

# Trap Every Gram: Design a Gas Catcher for a Fair Mass Test

**Investigation question: Which features of three cheap gas-trap designs should be combined so that a fizzing reaction keeps every gram on the balance, seals fast, and costs the least?**

Engineering design challenge

Groups of 4

2 sessions

Setup 10 · Activity 90 · Cleanup 10 min

MS-ETS1-3 · assesses

MS-ETS1-1 · practice

MS-PS1-5 · assesses

## Scientific purpose

Students define criteria and constraints for a container that turns an open-air reaction into a fair mass test, build and test three starter gas traps (a balloon on a bottle, a zip bag sealed in a race, and a plastic-wrap dome on a cup), pool the class data on mass change, sealing time and cost, identify the strongest feature of each design, and build a combined design that they predict will beat all three. The lab is the student version of the lesson's engineering story: no starter wins every test, and the best solution borrows from several.

## Why this helps students with this chapter

Lab 1 showed students that a sealed system keeps its mass. This lab makes them build the seal, and the balance grades their engineering: a trap that holds every bit of gas still reads about 0.7 g low from the lift of its puff, so every tenth of a gram lost beyond that mark is gas that got past the boundary. Because the three starters trade off against each other (the balloon seals before mixing but can slip, the bag is cheap but must be zipped in a race, the dome is fastest to build and leakiest), the pooled data push students toward combining features rather than picking a favorite, which is exactly what the lesson's engineers did with the ibuprofen process.

## Standards connections

**MS-ETS1-3** (assesses, analyzing pooled test data from several designs to identify the best characteristic of each and combine them): Students compare three designs against the same criteria using class data, name which feature made each design win a criterion, and justify a combined design with numbers. That is the evidence this PE asks for; the redesign test shows whether the combination actually improved the result. Listed for grades 6-8 in the California sequence.

**MS-ETS1-1** (practice, defining measurable criteria and constraints before building): The first step of the lab is writing criteria with a measurement and a target (mass change, sealing time, cost) and the constraints (materials, amounts, no rigid sealed containers). Students practice the precision this PE asks for, but the problem is given to them, so it is practice rather than assessment.

**MS-PS1-5** (assesses, using the atom model to explain the mass data of the traps): Students explain why a trap that keeps every atom keeps every gram, and why a leaky trap reads lower, by tracking the carbon and oxygen atoms of the gas before and after. No atomic masses or symbolic balancing are involved.

## Roles (rotate each session)

- **Builder:** Assembles each trap exactly as described, loads the baking soda packet, and runs the mixing step on the balance.
- **Timer and balance reader:** Zeroes the balance, reads 'before' and 'after' aloud twice, and runs the stopwatch from the moment the reactants touch until the seal is complete.
- **Recorder:** Writes the criteria, constraints, every reading, the cost from the price list, and the group's results on the class board.
- **Safety and boundary checker:** Confirms goggles are on, that no trap is a capped bottle or lidded jar, says what the system is and what could cross its boundary before each run, and keeps faces back during mixing.

## Materials

| Item                                                                           | Quantity                             | Per     | Note                                                                                                        |
|--------------------------------------------------------------------------------|--------------------------------------|---------|-------------------------------------------------------------------------------------------------------------|
| White vinegar (5 percent)                                                      | about 150 mL<br>(five runs of 30 mL) | group   |                                                                                                             |
| Baking soda, pre-measured half teaspoons (about 2.5 g) in folded paper packets | 5 packets                            | group   | Three starters, one redesign, one spare. Pre-measuring is the amount control and the safety control.        |
| Empty 500 mL plastic water bottle, rinsed, label removed, no cap               | 1                                    | group   | Collect caps before class so no group can seal a bottle.                                                    |
| Round balloons (non-latex if anyone in the room has a latex allergy)           | 2                                    | group   |                                                                                                             |
| Gallon-size zip bags                                                           | 2                                    | group   |                                                                                                             |
| Clear plastic cups, 250 mL                                                     | 3                                    | group   |                                                                                                             |
| Plastic-wrap squares (about 20 cm) and rubber bands                            | 2 squares, 3 bands                   | group   |                                                                                                             |
| Single-ply tissue paper squares (about 10 cm)                                  | 3                                    | group   | Wrapped around the baking soda, a tissue packet delays the reaction a few seconds while the trap is sealed. |
| Paper for a funnel cone, 50 mL measuring cup, stopwatch or phone timer         | 1 set                                | group   |                                                                                                             |
| Digital balance reading to 0.1 g                                               | 1                                    | group   | Two groups can share if runs are staggered.                                                                 |
| Goggles                                                                        | 1                                    | student |                                                                                                             |
| Tray or towel under the balance, paper towels for spills                       | 1 set                                | group   |                                                                                                             |

|                                     |   |         |  |
|-------------------------------------|---|---------|--|
| Recording sheet with the price list | 1 | student |  |
|-------------------------------------|---|---------|--|

**Estimated cost:** 15 to 25 per class (an estimate; Estimate for eight groups: one gallon of vinegar (about \$3), one box of baking soda (about \$1), a pack of balloons (about \$4), gallon zip bags (about \$4), cups and plastic wrap (about \$4), rubber bands and tissue from stock. Bottles are collected from recycling. Balances, timers and goggles are classroom equipment.)

## Safety

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- Goggles on for the whole lab. Vinegar stings eyes; rinse with water for several minutes if it gets in. Domes and balloons can spray droplets when they let go.
- Never seal this reaction inside a rigid container with a cap or lid (a bottle, a jar, a food container). The balloon, the bag and the wrap are allowed because they stretch or let go long before dangerous pressure builds. The Safety checker refuses any design that caps a bottle. The optional rigid-bottle demonstration in the debrief is for the teacher only.
- Use one pre-measured half-teaspoon packet per run and 30 mL of vinegar, never more; a bigger charge makes more gas than a balloon or bag should hold.
- Balloons: use non-latex balloons if anyone has a latex allergy; never put a balloon near the mouth or inhale from it; a balloon that slips off releases a puff of gas and droplets, so point the bottle away from faces; pick up any burst-balloon pieces at once, as they are a choking hazard.
- Keep faces back and hands clear while a trap inflates. If a bag or balloon is tight and still growing, open it away from faces.
- Wipe spills immediately (vinegar on the floor is a slip hazard), keep liquids off the balance, and wash hands at the end of each session. Nothing is tasted.

## Teacher preparation and setup

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1. Fold five half-teaspoon baking soda packets per group and collect rinsed 500 mL bottles without caps; keep every cap out of the room.
2. Run all three starter designs yourself once with the stated amounts so you know what your balances show; write your numbers down for the debrief, and note that every trap puffs up and so reads about 0.6 to 0.7 g low even when it does not leak (see the teacher notes).
3. Cut plastic-wrap and tissue squares ahead of time; they are fiddly with goggles on.
4. Write the hard rule on the board before class: sealed means a balloon, a bag or wrap, never a capped bottle or a lidded jar.
5. Draw the pooled-data table on the board with three rows (A, B, C) and columns for each group's mass change, sealing time and cost so the Recorders can fill it in as they finish session 1.
6. Print the recording sheet; the price list on it uses invented play-money prices so that cost is a real criterion without buying anything extra.

## Investigation design

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**Independent variable**    The trap design: balloon on a bottle (A), bag sealed after pouring (B), wrap dome on a cup (C), and the combined redesign

|                           |                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Dependent variable</b> | Change in the balance reading (g), sealing time (s) and cost per run from the price list                                                                                                                                                                                                                                                                    |
| <b>Controlled</b>         | Same charge every run: 30 mL of vinegar and one half-teaspoon packet of baking soda; Everything that was on the balance 'before' stays on it 'after' (bottle, cup, packet paper, wrap, band); Same balance, zeroed before each run, read after 30 seconds of steady reading; Same person on the stopwatch and the same start and stop rule for sealing time |
| <b>Trials</b>             | One run of each starter per group, pooled across the class for eight or more runs per design; one redesign run per group, also pooled.                                                                                                                                                                                                                      |
| <b>Comparison</b>         | Each design against the criteria, against the other designs, and against the open-cup loss measured in Lab 1.                                                                                                                                                                                                                                               |

## Student procedure

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1. Session 1, criteria first. Read the challenge and the price list. As a group, fill in the criteria and constraints table: how you will measure 'traps all the gas', 'seals fast' and 'costs little', one criterion of your own (for example, stays steady on the balance pan), the constraints you must obey, and a target for each. No building until the table is done.
2. Design A, balloon trap. Pour 30 mL of vinegar into the bottle. Make a paper cone and pour one baking soda packet into a balloon. Stretch the balloon's neck over the bottle mouth without letting any soda fall in, and let the balloon hang down beside the bottle. Put the whole assembly on the balance (nothing else), let the Safety checker name the system and its boundary, and record 'before'.
3. Lift the balloon upright so the soda falls into the vinegar. Sealing time is 0 s because the trap was sealed before mixing; record that. Point the bottle away from faces. When the fizzing stops and the reading has been steady for 30 seconds, record 'after', compute the change, note anything that went wrong (balloon slipped, soda stuck in the balloon), and compute the cost per run from the price list.
4. Design B, bag race. Put one soda packet (unfolded, soda loose) into a gallon zip bag and set the bag on the balance with a cup holding 30 mL of vinegar beside it; record 'before'. Timer ready. Pour the vinegar into the bag, set the empty cup back on the balance, and zip the bag closed; the timer runs from the moment vinegar touches soda until the zip is fully shut. Record the sealing time, wait for a steady reading, record 'after', the change and the cost.
5. Design C, cup dome. Put 30 mL of vinegar in a cup. Wrap one soda packet's worth in a tissue square and twist it closed. Put the cup, the tissue packet, a wrap square and a rubber band on the balance; record 'before'. Drop the packet in and start the timer, cover the cup with the wrap and band it tight; stop the timer when the band is on. Record the sealing time, wait, record 'after', the change and the cost. Expect the dome to lift or hiss at the rim.
6. Pool the data. The Recorder writes the group's three changes, times and costs in the class table on the board. Copy the class averages and the best single result for each design into the pooled table on your sheet. Note for the whole class: every trap puffs up, and a puffed-up trap is lifted by the air around it (roughly 1.2 g for every liter of puff), so even a perfect trap reads about 0.6 to 0.7 g low with this charge, which makes about 0.6 L of gas. Compare designs with each other, with that perfect-trap mark (about -0.7 g) and with the open-cup loss from Lab 1 (about -1.1 g), not with zero.

7. Session 2, analysis. For each criterion, decide from the pooled data which design won and name the feature that made it win (for example: sealed before mixing; wide opening and easy pour; cheapest parts; delay packet). Fill in the 'strongest feature' column. Then name the weakest point of each design.
8. Redesign. Sketch a combined trap that uses at least one feature from each of two different starters. Label every borrowed feature with the letter of the design it came from. Check it against every constraint (no cap, same amounts, fits on the pan, under the budget). Predict its mass change, sealing time and cost and write the predictions before building.
9. Build and test the redesign with the same amounts and the same reading rules as session 1. Record 'before', sealing time, 'after', change and cost. If it fails a constraint during the run (for example a seal pops), record what happened and the reading anyway.
10. Compare the redesign with all three starters on every criterion, add the class's best redesign to your table, and answer the analysis questions on your own before discussing them in your group.

## Expected observations

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- Design A: change between about  $-0.6$  and  $-0.8$  g when the balloon stays on (about  $-0.7$  g is the lift of the inflated balloon; anything beyond that is gas past the neck), sealing time 0 s, cost about 0.36 per run. A slipped balloon gives a loss close to the open cup's, about  $-1.1$  g.
- Design B: change between about  $-0.8$  and  $-1.0$  g depending on how fast the zip closes (gas made before the seal escapes; gas made after it stays and shows only as lift), sealing time 3 to 10 s, cost about 0.35 per run. Spilled vinegar or a soda pile stuck in the corner is common.
- Design C: change between about  $-0.9$  and  $-1.1$  g, close to the open cup's, as the dome lifts at the rim or the band slips, sealing time 5 to 15 s, cost about 0.21 per run, the cheapest and fastest to build.
- Redesigns that seal before mixing (soda in a corner, balloon or tissue packet inside a sealed bag) typically read about 0.6 to 0.8 g low, close to the perfect-trap mark, with sealing time 0 s and a cost near Design B's. These are estimates; the lab has not been physically tested by the authors.

## Likely difficulties

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- Groups build before writing criteria. Hold the materials until the Recorder shows a finished criteria table with a measurement and a target in every row.
- Students compare every design with zero and declare them all failures. Compare with the open cup's loss, with the perfect-trap mark of about  $-0.7$  g and with each other, and teach the lift of a puffed-up trap as a measurement effect.
- Something leaves the balance between readings (the paper cone, the empty cup, a dropped band), producing a fake change. Everything on the pan before stays on after; the Timer and balance reader checks the pan before reading 'after'.
- Balloons that do not stretch far enough over the bottle neck slip off during inflation. Have students work the neck down a full centimeter and hold the base while the soda falls.
- The tissue packet reacts before the dome is on, or does not open at all. Single-ply tissue, twisted lightly, gives a few seconds; a packet that never opens still counts (everything is on the balance), but the sealing time is then meaningless and should be noted.
- Groups treat 'combine' as 'choose A.' Insist on a labeled feature from at least two starters and a justification from the pooled numbers; the redesign may look like A and still borrow B's pour method

and C's cost cuts.

## Structured debrief

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1. Read the pooled table with the class. Expect A to win mass change and sealing time, C to win cost and build time, and B to sit in the middle on everything. Ask for the strongest feature of each in one phrase, then ask what the engineers in the lesson did with two good ideas: they kept both. Connect to the ibuprofen bars on the slides: the second improvement did not replace the first.
2. Raise the lift. Every trap read about 0.6 to 0.7 g low even when it did not leak, because a puffed-up trap is pushed up by the air around it, about 1.2 g for each liter of puff, and this reaction makes about 0.6 L of gas. Optional teacher-only demonstration: a 2-liter carbonated-drink bottle (never a thin water bottle or glass) with 30 mL of vinegar and one half-teaspoon packet, capped immediately and set on the balance, does not puff up and gives the same reading before and after. The pressure rise is small (about a third of an atmosphere, less than 5 psi, with half a teaspoon in a 2-liter bottle) but it is still a sealed rigid container, so it stays with you: goggles on, bottle pointed away from everyone, cap loosened slowly over a sink afterward. Skip it if your school's policy forbids sealing any reaction.
3. Ask what the redesigns had in common. Most will have moved the mixing inside a boundary that was sealed first (A's feature) and used the bag's room and easy pour (B's), and some will have added C's tissue delay packet. Point out that Lab 1's station B was one such design, and ask why the class now believes in it more than they did then: because they have data on what happens without it.
4. Close with the boundary language: a trap is a system boundary that matter cannot cross. Every tenth of a gram lost beyond the lift was carbon dioxide molecules crossing it. The law was never in doubt; the engineering question was how to build a boundary good enough to let the balance show it.

## Recording sheet: what students fill in

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### Lab 3 recording sheet: Trap every gram

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**The hard rule** — Sealed means a balloon, a bag or a plastic-wrap cover. A capped bottle or a lidded jar is never allowed, because the gas this reaction makes would build pressure inside it. Every design, including your redesign, must pass the Safety checker before it goes on the balance.

## Criteria and constraints

| Criterion or constraint                                  | How we will measure or check it | Target or limit |
|----------------------------------------------------------|---------------------------------|-----------------|
| Criterion 1: traps all the gas                           |                                 |                 |
| Criterion 2: seals fast                                  |                                 |                 |
| Criterion 3: costs little                                |                                 |                 |
| Criterion 4 (your own)                                   |                                 |                 |
| Constraint: materials and amounts                        |                                 |                 |
| Constraint: safety (no rigid sealed container)           |                                 |                 |
| Constraint: fits on the balance pan, built in 10 minutes |                                 |                 |

## Price list for the challenge (play-money prices, invented for this lab)

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

| Part                                   | Price per run (play dollars) |
|----------------------------------------|------------------------------|
| Bottle (reused, charged per run)       | 0.10                         |
| Balloon (single use)                   | 0.15                         |
| Gallon zip bag                         | 0.20                         |
| Cup                                    | 0.05                         |
| Plastic-wrap square                    | 0.03                         |
| Rubber band                            | 0.02                         |
| Tissue square                          | 0.01                         |
| Paper cone                             | 0.01                         |
| Vinegar and baking soda (every design) | 0.10                         |

These prices are made up so that cost can be compared fairly. Add the price of every part your design uses.

## Starter design tests (our group)

| Design               | Mass before (g) | Mass after (g) | Change (after minus before, g) | Sealing time (s) | Cost per run | What leaked or went wrong |
|----------------------|-----------------|----------------|--------------------------------|------------------|--------------|---------------------------|
| A: balloon on bottle |                 |                |                                |                  |              |                           |
| B: bag race          |                 |                |                                |                  |              |                           |
| C: cup dome          |                 |                |                                |                  |              |                           |

### Pooled class data and the strongest feature of each design

| Design               | Class average change (g) | Best single change (g) | Average sealing time (s) | Cost per run | Strongest feature, and the criterion it wins | Weakest point |
|----------------------|--------------------------|------------------------|--------------------------|--------------|----------------------------------------------|---------------|
| A: balloon on bottle |                          |                        |                          |              |                                              |               |
| B: bag race          |                          |                        |                          |              |                                              |               |
| C: cup dome          |                          |                        |                          |              |                                              |               |

-  Sketch your combined trap. Label every part, and next to each borrowed feature write the letter of the starter design it came from (A, B or C). Under the sketch write your three predictions: mass change, sealing time and cost per run.

**Answer:** Any labeled trap that obeys the constraints (no cap, same amounts, fits the pan, under budget) and borrows at least one labeled feature from each of two starters. A typical strong design: a gallon zip bag (B) sealed before mixing with the soda held apart from the vinegar by a tissue packet (C) or a twisted corner, so that mixing happens inside an already sealed boundary (A's feature). Predictions written under the sketch, with the mass change predicted as a loss of about 0.6 to 0.7 g (the lift of the puffed trap) rather than exactly zero.

**Why:** The sketch is graded on labeled borrowing and constraint checking, not on matching this example. A design that is simply Design A again earns partial credit only if it also labels a feature taken from B or C.

*Also acceptable: Accept a balloon on a cup, a bag inside a bag, or a balloon holding the soda inside a sealed bag, if labeled and justified.*

- Every part labeled
- At least two starters named as the source of a feature
- Passes every constraint, including no rigid sealed container
- Three predictions written before the test

### Redesign test

| Run                 | Mass before (g) | Mass after (g) | Change (g) | Sealing time (s) | Cost per run | Predicted change (g) | Did it pass every constraint? |
|---------------------|-----------------|----------------|------------|------------------|--------------|----------------------|-------------------------------|
| Our redesign        |                 |                |            |                  |              |                      |                               |
| Class best redesign |                 |                |            |                  |              |                      |                               |

1. Name one starter design that won one criterion but lost another. Give the numbers for both criteria.

**Answer:** Group-specific. Typical: Design A won mass change (for example -0.7 g) but lost cost (0.36 per run versus 0.21 for C); or Design C won cost and build time but lost mass change (for example -1.0 g).

**Why:** Students must notice that no starter wins everything, which is the premise of MS-ETS1-3.

- Names a design and two criteria
- Gives a number for each criterion from the group or class data

2. Which feature did you borrow from each starter for your redesign, and which number in the pooled table told you to borrow it?

**Answer:** Group-specific. For example: from A, sealing before mixing, because A's average sealing time was 0 s and its mass change was smallest; from B, the bag's wide opening and easy pour, because B had no slipped seals; from C, the tissue delay packet or the cheap parts, because C's cost was lowest.

**Why:** Each borrowed feature must be tied to a number in the pooled table; that is the data-analysis half of the standard.

- Names a feature from at least two starters
- Cites a specific pooled number for each

## Analysis questions: answer key

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3. A perfect trap keeps the same mass before and after. Explain why using atoms: where are the carbon and oxygen atoms of the carbon dioxide before the reaction, where are they after, and what has to be true of the boundary for the mass to stay the same?

**Answer:** Before the reaction the carbon and oxygen atoms that will make carbon dioxide are inside the baking soda and the vinegar, both on the balance. After the reaction the same atoms are in carbon dioxide molecules; if the trap holds, those molecules are still inside the boundary and still on the balance. No atom was made or destroyed and each atom keeps its mass, so the total mass can only change if atoms cross the boundary. For the mass to stay the same, the boundary must let nothing out (no gas past the seal) and nothing in.

**Why:** This is the MS-PS1-5 explanation applied to the trap. Full credit requires the atoms located before and after and the boundary condition stated.

- Locates the C and O atoms in the reactants before and in carbon dioxide after
- States that atoms are neither created nor destroyed and keep their mass
- States that the reading changes only if matter crosses the boundary

4. Design C's change was usually the largest. Did that reaction destroy more matter than the others? Where did the missing grams go?

**Answer:** No. Every design ran the same reaction with the same amounts, so the same atoms regrouped in every cup, bottle and bag. Design C read lower because more carbon dioxide escaped past the wrap at the rim; the missing grams are carbon dioxide molecules now in the room's air, not destroyed matter.

**Why:** Separates 'the trap failed' from 'the law failed.' The atoms must be located in the room's air.

- Says no matter was destroyed
- Attributes the larger change to more gas escaping the boundary
- Locates the escaped gas in the air

5. Even a trap that never leaked reads about 0.6 to 0.7 g low. Explain the lift of a puffed-up bag or balloon and why it is not lost matter. What kind of container would not puff up, and why are students not allowed to use one here?

**Answer:** A puffed-up bag or balloon takes up more space than it did before, and the air around it pushes up on it, the way water pushes up on a beach ball; the push is about 1.2 g for every liter of puff, and this reaction makes about 0.6 L of gas, so the reading drops by about 0.7 g even though every atom is still inside. The matter is all there; the balance is being pushed on from outside. A rigid container (a capped bottle or jar) would not puff up and would read the same, but the gas would build pressure inside it, which can pop a lid or burst the container, so students are not allowed to use one.

**Why:** This is the measurement effect behind most 'the sealed system lost mass' observations. Students need the buoyancy idea in everyday words and the safety reason for the rigid-container rule.

*Also acceptable: Accept 'like a helium balloon' as the analogy if the no-lost-matter point is made.*

- Explains the lift as the surrounding air pushing up on the larger volume
- States that no matter was lost
- Names a rigid container as the puff-free option and pressure build-up as the reason it is not allowed

6. The open cup in Lab 1 lost about 1.1 g, and a perfect trap reads about 0.7 g low from lift alone. Suppose your Design C read 0.9 g low (use your own number if you have it). Estimate the fraction of the gas that escaped as  $(C\text{'s drop} - 0.7\text{ g}) \div (1.1\text{ g} - 0.7\text{ g})$ , then the fraction the dome kept. Show the subtraction and the division.

**Answer:** Escaped:  $(0.9\text{ g} - 0.7\text{ g}) \div (1.1\text{ g} - 0.7\text{ g}) = 0.2 \div 0.4 = 0.5$ , about half. Kept:  $1 - 0.5 = 0.5$ , about half. With the student's own number, the same steps apply.

**Why:** A trap that keeps all the gas reads about 0.7 g low (the lift of its puff) and one that keeps none reads about 1.1 g low (the open cup), so every design's drop falls between those two marks. Gas that escapes lowers the reading by its full mass, while gas that is kept shows only as lift, so the position between the marks estimates the share that escaped. Subtracting C's drop from 1.1 g without the lift mark would wrongly make a perfect trap look as if it kept only about a third of the gas.

*Also acceptable: Accept any correct calculation with the group's own Design C value (a drop of 0.7 g or less means the dome kept nearly all the gas), and accept 'about half' with the arithmetic shown.*

7. The standard this lab is built on says pieces of several designs can be combined into one that beats each of them. Did your redesign beat all three starters on every criterion? Use numbers. If it lost on one criterion, which one, and would you accept that trade-off? Why?

**Answer:** Group-specific, with numbers. A strong answer: the redesign (for example  $-0.7\text{ g}$ ,  $0\text{ s}$ ,  $0.33\text{ per run}$ ) beat all three starters on mass change and sealing time but cost more than Design C ( $0.21$ ); the group accepts that trade-off because the purpose of the trap is a fair mass test, so mass change is the criterion that matters most, and the cost difference is small. An answer that reports the redesign lost on mass change and explains why (a seal failed) and what to change next also earns credit.

**Why:** The standard is about combining features to better meet criteria, not about winning; honest reporting of a trade-off, with a weighting of criteria, is the proficient response.

- Compares the redesign with all three starters using numbers
- Identifies any criterion the redesign lost
- Makes and justifies a decision about the trade-off

8. Which criterion did the price list pull against? Describe one feature that improved the mass result but raised the cost, and explain how your group decided whether it was worth it.

**Answer:** Cost pulls against mass change: the parts that seal best (a balloon or a whole zip bag) cost more than a wrap square and a band. Example: adding a balloon inside the bag to hold the soda improved the seal but added 0.15 per run; the group decided it was worth it because the trap's job is to hold gas, or decided against it because a twisted corner did the same job for free.

**Why:** Students should recognize that criteria compete and that a decision requires ranking them. Either decision is fine if it is reasoned.

- Names cost as competing with the seal quality
- Gives a concrete feature with its price
- Explains the decision

9. Name one thing that would make you distrust a design's mass data (for example, vinegar spilled on the balance pan during the pour). How would you catch it, and what would you do with that run's numbers?

**Answer:** Examples: vinegar spilled on the pan or outside the trap, the paper cone or cup taken off the balance between readings, a balloon that slipped off, a reading taken before the fizzing stopped, or the balance not zeroed. Catch it by checking the pan before each reading, watching for a steady reading for 30 seconds, and comparing the run with the class average; a run with a known fault is marked and left out of the average, and repeated if there is time.

**Why:** Assesses whether students can identify a measurement fault and treat flawed data properly rather than averaging it in.

- Names a specific fault that changes the reading
- Describes a check that would catch it
- Says the flawed run is flagged, excluded or repeated

## Individual evidence of learning

Each student submits their own criteria and constraints table, the group's test data, the pooled table with the strongest feature column filled in, the labeled redesign sketch with predictions, the redesign test row, and written answers to q1 through q9. The pooled table, the sketch and q7 are the primary evidence for MS-ETS1-3; q3 and q4 are the evidence for MS-PS1-5.

## Assessment criteria

| Criterion                       | Proficient looks like                                                                                                                                                                                           |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Criteria and constraints</b> | Each criterion has a measurement and a numeric target; the constraints include the amounts, the materials list and the no-rigid-container rule; the redesign is checked against all of them.                    |
| <b>Analyzing pooled data</b>    | Uses class averages (not just the group's run) to name which design won each criterion and identifies the feature responsible, with a weakness named for each design.                                           |
| <b>Combining features</b>       | The redesign sketch labels features borrowed from at least two starters, predictions are written before the test, and q7 compares the result with all three starters using numbers and discusses any trade-off. |

|                                          |                                                                                                                                                                                                                               |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Atom explanation of the mass data</b> | q3 and q4 track the carbon and oxygen atoms of the gas across the boundary and explain that lost grams are gas that crossed it, with the lift of a puffed-up trap recognized as a measurement effect rather than lost matter. |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## Accessibility adaptations

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- Provide a criteria table with one example row completed and a word bank for measurements (grams, seconds, play dollars) for students who need more support; let them test two starters instead of three and use the class data for the third.
- Let a partner pour and zip while a student with limited fine-motor control runs the stopwatch and reads the balance; accept a labeled physical prototype with a spoken justification in place of the sketch and q7.
- Offer sentence frames for q3 ('Before the reaction the carbon and oxygen atoms were in \_\_\_\_\_. After, they were in \_\_\_\_\_. The mass stayed the same because \_\_\_\_\_') and a glossary card for criterion, constraint, boundary and system in English and the student's home language.
- For students ready for more, add a fourth criterion with a price (for example, reusable parts only) and ask them to redesign to the new budget, or to design a trap for a reaction that makes twice the gas without breaking the safety constraint.

## Low-cost alternative

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Run Design A as a class demonstration on one balance and have groups test only B and C, which use the cheapest parts; or replace the balloon with a second zip bag so no balloons are needed. If balances are scarce, stagger the runs so each group uses a shared balance only for its three readings, and time the seals at the desk.

## Model limitations

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A trap only tests the boundary, not the law: the law of conservation of matter holds whether or not the trap works, and a leaky design shows gas escaping, not matter vanishing. Every allowed trap puffs up, and a puffed-up trap is buoyed by the air it displaces, roughly 1.2 g per liter, so even a perfect seal reads about 0.6 to 0.7 g low with this charge; a rigid container would avoid this but is not safe for students because pressure builds inside it. Some carbon dioxide stays dissolved in the liquid, so the open-cup loss used for comparison is a little less than the gas made. The play-money prices are invented and the time criterion depends on who holds the stopwatch. This activity has not been physically tested by the authors; the mass changes and sealing times above are estimates for the stated amounts.

## Teacher notes

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Hold the materials until each group's criteria table is complete; that step is most of MS-ETS1-1 and it is skipped the moment a balloon is in reach. Expect every trap, even a perfect one, to read about 0.6 to 0.7 g low from the lift of the inflated trap, so the useful range between a perfect trap and no trap at all is only about 0.4 g; pool the class data so the averages can separate the designs, and explain the lift before the data go on the board so students compare designs with each other and with Lab 1's open-cup loss rather than with zero. The play-money prices are invented; change them if you want cost to bite harder or softer. The rigid-bottle demonstration is optional and teacher-only; it is the cleanest closed system in the lesson,

but the no-cap rule for students must stay absolute. Keep the best redesign on the demonstration table for the synthesis slide.