

The Three-Cup Mystery: Rank the Temperatures by Watching Dye

Investigation question: Three cups of still water look identical, but each is at a different temperature. Can you rank them from coldest to warmest using only how fast a drop of dye spreads, and what does your ranking tell you about the particles in each cup?

Evidence-based mystery

Groups of 4

1 session

Setup 8 · Activity 37 · Cleanup 5 min

MS-PS1-4 · practice

MS-PS3-4 · supports

Scientific purpose

Groups receive three identical-looking cups of water labeled X, Y and Z at secret temperatures: cold, room and warm. Without touching them, they release one drop of food coloring into each at the same moment, score how far the color has spread at fixed times for twelve minutes, and graph the three spread curves. They must commit to a ranking, backed by evidence, before a thermometer reveals the truth. Pooled class data then link temperature to spreading, and the debrief turns the result into a particle explanation: in warmer water the particles move faster on average.

Why this helps students with this chapter

Students usually explain the warm cup with words like 'thinner' or 'the heat pushes the dye', which treat water as a smooth material. Ranking hidden temperatures from spreading alone makes them treat the dye as a sensor for something invisible, and the reveal rewards careful observation over guessing. Scoring at fixed times turns an impression into a graph, and comparing groups shows that the pattern holds even when individual cups differ by a few degrees. The lab gives the particle model its first piece of evidence: something in still water is always moving, and it moves faster when the water is warmer.

Standards connections

MS-PS1-4 (practice, the particle-motion link: a higher temperature means faster particle motion): Students use dye spreading as evidence that particles in still water are always moving and move faster on average when the water is warmer, one link in the PE's model of particle motion and temperature. No energy is added or removed to change a state, so the lab builds toward the PE rather than assessing it.

MS-PS3-4 (supports, only the idea that temperature measures the average kinetic energy of particles): This is a Grade 6 PE in the California integrated sequence. The lab relies on its core idea that a thermometer reading reflects the average motion of particles, but students do not plan the energy, mass and type-of-matter investigation the PE describes.

Roles (rotate each session)

- **Dropper captain:** Leads the '3, 2, 1, drop' countdown and, with two teammates, makes sure each cup gets exactly one drop from the same height at the same moment.

- **Timekeeper:** Runs the stopwatch, calls each check time aloud, and makes sure nobody touches the cups, the tray or the table during the run.
- **Scorer:** Compares each cup with the spread-score card at every check time and calls a score; the team agrees before it is written down.
- **Recorder and thermometer reader:** Writes every score, leads the sketch at the 2:00 check, and after the ranking is committed reads each cup's temperature at eye level.

Materials

Item	Quantity	Per	Note
Identical clear plastic cups, about 300 mL (10 oz), labeled X, Y and Z on masking tape	3	group	
Water at three temperatures, poured by the teacher: cold (about 5 to 10 °C), room (about 20 to 23 °C) and warm (about 40 to 45 °C)	200 mL in each cup	group	Never above 50 °C. Make the warm water by mixing hot tap water with cold and checking it with a thermometer.
Plastic transfer pipettes (droppers), each pre-filled by the teacher with blue food coloring from the same bottle	3	group	Dark blue or dark green shows up best.
Blue liquid food coloring	1 small bottle	class	
White paper: one sheet under the cups and one folded upright behind them as a backdrop	2 sheets	group	
Stopwatch or timer app	1	group	
Thermometer, digital probe or alcohol-filled (red liquid), reading at least –10 to 110 °C	1	group	Never a mercury thermometer.
Plastic tray to hold the cups, and paper towels	1 tray, a few towels	group	
Measuring cup or graduated cylinder, 250 mL, for the teacher's pouring	1	class	
Pitchers: one of refrigerator water, one of room-temperature water left out overnight, one insulated pitcher of warm water	1 of each	class	

Estimated cost: 10 to 15 per class (add about 20 if eight alcohol thermometers must be bought) (an estimate; A sleeve of 50 clear cups about \$5, a pack of 100 transfer pipettes about \$6 and a bottle of food coloring about \$3; cups and pipettes can be rinsed and reused. Thermometers, trays and pitchers are usually classroom stock; alcohol thermometers cost about \$2 to \$3 each. Estimated retail prices, not quotes.)

Safety

- The warm water is no hotter than 50 °C and is prepared and poured only by the teacher; students do not use hot-water taps, kettles or the warm pitcher.

- Use digital or alcohol-filled thermometers, never mercury. If a glass thermometer breaks, step back and tell the teacher; do not pick up the pieces.
- Spilled water is a slip hazard. Keep the cups on the tray and wipe up spills at once.
- Food coloring stains skin, clothing and paper. Roll up sleeves and keep recording sheets off the tray.
- Nothing in this lab is for drinking, not even the plain water.

Teacher preparation and setup

1. The day before, fill one pitcher with tap water and leave it out overnight so it reaches room temperature, and chill a second pitcher in a refrigerator.
2. Just before class, make the warm water by mixing hot tap water with cold until a thermometer reads 40 to 45 °C. Never use water above 50 °C; you pour it, not students.
3. For each group, decide which label (X, Y or Z) gets which temperature, and vary the order between groups so neighbors cannot copy. Write the assignments and the starting temperatures on a key card that you keep out of sight.
4. Pour 200 mL into each cup, set the three cups on white paper on a tray with a white backdrop, and place the tray at the group's table without saying which cup is which. Wipe any fogging off the cold cup.
5. Pre-fill three pipettes per group with food coloring, and practice releasing exactly one drop from about 1 cm above a water surface so you can demonstrate it.
6. Project or print the spread-score card (it is on the recording sheet) and agree with the class what 'most of the water' means before the run starts.

Investigation design

Independent variable	The temperature of the water in each cup (cold, room or warm), unknown to students until the reveal.
Dependent variable	The spread score of the dye at each check time, and the time until the color first looks even (score 4).
Controlled	The same cup type and 200 mL of water in every cup; One drop from the same bottle of food coloring, released from about 1 cm above the center; All three drops released at the same moment; No stirring, touching or bumping during the run; The same white backdrop and the same scoring card for every cup
Trials	One run per cup per group; the class pools results so each temperature has about eight runs.
Comparison	Spread scores of the three cups at the same check times, and the class's scores at 4:00 plotted against end temperature.

Student procedure

1. Read the spread-score card together. Before any dye goes in, write any clues you notice about the three cups in q1 (for example, fogging on the outside). Your final ranking must rest on the dye evidence, not on these clues.

2. From now until the thermometer step, do not touch the cups, the tray or the table. Wait one minute so the water stops swirling from being poured.
3. Three teammates each hold one pre-filled pipette straight up, about 1 cm above the center of one cup. On the dropper captain's '3, 2, 1, drop', each squeezes out exactly one drop. The timekeeper starts the stopwatch on 'drop'.
4. At 0:30, 1:00, 2:00, 3:00, 4:00, 6:00, 8:00, 10:00 and 12:00, the timekeeper calls the time and the scorer gives each cup a spread score from 0 to 4, looking from the side against the white backdrop. The team agrees on each score before the recorder writes it.
5. At the 2:00 check, every student sketches a side view of all three cups in the sketch box.
6. When a cup first reaches score 4, write that time in the summary table. If a cup has not reached 4 by 12:00, write 'more than 12 min'.
7. At 12:00, stop watching. As a team, rank the cups from coldest to warmest, write the ranking and your strongest evidence in q2, and show it to the teacher, who initials it. The ranking cannot change after this.
8. Reveal: the thermometer reader places the thermometer in each cup in turn, waits 30 seconds, and reads it at eye level. Record each end temperature. The teacher then reads the starting temperatures from the key card; record those too, and answer q3.
9. Plot all three cups on the spread-score graph, score against time, one line per cup, each labeled with its end temperature.
10. Add your group's results to the class table on the board (end temperature and score at 4:00 for each cup), copy the class table onto your sheet, and answer the analysis questions individually.

Expected observations

- Warm cup (about 40 to 45 °C at the start): the drop breaks into curling wisps within seconds; scores of 2 to 3 by 1:00 and usually 4 by about 2:00 to 4:00.
- Room cup (about 20 to 23 °C): the drop sinks as a thread and spreads along the bottom; scores of 1 to 2 at 2:00, about 3 by 4:00 to 6:00, and 4 by about 6:00 to 10:00.
- Cold cup (about 5 to 10 °C): the drop sinks to the bottom and sits as a dark patch; scores of 0 to 1 at 2:00, 1 to 2 at 4:00 and usually only 2 to 3 at 12:00.
- End temperatures drift toward room temperature during the run: the warm cup typically loses a few degrees and the cold cup gains a few.
- These are expected patterns, not measured results. The lab has not been physically tested, and real times depend on the dye brand, the drop size and the room.

Likely difficulties

- Pouring leaves the water swirling, and a drop released too soon is carried around in a spiral. Insist on the one-minute wait.
- Drops differ in size, especially when a pipette is squeezed hard. Practice once on a paper towel; if one drop is clearly larger, note it on the sheet.
- Scorers disagree between 2 and 3. Agree on a team rule before starting, for example that 'most' means more than three quarters of the cup.

- Fogging on the cold cup is common on humid days and gives away which cup is coldest. Wipe it during setup and remind students that clues cannot replace the dye evidence.
- Someone bumps the table and sends a ripple through all three cups. Record it, and if time allows rerun that cup with fresh water.

Structured debrief

1. Reveal the class pattern first: post the class table and ask each group whether its ranking held. Most will; where one did not, the cold and room cups are usually the pair confused, because both start slowly. Ask what scoring rule would separate them better (for example, scoring the top half and the bottom half of the cup separately).
2. Build the cause-and-effect chain on the board: higher temperature, faster particles on average, more frequent and harder bumps on the dye particles, faster spreading. Ask which links the data show directly (temperature and spreading) and which are the model's explanation (the two middle links).
3. Name what else moved the color: the dye sinking because it is a little denser than water, and gentle currents set up by temperature differences inside the cup. Propose the gelatin version as a cleaner test, and point out that a good explanation says how sure we are.
4. Close on the thermometer: it reported the average motion of the water's particles. Preview Lab 2, where students control the 'temperature' of a model directly by how hard they shake it.

Recording sheet: what students fill in

Lab 1 recording sheet: The three-cup mystery

Spread-score card. **0:** a tight blob or thread of color. **1:** color in less than a quarter of the water. **2:** color in about half of the water. **3:** color in most of the water, but streaky. **4:** evenly tinted, no streaks. Score each cup from the side, against the white backdrop.

1. Clues before the drop: write anything you notice about the three cups before any dye goes in.

Answer: Group-specific. Typical clues: the cold cup may fog or bead with water on the outside; otherwise the cups look identical.

Why: This box separates other clues from the evidence the claim must rest on. Fogging happens when water vapor in room air condenses on a cold surface; it is a fair observation, but not the evidence the lab asks for.

- Records at least one observation
- Keeps the observation separate from the ranking

Spread scores (0 to 4)

Time (mins)	Cup X	Cup Y	Cup Z
0:30			
1:00			
2:00			
3:00			
4:00			
6:00			
8:00			
10:00			
12:00			

 Sketch a side view of cups X, Y and Z at the 2:00 check. Shade where the color is, and label each cup.

Answer: Side views: the warmest cup mostly tinted, with wisps reaching the top; the room cup with a column or layer of color near the bottom and clear water above; the coldest cup with a dark patch on the bottom and clear water above.

Why: The 2:00 sketch captures the early difference before the warm cup turns uniform. Accept any sketch whose shading shows the order of spreading.

- Three cups drawn and labeled
- Shading shows the most spreading in the warmest cup
- Shows the color sinking toward the bottom in the slower cups

2. Before the reveal: our ranking from coldest to warmest is ___, ___, ___. Our strongest piece of evidence is: (Teacher initials: ___)

Answer: Group-specific. Expected: the cup with the slowest spreading ranked coldest and the fastest ranked warmest, for example 'Coldest Z, then X, then Y. Evidence: at 4:00, Y scored 4, X scored 2 and Z scored 1.'

Why: The claim must be committed before the reveal and must cite specific scores or times, not impressions.

- All three cups ranked
- Evidence uses at least one specific score or time comparison
- Written and initialed before the reveal

Summary

Cup	Time to first reach score 4	End temperature (°C)	Start temperature from the key card (°C)
X			
Y			
Z			

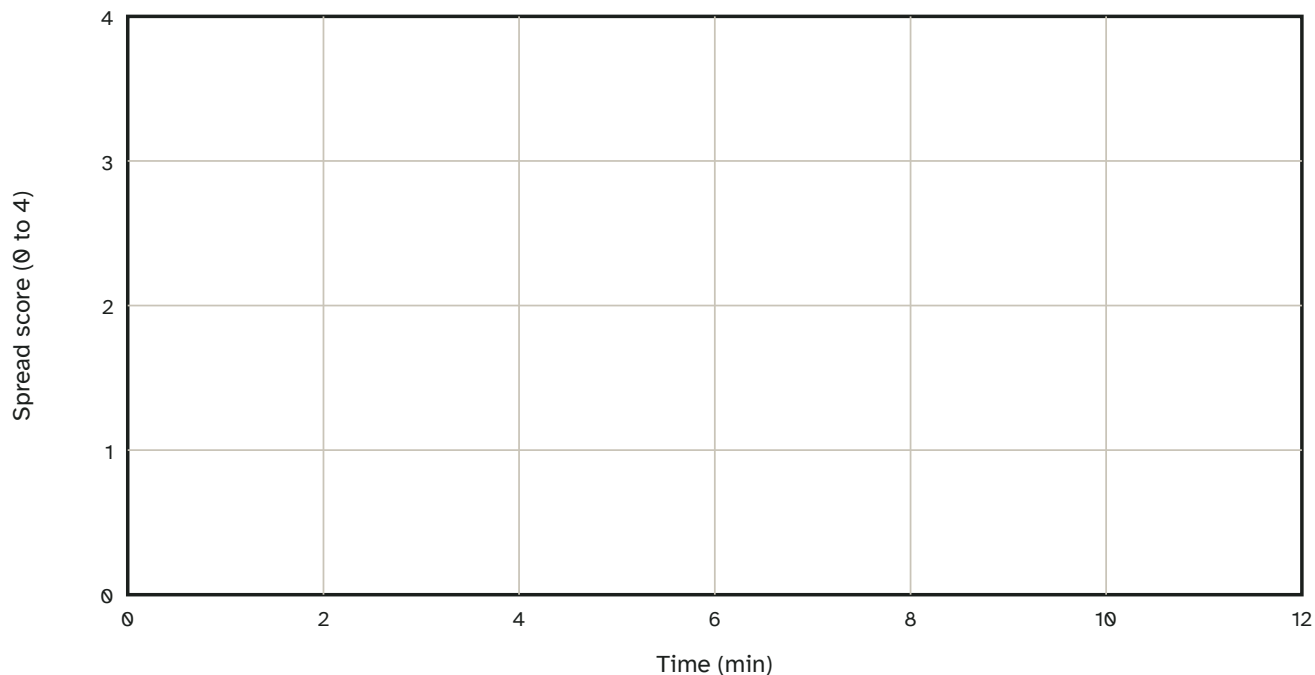
3. After the reveal: was your ranking correct? If not, what misled you?

Answer: Group-specific. Most groups will be correct. When a ranking is wrong, the usual mistake is swapping the cold and room cups, which both start slowly; a larger drop or a bump to the table can also mislead.

Why: Students should explain an error with evidence rather than calling it bad luck.

- States whether the ranking matched the thermometer
- If it did not, names a specific cause

Spread score against time



Class results

Group	Cold cup: end °C	Cold cup: score at 4:00	Room cup: end °C	Room cup: score at 4:00	Warm cup: end °C	Warm cup: score at 4:00
1						
2						
3						
4						
5						
6						
7						
8						

Analysis questions: answer key

4. Use your graph to describe how the three cups differed. Which cup changed fastest in the first two minutes, and which was slowest to become even?

Answer: Group-specific. Expected: the warm cup's line rises fastest, reaching 2 to 3 by 1:00 and 4 by about 2:00 to 4:00; the room cup rises more slowly and reaches 4 somewhere around 6:00 to 10:00; the cold cup stays lowest, usually only 2 to 3 by 12:00. The warm cup changed fastest early, and the cold cup was slowest to become even (or never did).

Why: Students should read the slopes and compare scores at the same times.

- Compares the three lines at named times
- Identifies the fastest and the slowest cup

5. Explain your ranking in terms of particles. What moves the dye when nobody stirs, and why does that happen faster in some cups than in others?

Answer: Water is made of particles that are always moving and bumping into one another. When a drop of dye goes in, the water particles keep knocking the dye particles into new places, so the color spreads without any stirring. In warmer water the particles move faster on average, so they hit the dye particles more often and harder and the color spreads sooner. In cold water the particles move more slowly on average, so the spreading is slower, but it does not stop.

Why: This is the target explanation: particle motion causes the spreading, and temperature measures the average motion.

Also acceptable: Accept 'kinetic energy' in place of motion. Accept answers that also mention currents, as long as particle motion is the main cause.

- States that particles are always moving
- Says the water's particles push the dye particles around
- Links higher temperature to faster average motion and faster spreading

6. A classmate says the cold water 'has no motion in it, so the dye can only sink'. Use your data to argue against this claim.

Answer: The cold cup's score did not stay at 0; it rose over the twelve minutes (for example, from 0 to 2), so the dye did spread through the cold water. Spreading without stirring needs moving particles, so the particles in cold water must be moving, just more slowly on average than in warm water.

Why: The data contradict 'no motion' directly. The best answers cite a specific change in the cold cup's score.

- Cites the cold cup's rising score
- Concludes that particles in cold water move, only more slowly

7. A fourth cup of water is at 30 °C. At the 4:00 check, where would its spread score most likely fall?

Answer: B. From the room cup's score up to the warm cup's score.

Why: 30 °C lies between room temperature (about 22 °C) and the warm cup (about 40 to 45 °C), so its particles' average motion, and its spreading, should fall between them. Because scores are whole numbers, it could tie one of them.

8. The spreading you watched was not caused by particle motion alone. Name one other thing that could move the color around in a cup, and describe how you could change the test so that particle motion is the only cause.

Answer: Other causes: the dye drop is a little denser than water, so it sinks and carries color downward, and temperature differences inside the cup (the warm cup cooling at its surface and sides) set up slow currents that stir the color. A test of particle motion alone: set plain gelatin in identical cups, push a toothpick dipped in dye into the center of each, keep one cup in a refrigerator and one at room temperature, and compare how far the color has spread after a day. Set gelatin has no currents, so only particle motion can move the dye.

Why: Students must separate the mechanism (diffusion by particle motion) from bulk flow. Any change that removes currents or the density difference earns credit. Gelatin melts at around body temperature, so a gelatin test compares cold with room temperature rather than with 45 °C.

Also acceptable: Keeping each cup in a water bath so its temperature stays even; placing a tiny drop at mid-depth with a syringe; mixing the dye with a little water so its density matches the water's.

- Names sinking, currents or the push of the drop as another cause
- Proposes a change that removes that cause
- Keeps a temperature comparison

9. Look at the class table. Did every group's warm cup have the same score at 4:00? Give two reasons groups could differ, and explain why pooling the class's data makes the conclusion stronger.

Answer: No; scores at 4:00 will usually differ by a point or so. Reasons: the warm cups started at slightly different temperatures and cooled at different rates; drop sizes differed; scorers judged 'most of the water' differently; a bump or a draft disturbed a cup. Pooling eight groups shows whether the pattern (warmer water, faster spreading) holds despite all of those differences. One group's run could be off by chance, but a pattern that appears in nearly every group is much more convincing.

Why: This is the logic of repeated trials and pooled data.

- Notes variation between groups
- Gives two plausible sources of variation
- Explains that results repeated across groups strengthen the conclusion

10. A bathtub of water is at 45 °C, the same as a warm cup. Which holds more thermal energy? Do the particles in the bathtub move faster than those in the cup? Explain both answers.

Answer: The bathtub holds far more thermal energy, because it contains far more moving particles. Its particles do not move faster: at the same temperature, the particles in the tub and in the cup have the same average motion.

Why: Temperature is an average per particle; thermal energy is a total for the whole sample. No calculation is needed.

- The bathtub has more thermal energy because it has more particles
- Same average particle motion because the temperatures are equal

Individual evidence of learning

Each student submits their own copy of the score table, the 2:00 sketch, the spread graph, the class table and answers to q1 through q10. The graph and q4 show data analysis; q5, q6 and q10 are the evidence that the student links temperature to the average motion of particles; q8 and q9 show that the student can judge the strength and limits of the evidence.

Assessment criteria

Criterion	Proficient looks like
Observation and recording	Scores recorded at every check time for all three cups, a sketch at 2:00, and a graph with one labeled line per cup.
Claim from evidence	Ranking written before the reveal and supported by a specific comparison of scores or times.
Particle explanation	Explains that particles in every cup are moving and that warmer water's particles move faster on average, so they bump the dye into new places more often (q5, q6).
Evaluating the evidence	Names sinking or currents as another cause of spreading and proposes a workable change such as a gelatin test (q8), and explains why pooled class data are more convincing (q9).
Temperature versus thermal energy	States that equal temperatures mean equal average particle motion while a larger sample holds more thermal energy (q10).

Accessibility adaptations

- Tape a picture strip of the five spread scores beside the cups so that scoring is done by matching rather than by reading descriptions.
- Use dark blue dye, large clear cups and a bright white backdrop for students with low vision; the scorer calls every score aloud.
- A student with limited fine-motor control can be the timekeeper or scorer while a partner handles the pipettes and the thermometer.
- Let students call observations aloud while a partner writes, and accept spoken or recorded answers to q5 and q8.
- Offer a sentence frame for q5: 'The dye spread faster in cup ___ because its particles ___.'

Low-cost alternative

If thermometers or pipettes are scarce, run the three cups as one teacher demonstration under a document camera, let groups score from the projection, and reveal the temperatures at the end. A toothpick or cotton swab dipped in food coloring and touched to the surface can replace the pipettes, as long as every cup gets the same method.

Model limitations

Dye spreading in a cup is not pure diffusion. The drop is slightly denser than water and sinks, and temperature differences inside the cup (a warm cup cooling at its surface and sides) set up gentle currents that carry color, more strongly in the warm cup. Faster particle motion is still the main reason warm water mixes sooner, but this test cannot separate it from currents; a gelatin version would. The spread score is a judgment, and the warm and cold cups drift toward room temperature during the run, so each cup's temperature is a range rather than one value. This lab has not been physically tested by the authors; times will vary with the dye brand, drop size and room temperature.

Teacher notes

Keep the key card out of sight until every group's ranking is initialed. Expect the cold and room cups to be the pair most often confused. The score at 4:00 is the most useful class number because every cup has one; plot the class's scores against end temperature on the board so W5 has a real class dataset to compare with its simulated one. If warm cups in your room reach score 4 before 2:00, add a 0:15 check. Remind students that 'spreading' is the observation and 'particle motion' is the explanation.