

Carbon by the Hour, Nitrogen by the Week: Two Teaching Datasets

Learning target: I can graph and calculate from data about a sealed terrarium and a fertilized pond to show that matter moves between reservoirs at measurable rates without being created or destroyed.

Data and graphing

About 45 min

Individual

MS-LS2-3 · practice

MS-LS2-4 · practice

MS-LS1-6 · supports

data analysis

independent practice

Standards connections

MS-LS2-3 (practice): The terrarium data let students see carbon moving between the air inside a sealed system and the plants, hour by hour, and reason about conservation of matter within a defined boundary. They analyze the model's behavior rather than build the model.

MS-LS2-4 (practice): The pond data show a change to a nonliving component (nitrate) followed by a change in a population (algae cover). Reading that pattern builds the data-analysis practice the PE calls for, though students do not yet write the full argument.

MS-LS1-6 (supports): The day-night pattern in carbon dioxide is the signature of photosynthesis in light and cellular respiration at all hours. The sheet uses the pattern as evidence but does not ask for the explanation the PE requires.

Purpose: practice · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

Part A: Carbon dioxide inside a sealed terrarium

A class sealed a clear 20-liter container holding moist soil, three small plants and a carbon dioxide sensor. A lamp on a timer lit the container from 6:00 a.m. to 6:00 p.m.; the rest of the time it was dark. The sensor reported carbon dioxide in parts per million (ppm) every two hours. Nothing entered or left the container except light and heat.

Carbon dioxide in the sealed terrarium over 24 hours (teaching dataset)

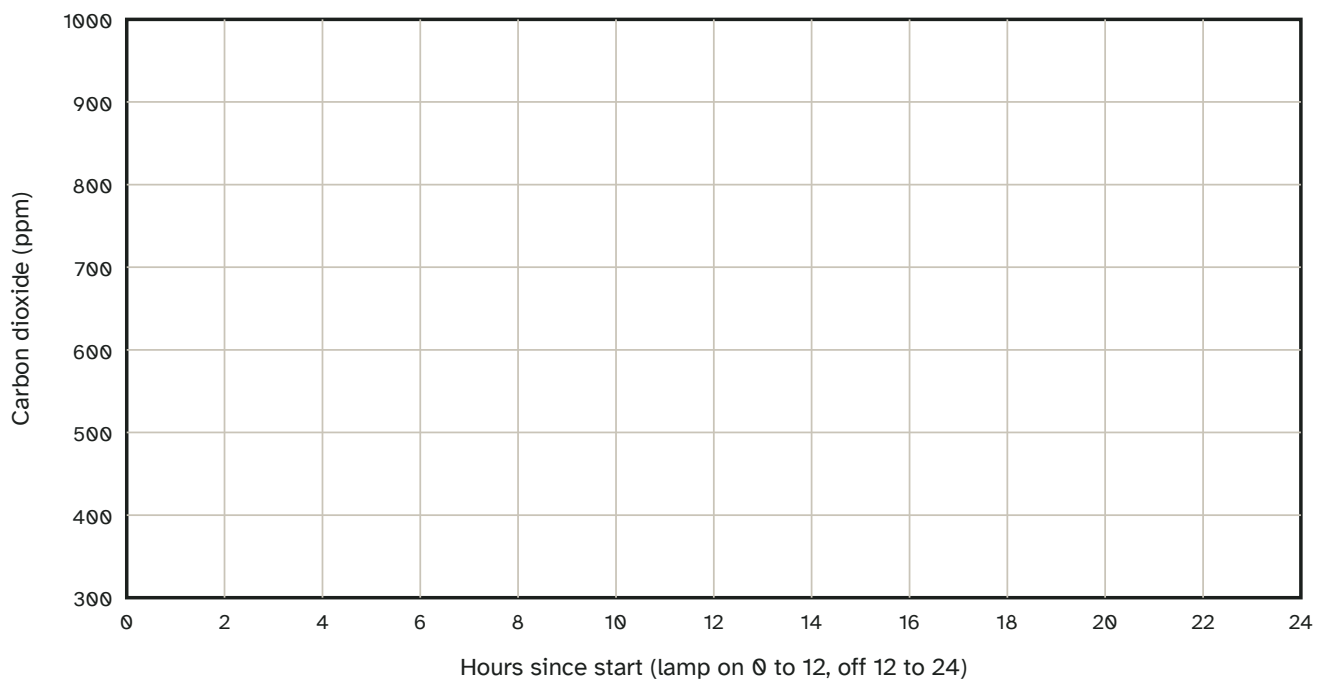
Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Clock time	Hours since start	Lamp	Carbon dioxide (ppm)
6:00 a.m.	0	on	900
8:00 a.m.	2	on	810
10:00 a.m.	4	on	725
12:00 noon	6	on	640

Clock time	Hours since start	Lamp	Carbon dioxide (ppm)
2:00 p.m.	8	on	560
4:00 p.m.	10	on	480
6:00 p.m.	12	off	400
8:00 p.m.	14	off	485
10:00 p.m.	16	off	565
12:00 midnight	18	off	645
2:00 a.m.	20	off	725
4:00 a.m.	22	off	805
6:00 a.m.	24	on	880

Simulated data for teaching. Realistic for a small planted container with a classroom sensor.

Carbon dioxide in the terrarium versus time



- Calculate the total drop in carbon dioxide while the lamp was on (hour 0 to hour 12), then the average rate of change in ppm per hour. Show your work.

Answer: Drop: $900 \text{ ppm} - 400 \text{ ppm} = 500 \text{ ppm}$. Rate: $500 \text{ ppm} \div 12 \text{ h} \approx 41.7 \text{ ppm per hour}$ (a decrease, so -41.7 ppm/h).

Why: Hour 0 reads 900 and hour 12 reads 400. The sign is negative because the amount fell.

Also acceptable: Accept 42 ppm/h or -42 ppm/h with work shown.

2. Calculate the total rise in carbon dioxide while the lamp was off (hour 12 to hour 24), then the average rate in ppm per hour. Show your work.

Answer: Rise: $880 \text{ ppm} - 400 \text{ ppm} = 480 \text{ ppm}$. Rate: $480 \text{ ppm} \div 12 \text{ h} = 40 \text{ ppm per hour}$.

Why: Hour 12 reads 400 and hour 24 reads 880.

Also acceptable: None; both numbers are exact.

3. What was the **net** change in carbon dioxide over the full 24 hours (hour 24 minus hour 0)? Is it positive or negative, and what does the sign tell you about where some carbon ended up?

Answer: Net change: $880 \text{ ppm} - 900 \text{ ppm} = -20 \text{ ppm}$. Negative. Over the full day the air inside lost a little carbon dioxide, so some carbon ended up stored in the plants (as new plant material) rather than returning to the air.

Why: Day uptake (500 ppm) slightly exceeded night release (480 ppm). The difference is the carbon the plants kept, which is how a plant grows.

Also acceptable: Accept 'the plants grew a little' as the meaning of the negative sign.

4. Describe the shape of your graph. Name the process that dominates during the lit hours and the process that continues during the dark hours, and explain how the graph shows that the second process never actually stopped during the day.

Answer: The graph falls in a nearly straight line from 900 to 400 during the lit hours, then rises in a nearly straight line back to 880 during the dark hours, making a V shape. Photosynthesis dominates while the lamp is on; cellular respiration continues all 24 hours. The graph shows respiration never stopped because the daytime drop (about 42 ppm/h) is the **net** result of photosynthesis removing carbon dioxide faster than respiration adds it; at night, with photosynthesis off, respiration alone raises the level at 40 ppm/h, so during the day photosynthesis must have been removing roughly 80 ppm/h to leave a net fall of 42.

Why: Full credit requires the V shape, both processes named correctly for their hours, and the inference that the daytime rate is a net rate. The 80 ppm/h estimate is a bonus, not required.

Also acceptable: Accept 'respiration happens day and night, so during the day photosynthesis had to beat it' without the arithmetic.

- Describes the V (fall then rise)
- Photosynthesis in light, cellular respiration all the time
- Explains that the daytime change is net of both processes

5. The container was sealed. During the lit hours, 500 ppm worth of carbon dioxide 'disappeared' from the air inside. Where was that carbon at 6:00 p.m.? Use the idea of reservoirs and the law of conservation of matter in your answer.

Answer: The carbon did not leave the container, because it was sealed and the law of conservation of matter says atoms are not destroyed. At 6:00 p.m. the carbon that had been in the air reservoir (as carbon dioxide) was in the living reservoir: built into sugar and other molecules inside the plants by photosynthesis. Some of it would later be released back to the air by cellular respiration overnight, and a little would stay in the plants as growth.

Why: The answer must name the plants as the reservoir and use conservation to rule out the carbon leaving.

Also acceptable: A student who says 'in the plants' leaves' or 'in the plants as sugar' is correct; 'in the soil' alone is not, since the daytime drop is driven by photosynthesis.

- States that matter cannot leave the sealed container
- Names the plants (sugar or plant material) as the carbon's reservoir
- Uses the term reservoir or conservation of matter correctly

Part B: Nitrate and algae in a pond after a fertilizer spill

Heavy rain washed nitrate fertilizer off a field into a farm pond during week 1. A student measured nitrate in the water and estimated the percent of the surface covered by algae every week for eight weeks.

Pond nitrate and algae cover after a fertilizer spill (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Week	Nitrate (mg/L)	Algae cover (% of surface)
0	0.4	5
1	6.2	8
2	5.1	20
3	3.6	45
4	2.0	70
5	1.1	85
6	0.7	80
7	0.5	60
8	0.4	35

Simulated data for teaching. Patterns are realistic for a small warm pond; the numbers were not measured at a real site.

6. By how much did nitrate fall from week 1 to week 5? What was the average fall per week over those four weeks? Show your work.

Answer: Fall: $6.2 \text{ mg/L} - 1.1 \text{ mg/L} = 5.1 \text{ mg/L}$. Average fall per week: $5.1 \text{ mg/L} \div 4 \text{ weeks} \approx 1.3 \text{ mg/L per week}$ (1.275 exactly).

Why: Four weeks separate week 1 and week 5. Students should keep units on both numbers.

Also acceptable: Accept 1.28 or 1.3 mg/L per week.

7. Describe the relationship between nitrate and algae cover from week 1 to week 5. Where did the nitrogen that left the water go? Name the reservoir.

Answer: As nitrate falls, algae cover rises: the two move in opposite directions week after week. The nitrogen that left the water went into the algae, where it was built into proteins and other molecules in their cells; the living algae became the new reservoir.

Why: The inverse relationship is the key observation; naming the algae's bodies as the reservoir shows the student is tracking matter, not just the numbers.

Also acceptable: Accept 'the algae used it up to grow' if the student says it is now part of the algae.

- States the inverse relationship
- Names the algae (their bodies or proteins) as the reservoir

8. From week 5 to week 8 the algae cover falls but nitrate stays low. Explain why the algae decline, and predict which process is now moving nitrogen and what reservoir it is moving it to.

Answer: The algae decline because the nitrate that fed the bloom is nearly gone (down to about 0.4 to 0.7 mg/L), so they can no longer grow faster than they die. Decomposers are now the main movers of nitrogen: as dead algae sink, bacteria break them down and release ammonium into the water and bottom mud (and some nitrogen may be returned to the air by denitrifying bacteria in the oxygen-poor mud).

Why: Students should connect the low nitrate to the end of growth and predict decomposition as the next process, with the water and mud (or air) as the reservoirs.

Also acceptable: Accept 'the algae are dying and being broken down by decomposers' with any correct reservoir.

- Explains the decline by the exhausted nitrate
- Predicts decomposition by bacteria
- Names a destination reservoir (water, mud or air)

Part C: Real reference values

Composition of dry air near the ground (real rounded values)

Gas	Share of air by volume
Nitrogen gas	78%
Oxygen gas	21%
Argon	0.9%
Carbon dioxide	about 0.04%
All other gases	less than 0.1%

Carbon dioxide is given as 'about' because it rises every year; it passed 0.04% (400 ppm) in the 2010s.

9. Air is 78 percent nitrogen, yet the pond in Part B only bloomed when nitrate was added. Use the table and what you know about nitrogen fixation to explain why the air's huge nitrogen reservoir did not cause the bloom.

Answer: The nitrogen in air is nitrogen gas, and algae, like plants, cannot use nitrogen gas; only nitrogen-fixing bacteria (and lightning or factories) can change it into forms such as ammonium and nitrate. The pond bloomed only when fixed nitrogen (nitrate) arrived in the water. The size of the air reservoir does not matter if there is no route from it into the algae.

Why: The answer links the composition table to the fixation idea: a huge reservoir with no usable route is not a supply.

Also acceptable: Accept 'the nitrogen in air is locked up' with the fixation explanation.

- States that algae cannot use nitrogen gas
- Names fixation as the only route from the air
- Connects the bloom to the arrival of nitrate

10. Both datasets show matter leaving one reservoir and appearing in another. Using at least one number from each dataset, explain how the two datasets together support the law of conservation of matter.

Answer: In the terrarium, 500 ppm of carbon dioxide left the air during the day inside a sealed container, and almost all of it (480 ppm) came back overnight, with the remaining 20 ppm stored as plant growth; the carbon moved from air to plants and back rather than vanishing. In the pond, 5.1 mg/L of nitrate left the water while algae cover rose from 8 to 85 percent; the nitrogen moved from the water into the algae. In both cases, when matter dropped in one reservoir it rose in another, which is what conservation of matter predicts: atoms change reservoirs and forms, but their total stays the same.

Why: Full credit requires a number from each dataset and the explicit idea that a decrease in one place is matched by an increase elsewhere.

Also acceptable: A student who notes that the pond is open, so some nitrogen may have left in outflow, is reasoning well about boundaries and still earns credit if the main point is made.

- At least one number from Part A
- At least one number from Part B
- States that matter moved between reservoirs rather than being destroyed

Teacher notes

Both datasets are simulated. Part A's shape is realistic: in a small sealed planted container, classroom sensors commonly show daytime declines and nighttime rises of hundreds of ppm, and the slight net loss over a day corresponds to growth. The day rate (41.7 ppm/h) is a net rate; if students ask, the gross photosynthesis rate is roughly the night respiration rate plus the net daytime fall (about 80 ppm/h), assuming respiration is similar day and night. Part B's lag between nitrate rise and peak algae is typical of blooms. Part C values are real rounded shares of dry air by volume; carbon dioxide is stated as 'about 0.04%' because it continues to rise. Common errors: dividing by 13 data points instead of 12 hours; forgetting the negative sign; and in q7 saying nitrate 'turned into' algae without naming the algae's bodies as the reservoir. The extension's no-plant control would show a slow steady rise from soil respiration with no daytime dip; the difference between the two curves isolates the plants' net uptake.

Scaffold offered to students: Rate means change divided by time

For every rate question: (1) write the later value minus the earlier value to get the change, with units (ppm or mg/L); (2) write the number of hours or weeks between them; (3) divide the change by the time. Keep the sign: a negative change means the amount went down. Example with made-up numbers: $650 \text{ ppm} - 710 \text{ ppm} = -60 \text{ ppm}$ over 3 hours gives -20 ppm per hour .

Extension: A second terrarium, no plants

Predict the 24-hour carbon dioxide graph for an identical sealed container holding the same moist soil but no plants. Sketch it on the same axes as your Part A graph, explain the difference in shape, and then describe how you could use the two containers together to measure how much carbon dioxide the plants alone take in per hour. State what you would have to keep the same in both containers.