challenges any token or card that crosses the line without being recorded.
- **Atom mover:** Builds molecules from tokens, rearranges them at each stage, and keeps every token on the poster, never in a pocket or on the floor.
- **Energy tracker:** Moves the energy cards: brings light cards in across the boundary, attaches them to sugar, and carries heat cards out when energy is released.
- **Counter and recorder:** Counts carbon, hydrogen and oxygen tokens inside the boundary at every stage, records the counts and the location of the energy cards, and calls a halt if a count changes.

Materials

Item	Quantity	Per	Note
Carbon tokens (black squares, labeled C)	12	group	Printed on card stock and cut, or black pony beads.
Hydrogen tokens (white squares, labeled H)	24	group	
Oxygen tokens (red squares, labeled O)	36	group	
Energy cards, yellow on one side (LIGHT) and orange on the other (HEAT)	12	group	Index cards colored on each side work.
Poster paper or a large sheet of butcher paper	1 sheet	group	
Markers in two colors (one for matter arrows, one for energy arrows)	2	group	
String or yarn to lay out the boundary, about 2 m	1 piece	group	
Two 'SUGAR' cards, each a folded index card that can hold 6 C, 12 H and 6 O tokens	2	group	
Small zip bag to store the token set	1	group	
Recording sheet	1	student	

Estimated cost: 6 to 12 per class, reusable (an estimate; Three sheets of colored card stock per group (about \$0.50) or one bag of pony beads in three colors (\$5 for the class), index cards, string and poster paper. Token sets go in zip bags and last for years.)

Safety

- No hazards beyond ordinary classroom materials. Pony beads are a choking hazard for young children; keep the sets bagged and off the floor.
- If a live jar with pondweed and a snail is used at the front, wash hands after handling it and return the organisms to the aquarium afterward; do not seal a live animal in a jar for more than the class period.

Teacher preparation and setup

1. Print or cut the token sets: 12 C (black), 24 H (white), 36 O (red) and 12 two-sided energy cards per group. Count each bag before class; a missing token wrecks the conservation result.
2. Prepare two folded SUGAR cards per group large enough to hold 24 tokens, labeled $C_6H_{12}O_6$ on the outside.
3. Post the balanced equation on the board: $6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$, and under it the reverse for energy use: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy released}$.
4. Set up one model jar at the front (a real jar with a sprig of pondweed and a snail, or a drawing) so students have a picture of the system they are modeling.
5. Print the recording sheet; the stage column is filled in so students only write counts and locations.

Investigation design

Independent variable	The stage of the model (starting jar, light in, photosynthesis, energy use, storage, eating, consumer energy use)
Dependent variable	The number of carbon, hydrogen and oxygen tokens inside the boundary, and the location and side (light, stored, heat) of each energy card
Controlled	Fixed token set of 12 C, 24 H, 36 O; Boundary never moved once drawn; Every crossing recorded with an arrow; Same equation used for every photosynthesis round and its reverse for every energy-use round
Trials	One full run per group; groups then compare final counts and arrow diagrams on the wall.
Comparison	Atom counts at stage 1 against stage 8, and energy cards inside the boundary at stage 2 against stage 8.

Student procedure

1. Lay the string on the poster in a large jar shape. This is the system boundary. Inside it, draw and label four zones: AIR at the top, WATER below, a PLANT in the water, and a SNAIL on the plant. Everything outside the string is 'outside the system.' Nothing may cross the string without an arrow being drawn and a note in the record.
2. Stage 1, starting jar: in the AIR zone build 12 carbon dioxide molecules (each C with two O). In the WATER zone build 12 water molecules (each O with two H). Count C, H and O inside the boundary and record them on the sheet. There are no energy cards inside yet.
3. Stage 2, light arrives: the energy tracker brings 12 LIGHT cards (yellow side up) across the boundary into the PLANT zone and draws a dashed arrow across the string to show it. Record where the energy cards are.
4. Stage 3, photosynthesis, round one: in the PLANT zone, take 6 CO_2 and 6 H_2O apart and rebuild the tokens as one sugar: put 6 C, 12 H and 6 O into SUGAR card 1. The 12 leftover O tokens become 6 O_2 molecules; move them to the AIR zone and draw a solid arrow from plant to air. Tuck 6 LIGHT cards inside SUGAR card 1, yellow side up; a card inside a sugar card counts as 'stored.' Count all atoms inside the boundary and record.

5. Stage 4, photosynthesis, round two: repeat stage 3 with the remaining 6 CO₂ and 6 H₂O to fill SUGAR card 2 with the other 6 energy cards. Count and record. Now the AIR zone should hold 12 O₂ and no CO₂, and the WATER zone no free water molecules.
6. Stage 5, the plant uses sugar 1 now: the plant reacts SUGAR card 1 with 6 O₂ from the air. Take the 24 tokens out of the card, rebuild 6 CO₂ (to AIR) and 6 H₂O (to WATER), and take out the 6 energy cards. Flip them to the orange HEAT side; the plant used that energy to grow and move materials, and all of it ends up leaving the jar as heat. Carry the 6 HEAT cards across the boundary and draw a dashed arrow out. Count and record.
7. Stage 6, the plant keeps sugar 2 as biomass: SUGAR card 2 stays in the PLANT zone. Label it 'stored as starch or built into cell wall.' This is the plant's body. Record where its 6 energy cards are (still inside the plant, stored).
8. Stage 7, the snail eats: move SUGAR card 2 from the PLANT zone to the SNAIL zone with a solid arrow. The atoms and the stored energy cards are now part of the snail. Count and record; nothing has crossed the boundary.
9. Stage 8, the snail uses the sugar: the snail reacts SUGAR card 2 with the remaining 6 O₂. Rebuild 6 CO₂ and 6 H₂O into the AIR and WATER zones, flip the 6 energy cards to HEAT, and carry them out across the boundary with a dashed arrow. Final count: record it and compare with stage 1.
10. Draw the finished model on the recording sheet: the boundary, the four zones, solid arrows for every matter movement and dashed arrows for every energy movement, each arrow labeled with what moved. Then answer the questions.

Expected observations

- Atom counts read 12 C, 24 H, 36 O at every stage; a different number at any stage means a token was dropped or a molecule was built wrong.
- At stage 4 the air zone holds 12 O₂ and no CO₂, the water zone is empty of free water molecules, and both sugar cards are full with 6 energy cards each.
- At stage 8 the air zone again holds 12 CO₂ and the water zone 12 H₂O, both sugar cards are empty, and all 12 energy cards are outside the boundary on the HEAT side.
- Students usually hesitate at stage 5 about where the 'used' energy goes; the orange heat side and the dashed arrow out resolve it.

Likely difficulties

- Building CO₂ with one O or water with one H; have the counter check the first three molecules before the group builds the rest.
- Forgetting the leftover oxygen tokens at stage 3 and leaving 12 O unassigned; remind groups that every token must be in a molecule in a zone.
- Treating the energy cards as atoms and trying to put them in the atom count; the energy tracker keeps them in a separate row.
- Groups that want the snail to 'make' energy. The snail only releases energy that was stored in the sugar, which came from light.

- Time: stages 5 and 8 are the reverse of stages 3 and 4 and go faster once the group sees that; if short on time, let one group skip stage 4 and 8 and share with a neighbor.

Structured debrief

1. Post every group's stage 1 and stage 8 counts side by side on the board. They should all read 12 C, 24 H, 36 O at both ends. Ask what it means that the jar ends with the same molecules it started with, even though a plant grew and a snail ate it: matter cycled inside the boundary; nothing was created or lost.
2. Then post the energy card locations: 12 inside at stage 2, 0 inside at stage 8, all out as heat. Ask whether energy was conserved. It was; it entered as light and left as heat. Energy flows through the system in one direction; it does not cycle back into light.
3. Ask where the plant's body came from in the model (stage 6): atoms that were in the air and water at stage 1. Connect to the willow and the sequoia: wood is sugar 2 kept and linked into cellulose, built from carbon dioxide that came in through the leaves.
4. Name the model's limits as a class (see modelLimitations) so students do not think a real jar is this tidy.

Recording sheet: what students fill in

Lab 2 recording sheet: Follow the atoms, follow the energy

After each stage, count every token inside the string boundary and write where the energy cards are and which side is up. If a count changes between stages, stop and find the missing token before going on.

Atom and energy count at each stage

Stage	C inside	H inside	O inside	Energy cards inside and where	Light / stored / heat?
1. Starting jar (12 CO ₂ in air, 12 H ₂ O in water)					
2. 12 light cards enter the plant					
3. Photosynthesis round one (sugar 1 made)					
4. Photosynthesis round two (sugar 2 made)					
5. Plant uses sugar 1 with oxygen					
6. Plant keeps sugar 2 as biomass					
7. Snail eats the plant (sugar 2 moves)					
8. Snail uses sugar 2 with oxygen					

Molecules in each zone at the start and at the end

Zone	Start: molecules present	End: molecules present	Same or different?
Air			
Water			
Plant			
Snail			

- ✎ Draw the finished jar model: the boundary, the four zones, a solid arrow for each movement of matter and a dashed arrow for each movement of energy. Label every arrow with what moved (for example 'O₂ to air', 'light in', 'heat out').

Answer: A closed boundary with four labeled zones (air, water, plant, snail). Solid arrows: CO₂ from air to plant and H₂O from water to plant (photosynthesis), O₂ from plant to air, sugar from plant to snail (eaten), and CO₂ back to air and H₂O back to water from both plant and snail (energy use). Dashed arrows: light crossing the boundary into the plant, and heat crossing the boundary out from the plant and from the snail. No solid arrow crosses the boundary.

Why: The diagram is the bounded model itself: matter cycles inside, energy flows through. The two checks are that every matter arrow stays inside the string and that both energy arrows cross it.

- Boundary and four zones present
- Solid arrows for CO₂, H₂O, O₂ and sugar movements, correctly directed
- Dashed arrows for light in and heat out, crossing the boundary
- No matter arrow crosses the boundary
- Every arrow labeled

1. Compare your atom counts at stage 1 and stage 8. What happened to the number of C, H and O atoms inside the boundary during the whole run?

Answer: They stayed the same: 12 C, 24 H and 36 O at stage 1 and at stage 8, and at every stage between.

Why: Conservation of matter inside a closed boundary; no atom crossed the string.

- States the counts did not change
- Gives the numbers or refers to the table

2. List everything that crossed the boundary, in each direction, during the run. Was any of it matter?

Answer: In: 12 light cards (energy) at stage 2. Out: 6 heat cards at stage 5 and 6 heat cards at stage 8. Nothing else crossed. None of it was matter; only energy crossed the boundary.

Why: The jar is closed to matter and open to energy, which is why the atom count is fixed and the energy card count inside falls to zero.

- Lists light in and heat out with the right numbers
- States that no matter crossed

Analysis questions: answer key

3. At stage 4 the plant's two sugar cards hold 12 carbon atoms. Where exactly were those 12 carbon atoms at stage 1, and what did the plant have to do to get them?

Answer: They were in the 12 carbon dioxide molecules in the AIR zone. The plant had to take in the carbon dioxide and, using light energy, take the molecules apart and rebuild the carbon atoms into sugar along with hydrogen and oxygen from water.

Why: Every carbon in a plant's body came in as carbon dioxide; this is the core of MS-LS1-6.

- Locates the carbon in air as CO₂
- Says the plant took in CO₂ and rearranged it using light energy

4. At stage 7 the snail's body contains sugar 2. Trace one carbon atom in that sugar from stage 1 to stage 7 in a chain of locations (air → ... → snail).

Answer: Air (in a CO₂ molecule) → plant (taken in, rebuilt into sugar 2 at stage 4) → plant's body (kept as biomass, stage 6) → snail (eaten, stage 7). If continued: → air again as CO₂ after the snail uses the sugar (stage 8).

Why: The chain shows matter moving from a nonliving reservoir to a producer to a consumer, which is the beginning of the Lesson 6 food-web idea.

Also acceptable: Accept chains that start at the water zone for an oxygen or hydrogen atom if the question is reinterpreted, as long as the order is correct.

- Correct order of locations
- Names the form at each step (CO₂, sugar, biomass)

5. Light cards came in; heat cards went out. Explain why a solid arrow (matter) would be the wrong kind of arrow for both, and what the energy was doing while it was 'stored' inside a sugar card.

Answer: Light and heat are energy, not matter: they have no atoms, so they never change the atom count and cannot be drawn as matter moving. While a light card was 'stored' in a sugar card, its energy was held as chemical energy in the sugar; the sugar did not get heavier and no atoms were added. The energy stayed there until the sugar reacted with oxygen, when it was released to do work and finally left as heat.

Why: Keeps the two conservation ideas apart and uses the accurate wording (stored as chemical energy in the sugar; released in the reaction with oxygen), not 'stored in bonds that break.'

- Says energy has no atoms and so cannot be a matter arrow
- Says the energy was stored as chemical energy in the sugar
- Says it was released when the sugar reacted with oxygen and left as heat

6. Suppose the jar had been kept in the dark from the start. Which stages could still happen and which could not? What would the final atom count be?

Answer: Stage 1 could happen (the starting molecules exist), but stage 2 could not (no light enters), so stages 3 and 4 could not happen: no sugar is made, no oxygen is released, and the air keeps its 12 CO₂. With no sugar, stages 5 to 8 cannot happen either; a real plant would survive for a while on stored starch from before and then starve, and the snail would have nothing to eat. The final atom count would still be 12 C, 24 H, 36 O, because atoms are conserved whether or not anything is built.

Why: Tests that students see light as the required energy input and that conservation of matter holds regardless of what the organisms do.

Also acceptable: Credit answers that let the plant use previously stored starch for a while, since real plants do.

- States that no photosynthesis occurs without light
- Explains the chain of consequences for storage and the snail
- States that the atom count is unchanged

7. The real plant's body is mostly cellulose and other cell-wall materials made by linking many sugar units into chains, with the atoms of one water molecule left out at each link. If you linked sugar 2 to a neighboring group's sugar card, which tokens would you have to set aside, and would any atom be lost?

Answer: You would set aside 2 H and 1 O, the atoms of one water molecule, for each link, and put them in the WATER zone. No atom is lost: the chain has those atoms fewer, and the water has them more. The count inside the boundary stays 12 C, 24 H, 36 O (or the combined total if two groups pool their tokens).

Why: Each link in starch or cellulose leaves out the composition of one water molecule; the point is that even building materials obey conservation.

- Names 2 H and 1 O (one water molecule's atoms)
- States no atom is lost and the atoms go to the water zone

8. Write a four-sentence explanation of how the snail's body was built from air and water, naming what supplied the atoms and what supplied the energy at each step.

Answer: Example: The atoms in the snail's body started as carbon dioxide in the air and water in the jar. The plant took them in and, using light energy from outside the jar, rearranged them into sugar and released leftover oxygen into the air. The plant kept some of that sugar as its body, with the light's energy stored in it as chemical energy. When the snail ate the plant, those atoms and that stored energy became part of the snail, and when the snail used the sugar with oxygen, the atoms went back to the air and water and the energy left the jar as heat.

Why: This is the MS-LS1-6 explanation in the model's terms, tracing matter from nonliving to producer to consumer and energy from light to stored to heat.

- Atoms come from CO₂ and water, not from light
- Light supplies the energy; it is stored as chemical energy in the sugar
- The consumer's body is built from the producer's matter
- Energy leaves as heat; atoms return to air and water

Individual evidence of learning

Each student submits a completed count table, a zone table, a boundary drawing with labeled solid and dashed arrows, and written answers to q1 through q8. The drawing and q8 are the evidence for the bounded model; q3, q4 and q5 show whether matter and energy are kept separate.

Assessment criteria

Criterion	Proficient looks like
Conservation record	Counts of 12 C, 24 H, 36 O at every stage, with energy cards tracked in a separate column and correctly located.
Boundary diagram	Boundary drawn, four zones labeled, every matter movement shown with a solid labeled arrow and every energy movement with a dashed labeled arrow; light in and heat out cross the boundary and no matter does.
Tracing matter	Follows a carbon atom from air to sugar to the plant's body to the snail and back to air in the correct order.
Separating matter from energy	Explains that light contributed no atoms, that the energy was stored as chemical energy in the sugar, and that it left as heat after being released, without saying bonds release energy when broken.

Accessibility adaptations

- Provide large tokens (3 cm) with raised or textured shapes in addition to color: square for carbon, circle for oxygen, triangle for hydrogen, so the model does not rely on color alone.
- Let one student narrate each stage while another moves tokens; accept a photographed poster in place of a redrawn diagram.
- Give the count table with stage 1 filled in and a reminder strip ('every token in a molecule, every molecule in a zone') taped to the poster.
- Offer the four-sentence explanation (q8) as a sentence-strip ordering task for students who need support, and allow a spoken recording.

Low-cost alternative

Use paper squares cut from three colors of construction paper, or draw the tokens with colored pencil on sticky notes. If poster paper is unavailable, use a desk with masking-tape boundaries and photograph the stages instead of drawing them.

Model limitations

A real plant makes sugar continuously in light, uses some of it at every moment, and never converts all the carbon dioxide in a jar; the model runs the steps one at a time to make counting possible. The sugar card stands for glucose, while real plants move sugar as sucrose and store it as starch. The energy cards are a simplification: the plant and snail use released energy to do work, and that energy becomes heat only after it has done the work. The model also ignores the snail's own waste and the oxygen used by microbes in the water, and it treats the jar as perfectly sealed to heat flow except where the cards cross. This activity has not been physically tested by the authors; the token counts and stage sequence have been checked arithmetically.

Teacher notes

Check the count table first; a group with a wrong count at any stage has usually built a molecule wrong, and the rest of their reasoning will be sound once the token is found. For the drawing, the two things to look for are that no matter arrow crosses the boundary and that both energy arrows do. If a group finishes early, have them run the optional cellulose link in q7 with a neighboring group's sugar card and show the water molecule they set aside. The language to insist on in q5 and q8 is 'stored as chemical energy in the sugar' and 'released when the sugar reacts with oxygen'; correct any answer that says energy is released by breaking bonds.