

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

Scientific purpose

Each team receives a client brief for either a warming pack (calcium chloride dissolving in water) or a cooling pack (citric acid reacting with baking soda in water), with criteria for temperature at two minutes and at ten minutes and constraints on maximum temperature, amount of reagent, venting and cost. Teams build a first prototype from teacher-measured packets, record its temperature every 30 seconds and then every minute for ten minutes, score it against the criteria and constraints, change exactly one feature (amount of reagent, volume of water, acid-to-soda ratio, or insulation), and test again, for three prototypes in all. The final product is a data-backed justification of the best design and of the one change they would make next.

Why this helps students with this chapter

Students who have only read about the hand-warmer engineers tend to think a design either works or does not. Building a pack that reaches the two-minute target but fades by ten minutes, or that lasts but never gets warm enough, shows that criteria can pull against each other and that a prototype which fails is still a source of data. Having only one feature to change per loop forces the question the lesson keeps asking: what caused the difference? Measuring the water, not the hand, keeps the evidence on the thermometer and keeps the energy language honest: the reagents release energy to the water or absorb it from the water; nothing is created.

Standards connections

MS-PS1-6 (assesses, the whole PE: construct, test and modify a device that releases or absorbs thermal energy by chemical processes): Students build a real device from safe reagents, test it by amount of substance, time and temperature (the PE's assessment boundary), and modify it twice on the basis of their own data. The clarification statement names dissolving calcium chloride as a qualifying chemical process, and the citric acid reaction is a genuine chemical reaction, so both pack types produce evidence for the PE.

MS-ETS1-4 (practice, iterative testing and modification using data from a working prototype): The prototype pack is the model that generates temperature-versus-time data, and each new prototype is modified from that data. The criteria and the test procedure are supplied by the brief rather than developed by students, so this builds toward the PE rather than fully assessing it.

MS-ETS1-1 (supports, distinguishing criteria from constraints): Students restate the brief's criteria and constraints in their own words and write how each will be tested, which supports the PE without asking them

to define a problem from scratch.

Roles (rotate each session)

- **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.

Materials

Item	Quantity	Per	Note
Snack-size zip bags (about 16 by 8 cm)	4	group	One per prototype plus a spare. The bag is the pack body; it stands inside a foam cup and is never fully sealed.
Foam cups, 12 to 16 oz	4	group	One holds each prototype; extra cups are an insulation option teams can buy from the price list.
Digital thermometer or temperature probe reading to 0.1°C	1	group	A kitchen instant-read thermometer works. Rinse and dry between prototypes.
Stopwatch or phone timer	1	group	
Graduated cylinder or measuring cup marked at 25 mL steps	1	group	
Room-temperature tap water in a pitcher	about 400 mL	group	Set out the day before so every prototype starts near the same temperature.
Hot-pack packets: calcium chloride pellets (ice-melt or pickling grade), teacher-measured 3 g each	up to 9 packets	group	Hot-pack teams only. A prototype may use 1, 2 or 3 packets (3, 6 or 9 g). Keep sealed until used; the pellets pull water from the air.
Cold-pack packets: citric acid, teacher-measured 2 g each, and baking soda, teacher-measured 2 g each, in separate labeled packets	up to 9 of each	group	Cold-pack teams only. A prototype may use any mix up to 12 g total; packets of the two reagents are different colors so the ratio is easy to track.

Insulation options: paper towels, aluminum foil squares (for a lid with a probe hole), second foam cups	a small supply	class	Priced on the teaching price list so insulation costs budget.
Wooden stirring sticks	3	group	
Plastic tray or baking sheet	1	group	Every prototype is tested on the tray; it catches foam from cold packs and any spill.
Safety goggles	1 pair	student	
Kitchen or lab balance (0.1 g) for the teacher's packet preparation	1	class	
Recording sheet and graph paper	1 set	student	
Paper towels and a waste bucket	1 set	class	

Estimated cost: 15 to 30 per class of 8 groups, excluding thermometers (an estimate; Estimate. If Lab 1 supplies are on hand, the extra cost is mostly zip bags (about \$3 for 50), foam cups (about \$5 for 50) and foil. Bought fresh: a 10 lb bag of calcium chloride ice melt about \$15, a 1 lb jar of citric acid about \$8, baking soda about \$2. Each group uses at most 27 g of calcium chloride or 36 g of the two cold-pack reagents across three prototypes. Digital thermometers run \$8 to \$12 each if the room has none.)

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.

Teacher preparation and setup

1. Weigh packets the day before on a 0.1 g balance: 3 g calcium chloride per packet (nine per hot-pack group), 2 g citric acid and 2 g baking soda per packet (nine of each per cold-pack group). Fold each in a

- small square of paper or a labeled mini cup; use two colors of paper for the two cold-pack reagents.
2. Pilot the hottest possible hot pack with your actual product: 9 g of your calcium chloride in 50 mL of room-temperature water in a bag inside two nested foam cups with a foil lid (more insulation than any team can buy within the budget, so this is the worst case). Record the peak. If it reaches 48 °C or more, reduce the largest packet count to two (6 g) for the whole class and tell the hot-pack teams the constraint is 6 g. Hydrated or lower-purity ice melt usually peaks well under 45 °C; anhydrous pellets can go higher. Use pellets rather than flakes: flakes are the hydrated form and release less than half as much energy per gram, which can put the +10 °C criterion out of reach.
 3. Pilot one cold pack at 6 g citric acid plus 6 g baking soda in 50 mL water to see how much foam your bag produces; if it overflows the bag top, tell teams to leave the bag zip fully open and to use the tray.
 4. Decide which teams build hot packs and which build cold packs (half and half works), or let teams choose with a cap on each type. Print the recording sheet, which carries both briefs and the price list.
 5. Write the reading schedule on the board: 0, 30, 60, 90, 120 s, then 3, 4, 5, 7 and 10 minutes. Set the pitchers of water out the night before.
 6. Plan the two sessions: session 1 is the brief, criteria and constraints in the team's words, prototype 1 built and tested, and the first change decided; session 2 is prototypes 2 and 3, the scorecard and the justification.

Investigation design

Independent variable	One design feature changed per prototype: amount of reagent, volume of water, acid-to-soda ratio (cold packs only), or insulation
Dependent variable	Temperature of the water over ten minutes; the change at two minutes and at ten minutes; the peak (or lowest) temperature; whether the 48 °C stop was triggered
Controlled	Same starting water temperature (room-temperature pitcher) for every prototype; Same bag type, same cup, same tray position and same probe depth; Same reading schedule and the same two stirs at the start; Reagent amounts set by teacher-measured packets, so the only change between prototypes is the one the team planned
Trials	One test per prototype, three prototypes per team; the class pools the scorecards by pack type so that each feature change appears in several teams' data.
Comparison	Each prototype is compared with the one before it (one feature different) and with the criteria lines on the graph; hot-pack and cold-pack teams compare which features controlled the two-minute change and which controlled the ten-minute change.

Student 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 back to the teacher, hands washed.

Expected observations

- Hot packs: 3 g in 50 mL typically rises 7 to 10 °C by 2 minutes and peaks by about 2 minutes; 6 g rises about 14 to 20 °C; 9 g in 50 mL can rise 20 to 30 °C with anhydrous pellets and is the design most likely to trigger the 48 °C stop. In a single foam cup the water loses about 3 to 6 °C of its rise by 10 minutes; a foil lid or second cup keeps roughly 2 °C more.
- Cold packs: 3 g acid plus 3 g soda in 50 mL drops about 3 to 6 °C with most of the drop in the first minute; 6 g plus 6 g in 50 mL drops about 7 to 11 °C with strong foam that can climb the bag; by 10 minutes the water has usually recovered 2 to 4 °C toward room temperature.
- Doubling the water with the same reagent roughly halves the change at 2 minutes and makes the 10-minute change a larger fraction of the 2-minute change, because more water stores more thermal energy for the same loss to the room.

- Teams that change ratio alone on a cold pack see smaller effects than teams that change total mass; a mix far from about 1 g citric acid to 1.3 g baking soda leaves one reagent unreacted and cools less per gram.
- Insulation changes the 10-minute number by a few degrees and the 2-minute number hardly at all, which is the cleanest evidence in the lab that time and temperature are separate criteria.

Likely difficulties

- Teams want to change two things at once after a bad prototype 1. Hold them to one change; the design lead's plan table requires the single change and its data reason before packets are handed out.
- The probe touches the bag bottom or sits in foam; coach the reader to hold it mid-liquid and under the foam, and to keep the same depth for all three prototypes.
- Hot-pack teams go straight to 9 g in 50 mL and trigger the stop; treat it as data (the constraint was broken) and expect the next prototype to add water or remove a packet. If your pilot showed 9 g is too hot for your product, cap packets at two before the lab starts.
- Cold-pack foam leaves the bag with 12 g in 50 mL; the tray catches it, the test counts as failed on K4, and the team learns that more water or less reagent is the fix.
- The negative sign on cold-pack changes and the 'start plus or minus' criterion lines on the graph confuse some students; model one example on the board before session 2.
- Teams forget to price insulation; the cost column on the plan table is checked by the design lead before building.

Structured debrief

1. Pool the scorecards on the board by pack type: for each prototype, the feature changed and the changes at 2 and 10 minutes. Ask the class to find the pattern: amount of reagent moves the two-minute number most; water volume and insulation move the ten-minute number most; cold-pack ratio changes matter less than total mass unless a team went far from about 1 g of citric acid to 1.3 g of baking soda.
2. Ask every team for one prototype that failed and what that failure told them. Land the point from the lesson: the engineers' first pouch reached only 28 °C and that number is what sent them to double the iron. A failed test with good data is a successful experiment.
3. Return to energy language. Hot packs: the calcium chloride separated into ions and water surrounded them, and the net result released energy to the water (the surroundings), so the water's particles sped up. Cold packs: breaking apart the citric acid and baking soda cost more energy than forming the new bonds in sodium citrate, carbon dioxide and water paid back, so the system absorbed energy from the water, which cooled. Nobody made or destroyed energy; it moved across the boundary.
4. Ask what the 48 °C stop rule models: a constraint from the world (skin burns), not from the client's wishes. Criteria are targets; constraints are walls. Any team that hit the stop should explain what they would change, and the usual answer (more water, fewer packets) shows that the same features control temperature in both directions.
5. Preview Lab 3: the class will now sit on the other side of the table and judge six finished hand-warmer prototypes from test data, for three customers with different criteria, and combine the best features into a new design.

Recording sheet: what students fill in

Lab 2 recording sheet: Build a better pack

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 A: warming pack (calcium chloride) — Criteria (goals): C1, the water is at least 10 °C above its starting temperature within 2 minutes. C2, the water is still at least 6 °C above its starting temperature at 10 minutes. **Constraints (limits):** K1, the reading never reaches 48 °C (the pack must stay under 50 °C; a stop at 48 °C fails this constraint). K2, no more than 9 g of calcium chloride (three packets). K3, at least 50 mL of water. K4, the bag is never fully sealed and stays in its cup on the tray. K5, total cost on the price list is \$1.50 or less.

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.

Teaching price list (invented prices for budgeting practice, not store prices) — Calcium chloride packet (3 g): \$0.40. Citric acid packet (2 g): \$0.20. Baking soda packet (2 g): \$0.08. Zip bag: \$0.10. Foam cup (first one): \$0.10. Second foam cup (insulation): \$0.10. Paper-towel wrap: \$0.05 each. Foil lid with probe hole: \$0.05. Water: free. Add up every item in a prototype; the total must be \$1.50 or less.

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

[illegible]

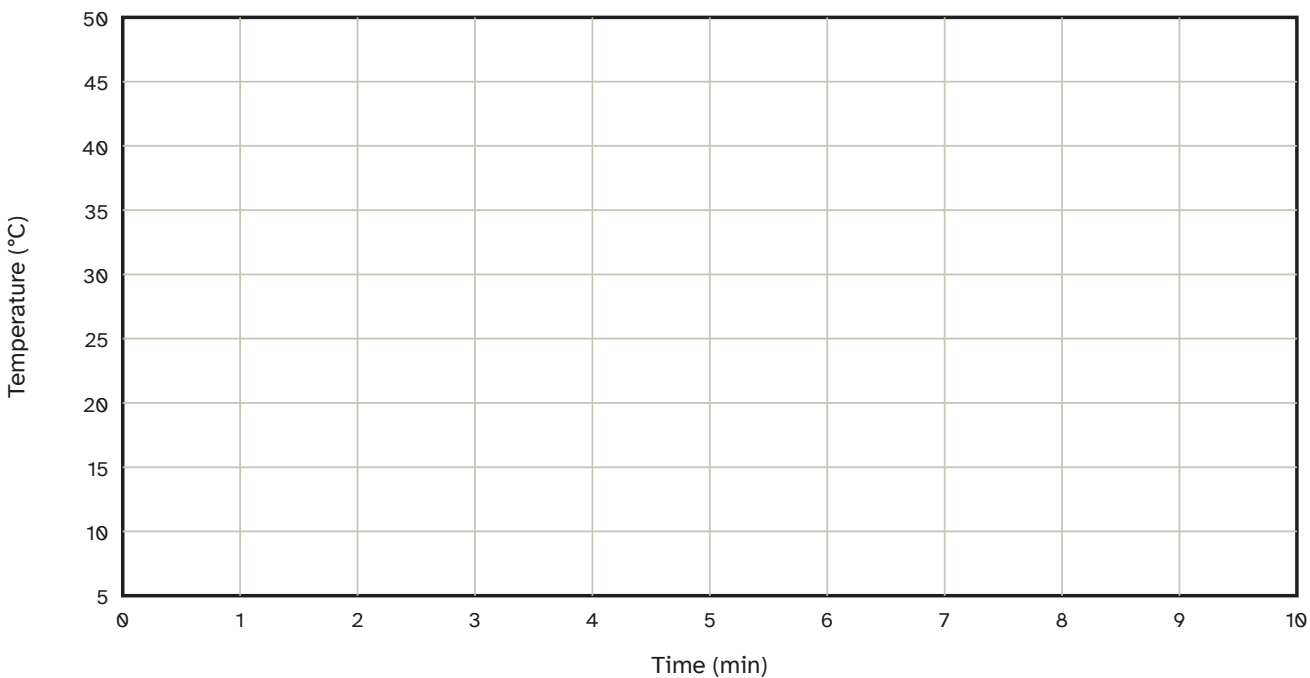
Prototype plans (change exactly one feature between prototypes)

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).

Answer: Team-specific. Check that the numbers copied match the data table and scorecard, that the criterion values are the brief's (hot: +10 at 2 min, +6 at 10 min; cold: −8 at 2 min, −4 at 10 min), and that the cost is at or under \$1.50.

Why: A quick consistency check between the fill-in line and the tables catches copying errors before grading q2.

Also acceptable: Any internally consistent set of values from the team's own data.

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.

Answer: Team-specific. A full-credit justification names the recommended prototype, quotes its 2-minute and 10-minute changes against the criteria, confirms every constraint including cost, states what each of the two changes did to the numbers (for example 'adding a packet raised the 2-minute change from +7 to +13 °C; the foil lid raised the 10-minute change from +4 to +7 °C'), and proposes one further change tied to the criterion still missed or to lowering cost.

Why: This is the core MS-PS1-6 evidence: a device constructed, tested and modified, with the modifications justified by amount, time and temperature data.

- Recommends the prototype that best meets the criteria within every constraint
- Quotes the 2-minute and 10-minute numbers against the criteria
- States the measured effect of each single change
- Proposes one next change with a data reason

-  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.

Answer: Hot pack: dashed boundary around the calcium chloride and the calcium and chloride ions it becomes; water, bag, cup, air and probe labeled outside; arrow from inside to outside; labeled exothermic; equation 'calcium chloride → calcium ions + chloride ions + energy'. Cold pack: boundary around the citric acid and baking soda and their products (sodium citrate, carbon dioxide, water); same surroundings; arrow from outside to inside; labeled endothermic; equation 'citric acid + baking soda + energy → sodium citrate + carbon dioxide + water'.

Why: The arrow direction and the side of the energy term must agree with the measured temperature direction. Accept the pack's water drawn inside the boundary if the student explains it is where the ions spread; the key point is that the thermometer measured the surroundings.

- Boundary encloses the reagent and what it becomes
- Energy arrow out for the hot pack, in for the cold pack
- Energy word on the product side (hot) or reactant side (cold)

Analysis questions: answer key

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.

Answer: Prototype 1: $9.0\text{ °C} \div 3\text{ g} = 3.0\text{ °C per g}$. Prototype 2: $17.0\text{ °C} \div 6\text{ g} \approx 2.8\text{ °C per g}$. Prototype 3: $8.0\text{ °C} \div 6\text{ g} \approx 1.3\text{ °C per g}$. The 6 g released about the same amount of energy in prototypes 2 and 3, but in prototype 3 that energy was shared among twice as much water, so each gram of water received about half as much and its temperature rose about half as far (8 °C instead of 17 °C). The slightly lower per-gram value in prototype 2 than in prototype 1 is expected: a hotter cup loses energy to the air faster.

Why: Division with units, then the energy-sharing argument: same energy released, more matter to warm, smaller temperature change. Accept 2.83 and 1.33; accept 'half' as approximate since 8 is a little less than 8.5. Also acceptable: Accept an answer that reasons from thermal energy and temperature (temperature depends on energy per amount of matter) without the phrase 'per gram of water'.

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.

Answer: Hot pack: the system is the calcium chloride and the ions it becomes. As the solid separates into ions and water molecules surround them, more energy is released than absorbed, so the net flow of energy is out of the system into the surroundings, the water, whose particles speed up and whose temperature rises. Cold pack: the system is the citric acid and baking soda and the products they form. Breaking apart the reactants costs more energy than forming the new bonds in sodium citrate, carbon dioxide and water pays back, so the system absorbs energy from the surroundings, the water, whose particles slow down and whose temperature falls. In both cases energy moved across the boundary; none was made or used up.

Why: Both halves must name the system, the surroundings and the direction, and the answer must be free of 'creates heat' or 'uses up energy'. Qualitative only; no bond energies.

- Names the system and the water as surroundings for both packs
- Hot pack: net energy released to the water; cold pack: net energy absorbed from the water
- No statement that energy was created, 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.

Answer: Team-specific. Typical finding: the amount of reagent had the largest effect at 2 minutes (for example, 3 g to 6 g moved the change from +8 to +16 °C), while water volume or insulation had the largest effect at 10 minutes (for example, a foil lid kept the water 3 °C warmer at 10 minutes but changed the 2-minute reading by less than 1 °C). A team that changed the same feature twice should say they would need a prototype that changed water or insulation to find out what controls the 10-minute result.

Why: The question checks that students can read cause and effect from one-change comparisons and recognize when their design did not test a factor.

- Names a feature for each criterion with the numbers that show its effect
- Compares prototypes that differ by one feature only
- If applicable, identifies the untested factor

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.

Answer: It breaks K1, the rule that the reading never reaches 48 °C so the pack stays under 50 °C. K1 is a constraint because it is a limit the design must not cross, not a target to aim for; crossing it does not make the pack 'better', it makes it unsafe. A company that ignored it would sell packs that could burn skin, with injuries, recalls and lost trust as the cost.

Why: Criteria are goals; constraints are walls. The question also checks that students see constraints as coming from the world (skin burns), not from the client's taste.

- Identifies the temperature constraint
- Explains limit versus goal
- Names a real consequence for people

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.

Answer: Options include: add a foil lid or a second cup (costs \$0.05 or \$0.10; slows energy loss to the room so the 10-minute change stays larger; barely affects the 2-minute change); increase the water (free; more water stores more thermal energy so it cools or warms back toward room temperature more slowly, but the same reagent spread over more water gives a smaller 2-minute change and may break C1); add reagent (costs \$0.40 per calcium chloride packet, or \$0.20 per citric acid and \$0.08 per baking soda packet; raises both numbers but risks the 48 °C stop, the 12 g cap or the budget). A good choice names the trade-off: for example, the foil lid, because it helps C2 without hurting C1 and costs only \$0.05.

Why: Students must see that time and temperature are separate criteria with separate levers, and that every lever has a cost on the price list or a risk to another criterion.

- Two distinct changes that plausibly lengthen working time
- Cost from the price list and the effect on the 2-minute result for each
- A choice with a stated trade-off

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.

Answer: 'More iron' is like adding a reagent packet: it raised the peak or the 2-minute change. 'Thicker pouch' is like adding water or insulation: it stretched the working time but, for water, lowered the 2-minute change, just as the felt pouch lowered the engineers' peak. A failed prototype was useful because it produced a number: the engineers' 28 °C told them how far short they were and which feature to change; our prototype that reached only +6 °C told us to add a packet rather than change the water. Without the failure there is no data to decide the next change.

Why: Connects the lab's single-change loop to the lesson's engineering narrative and to the idea that iteration depends on test data.

- Maps one lab feature to iron amount and one to pouch material
- Explains that a failed prototype supplies the data for the next change
- Uses an example number from the lab or the lesson

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.

Answer: Differences include: the cup loses energy to still room air, while a hand keeps taking energy from a hot pack (so a real hot pack would seem to fade faster) or keeps supplying energy to a cold pack (so a real cold pack would warm back faster); the cup holds 50 to 100 mL of water with the reagent spread through it, while a real pack holds its reagent and water in a thin pouch pressed against skin, so the skin feels the change sooner; the cup is open so cold-pack gas and foam escape freely, which a sealed commercial pack cannot allow. The thermometer measured the water, which is the nearest surroundings, but never the hand, which is the part of the surroundings the client actually cares about.

Why: Model limitations: the student should name the hand as surroundings the test ignored and reason about the direction of the error for at least two differences.

- Two differences between the cup test and real use
- For each, says whether the real pack would do better or worse
- Identifies the hand (skin) as the unmeasured surroundings

Individual evidence of learning

Each student submits their own criteria-and-constraints table, prototype-plan table, data table, graph with criterion lines, scorecard, the q2 justification, the system-and-surroundings drawing and individual answers to q3 through q9. The plan table (one change with a data reason) together with the scorecard and q2 is the evidence for MS-PS1-6; q4 and the drawing are the evidence for the energy-flow targets.

Assessment criteria

Criterion	Proficient looks like
Criteria and constraints understood	Every item in the brief is restated correctly, sorted as criterion or constraint, and paired with a test the team can actually perform.
Iterative testing with single changes	Three prototypes tested with the same procedure; prototypes 2 and 3 each change exactly one feature, with a written data reason drawn from the previous scorecard.
Data quality and scoring	All ten readings per prototype recorded to 0.1 °C, changes at 2 and 10 minutes computed with the correct sign, every criterion scored with a number and every constraint checked, including cost.
Justified recommendation	The recommended design is the one that best meets the criteria within all constraints, the justification cites numbers for what each change did, and the proposed prototype 4 change follows from the data.
Energy explanation	The drawing and q4 place the reagent inside the boundary, the water outside, draw the energy arrow in the correct direction, and describe energy as transferred to or from the surroundings, never created or used up.

Accessibility adaptations

- Assign the data recorder or design lead role to students who should not handle reagents; one pair of hands on the chemicals is the rule for everyone.
- Provide a large-display or talking thermometer and allow readings to be called to a partner; provide the data table with the time column pre-printed and the sign rule written at the top.
- Offer a graph with axes pre-scaled and the start line drawn, and a decision frame for the plan table: 'Prototype ___ reached ___ °C; the criterion is ___ °C; so we will change ___ because ___.'
- Accept q2 as a recorded one-minute pitch to the client and q4 as a labeled diagram with captions; provide a bilingual card for criterion, constraint, prototype, system, surroundings, release and absorb.
- Students with chemical sensitivities or a respiratory condition can sit away from cold-pack foam, complete the scoring and justification from the team's data, or do W9, the paper version of the same design task.

Low-cost alternative

Run one hot-pack line and one cold-pack line as teacher demonstrations under a document camera, with the class voting on the single change for each new prototype and recording the readings. If calcium chloride is unavailable, Epsom salt (magnesium sulfate) that the teacher has dried in a kitchen oven warms water noticeably as it dissolves, because drying removes most of the water built into its crystals (undried Epsom salt cools water slightly instead); if citric acid is unavailable, 30 mL of vinegar in place of the water with 3 g of baking soda cools by a few degrees. Foam cups can be replaced by paper cups inside a second cup.

Model limitations

A bag of water in a foam cup is a stand-in for a pack against skin: the cup loses energy to the room air, while a real pack trades energy with a hand that keeps supplying or taking energy, so working times and peaks in a real pack differ from the lab's. The hot pack uses dissolving, which is an exothermic process rather than a chemical reaction in the strict sense (no new substance forms), while the cold pack is a genuine reaction; the state standard's clarification statement accepts both for the design task. Amounts are capped for safety, so the packs are weaker than commercial ones. The expected temperature changes are estimates from the reagents' known behavior; this activity has not been physically tested by the authors, and the teacher's pilot of the 9 g hot pack is required before class.

Teacher notes

Check the criteria-and-constraints table and the prototype-1 plan before handing out any packets; the lab's evidence for MS-PS1-6 lives in the plan table's single change with a data reason and in the scorecard. The chemically matched cold-pack recipe is about 1 g of citric acid to 1.3 g of baking soda; teams that go far from that ratio will find that total mass matters more than ratio, which is a legitimate finding. If a hot-pack team triggers the 48 °C stop, record it as a constraint failure, cool the pack on the tray and let the team continue with a safer plan; the pilot of 9 g in 50 mL with your actual product decides whether three packets are allowed at all. Keep the pooled scorecards; Lab 3 asks students to apply the same amount-time-temperature logic to six finished hand-warmer prototypes.