

Three Prototypes, One Winter: Reading Hand-Warmer Test Curves

Learning target: I can graph temperature-versus-time data from three hand-warmer prototypes, calculate peak rise, warming rate and time above a threshold, and decide which prototype meets the criteria and which characteristics to combine.

Data and graphing

About 45 min

Individual

MS-ETS1-3 · practice

MS-PS1-6 · practice

data analysis

independent practice

Standards connections

MS-ETS1-3 (practice): Students compare test data from three prototypes, name what each did best and worst, and propose a fourth design that combines the best characteristics. The set is small and the criteria are supplied, so this builds the practice that Lab 3 assesses with six prototypes and three users.

MS-PS1-6 (practice): The data are judged exactly by the PE's assessment boundary, amount of substance, time and temperature, and students must say what they would modify next. They analyze rather than build, so this is practice toward the design project in Lab 2 and W9.

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

Answers with reasoning

The club's criteria and constraints

Kind	Statement	How it is checked
Criterion 1	Peak temperature at least 42 °C	Highest reading in the table
Criterion 2	Stays at or above 38 °C for at least 3 hours	Time from the first reading at or above 38 °C to the last reading at or above 38 °C
Constraint A	Never above 50 °C (skin safety)	No reading above 50 °C
Constraint B	No more than 25 g of iron per pouch (cost)	Mass of iron used

Temperature of three prototypes over 5 hours (teaching dataset)

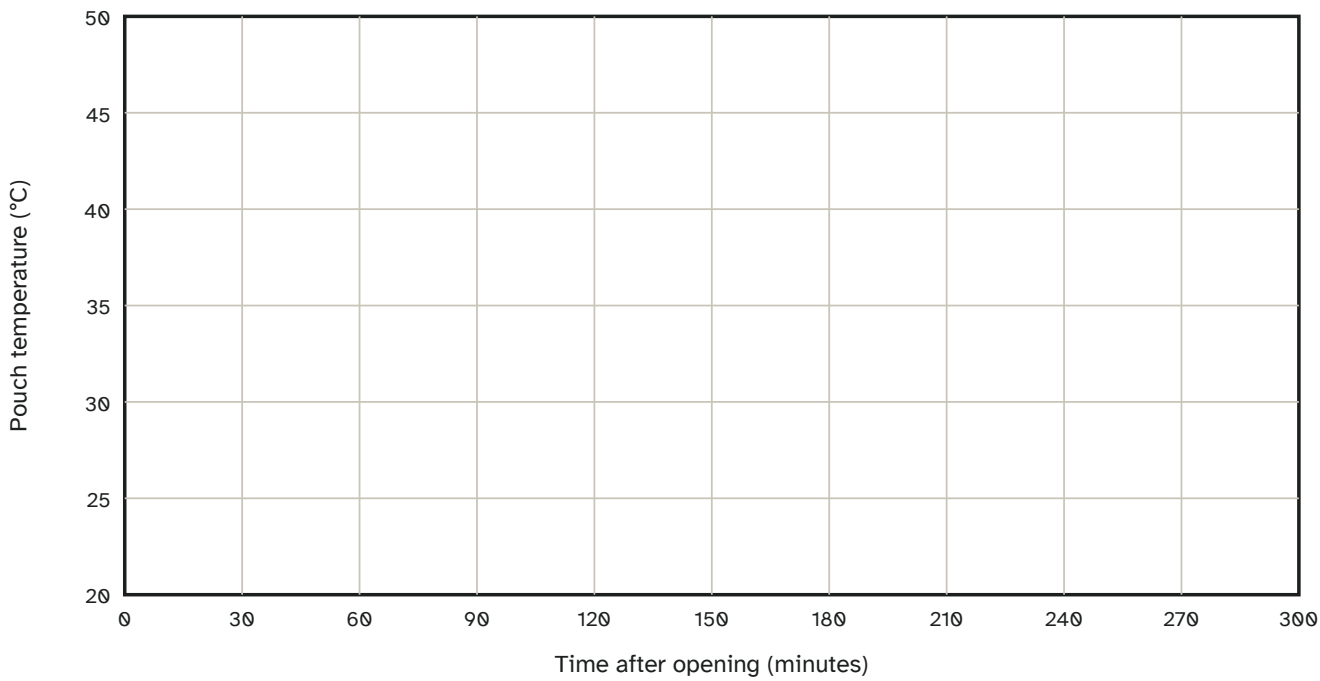
Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Time (min)	A: 10 g, thin pouch (°C)	B: 20 g, thin pouch (°C)	C: 20 g, thick pouch (°C)
0	22	22	22
30	41	44	33
60	43	49	39

Time (min)	A: 10 g, thin pouch (°C)	B: 20 g, thin pouch (°C)	C: 20 g, thick pouch (°C)
90	40	47	42
120	36	44	43
150	32	41	43
180	28	38	42
210	25	34	41
240	23	30	40
270	22	26	38
300	22	23	36

Simulated readings for a classroom scenario. Room temperature 22 °C throughout. Prototype A: 10 g iron, thin cloth pouch. Prototype B: 20 g iron, thin cloth pouch. Prototype C: 20 g iron, thick cloth pouch that lets air in slowly.

Pouch temperature versus time for prototypes A, B and C



Part A: Reading the curves

1. Complete the table from the dataset. The rise is the peak minus the 22 °C starting temperature; show one subtraction below the table.

Answer: A: peak 43 °C at 60 min; rise $43 - 22 = 21$ °C. B: peak 49 °C at 60 min; rise $49 - 22 = 27$ °C. C: peak 43 °C at 120 min (also 43 °C at 150 min; accept either); rise $43 - 22 = 21$ °C.

Why: Peaks are the maximum readings in each column; the rise is peak minus the 22 °C start.

Also acceptable: Accept 120-150 min for C's peak time, since the plateau holds 43 °C at both readings.

2. Calculate the average warming rate of prototype A and of prototype C during the first 30 minutes, in °C per minute. Round to the nearest hundredth. Which warmed faster, and by how many times?

Answer: A: $(41 - 22) \div 30 = 19 \div 30 = 0.63$ °C per minute. C: $(33 - 22) \div 30 = 11 \div 30 = 0.37$ °C per minute. A warmed faster, by $0.63 \div 0.37 \approx 1.7$ times.

Why: Rate is change in temperature over time. The thin pouch lets oxygen reach the iron faster, so the reaction runs faster at the start.

Also acceptable: Accept 'about 1.7 times' or 'almost twice as fast.'

3. Use your dashed 38 °C line and the table to estimate how long each prototype stayed at or above 38 °C. Convert minutes to hours.

Answer: A: first ≥ 38 °C at 30 min, last at 90 min; 60 min = 1.0 h. B: 30 min to 180 min; 150 min = 2.5 h. C: 60 min to 270 min; 210 min = 3.5 h.

Why: Using the readings only, the span is from the first reading at or above 38 °C to the last. (Interpolation in the extension lengthens A to about 1.25 h and B to about 2.5 h; the pass/fail results do not change.)

Also acceptable: Accept $A \approx 1.0$ -1.25 h and $B \approx 2.5$ h if the student interpolated between readings and shows the work.

Part B: Judging against the criteria

4. Write PASS or FAIL in every cell, using your answers above.

Answer: A: PASS (43 °C), FAIL (1.0 h), PASS, PASS (10 g). B: PASS (49 °C), FAIL (2.5 h), PASS (49 °C is not above 50), PASS (20 g). C: PASS (43 °C), PASS (3.5 h), PASS, PASS (20 g).

Why: Each cell follows from q1 and q3 and the masses in the dataset caption.

Also acceptable: If a student marks B as FAIL on Constraint A, ask them to reread the constraint ('never above 50 °C'); 49 °C is within it.

5. Which prototype meets every criterion and constraint? Which prototype came closest to breaking Constraint A, and what reading tells you?

Answer: Prototype C meets every criterion and constraint. Prototype B came closest to breaking Constraint A: its 49 °C reading at 60 min is only 1 °C below the 50 °C limit.

Why: C is the only all-PASS row; B's 49 °C peak is the nearest approach to the safety ceiling.

Also acceptable: None.

- Names C
- Names B with the 49 °C reading

6. Prototypes B and C hold the same 20 g of iron, yet B got hotter and C lasted longer. Explain both differences using the thickness of the pouch, the speed of the reaction, and the idea that the same amount of iron releases the same total energy to the surroundings.

Answer: The thin pouch of B lets oxygen reach the iron quickly, so the reaction runs fast and releases energy to the surroundings quickly; a fast release raises the temperature high (49 °C) but uses up the iron sooner, so B cools after about 3 hours. The thick pouch of C lets oxygen in slowly, so the same reaction runs slowly: the energy is released at a lower rate, giving a lower peak (43 °C) but spread over a longer time (above 38 °C for 3.5 h). Both hold 20 g of iron, so both release about the same total energy; the pouch only changes how fast it comes out.

Why: This is the chapter's temperature-versus-time distinction: the amount of iron sets the total energy released, the oxygen supply sets the rate, and rate sets the temperature while total sets the duration.

Also acceptable: Accept 'B burns through its iron faster' as a description of the rate.

- Thin pouch means faster oxygen supply and faster reaction
- Faster release gives higher temperature but shorter time
- Same iron means same total energy; only the rate differs

Part C: Combine the best characteristics

7. For each prototype, name its one best characteristic and its one worst result from the tests.

Answer: A: best, uses the least iron (10 g) and still warms quickly (0.63 °C/min, faster than C); worst, lasts only about 1 hour. B: best, highest peak (49 °C) and fastest warm-up (0.73 °C/min over the first 30 minutes); worst, time above 38 °C only 2.5 h and runs close to the 50 °C limit. C: best, longest time above 38 °C (3.5 h) with a steady plateau; worst, slow warm-up (only 33 °C at 30 min, not above 38 °C until 60 min).

Why: Each prototype has a strength tied to its design choice; naming both sides is what ETS1-3 asks for.

Also acceptable: Accept 'cheapest' for A's strength.

- One strength and one weakness for each prototype
- Each is backed by a number from the data

8. Propose a prototype D for the club that combines the best characteristics and stays inside both constraints. State the mass of iron and the pouch type, predict its peak temperature and its time at or above 38 °C, and justify both predictions with numbers from the dataset.

Answer: Sample: Prototype D: 25 g of iron (the maximum allowed) in a thick pouch, or 20 g in a medium-thickness pouch. Prediction for 25 g thick: peak about 45–46 °C (more iron than C raises the peak, as going from 10 g to 20 g in the thin pouch raised it from 43 to 49 °C; a thick pouch keeps it well below 50 °C) and time above 38 °C about 4 h or more (C lasted 3.5 h with 20 g; 25 g is 25 percent more iron, so more total energy released over a longer plateau). Prediction for 20 g medium pouch: peak about 46 °C and time above 38 °C about 3 h, between B's 2.5 h and C's 3.5 h, because a medium oxygen supply gives a rate between the two.

Why: A good proposal combines C's slow oxygen supply (the characteristic that produced the long plateau) with a modest increase in iron or air supply to lift the peak and warm-up, and keeps iron at or under 25 g and the peak under 50 °C. Predictions must be justified with trends from the dataset, not guessed.

Also acceptable: A proposal of 20 g in a thick pouch with a small vent to speed the first 30 minutes is a thoughtful answer; accept any design with reasoned predictions.

- States iron mass (≤ 25 g) and pouch type
- Predicts a peak below 50 °C and a time at or above 3 h
- Justifies both predictions with numbers or trends from A, B and C
- Explains which characteristic was taken from which prototype

9. The club can run only one more test. Explain why testing prototype D with the exact same procedure (same room, same reading times) matters for comparing it fairly with A, B and C.

Answer: If the room temperature, the reading times or the thermometer changed, a difference in D's results could come from the test conditions instead of from the design change. Keeping everything the same except the design means the only cause of a different curve is the prototype itself, so the comparison with A, B and C is fair.

Why: This is the controlled-comparison idea behind one-change-at-a-time testing.

Also acceptable: Accept 'so the only variable is the prototype.'

- Identifies that changed conditions would confuse the cause
- States that only the design should differ

Teacher notes

All numbers are simulated; the trends are realistic (commercial iron warmers typically peak between 40 and 55 °C and last several hours; a slower oxygen supply lowers the peak and lengthens the plateau). Expect the most errors in q3, where students sometimes count readings instead of measuring the span between them, and in q4 if they treat 49 °C as a violation of the 50 °C ceiling. The q6 explanation is the heart of the sheet and prepares the Lab 2 modification decision; press for 'same total energy, different rate' rather than 'B is just stronger.' The extension interpolation gives A crossing 38 °C at about 105 min (40 → 36 over 30 min is 4 °C per 30 min, so 2 °C takes 15 min) and B at exactly 180 min (its 180 min reading is 38 °C), then falling to 34 by 210.

Scaffold offered to students: Rate and time, one step at a time

A warming rate is a change in temperature divided by the time it took: (reading at 30 min – reading at 0 min) $\div$ 30 min, in °C per minute. Write the subtraction on one line and the division on the next. For time above 38 °C, run your finger down a prototype's column and circle every reading that is 38 or more; the time is from the first circled row to the last circled row. Divide minutes by 60 to get hours (for example, 150 min $\div$ 60 = 2.5 h).

Extension: Between the readings

Prototype A read 40 °C at 90 min and 36 °C at 120 min, so it crossed below 38 °C somewhere between those readings. Assuming the temperature fell at a steady rate between the two readings, calculate the minute at which A reached exactly 38 °C and revise its time above 38 °C. Then do the same for prototype B between 180 and 210 min. Write a sentence on how reading every 10 minutes instead of every 30 would change the certainty of the club's time measurements, and what it would cost in effort.