

Build a Better Pack: Design, Test and Improve a Hot or Cold Pack

Investigation question: Can your team build a pack that warms (or cools) by a set amount within two minutes and is still working at ten minutes, without crossing the safety, mass and cost limits, and what single change should each new prototype make?

Engineering design challenge

Groups of 4

2 sessions

Setup 8 · Activity 85 · Cleanup 10 min

MS-PS1-6 · assesses

MS-ETS1-4 · practice

MS-ETS1-1 · supports

Name _____

Group _____

Date _____

Your role today

- ☐ **Design lead:** Reads the brief aloud, runs the criteria-and-constraints discussion, makes sure the plan for each prototype names exactly one change and the data reason for it, and keeps the team to the ten-minute test schedule.
- ☐ **Safety captain and builder:** Checks goggles, measures the water, assembles the pack (bag in cup), adds the reagent packet on the timer's signal, and handles every reagent and used bag. The only person who touches chemicals; never picks up the bag by hand once the test has started.
- ☐ **Timer and reader:** Starts the stopwatch as the packet goes in, calls out each reading time, holds the probe in the middle of the liquid without touching the bag bottom, and reads the temperature aloud to 0.1 °C. Calls 'stop' if a reading reaches 48 °C.
- ☐ **Data recorder:** Writes every reading, computes the changes at two and ten minutes, fills in the scorecard and the cost line, and leads the team's decision about what to change next.

Safety

- Goggles on from the moment the first packet is opened until the last bag is in the trash. Calcium chloride and citric acid are eye irritants.
- Only the safety captain touches reagents, with dry hands. Calcium chloride pellets warm when wet and can irritate skin; if any touches skin, rinse under running water for a minute.
- The 50 °C ceiling is a real safety limit, not a game rule. The reader calls 'stop' at 48 °C; the team records that the prototype failed the constraint, leaves the pack in its cup on the tray to cool, and tells the teacher. If the reading keeps climbing past 50 °C, only the teacher moves or empties the pack. No one picks up a warm bag. Teams may touch the outside of the foam cup with one fingertip to feel the warmth; never the bag.
- No bag is ever fully sealed. Cold packs make carbon dioxide gas; a sealed bag can burst. The bag zip stays open at least 2 cm on every prototype, and the pack stands inside its cup on the tray at all times.
- Cold-pack foam can rise over the bag top; that is why the pack is in a cup on a tray. Wipe spills with a paper towel; the solutions are drain-safe in these amounts.

- Nothing is tasted or sniffed up close. No cup or bag is held near the face. Hands are washed at the end of each session.
- No flames, no hot plates, no microwaves. Insulation means paper, foil and foam only.
- Disposal: pour liquids down the sink with running water; bags, cups and sticks go in the trash. Unused packets go back to the teacher. This activity has not been physically tested by the authors; pilot the maximum hot pack and one cold pack before class.

Procedure

1. Session 1, read the brief. Put on goggles. The design lead reads your team's client brief (hot pack or cold pack) from the recording sheet. In the criteria-and-constraints table, rewrite each criterion and each constraint in your own words and write how your team will test it with the thermometer, the timer, the balance list or the price list.
2. Plan prototype 1. Choose the amount of reagent (hot: 1, 2 or 3 packets; cold: any combination of acid and soda packets up to 12 g), the volume of water (50, 75 or 100 mL; never less than 50 mL), and the insulation (none, one paper-towel wrap, a foil lid with a probe hole, or a second cup). Price the design using the price list and write the plan and the predicted temperature at two minutes in the prototype-plan table.
3. Build and test prototype 1. The safety captain measures the water into a fresh bag standing in a foam cup on the tray, adds any insulation, and the reader places the probe in the water through the open top. Read and record the starting temperature. On 'go', the captain tips in the reagent packet(s), stirs twice with a stick, and the timer starts. Record the temperature at 30, 60, 90 and 120 seconds, then at 3, 4, 5, 7 and 10 minutes. Note foam, fizzing, and whether pellets have disappeared.
4. Score prototype 1. Compute the change at two minutes and at ten minutes (reading minus start; a drop is negative). On the scorecard, mark each criterion met or not met with the number, check every constraint, and write the cost. If the reading ever reached 48 °C, the prototype fails the temperature constraint no matter what else it did.
5. Decide the one change. Using the scorecard, choose the single feature to change for prototype 2 and write the data reason (for example: 'reached only +6 °C at two minutes, criterion is +10, so we add one packet'). Everything else stays the same. Rinse the probe; the captain puts the used bag in the trash and the cup on the tray to dry.
6. Session 2, build and test prototype 2 exactly as in step 3, with the one change. Score it. Then plan prototype 3 with one more single change, informed by prototype 2's data, and build, test and score it the same way.
7. Plot all three prototypes on one temperature-versus-time graph with a different symbol for each, label the start temperature and draw a horizontal line at each criterion level (start plus or minus the required change) so the graph shows at a glance when each prototype was inside the target.
8. Choose the best design. In the justification box, name the prototype that met the most criteria within every constraint, give the numbers, explain what each change did, and state the one change you would make for a prototype 4 and what data tells you to expect from it.
9. Draw your final pack as a system-and-surroundings diagram and complete the analysis questions individually. Clean up: liquids to the sink with running water, bags and sticks to the trash, unused packets

Record your observations

Your team is a small design company. A camping-gear client wants a single-use pack that works with a squeeze: no plug, no flame, no freezer. You will build three prototypes, test each one the same way, and change exactly one feature between prototypes. Your final report must show the data behind every decision.

Client brief B: cooling pack (citric acid and baking soda) — Criteria (goals): C1, the water drops at least 8 °C below its starting temperature within 2 minutes. C2, the water is still at least 4 °C below its starting temperature at 10 minutes. **Constraints (limits):** K1, no more than 12 g of reagent in total, in any mix of citric acid and baking soda packets. K2, at least 50 mL of water. K3, the bag is vented (zip open at least 2 cm) because the reaction makes carbon dioxide gas; it stays in its cup on the tray. K4, foam that leaves the bag counts as a failed test. K5, total cost on the price list is \$1.50 or less.

Criteria and constraints in our own words (one row per item in the brief)

[illegible]

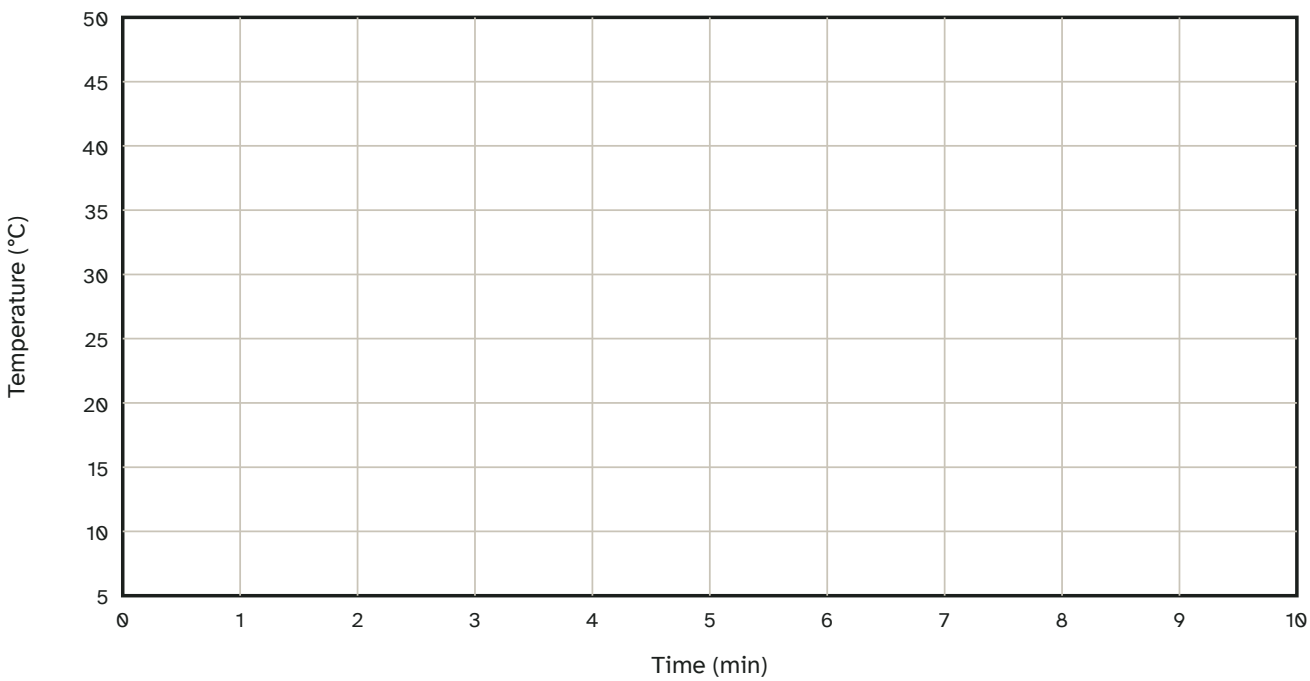
Prototype plans (change exactly one feature between prototypes)

Prototype	Reagent packets used (and grams)	Water (mL)	Insulation	The ONE change from the previous prototype	Data reason for the change	Predicted change at 2 min (°C)	Cost (\$)
1				first design			
2							
3							

Temperature readings (°C) for each prototype

Time	Prototype 1	Prototype 2	Prototype 3	Notes (foam, pellets gone, stop called)
0 s (start, before reagent)				
30 s				
60 s				
90 s				
120 s (2 min)				
3 min				
4 min				
5 min				
7 min				
10 min				
Change at 2 min (2 min minus start)				
Change at 10 min (10 min minus start)				

Temperature of the water over ten minutes for all three prototypes (draw the start



Scorecard: criteria met and constraints kept

Prototype	C1 met? (write the number)	C2 met? (write the number)	Any constraint broken? (which one)	Peak or lowest temperature (°C)	Cost (\$)	Overall: success, partial or fail
1						
2						
3						

1. Our pack type: _____. Best prototype: number _____. Its change at 2 min: _____ °C (criterion _____ °C). Its change at 10 min: _____ °C (criterion _____ °C). Its cost: \$_____ (limit \$1.50).
- _____
- _____

2. Justification for the client: which prototype do you recommend, what did each of your two changes do to the data, and what single change would you make for a prototype 4? Use numbers from your scorecard.

-  Draw your best prototype as a system-and-surroundings diagram: a dashed boundary around the reagent and what it becomes, the water, bag, cup, air and probe labeled as surroundings, and an arrow showing which way energy crossed the boundary. Label the diagram exothermic or endothermic and write the energy word equation underneath.



Analysis questions

3. A hot-pack team recorded these changes at 2 minutes: prototype 1, 3 g in 50 mL, +9.0 °C; prototype 2, 6 g in 50 mL, +17.0 °C; prototype 3, 6 g in 100 mL, +8.0 °C. Calculate the temperature rise per gram of calcium chloride for each prototype. Then explain, using energy and the amount of water, why doubling the water in prototype 3 roughly halved the rise.

4. Using the words system, surroundings and energy, explain why the water in a hot pack warms and why the water in a cold pack cools. Your answer must say where the energy came from or went to; it must not say energy was made or used up.

5. Look at your three prototypes. Which feature had the biggest effect on the change at 2 minutes, and which had the biggest effect on the change at 10 minutes? Quote the numbers that show it. If you changed the same feature twice, say what you would have needed to test to answer the second part.

6. A teammate on a hot-pack team says, 'Hotter is better, so let's aim for 55 °C.' Explain which item in the brief this breaks, why that item is a constraint rather than a criterion, and what a real pack company would risk by ignoring it.

7. Suppose a prototype meets C1 (the two-minute criterion) but fails C2 (the ten-minute criterion). Name two different changes that could help it last longer. For each, say what it costs on the price list and what it might do to the two-minute result. Choose one and give your reasoning.

8. The hand-warmer engineers in the lesson found that more iron raised the peak temperature while a thicker pouch stretched the working time but lowered the peak. Compare their design loop with yours: name one feature in your lab that behaved like 'more iron' and one that behaved like 'thicker pouch', and explain why a prototype that failed a criterion was still useful to both teams.

9. Your tests measured water in a cup on a tray. A real pack is held against skin. Name two ways the cup test differs from the real use, say for each whether it would make the real pack seem to work better or worse than your data suggests, and explain which part of the real surroundings your thermometer never measured.
