

Fixing Jordan's Notebook: Heat, Cold and the Missing Flat Lines

Learning target: I can find the errors in another student's statements and graph about heat, temperature and state changes, name the idea that went wrong, and rewrite each one so it is scientifically accurate.

Error analysis

About 45 min

Individual

MS-PS1-4 · practice

MS-PS3-4 · supports

writing

independent practice

Standards connections

MS-PS1-4 (practice, correcting a flawed model of temperature and state when thermal energy is added): Diagnosing Jordan's straight-line heating curve and his particle statements, then drawing the corrected curve, exercises exactly what the PE's model must get right: temperature holds steady during a change of state, particles do not change, and evaporation does not need the boiling point. Students repair a model rather than build one from scratch.

MS-PS3-4 (supports, only the distinction between temperature and total thermal energy): MS-PS3-4 is a California Grade 6 PE. Statements 1 and 2 rely on its idea that temperature measures average kinetic energy while total thermal energy also depends on mass. No item asks students to plan an investigation or calculate energy.

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

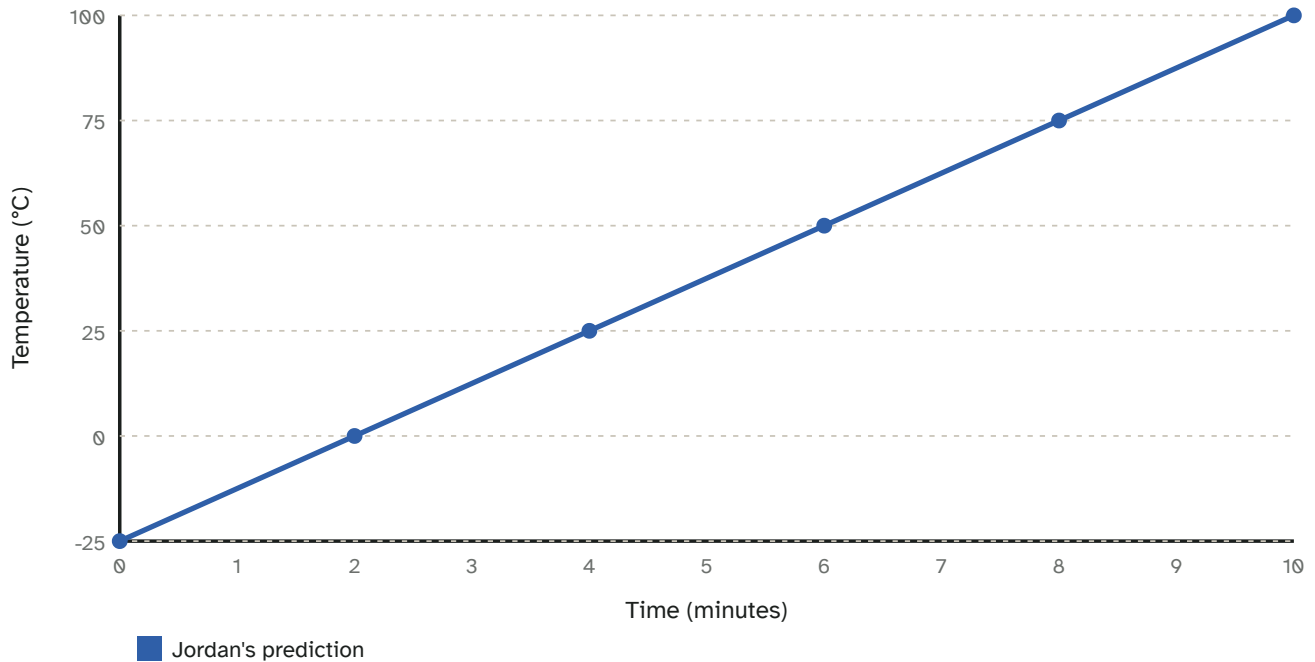
Answers with reasoning

Jordan's notebook page

Jordan's notes: 'The class put crushed ice from the freezer in a beaker on a hot plate and recorded the temperature every minute until the water boiled. This is the graph I think they got.'

Jordan's sketch: temperature of ice heated on a hot plate

simulated data



Jordan's predicted heating curve for ice warmed from -25°C on a hot plate. This is a student's sketch, not real data.

1. My thermometer measures how much heat is in the water.
2. A 90°C mug of cocoa has more thermal energy than a 35°C bathtub of water, because the cocoa is hotter.
3. When I held an ice cube, cold flowed out of the ice and into my hand.
4. While the ice melted, the temperature kept rising, because the hot plate kept adding energy. (See my graph.)
5. When the water boiled, the big bubbles were air escaping from the water.
6. Water only turns into a gas at 100°C , so yesterday's puddle on the blacktop must have soaked into the ground.
7. The white cloud above the boiling beaker is water vapor.
8. When the ice melted, the water molecules melted too and became soft.
9. When the warm water and the cooler room air reached the same temperature, the overall flow of energy between them stopped.
10. Tomorrow I will wrap an ice cube in a wool sock, so the heat from the wool will melt it faster.
11. Helium boils at about -269°C because its atoms attract one another very weakly.

Part A: Diagnose

1. Complete the table for all eleven statements. If a statement is partly right, mark it incorrect and name only the part that is wrong.

Answer: 1 incorrect: a thermometer reads temperature, not heat. 2 incorrect: thermal energy depends on amount of matter as well as temperature. 3 incorrect: energy moved from the hand to the ice; cold does not flow. 4 incorrect: temperature stays level while ice melts. 5 incorrect: the big bubbles are water vapor. 6 incorrect: water evaporates at many temperatures. 7 incorrect: the cloud is tiny liquid droplets; vapor is invisible. 8 incorrect: molecules do not melt or change; their arrangement and motion change. 9 correct. 10 incorrect: wool makes no energy; it slows energy transfer. 11 correct.

Why: Nine statements contain one of the chapter's listed misconceptions; statements 9 and 11 are accurate and test whether students can recognize correct science.

Also acceptable: For statement 6, accept 'partly right: some water may soak in, but most can evaporate' marked incorrect.

- Statements 9 and 11 marked correct
- At least eight of the nine incorrect statements identified with the right idea

Part B: Explain and rewrite

2. Statements 1 and 2: What does a thermometer actually measure? Explain why the bathtub has more thermal energy than the cocoa even though it has a lower temperature. Rewrite both statements.

Answer: A thermometer measures temperature, which tracks the particles' average kinetic energy. The bathtub holds far more water, so even though each particle is less energetic on average, the total energy of all its particles is much greater. Rewrites: 'My thermometer measures the temperature of the water.' 'A 90 °C mug of cocoa has a higher temperature than a 35 °C bathtub, but the bathtub has more thermal energy because it contains much more water.'

Why: Temperature is an average; thermal energy is a total that depends on the amount of matter.

Also acceptable: Accept 'heat is the energy that moves; the thermometer reads temperature' for statement 1.

- Thermometer measures temperature (average kinetic energy)
- Bathtub has more thermal energy because of its much larger amount
- Both statements rewritten correctly

3. Statement 3: Use particle collisions to explain which way energy really moved between Jordan's hand and the ice cube, and why his hand felt cold. Rewrite the statement.

Answer: Jordan's hand was warmer than the ice, so the more energetic particles of his skin collided with the less energetic particles of the ice and passed energy to them. Energy flowed from his hand into the ice, and his hand felt cold because it was losing energy. Rewrite: 'When I held an ice cube, energy flowed as heat from my warmer hand into the colder ice, so my hand felt cold.'

Why: Heat flows from warmer to cooler; cold is the feeling of losing energy, not a substance.

Also acceptable: None.

- Energy moves from hand to ice
- Explains with collisions between more and less energetic particles
- Rewrite has no 'cold' moving

4. Statement 4 and Jordan's graph: Sketch a corrected heating curve for ice warmed from $-25\text{ }^{\circ}\text{C}$ until the water boils. Label the melting and boiling stretches with their temperatures and the state or states present in each part.

Answer: The corrected sketch rises from $-25\text{ }^{\circ}\text{C}$ to $0\text{ }^{\circ}\text{C}$ (solid), runs level at $0\text{ }^{\circ}\text{C}$ (solid and liquid, melting), rises from $0\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$ (liquid), then runs level at $100\text{ }^{\circ}\text{C}$ (liquid and gas, boiling). The level stretch at $0\text{ }^{\circ}\text{C}$ is labeled melting and the level stretch at $100\text{ }^{\circ}\text{C}$ is labeled boiling.

Why: A pure substance at constant pressure holds its temperature during each change of state.

Also acceptable: Accept a sketch that ends partway through boiling, as long as the $100\text{ }^{\circ}\text{C}$ stretch is level.

- Two level stretches, at $0\text{ }^{\circ}\text{C}$ and $100\text{ }^{\circ}\text{C}$
- Rising parts between them
- States labeled for each part
- Axes labeled

5. Statement 4: Jordan is right that the hot plate kept adding energy. Explain where that energy went while the ice was melting, and rewrite the statement.

Answer: While the ice was melting, the energy went into pulling water molecules free of their fixed positions in the ice, against their attractions, instead of making them move faster on average. Because the average kinetic energy did not change, the temperature stayed at $0\text{ }^{\circ}\text{C}$. Rewrite: 'While the ice melted, the temperature stayed at $0\text{ }^{\circ}\text{C}$ even though the hot plate kept adding energy, because the energy was freeing molecules from the solid instead of speeding them up.'

Why: The added energy still increases the sample's thermal energy, but it changes the state, not the temperature.

Also acceptable: Accept 'the energy went into melting the ice, not into raising the temperature' as a minimum rewrite.

- Energy frees molecules from fixed positions (overcomes attractions)
- Temperature stays at $0\text{ }^{\circ}\text{C}$ because average kinetic energy does not change
- Rewrite correct

6. Statements 5 and 7: What are the big bubbles in boiling water really made of, and what is the white cloud above the beaker made of? Rewrite both statements.

Answer: The big bubbles are water vapor, gas that forms inside the liquid at the boiling point. The white cloud is tiny drops of liquid water that formed when the invisible water vapor cooled in the air and condensed.

Rewrites: 'When the water boiled, the big bubbles were water vapor forming inside the water.' 'The white cloud above the beaker is tiny droplets of liquid water that condensed from invisible water vapor.'

Why: Water vapor is invisible. The small bubbles that appear early in heating are dissolved air coming out, but the large, rolling bubbles at boiling are water vapor.

Also acceptable: Give extra credit if the student notes that the first tiny bubbles before boiling are dissolved air.

- Bubbles are water vapor
- Cloud is liquid droplets from condensation
- Both rewrites correct

7. Statement 6: Explain how the puddle could disappear without the water ever reaching 100 °C. Name the change of state and rewrite the statement.

Answer: The puddle evaporated. At the surface, some water molecules always move fast enough to escape into the air as vapor, at almost any temperature, and the warm blacktop and sun speed this up. Rewrite: 'Water can turn into a gas below 100 °C by evaporating from its surface, so yesterday's puddle probably evaporated (and some may have soaked in).'

Why: Evaporation happens at many temperatures; boiling is the special case at the boiling point.

Also acceptable: Accept 'some soaked in and some evaporated' if evaporation is explained.

- Names evaporation
- Explains surface molecules escaping at temperatures below boiling
- Rewrite correct

8. Statement 8: What actually changes when ice melts, and what stays the same about the water molecules? Rewrite the statement.

Answer: The molecules themselves stay exactly the same: same size, same shape, same water molecules. What changes is their arrangement and motion: they leave their fixed positions and slide past one another. Rewrite: 'When the ice melted, the water molecules broke free of their fixed positions and began sliding past one another; the molecules themselves did not change.'

Why: Melting is a change in how particles are arranged and move, not a change in the particles.

Also acceptable: None.

- Molecules stay the same
- Arrangement and motion change
- Rewrite correct

9. Statement 10: Predict what the wool sock will really do to the ice cube compared with a bare ice cube, and explain why. Rewrite the statement.

Answer: The ice cube in the sock will melt more slowly than a bare ice cube. Wool produces no energy; it traps still air, which slows the transfer of energy from the warmer room into the ice. Rewrite: 'Tomorrow I will wrap an ice cube in a wool sock to test whether the trapped air slows the energy flowing into it, so it melts more slowly.'

Why: Insulators slow energy transfer in either direction; a sweater feels warm because it slows energy leaving your body. Lab 3 tests this directly.

Also acceptable: Accept 'the sock is an insulator' with the slower-melting prediction.

- Predicts slower melting
- Wool makes no energy and slows transfer
- Rewrite correct

Part C: The rule behind the mistakes

- 10.** Statements 3 and 10 come from the same confusion, and so do statements 4 and 6. Choose one of these pairs. Name the confusion and write a two-sentence rule Jordan could tape inside his notebook that would prevent both mistakes.

Answer: Pair 3 and 10: the confusion is treating heat and cold as substances that objects contain or give off. Rule: 'Objects store thermal energy, and only energy moves, always from warmer to cooler. Cold is just less energy, and materials like wool do not make energy; they only slow it down.' Pair 4 and 6: the confusion is tying changes of state to temperature changes or to one special temperature. Rule: 'During melting and boiling the temperature stays level because the energy is changing the state, not the temperature. Evaporation happens at the surface at many temperatures; only boiling needs the boiling point.'

Why: Either pair earns full credit if the confusion is named accurately and the rule would prevent both errors.

Also acceptable: Accept rules worded differently that carry the same science.

- Names the shared confusion for the chosen pair
- Rule is two sentences
- Rule would prevent both statements in the pair

Teacher notes

Each incorrect statement maps to one of the chapter's misconceptions: heat versus temperature (1, 2), cold flowing (3), temperature always rising (4), bubbles and the white cloud (5, 7), evaporation only at boiling (6), particles changing (8) and fabric making heat (10). Statements 9 and 11 are correct on purpose; students who mark everything wrong are guessing. Jordan's graph is labeled as a sketch so no one mistakes it for data. In q6, the first tiny bubbles that cling to the beaker before boiling really are dissolved air; the error is about the large bubbles at the boiling point. Use q4 as a quick check on whether students can now draw the plateaus without looking at W4.

Scaffold offered to students: Three checks for every statement

For each statement ask: (1) Does it treat heat or cold as a substance that objects contain? Only thermal energy is stored, and only energy moves, from warmer to cooler. (2) Does it say temperature must change whenever energy is added? During melting and boiling the temperature holds steady. (3) Does it say the particles themselves change? Particles keep their size and identity; only their arrangement and motion change.

Extension: Write three new mistakes

Write three new statements about heat, temperature or state changes that each contain a different mistake not on Jordan's page (for example, about frost, about dry ice, about why sweating cools you, or about boiling on a mountain). Trade with a partner, diagnose each other's statements, and rewrite them. Then decide together which of your six mistakes would be hardest for a seventh grader to notice, and explain why.