

Field Investigation: What Your Body Changes When Your Muscles Work Harder

Investigation question: How do breathing rate and the carbon dioxide in exhaled breath change after two minutes of brisk activity, and what do those changes tell us about cellular respiration inside muscle cells?

Classroom field investigation

Groups of 4

1 session

Setup 10 · Activity 35 · Cleanup 10 min

MS-LS1-7 · practice

MS-LS1-6 · supports

Scientific purpose

Students take their investigation out of the classroom to a hallway, gym or yard, measure a partner's breathing rate and the time it takes exhaled breath to change a carbon dioxide indicator at rest and right after exercise, pool the class data, and reason from the body's visible response back to the invisible reaction in muscle cells. They decide what to control, how many readings to take, and what the pooled pattern does and does not prove.

Why this helps students with this chapter

Students know they breathe harder when they run, but most think breathing itself is respiration. Measuring that exhaled breath carries more carbon dioxide after exercise, and reasoning that the carbon dioxide had to be made somewhere, turns breathing into evidence for a reaction happening in cells they cannot see. The field setting, real bodies and pooled data make the cause-and-effect argument theirs.

Standards connections

MS-LS1-7 (practice, gathering evidence that food is rearranged to release energy, with carbon dioxide as a product that leaves the organism): Students collect evidence for the model built in Lab 2: harder work means more sugar reacted with oxygen, more energy released and more carbon dioxide produced. The lab builds the evidence base for the PE's model rather than producing the model itself, so the role is practice.

MS-LS1-6 (supports, tracing the flow of energy out of an organism): The investigation shows energy from food leaving the body as work and heat and carbon dioxide leaving in breath, the organism-level end of the energy flow that photosynthesis began.

Roles (rotate each session)

- **Mover:** Sits quietly for the baseline readings, does the two minutes of activity at the agreed pace, and exhales gently through the straw for the indicator tests. Can decline to exercise at any time and switch roles.
- **Timer:** Runs the stopwatch for the one-minute breath counts, the two-minute activity and the indicator color-change timing, and calls start and stop.

- **Breath counter:** Counts the Mover's breaths for one minute by watching the chest or shoulders, without telling the Mover when counting starts.
- **Indicator technician and recorder:** Pours the indicator, holds the cup steady and level, watches for the color change against the key, and writes every value on the recording sheet.

Materials

Item	Quantity	Per	Note
Stopwatch or phone timer	1	group	
Bromothymol blue indicator, 0.04% solution	about 100 mL	group	20 mL per test; red cabbage juice is a food-safe substitute but changes more slowly.
Clear plastic cups, 150-250 mL	4	group	
Drinking straws	1 per test (about 4)	group	One straw per student, never shared; discard after use.
Printed indicator color key (blue, green, yellow) and a clipboard	1	group	
Measuring cup or graduated cylinder for 20 mL	1	group	
Safety goggles	1	student	
Paper towels and a bucket or tray for used indicator	1	class	
A marked walking course, stairs or open space for jumping jacks or step-ups	1	class	

Estimated cost: 10 to 15 per class (an estimate; A 500 mL bottle of 0.04% bromothymol blue is \$8 to \$12; a box of straws and a sleeve of clear cups are \$3 to \$5; timers, goggles and cups are usually on hand.)

Safety

- Exercise is voluntary and moderate. Any student with asthma, a heart condition, an injury, illness or a parent note does not exercise and takes another role. The Mover stops at once and sits if dizzy, short of breath beyond normal, or in any pain, and the teacher is told.
- Never suck through the straw; exhale only, gently. Use a new straw for each student and throw it away afterward. Do not share straws or cups.
- Bromothymol blue is a mild skin and eye irritant and stains. Goggles on during every indicator test; hold the cup low and level so bubbling does not splash; wipe spills with a wet towel and wash hands before leaving.
- Keep the activity area clear of cups, bags and cords; do step-ups only on a stable low step or bottom stair with a hand near the rail.
- Used indicator goes in the class bucket, not on the ground; cups and straws go in the trash.

Teacher preparation and setup

1. Choose the site and the activity the day before: a hallway loop or yard for brisk walking, a stairwell for step-ups, or an open gym floor for jumping jacks. Clear it with whoever supervises the space and check for trip hazards.
2. Pour and test one indicator cup yourself: exhale gently through a straw and time the change from blue through green to yellow so you know the typical seconds in your room; adjust the volume to 20 mL if the change is too slow or too fast.
3. Send a note home or check records for students who should not exercise (asthma, heart conditions, injury, illness). Those students take the Timer, Breath counter or Indicator role; no one is required to exercise or to use a straw.
4. Print the recording sheet and color key; pre-measure 20 mL of indicator into labeled cups if groups are young, or have the technician measure on site.
5. Decide the activity pace and demonstrate it: brisk, able to talk in short sentences, never a sprint. Two minutes is enough.

Investigation design

Independent variable	Activity level of the same person: at rest versus immediately after two minutes of brisk activity
Dependent variable	Breaths per minute, and seconds of exhaled breath needed to turn 20 mL of indicator yellow
Controlled	Same person for the rest and after tests; Same volume (20 mL) and starting color of indicator in every cup; Same gentle, steady exhaling through the straw; Same two-minute activity at the same pace for every Mover; Breath counts taken over a full minute, and the Mover not told when counting starts
Trials	Two baseline breath counts per Mover averaged; one indicator test per condition per Mover; about eight Movers pooled across the class so the pattern can be judged against person-to-person variation.
Comparison	Each Mover's own rest values against their own after-activity values, then the class pattern.

Student procedure

1. At the site, set up the group's cups: measure 20 mL of indicator into two cups for the Mover's two tests and label them REST and AFTER. Record the starting color number of each from the key.
2. Baseline breathing: the Mover sits still for two minutes. The Breath counter then counts breaths for one full minute without the Mover knowing when the count starts; repeat for a second minute. Record both counts and the average as breaths per minute at rest.
3. Baseline indicator test: goggles on. The Mover exhales gently and steadily through a new straw into the REST cup while the Timer runs the stopwatch; the technician watches for the color to reach yellow (3) and the Timer stops. Record the seconds. If the Mover needs to take a breath, keep the straw in the cup and keep timing.

4. Activity: the Mover does two minutes of the agreed activity at the agreed brisk pace while the Timer calls out each 30 seconds. The rest of the group watches for any sign the Mover should stop.
5. Immediately after: the Breath counter counts breaths for one minute while the Mover stands or sits; record it as breaths per minute after activity.
6. Immediately after that count: with a new straw, the Mover exhales into the AFTER cup while the Timer times the change to yellow. Record the seconds.
7. Recovery: count breaths for one minute again at three minutes after the activity ended. Record it.
8. If time allows and a second group member wants to be the Mover, repeat the whole sequence with fresh cups and straws. Otherwise, compute the group's changes and add the Mover's values to the class table.
9. Back in the classroom, graph the pooled class data (rest versus after) and answer the recording-sheet and analysis questions individually.

Expected observations

- Resting breath counts of roughly 12 to 20 per minute; immediately after two minutes of brisk activity, roughly 22 to 40 per minute; at three minutes, partway back toward rest.
- Seconds to yellow at rest in the range of about 40 to 120 s depending on the volume and the student's exhaling; after activity typically a third to a half shorter for the same person.
- Person-to-person values vary widely, but the direction of change is the same for nearly every Mover, which is the pattern the pooled table is there to show.
- Movers report feeling warm and sometimes that their breaths are deeper as well as faster.

Likely difficulties

- The Mover changes their breathing once they know they are being counted; the hidden-start rule and two counts averaged reduce this but do not remove it.
- Students blow hard into the AFTER cup because they are excited, which speeds the change on its own; have the technician coach a gentle, steady exhale and note it in the table if the Mover blew harder.
- Indicator that starts green rather than blue because the cup was breathed over or left open gives a short time in both conditions; start with fresh blue indicator and record the starting color.
- Groups rush the baseline and start the activity before the rest count is finished; the Timer should run the sequence from a written checklist.
- A Mover who is already winded from recess gives a high rest value; record it anyway and discuss it as a reason to pool data.

Structured debrief

1. Build the class table and the four bars on the board. Ask the class to say the pattern in one sentence before anyone explains it: after activity, breaths per minute go up and seconds to yellow go down, for nearly every Mover.
2. Work the causal chain backward from the cup: more carbon dioxide per second came out of the lungs, so more was in the blood, so more was being made in cells, so more sugar was being reacted with oxygen, so more energy was being released, because the muscles were doing more work. Each arrow is a

claim; ask which ones the lab directly measured (the first) and which are inferred from the model (the rest).

- 3. Separate breathing from respiration explicitly: breathing is the delivery service; cellular respiration is the reaction. Faster breathing is the body's response to the reaction speeding up. Ask what a plant does when its root cells need more oxygen: it has no lungs, so it depends on air spaces in the soil, which connects to the flooded-root discussion.
- 4. Discuss the design weaknesses from q8 honestly: blowing harder also speeds the change, and the body can change how deeply it breathes. The two readings together, faster breathing and faster change, are stronger than either alone. A student who proposes measuring breath volume or timing a fixed number of breaths has improved the design.
- 5. Close on heat: ask Movers whether they felt warm. The released energy that did not become movement left as heat, the same heat that warmed the seed jar in Lab 1.

Recording sheet: what students fill in

Lab 3 recording sheet: What your body changes when your muscles work

Record the Mover's values in the order the procedure gives. Color key numbers: 1 = blue, 2 = green, 3 = yellow. Time the indicator until it reaches 3.

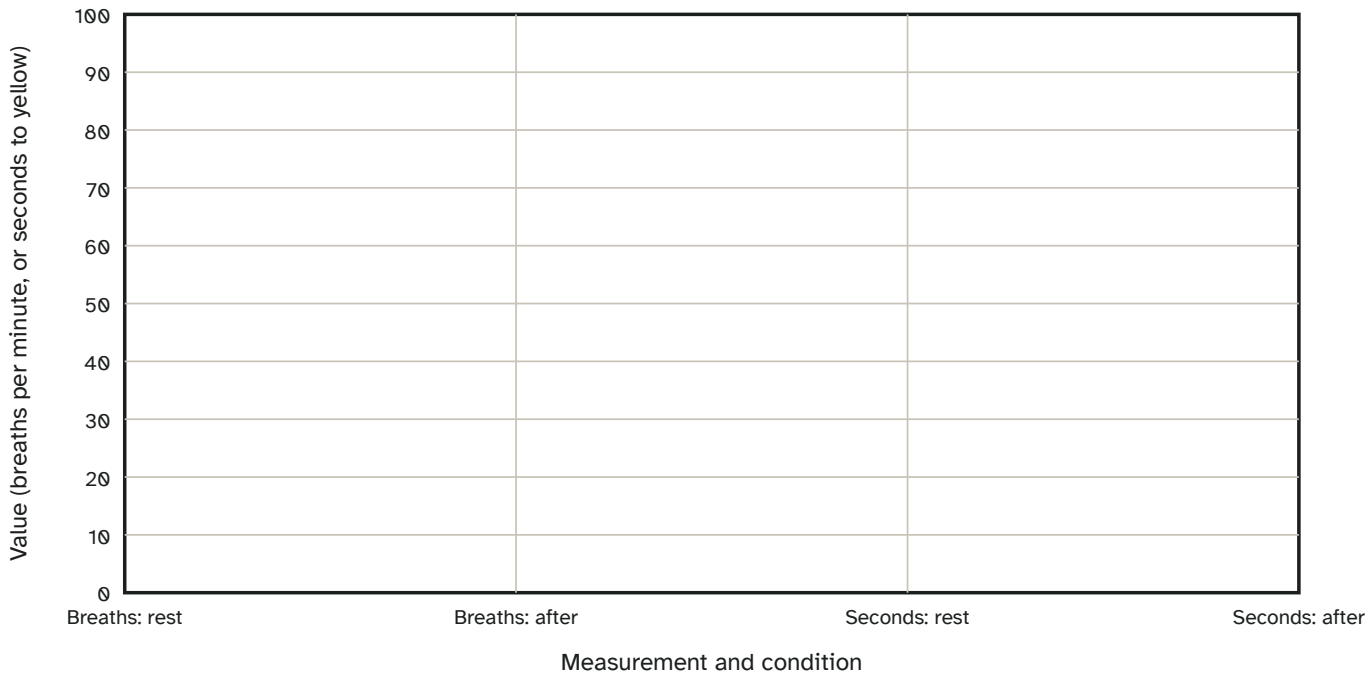
Our Mover's data

Measurement	At rest	Immediately after 2 minutes of activity	3 minutes after activity	Change (after minus rest)
Breaths per minute, count 1				
Breaths per minute, count 2				
Breaths per minute, average				
Seconds to turn 20 mL of indicator yellow				
Activity done and pace				

Class pooled data (copy from the board)

Mover (group letter)	Breaths per minute at rest	Breaths per minute after	Seconds to yellow at rest	Seconds to yellow after
A				
B				
C				
D				
E				
F				
G				
H				
Class average				

Class averages: rest versus after activity



1. Describe what happened to each of the two measurements after the activity, using your Mover's numbers and the class averages.

Answer: Breaths per minute rose after the activity (for example from 16 to 30 for our Mover; class average from about 15 to about 29) and seconds to yellow fell (for example from 75 s to 40 s; class average from about 70 s to about 38 s). At three minutes the breathing was partway back down.

Why: Students must use their own numbers and the class averages, and state direction for both measurements.

- Both measurements described with direction
- Mover's numbers and class averages both cited

2. Why did the procedure take two breath counts at rest and not tell the Mover when counting started? What could go wrong without those steps?

Answer: Two counts averaged reduce the effect of one odd minute. Not telling the Mover prevents them from changing their breathing on purpose or by nerves, since breathing is partly under conscious control. Without these steps the rest value could be too high or too low, and the change after activity would be exaggerated or hidden.

Why: This checks that students see breathing as a measurement that the subject can disturb, which is a real design issue in human investigations.

- Averaging reduces random variation
- Hidden start prevents the Mover from controlling their breathing
- Names a consequence for the comparison

Analysis questions: answer key

3. Fewer seconds to turn the indicator yellow means more carbon dioxide arrived in the cup per second. Where in the body was that extra carbon dioxide made, and from what? Use the word equation for cellular respiration in your answer.

Answer: In the muscle cells (and other working cells), by cellular respiration: sugar + oxygen → carbon dioxide + water + energy. The carbon atoms in the extra carbon dioxide came from sugar the Mover ate earlier (or from glycogen stored in the muscles and liver), and the oxygen came from the air breathed in. More work meant more sugar reacted, so more carbon dioxide was made, carried by the blood to the lungs and breathed out into the cup.

Why: The answer should locate the reaction in cells, name sugar as the carbon source and oxygen from breathing, and connect to the cup through blood and lungs.

- Carbon dioxide made in cells by cellular respiration, with the word equation
- Carbon came from sugar (food or glycogen), oxygen from breathed air
- Path from cells through blood and lungs to the cup

4. Explain the chain of cause and effect from 'muscle cells need more energy' to 'the Mover breathes faster'. Put at least four steps in order.

Answer: 1. Muscle cells contract more, so they need energy faster. 2. The cells speed up cellular respiration, reacting more sugar with more oxygen. 3. That uses up oxygen in the blood faster and adds carbon dioxide to the blood faster. 4. The brain senses the change (especially the rising carbon dioxide) and signals the breathing muscles. 5. The Mover breathes faster and deeper, bringing in more oxygen and removing more carbon dioxide. 6. The heart also beats faster to move the blood between muscles and lungs more quickly.

Why: At least four ordered steps from energy demand to faster breathing. The brain-sensing step is a plus, not a requirement; the key links are more respiration, more carbon dioxide in blood, faster breathing to remove it and supply oxygen.

Also acceptable: Accept the heart rate step in place of the brain step.

- Starts with muscle energy demand
- More respiration means more oxygen used and more carbon dioxide made
- Faster breathing is the response that supplies oxygen and removes carbon dioxide
- Steps in a sensible order

5. Breathing changed, but breathing is not cellular respiration. Using this lab, explain the difference between the two and how one serves the other.

Answer: Breathing is moving air into and out of the lungs; it is what the Breath counter counted. Cellular respiration is the reaction inside cells that uses the oxygen and makes the carbon dioxide; nobody could see it, but the yellow indicator showed its product. Breathing serves respiration: it delivers the oxygen reactant and carries away the carbon dioxide product. When respiration sped up in the muscles, breathing sped up to keep up. A plant respire without breathing at all, which shows the two are different things.

Why: Students should define both, use a lab observation for each, and state the serving relationship.

- Breathing defined as gas movement in and out of lungs
- Cellular respiration defined as the reaction in cells
- States that breathing supplies and removes the reaction's gases
- Uses evidence from the lab

6. Compute the class average change in breaths per minute (after minus rest) and the class average change in seconds to yellow. Then say whether every Mover showed the same direction of change, and what it would mean if one did not.

Answer: Class-specific. Example: average breaths after 29 minus average at rest 15 gives a change of +14 breaths per minute; average seconds after 38 minus at rest 70 gives a change of -32 s. Nearly every Mover shows the same direction (breaths up, seconds down). If one Mover did not, it could be a measurement problem (blowing softly, a rest count taken while winded, indicator that was not fresh) or a real difference in that person; one exception does not overturn a pattern shown by the rest of the class, but it should be noted and, if possible, re-tested.

Why: Numeric: two subtractions from the class averages, with signs. The second half checks that students treat an outlier as something to examine rather than ignore or over-weight.

- Both average changes computed with correct sign
- States whether all Movers changed in the same direction
- Treats an exception as something to investigate, not proof against the pattern

7. The Mover's breathing was still above rest three minutes after stopping. Explain why the body does not return to normal the instant the muscles stop working.

Answer: The muscles' extra carbon dioxide is still in the blood and still being carried to the lungs for a few minutes after the work stops, and the cells are still repaying the energy and oxygen they ran short of during the effort, so respiration stays above resting for a while. The body also has to shed the extra heat. Breathing stays faster until the blood's carbon dioxide and oxygen are back to normal.

Why: Full credit needs the idea that the products from the effort are still being cleared and that respiration does not drop instantly. 'Oxygen debt' language is a bonus, not required.

- Carbon dioxide from the effort is still being removed
- Respiration in cells stays elevated briefly after work stops

8. A faster indicator change after exercise could be because each breath carries more carbon dioxide, because the Mover blew harder, or both. Which of these did the procedure try to control, and how? Suggest one improvement to the design.

Answer: The procedure tried to control blowing by having the technician coach the same gentle, steady exhale, using the same 20 mL and starting color each time, and using the same person for both tests. It could not fully control it, because an excited Mover moves more air. Improvements: have the Mover exhale a fixed number of breaths (say three) into the cup and compare the color reached rather than timing to yellow; or exhale through the straw into the cup for a fixed 20 seconds and compare the color; or use a balloon to collect one exhaled breath and bubble the same volume through the indicator for both conditions.

Why: The point is recognizing a confound and designing around it. Any improvement that fixes the volume of breath or the time rather than the endpoint color earns credit.

- Names what was controlled (same exhale, same volume, same person)
- Recognizes that blowing harder is not fully controlled
- Proposes an improvement that fixes breath volume or time

Individual evidence of learning

Each student submits their own completed recording sheet (the group data table, the pooled class table and the bar graph) and written answers to q1 through q8. The graph and q6 are the evidence for data analysis; q3, q4 and q5 are the evidence that the student connects the body's response to cellular respiration and separates it from breathing.

Assessment criteria

Criterion	Proficient looks like
Data collection and pooling	All of the Mover's readings recorded with units, class table complete, averages and changes computed correctly and graphed.
Reasoning from evidence to the reaction	Explains that the extra carbon dioxide was produced in muscle cells by reacting sugar with oxygen, and orders the cause-and-effect chain correctly.
Breathing versus cellular respiration	States that breathing moves gases to and from the reaction while cellular respiration is the reaction itself, with an example from the lab.
Evaluating the design	Identifies the controlled factors, names the blowing-harder weakness and proposes a workable improvement.

Accessibility adaptations

- No student is required to exercise or to blow through a straw; any role can be taken, and the Timer, Breath counter and Indicator roles carry the same analysis work.
- For a Mover who uses a wheelchair or cannot do the class activity, agree on an alternative two-minute effort (brisk arm raises, wheeling a lap) and record it in the activity row; the comparison is still rest versus after for the same person.
- Provide the color key with large swatches and let the technician call the change aloud; a color-blind student can run the stopwatch or count breaths.
- Offer sentence frames for q4 ('Because ___, the cells ___, so the blood ___, so the lungs ___') and allow a spoken answer to q5 recorded on a device.
- Provide a multilingual card for breath, rest, activity, indicator, carbon dioxide and muscle.

Low-cost alternative

Use red cabbage juice as the indicator (blue-purple to pink) and 30 mL cups. If no indicator is available, run the investigation on breathing rate and pulse only, and add a third observation by holding a cold mirror or a pair of glasses near the mouth at rest and after activity to compare how quickly it fogs; the carbon dioxide reasoning then rests on the breathing data and the Lab 2 model.

Model limitations

The indicator timing is a rough measure: it responds to carbon dioxide reaching the cup per second, which rises both because the body is producing more carbon dioxide and because the Mover is moving more air; the procedure controls the exhale as well as it can, but the two cannot be fully separated with a straw and a cup. Breath counts are affected by awareness and by how deep each breath is, which the lab does not measure. The lab shows the body's response to faster respiration, not the reaction itself, and in hard, sudden exercise muscle cells also release some energy from sugar without oxygen for a short time, which is beyond this lesson. This activity has not been physically tested by the authors; the time ranges are estimates for 20 mL of 0.04% indicator.

Teacher notes

Expect wide person-to-person variation and a consistent direction of change; that contrast is the main data lesson. If several Movers show no change in seconds to yellow, check whether the REST cups were left open and already green. Keep the class table for W5, whose dataset has the same shape, and for the L06 discussion of energy leaving as heat. Any Mover who felt unwell during the activity should be noted and the family informed as school policy requires.