

Three Cups in Numbers: Temperature Clues and the Recovery Test

Learning target: I can graph temperature data, calculate before-and-after differences in solubility, and use those numbers to decide which cup made a new substance and which only looked like it did.

Data and graphing

About 45 min

Individual

MS-PS1-2 · assesses

data analysis

independent practice

Standards connections

MS-PS1-2 (assesses, analyzing solubility and odor data before and after substances interact, with temperature and fizzing treated as clues): Table 2 gives solubility and odor for each starting solid and for the solid recovered afterward, measured at the same temperature. Students compute the differences and decide which cup produced a substance with different characteristic properties, which is the analysis the PE asks for and stays inside its assessment boundary.

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

Answers with reasoning

Part A: The temperature story

Mr. Delgado's class repeated the three-bag demonstration in open cups so that a thermometer could stand in each one. Cup A held 2.5 g of baking soda (half as much, so that the vinegar was enough to use all of it up), and 50 mL of white vinegar was poured in. Cup B held 5.0 g of calcium chloride pellets, and 50 mL of water was poured in. Cup C held 5.0 g of Epsom salt, and 50 mL of water was poured in. Every liquid and every cup started at 21.0 °C, and the room stayed at 21 °C the whole time. Cup A fizzed for about two minutes. In Cups B and C the solids disappeared within a minute. The class read each thermometer at the times shown.

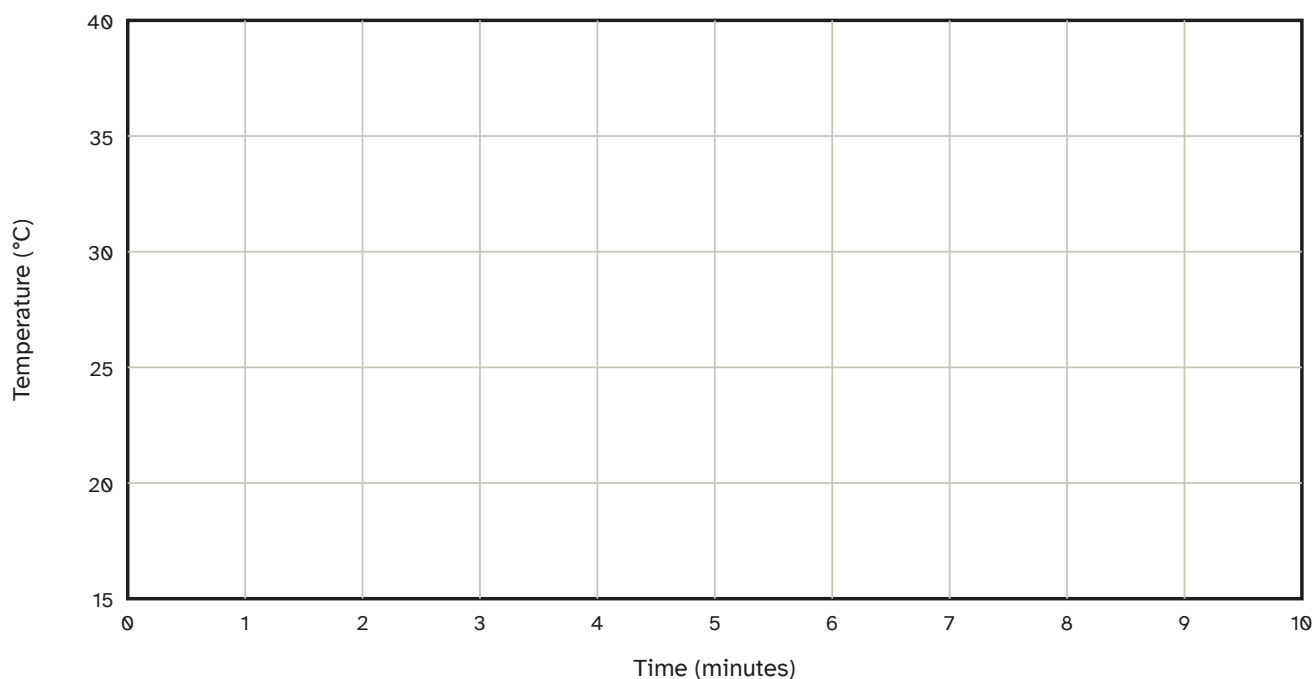
Table 1. Temperature in each cup (teaching dataset)

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

Time (minutes)	Cup A: baking soda + vinegar (°C)	Cup B: calcium chloride + water (°C)	Cup C: Epsom salt + water (°C)
0	21.0	21.0	21.0
1	18.9	31.4	19.9
2	17.8	36.2	19.2
3	17.5	37.0	19.0
5	17.9	35.1	19.3
10	19.4	30.6	20.2

Simulated data for teaching. Realistic for the amounts described, each in 50 mL of liquid at room temperature.

Temperature in each cup over ten minutes



1. For each cup, find the reading farthest from the starting temperature and calculate the change (that reading minus 21.0 °C). Write a + sign for warming and a – sign for cooling, and say at what time it happened.

Answer: Cup A: $17.5\text{ °C} - 21.0\text{ °C} = -3.5\text{ °C}$ (cooled), at 3 minutes. Cup B: $37.0\text{ °C} - 21.0\text{ °C} = +16.0\text{ °C}$ (warmed), at 3 minutes. Cup C: $19.0\text{ °C} - 21.0\text{ °C} = -2.0\text{ °C}$ (cooled), at 3 minutes.

Why: The farthest reading from the start in every column is at 3 minutes. Signs matter: two cups cooled and one warmed. Students who use the 10-minute reading have measured the leftover change, not the largest change.

Also acceptable: Accept the changes without the time if the calculation is shown; accept 'about -3.5, +16 and -2'.

2. Describe the shape of each line. Then explain why all three lines head back toward 21 °C by 10 minutes, even though nothing new was added to the cups.

Answer: Cup A drops quickly for three minutes, then slowly climbs back. Cup B rises steeply for three minutes, then slowly falls. Cup C dips a little for three minutes, then slowly climbs. All three head back toward 21 °C because the cups sit in a 21 °C room: a warm cup loses energy to the air and a cool cup gains energy from it, so every cup drifts toward room temperature once the change inside it has finished.

Why: The return to room temperature is heat exchange with the surroundings, not a second change. Students should see that the shape (a peak or a dip, then a drift back) means the change happened early and was over by about three minutes.

Also acceptable: Accept 'the cups cool down or warm up to match the room'.

- Describes a dip (A, C) and a peak (B) followed by a return
- Explains the return as energy exchange with the room

3. Cups A and C both cooled. Using **only** Table 1 and your graph, can you tell which cup, if either, made a new substance? Explain what temperature data can and cannot show.

Answer: No. Both cups cooled, so the temperature data alone cannot tell them apart; Cup A (which fizzed and, as Part B shows, made a new substance) and Cup C (which only dissolved) both show a dip. A temperature change shows that energy moved in or out during the change, which is a clue that something happened. It cannot show whether the substance that remains is the same substance or a different one; only a property comparison can.

Why: This is the central point: temperature change is an indicator, not proof. The two cooling cups make the point directly.

Also acceptable: Accept 'both went down, so you cannot tell' with the clue-versus-proof idea.

- Says the temperature data cannot decide
- Explains that a temperature change shows energy moved but does not identify the substance

4. Which statement about Cup B is best supported by Part A alone?

Answer: C. Something happened that released energy to the water, but these data do not show whether a new substance formed.

Why: A is the misconception (heat proves a reaction). B is in fact what happened, but Part A alone does not show it; the dissolving is only established by Table 2. D is wrong because dissolving calcium chloride really does warm water.

Also acceptable: None.

Part B: The recovery test

The class left each cup uncovered on a warm shelf for three days, until the liquid was gone. They scraped the dry solid out of each cup and tested it beside a fresh sample of the solid that had gone into that cup. Every solubility test was done at 20 °C by stirring the solid into 100 mL of water a little at a time until no more would dissolve. When the class repeated a solubility test on the **same** powder, the two results were always within 2 g per 100 mL of each other.

Table 2. Before-and-after tests on the solids (teaching dataset)

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

Cup	Solid tested	Appearance	Solubility at 20 °C (g per 100 mL)	Fizzes when vinegar is added?	Odor
A	Baking soda (before)	white powder	9.6	yes, strongly	none
A	Solid recovered (after)	white, slightly glassy crust	121	no	none
B	Calcium chloride (before)	white pellets	74	no	none
B	Solid recovered (after)	white crust	75	no	none
C	Epsom salt (before)	clear, colorless crystals	71	no	none
C	Solid recovered (after)	clear, colorless crystals	70	no	none

Simulated data for teaching. 'Before' is the solid that went into the cup; 'after' is the dry solid recovered when the liquid was gone.

5. For each cup, calculate the change in solubility (after minus before) in g per 100 mL. Then calculate how many times larger Cup A's 'after' solubility is than its 'before' solubility (divide). Round to one decimal place.

Answer: Cup A: $121 - 9.6 = +111.4$ g per 100 mL. Cup B: $75 - 74 = +1$ g per 100 mL. Cup C: $70 - 71 = -1$ g per 100 mL. Cup A ratio: $121 \div 9.6 = 12.6$, so the recovered solid is about 12.6 times (roughly 13 times) as soluble as baking soda.

Why: After minus before gives the sign. The ratio shows the scale of the Cup A change compared with the 1 g changes in B and C.

Also acceptable: Accept +111 for Cup A; accept 12.6 or 'about 13 times'.

6. Cups B and C each show a difference of 1 g per 100 mL. Use the sentence about repeated tests in the Part B description to explain why a difference this small is **not** evidence of a new substance.

Answer: Repeating a solubility test on the same powder gives results that differ by up to 2 g per 100 mL, so a difference of 1 g per 100 mL is smaller than the normal spread between two measurements of the same substance. It could easily come from measuring, not from a different substance. Cup A's difference of 111 g per 100 mL is more than fifty times that spread, so it cannot be a measurement wobble.

Why: Students must compare the difference with the stated uncertainty. This is the quantitative version of 'is the change real?'.

Also acceptable: Accept 'the test is not exact enough to trust a 1 g difference'.

- Uses the 2 g per 100 mL repeat spread
- Concludes that 1 g is within normal measurement variation

7. Which cup made a new substance? Give **two independent** pieces of evidence from Table 2, and name the one property in that cup's row that did **not** change.

Answer: Cup A. Evidence 1: the recovered solid dissolves 121 g per 100 mL at 20 °C while baking soda dissolves 9.6 g per 100 mL at the same temperature, a difference far beyond the 2 g repeat spread. Evidence 2: baking soda fizzes strongly with vinegar and the recovered solid does not, so the recovered solid does not have baking soda's chemical property. (A third, weaker piece: the appearance changed from powder to a glassy crust.) The property that did not change: odor, which is 'none' both before and after.

Why: Two independent properties (a physical one, solubility; a chemical one, reactivity with vinegar) agree, which makes the claim strong. Odor is unchanged on purpose, to show that a product need not differ in every property.

Also acceptable: Accept appearance as one of the two pieces of evidence only if solubility is the other; appearance alone is weak.

- Names Cup A
- Solubility difference with numbers
- Fizz-with-vinegar difference
- Odor named as the unchanged property

8. Cup B warmed the most of all three cups, yet Table 2 shows no change. What happened to the calcium chloride in Cup B, what kind of change is it, and which Table 2 result shows it?

Answer: The calcium chloride dissolved in the water, which is a physical change: the pellets spread out among the water particles but stayed calcium chloride. Table 2 shows it because the recovered solid has the same appearance, the same odor, does not fizz, and has a solubility (75 g per 100 mL) within 1 g of the original (74 g per 100 mL), which is inside the repeat spread. Dissolving calcium chloride releases energy, which is why the cup warmed, but the same substance came back when the water left.

Why: The recovery test is the student-level justification for calling dissolving a physical change. The warmth is explained without calling it a reaction.

Also acceptable: Accept 'the same stuff came back when the water evaporated'.

- Says the calcium chloride dissolved
- Calls it a physical change
- Cites the matching 'after' row, especially solubility within the spread

9. A student wants to repeat the Cup A solubility tests with only 25 mL of water at 20 °C. Using Table 2, calculate how many grams of baking soda and how many grams of the recovered Cup A solid should dissolve in 25 mL. Show your work.

Answer: 25 mL is one quarter of 100 mL, so multiply each solubility by 0.25. Baking soda: $9.6 \text{ g} \times 0.25 = 2.4 \text{ g}$. Recovered Cup A solid: $121 \text{ g} \times 0.25 = 30.25 \text{ g}$, about 30 g.

Why: Scaling by the volume ratio keeps the units in grams. Students who divide by 4 instead of multiplying by 0.25 get the same result.

Also acceptable: Accept 2.4 g and 30.25 g or 30.3 g or 'about 30 g'.

10. Three kinds of evidence appeared in this investigation: a temperature change (Table 1), fizzing (seen in Cup A), and a difference in solubility measured at the same temperature (Table 2). Rank them from **weakest** to **strongest** as evidence that a new substance formed. Justify each ranking with a specific cup.

Answer: Weakest: temperature change. Cup B warmed by 16 °C and Cup C cooled by 2 °C, yet both only dissolved; Cup A cooled too. A temperature change shows energy moved, not that a new substance formed. Middle: fizzing. Only Cup A fizzed, and the gas was something not seen before, so it is a stronger clue than warmth; but bubbles can also come from boiling or from gas that was already dissolved, so fizzing alone does not identify what is left in the cup. Strongest: the solubility difference measured at the same temperature. Solubility is a characteristic property, the 111 g per 100 mL change in Cup A is far beyond the 2 g repeat spread, and Cups B and C show no real change, so this one test separates the reaction from the two dissolvings. It is strongest of all when a second property (the lost fizz with vinegar) agrees with it.

Why: The ranking should move from indicator to characteristic-property comparison. Full credit requires a specific cup for each level and the idea that the strongest evidence is a measured property compared under the same conditions.

Also acceptable: A student who ranks fizzing weakest and temperature in the middle can earn credit if the reasons are sound (for example, 'a soda fizzes with no reaction'), as long as solubility is ranked strongest.

- Temperature ranked weakest with Cup B or Cup C as the reason
- Fizzing ranked in the middle with a reason it can mislead
- Solubility ranked strongest with the same-temperature and repeat-spread reasoning
- Each rank tied to a specific cup

Teacher notes

Both tables are simulated. Cup A uses 2.5 g of baking soda so that the vinegar is in excess (2.5 g needs about 1.8 g of acetic acid; 50 mL of 4-6% vinegar holds 2-3 g), so no baking soda is left in the recovered solid to fizz. Reference points behind them: baking soda dissolves about 9.6 g per 100 mL at 20 °C and anhydrous sodium acetate about 123 g per 100 mL at 20 °C; calcium chloride dissolves about 74.5 g per 100 mL at 20 °C; Epsom salt values depend on how the water in the crystals is counted, so treat Cup C's 70-71 g as teaching numbers. Dissolving 5 g of calcium chloride in 50 mL of water really does warm it by well over 10 °C, and both baking soda with vinegar and Epsom salt in water cool slightly. In a real recovery test, calcium chloride and Epsom salt pick up or lose water of crystallization as they dry, which shifts masses and apparent solubility a little; that is why the table avoids masses and why the repeat-test spread of 2 g per 100 mL is stated; in a humid room calcium chloride may never dry completely. The recovered Cup A solid is sodium acetate; students do not need its name, only that its properties differ from baking soda's. In the extension, the salt values are real: 36 g per 100 mL at 20 °C and 39 g per 100 mL at 100 °C, so a hot 'after' test would show a 3 g difference that looks real against a 2 g spread; the lesson is that both measurements must be made at the same temperature before the spread can be used at all.

Scaffold offered to students: Changes have signs

A change is always 'after minus before'. If the answer is negative, the cup cooled or the value dropped; if it is positive, the cup warmed or the value rose. For q1, run your finger down each cup's column, mark the reading farthest from 21.0, and subtract 21.0 from it. For q5, Table 2 comes in pairs: the 'after' row sits right under the 'before' row for the same cup, so subtract the upper number from the lower one.

Extension: Design Cup D and spot the temperature trap

Reference values: table salt (sodium chloride) dissolves 36 g per 100 mL of water at 20 °C and 39 g per 100 mL at 100 °C. Imagine a Cup D with 5.0 g of table salt and 50 mL of water. Predict its two rows of Table 2 (before and after) and its temperature change in Table 1, with a reason for each prediction. Then explain the trap: a student measures the 'before' solubility in 20 °C water and the 'after' solubility in freshly boiled water. What numbers would that student get, what would they wrongly conclude, and how does the 2 g per 100 mL repeat-test spread help you decide whether a 3 g difference is real?