

Timing the Spread: Dye, Temperature and the Shape of the Curve

Learning target: I can organize, graph and calculate with spreading-time data, describe the shape of the relationship between temperature and spreading, and explain it with the average motion of particles.

Data and graphing

About 45 min

Individual

MS-PS1-4 · practice

MS-PS3-4 · supports

data analysis

independent practice

writing

Standards connections

MS-PS1-4 (practice, the link between temperature and particle motion in the model): Students analyze data showing that dye spreads faster in warmer water, then use a gel test that removes currents to isolate diffusion. Explaining the pattern with faster average particle motion practices the motion-and-temperature part of the PE; no change of state is modeled here.

MS-PS3-4 (supports): This is a Grade 6 PE in the California integrated sequence. The sheet relies on its central idea, that temperature reports the average kinetic energy of a sample's particles, but students analyze given data rather than plan the energy-transfer investigation the PE describes, and no energy is calculated.

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

Answers with reasoning

Part A: Dye in still water

A class filled tall 250 mL graduated cylinders with 200 mL of water at six temperatures (the teacher prepared and poured all the water), let each cylinder sit until the water was still, and added one drop of blue food dye to the center without stirring. They recorded the time until the color looked even from top to bottom against a white card. Each temperature was tested three times with fresh water.

Time for one drop of dye to spread evenly in a tall cylinder of still water (200 mL) (teaching dataset)

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

Water temperature (°C)	Trial 1 (min)	Trial 2 (min)	Trial 3 (min)	Mean (min)
5	58	55	55	
15	41	38	41	
25	30	33	30	
35	26	24	12*	
45	21	22	20	
55	18	19	20	

A teaching dataset; the times are realistic for this setup but were not measured in a real class. *During trial 3 at 35 °C, a student bumped the table two minutes after the drop.

1. Calculate the mean time for each temperature and write it in the last column of the table. Show your calculation for 5 °C here.

Answer: 5 °C: $(58 + 55 + 55) \div 3 = 168 \div 3 = 56$ min. 15 °C: $120 \div 3 = 40$ min. 25 °C: $93 \div 3 = 31$ min. 35 °C: $(26 + 24) \div 2 = 25$ min (leaving out the bumped trial). 45 °C: $63 \div 3 = 21$ min. 55 °C: $57 \div 3 = 19$ min.

Why: Each mean is the sum of the trials divided by the number of trials used. At 35 °C the bumped trial is left out (see q2); if it is included, $(26 + 24 + 12) \div 3 = 62 \div 3 \approx 20.7$, about 21 min, which breaks the smooth pattern.

Also acceptable: Accept 20.7 or 21 min at 35 °C only if the student also answers q2 by including the trial with a reason.

- 5 °C calculation shown: $168 \div 3 = 56$
- Means of 40, 31, 21 and 19 min
- 35 °C mean of 25 min with the bumped trial excluded, or 21 min with a note that it was included

2. Should trial 3 at 35 °C be included in the mean? Explain your decision using what bumping the table would do to the water, and write the mean you used.

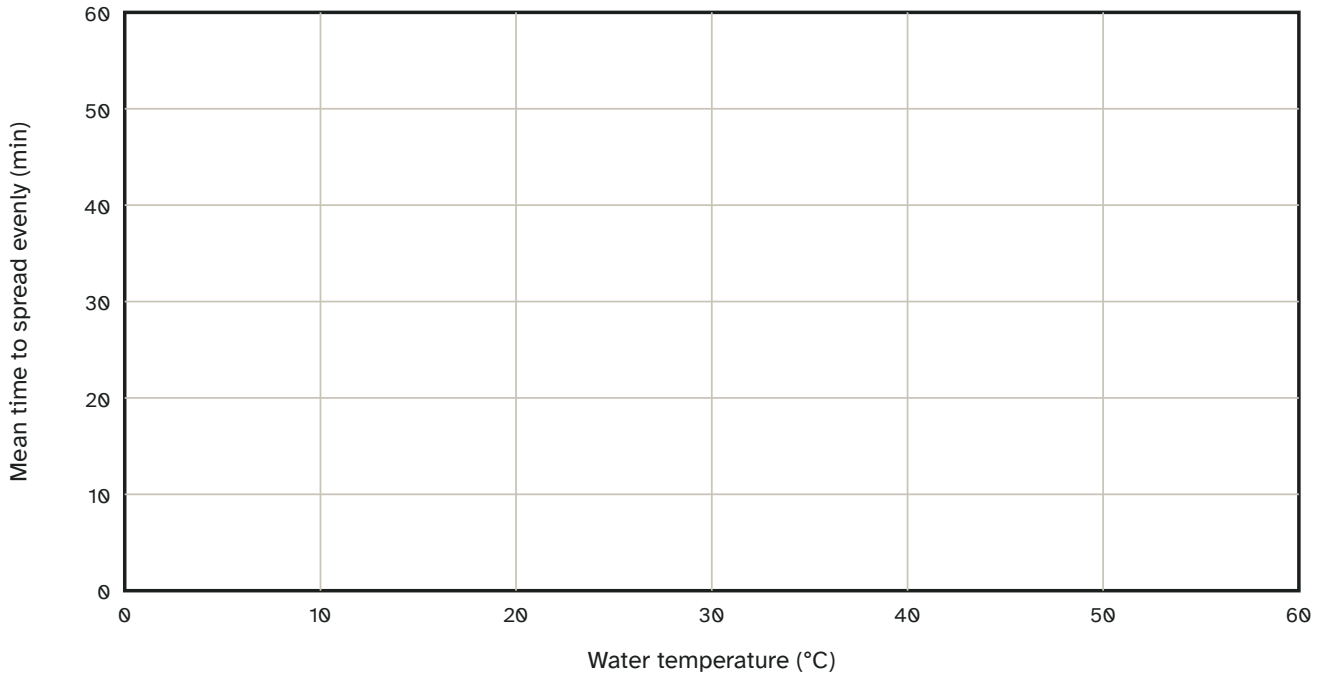
Answer: No. Bumping the table jolts the water and stirs it, so the dye was carried by sloshing water, not just by particle motion and gentle currents. That trial measured something different, which is why it is so much shorter (12 min) than the other two (26 and 24 min). Mean used: $(26 + 24) \div 2 = 25$ min.

Why: A trial may be left out when there is a recorded reason it was not a fair repeat. The reason here is in the caption, and the value is far from the other trials.

Also acceptable: A student who keeps the trial must say why and should note how much it changes the mean; give partial credit.

- Decides to exclude the trial
- Explains that the bump stirred the water
- Uses the recorded event, not just 'it looks wrong'
- Gives a mean of 25 min

Mean spreading time at each water temperature



3. Describe the shape of your graph in one or two sentences. Is it a straight line? Where is it steepest?

Answer: It is a curve, not a straight line: the time falls steeply between 5 °C and about 25 °C and then levels off, falling only a little between 45 °C and 55 °C.

Why: The points are (5, 56), (15, 40), (25, 31), (35, 25), (45, 21), (55, 19). The drops between neighbors shrink: 16, 9, 6, 4 and 2 minutes.

Also acceptable: Accept 'it curves downward and levels out'.

- Says the graph is not a straight line
- Says it is steepest at the cold end and flattens at the warm end

4. By how many minutes did the mean time drop between 5 °C and 15 °C? Between 45 °C and 55 °C? Show both subtractions.

Answer: 5 °C to 15 °C: $56 - 40 = 16$ min. 45 °C to 55 °C: $21 - 19 = 2$ min.

Why: The same 10 °C change makes a much bigger difference at the cold end than at the warm end, which is the numerical form of the curve's shape.

Also acceptable: None.

5. How many times longer did the dye take to spread at 5 °C than at 55 °C? Show the division and round to one decimal place.

Answer: $56 \div 19 \approx 2.9$, so about 2.9 times (nearly three times) as long.

Why: Divide the 5 °C mean by the 55 °C mean.

Also acceptable: Accept 3 if the division is shown.

6. Use your graph to estimate the mean spreading time at 30 °C. Mark the point on your graph.

Answer: About 28 min (read from the curve between 31 min at 25 °C and 25 min at 35 °C).

Why: 30 °C is halfway between 25 °C and 35 °C, and over such a short stretch the curve is nearly straight, so halfway between 31 and 25 is a good estimate.

Also acceptable: Accept 27 to 29 min.

7. A student notices the time drops about 2 minutes for each 10 °C near 50 °C and predicts: 'At 95 °C the dye will take about 11 minutes, and at 150 °C it will spread in 0 minutes.' Give **two** reasons this prediction does not hold up.

Answer: First, the graph is a curve that is flattening, not a straight line, so the drop per 10 °C keeps shrinking; it will not continue at 2 minutes per 10 °C, and the time will never reach zero, because spreading always takes some time. Second, the prediction goes far beyond the data: water at sea-level pressure boils at 100 °C, so there is no liquid water at 150 °C to put dye in.

Why: Extending a straight-line trend outside the measured range (extrapolation) is risky, especially for a curve. The second reason links the data back to boiling point and pressure.

Also acceptable: Accept 'you can only trust predictions inside the range you measured' as the extrapolation reason. A student who notes that water could stay liquid above 100 °C under high pressure is correct and should still give the curve reason.

- Names the curve flattening, or that the time cannot reach zero
- Names that 150 °C is beyond the data range or above water's boiling point at sea-level pressure

Part B: Dye in a gel

Some of the spreading in a cylinder comes from gentle currents in the water. To remove them, a researcher used dishes of agar gel, a firm jelly that is almost entirely water but cannot flow. She placed one drop of dye on each dish, making a colored spot 5 mm across, covered the dishes, and kept them at four temperatures. After 6 hours she measured the width of the colored circle.

Width of the colored circle in agar gel after 6 hours (teaching dataset)

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

Gel temperature (°C)	Width of colored circle after 6 hours (mm)
5	14
20	17
35	19
50	22

A teaching dataset; the widths are realistic for a food dye in agar but were not measured in a real lab. Every spot started 5 mm across.

8. How many millimeters wider than the starting 5 mm spot did the circle become at 5 °C, and at 50 °C? About how many times as much did it widen at 50 °C as at 5 °C?

Answer: At 5 °C: $14 - 5 = 9$ mm wider. At 50 °C: $22 - 5 = 17$ mm wider. $17 \div 9 \approx 1.9$, so it widened about twice as much at 50 °C.

Why: Subtract the starting width, then compare by division.

Also acceptable: Accept 'about 2 times' with both subtractions shown.

9. Why did the researcher use a gel instead of plain water? What does Part B show that Part A by itself could not?

Answer: The gel holds the water still, so no currents can carry the dye; any spreading has to come from the random motion of the particles alone, which is diffusion. Part B shows that diffusion by itself is faster at higher temperature. Part A could not show that, because in a cylinder of water both diffusion and currents could be speeding up the spreading.

Why: Part B isolates one cause by removing the other. Warm still wins, so particle motion depends on temperature even when nothing flows.

Also acceptable: Accept 'it makes it a fairer test of just the particles'.

- Says the gel prevents currents or flow
- Says the spreading in gel is diffusion only
- Says the gel shows diffusion itself is faster when warmer

10. Write a claim that answers: **How does water temperature affect how fast dye spreads, and why?** Support it with at least two numbers from Part A and one from Part B, and explain the pattern using the motion of particles. Use the words *on average* and *diffusion*.

Answer: Example: Dye spreads faster in warmer water. In Part A the mean time dropped from 56 min at 5 °C to 19 min at 55 °C, almost three times faster, and in Part B, where currents were impossible, the colored circle widened 17 mm at 50 °C but only 9 mm at 5 °C. The particles of water and dye are always moving and colliding, and at a higher temperature they move faster on average, so the dye particles wander away from the crowded drop sooner. This spreading by random particle motion is diffusion, and it is faster when warmer. The effect is largest at the cold end of the range, where a 10 °C rise cut the time by 16 minutes.

Why: A full answer makes a claim, uses specific numbers from both parts, and explains with average particle motion rather than with heat 'pushing' the dye.

Also acceptable: A claim that also says currents add to spreading in cylinders and cups but are not the only reason is a strong answer.

- Claim: warmer water, faster spreading
- At least two numbers from Part A and one from Part B
- Explains with faster average particle motion at higher temperature
- Uses 'on average' and 'diffusion' correctly

Teacher notes

Both datasets are simulated but follow the real pattern: spreading gets faster with temperature, and the time curve flattens because time is roughly the inverse of the spreading rate: as the rate keeps rising, each further 10 °C shaves off fewer minutes. Part A extends the reasoning of Lab 1 and the W1 phenomenon. A tall, narrow column of water mixes far more slowly than the wide 200 mL cups of Lab 1 and slide 12, where a 45 °C cup is even within a few minutes, so compare the shape of the pattern, not the minutes. Part B matters for

accuracy: food dye spreading through a whole cylinder in under an hour is helped by gentle currents and by the drop sinking, while diffusion alone over several centimeters would take days. The gel removes bulk flow, so the temperature effect there is diffusion only. In warm water two things speed diffusion, faster particles and lower viscosity; the extension introduces the second idea. No energy or heat calculations appear on this sheet; all calculations are means, differences and ratios of time and distance. If you run a gel demonstration, plain unflavored gelatin works at room temperature but melts at about 35 °C, so use agar for warm dishes.

Scaffold offered to students: Steps for a mean

To find a mean, add the trials and divide by how many you added. For 15 °C: $41 + 38 + 41 = 120$, and $120 \div 3 = 40$ minutes. If you leave out a trial, divide by the number of trials you kept. For the graph, put each temperature on the bottom axis and go straight up to the mean time; check your points by reading them back off the axes.

Extension: Is it the particles or the stickiness?

Warm water is also less 'sticky' than cold water: it flows more easily. Scientists say its viscosity is lower. Both faster particles and lower viscosity help dye spread faster in warm water. Design a test that could show whether temperature still matters when stickiness is held the same, for example by comparing water with a liquid that is thicker at the same temperature. Say what you would keep the same, what you would change, what you would measure, and what result would show that particle speed matters on its own.