Quick start · Choose, Test and Improve a Thermal Protector

Target: evaluate all criteria and constraints, justify a tradeoff, propose a design and test, then revise against new evidence. Intended for middle school. Prerequisites: table headings, °C, time, temperature change, comparable trials and claim scope; teach the prerequisite bridge when needed. Materials: paper and pencil; optional calculator, projection, pointing, oral responses or labeled responses.

Print and sequence

Print Teach the Design Challenge (PDF) (Prerequisite bridge/Teacher model/Guided practice/Initial independent record/New independent evidence); hand out Initial independent record before New independent evidence. Model Teacher model, guide Guided practice, collect the independent response independently, reveal fictional prototypes, then revise. Quick Check repeats Initial independent record/New independent evidence; use it only before exposure. The full packet preview is not a class handout that preserves the new-evidence sequence.

Other print choices: Use a Quick Check; Reteach: Meet Every Requirement; Reteach: Improve the Design and the Test; Use a Later Check. In the classroom ZIP, these are in Print choices. Match each activity title and question number to the corresponding teacher key.

Notice → next supplied task

Missing a constraint or the rule for all trials → Meet Every Requirement, then the “What if None Qualifies?” follow-up check. Unsupported improvement or a confounded feature claim → Improve the Design and the Test, then the “Whole Design or One Feature?” follow-up check. Unclear writing → clarify aloud first. After Independent task, use still unseen Later check, not Quick Check. Record response mode, support and actual exposure; do not assign a score or mastery label.

Planning estimates: preparation 12–18 min; full route 55–70 min or two sessions (break after guided practice); reteach 12–18 min; later check 10–15 min. No apparatus is required. Cool-water investigation is separate; paper analysis does not demonstrate physical construction or testing. Constructed data labels travel with every table.

Teach the bridge

Say: “A criterion tells us what performance must do; constraints tell us what resources and size we may use. I check each separately. A prediction says what might happen in a future test; supplied results concern a specified completed fictional record.”

Supplied design record

Constructed teaching data: these values were invented for this activity, not collected in an experiment.

Design	Tokens	Added mm	Trial 1 final °C	Trial 2 final °C	Trial 3 final °C
H	3	12	16	16	16

Requirements and predictions, question 1 · Criterion: final ≤16°C in every 15-minute trial; constraints ≤4 tokens and ≤15 mm. H: 16/16/16°C, 3 tokens, 12 mm; all pass nominally, at the temperature boundary.

Requirements and predictions, question 2 · It warms 6°C; it neither cools nor stops transfer. Sealing a gap is an untested prediction. Compare fresh matched samples with unchanged H, using the same mass, start, room, time, cups, lids and procedure, with repeated trials. A fair comparison of whole designs is enough for the complete modified design; it does not uniquely isolate a mechanism.

Trace 10→16°C on a number line if the direction is unclear. Ask which conditions must match; if the learner can only name a winner, ask for a check of all requirements. If the learner needs more measurement practice, use the Read Temperature Data Before Explaining It measurement reteach; the prerequisite bridge itself provides the necessary bridge now. Respond in connected prose, orally while pointing to data, or with a labeled representation. Clarify the question, table access, vocabulary and response mode before choosing a reteach. Sparse language can express adequate reasoning.

Think aloud and constraint checks

Worked example (student p. 2): 100 g water starts at 10°C in a 22°C room; 20 minutes; fresh matched trials and passive conditions as stated in the model. Each requirement is checked separately.

Completed constraint-check table

Teacher calculations from constructed teaching data, not experimental measurements.

Design	Every trial ≤15.5°C	Tokens ≤8	Added ≤20 mm	Feasible?
A	15 / 15.5 / 15: PASS	5: PASS	18 mm: PASS	Yes
B	14 / 14.5 / 14: PASS	8: PASS	20 mm: PASS	Yes
C	13.5 / 14 / 13.5: PASS	9: FAIL	18 mm: PASS	No
D	14.5 / 15 / 14.5: PASS	6: PASS	24 mm: FAIL	No

Say: “First, temperatures: all must be at most 15.5°C, not just one or the mean. Next, tokens: at most 8; then added thickness: at most 20 mm. A: pass/pass/pass; B: pass/pass/pass; C: pass/fail/pass; D: pass/pass/fail. I retain the raw records for C and D but do not call them feasible. A conserves resources; B has lower recorded warming. The brief does not declare one priority, so I explain mine.”

Check the complete brief, question 1 · A and B are feasible. A has temperatures of 15/15.5/15°C, uses 5 tokens and adds 18 mm; B has 14/14.5/14°C, uses 8 tokens and adds 20 mm. C violates the token limit: 9>8 tokens; D violates the thickness limit: 24>20 mm. All temperature changes are positive: A 5/5.5/5°C, B 4/4.5/4°C, C 3.5/4/3.5°C, D 4.5/5/4.5°C.

Check the complete brief, question 2 · A has a defensible priority: conserve 3 tokens and 2 mm while satisfying the supplied brief. B has a defensible priority: smaller warming in all three pairs, with final readings 1°C below A, using the full budget and size allowance. Both choices are accepted; neither is universally best. At a displayed boundary, accuracy and limited trials are relevant; numerical headroom is not a reliability probability.

Limits: the room is warmer than the water, so net transfer is inward; cold is not escaping. Both A and B warm; neither cools nor stops transfer. Compare whole constructions; do not infer material properties or a specific pathway. Threshold headroom describes numbers, not accuracy or robustness. No real material or product performance is established.

Prompts and teaching moves

Supplied design record

Constructed teaching data: these values were invented for this activity, not collected in an experiment.

Design	Tokens	Added mm	Trial 1 final °C	Trial 2 final °C	Trial 3 final °C
E	4	12	16	16.5	16
F	6	18	15	15.5	15
G	5	15	16	17.5	16

Ask: “Which exact trial could rule out an otherwise promising design?” Anticipated response: G passes on its mean. Move: point to “EVERY” and 17.5°C. Ask: “What do we give up choosing F? When would E be reasonable?” Anticipated response: the lowest temperature is automatically best. Move: compare 2 tokens and 6 mm with the 1°C difference, and require a priority.

A decision needs a priority, question 1 · E and F are feasible. G fails: 17.5>17°C in trial 2, even though its mean of 16.5°C is under 17°C. Checking an average cannot replace the criterion for every trial.

A decision needs a priority, question 2 · E saves 2 tokens and 6 mm; F ends 1°C below E in every pair (e.g., 16 vs 15°C and 16.5 vs 15.5°C). Either priority is justified. The room at 24°C is warmer than the water at 12°C, so net thermal energy transfers toward the water. Less warming of matched mass is consistent with less net energy entering over the interval, without proving a unique pathway.

Say: “The room is warmer; the thermal energy account explains warming. The table supports recorded performance, not unique proof of conduction.” Accept oral or labeled answers; do not demand a fixed paragraph. Avoid requiring means.

Independent and redesign keys

Collect Initial independent record before New independent evidence. The teacher does not model Independent task. The New independent evidence record concerns specified fictional prototypes only. Quick Check reuses the exact independent task; it is not fresh after the lesson.

Independent challenge · Record a proposal first, question 1 · J and K are feasible. L fails: 17>16.5°C in trial 2; N exceeds the token limit: 6>5 tokens. J uses 3 tokens and adds 14 mm versus K at 5 tokens and 19 mm; K endpoints are 1/0.5/1.5°C below J. Both choices are accepted with a stated priority and bounded claim. Changes: J 5/5/5.5°C; K 4/4.5/4°C; L 4/6/4°C; N 3/3.5/3°C.

Independent challenge · Record a proposal first, question 2 · Accept a specified seam, wrap or geometry change satisfying ≤5 tokens and ≤19 mm, with a reason and prediction. Actual success remains unknown. Test the modified design against the unchanged choice, using fresh 80 g samples starting at 11°C in a 23°C room for 16 min, with matched cups, lids, exposure and readout; use ≥3 paired fresh trials for instructional comparison, not a statistical guarantee. Retain raw starts, endpoints, room temperatures, times and departures from the procedure. Any repeated larger warming or criterion miss would challenge success; close values may remain uncertain.

Independent challenge · Separate redesign evidence, question 1 · J-sealed misses the criterion: 17>16.5°C in trial 3. It is not a feasible improvement, even though trials 1 and 2 are equal to or lower than J. K-thin passes all requirements: 15.5/16/16°C, 5 tokens, 17 mm. It reduces thickness by 2 mm but warms more than K by 0.5/0.5/1°C. Accept K-thin for smaller size and a nominal pass, original K for lower recorded warming, or J for saving resources. There is no universal or reliable superiority or attribution to a unique pathway. The redesign record is separately constructed, not an empirical test of the student proposal.

Independent challenge · Separate redesign evidence, question 2 · Keep an explicit hypothesis with scope, or revise a choice using the tradeoff. An actual matched repeated test with known construction, accuracy and conditions is needed to claim real performance; room, duration and mass variations require new tests. Unsupported conclusions include: always succeeds, stops transfer, proves the exact mechanism, or guarantees the student proposal.

The independent task can elicit feasibility, tradeoff, a proposal, reassessment and a bounded explanation; it cannot establish mastery, real construction or testing, or actual design performance. Accept different modifications with correct constraints and a matched test; do not grade against one preferred prototype.

Meet every requirement: practice and follow-up check

Supplied design record

Constructed teaching data: these values were invented for this activity, not collected in an experiment.

Design	Tokens	Added mm	Trial 1 final °C	Trial 2 final °C	Trial 3 final °C
P	7	14	13	13.5	13
Q	5	21	14	14	14.5
R	4	18	14	16	14
S	5	18	14.5	15	14.5

Intervention: make three columns: performance / tokens / thickness. Say: “I keep the attractive number but it cannot erase another requirement. I check every trial before deciding.” The learner checks P, then R; model S without inventing a margin.

Meet every requirement, question 1 · Only S is feasible. P exceeds the budget: 7>5 tokens, despite having the lowest readings. Q exceeds the thickness limit: 21>18 mm. R has trial 2=16>15°C; its mean of 14.67°C is irrelevant to the rule for all trials. S has 14.5/15/14.5°C, 5 tokens and 18 mm, so it passes nominally.

Meet every requirement, question 2 · Recommend S for these records: 20 min, 100 g, a 10°C start and a 22°C room. Trial 2 is exactly 15°C: a 0°C displayed margin. Accuracy and future variability are unknown; seek a matched repeat with a characterized instrument and procedure, and potentially a modified design, retaining raw readings. Margin alone is no reliability estimate.

Save the “What if None Qualifies?” follow-up check until practice ends. It changes the budget and has an empty feasible set; the complete key follows.

Follow-up check · What if none qualifies?, question 1 · None is feasible. U exceeds the budget: 5>4 tokens; V exceeds the thickness limit: 19>18 mm; W has trial 2=16>15°C. Propose a change within the existing limits and then test it, or explicitly request a revised brief. Do not silently relax limits, average away failure or fabricate results.

If the learner insists on a winner, ask whether any row passes all three checks. If arithmetic is right but language is unclear, ask for an explanation through pointing or speech. The “What if None Qualifies?” task gives a new check only if students have not seen it.

Improve the design and the test: practice and follow-up check

Supplied design record

Constructed teaching data: these values were invented for this activity, not collected in an experiment.

Setup	Water g	Start °C	After 15 min °C
Old whole design	100	10	16
New whole design	200	12	15

Say: “The new water has a different mass and start. I can calculate changes, but that does not remove confounds. I need a comparison matched to my question. A comparison of whole designs may vary multiple construction features; a claim about the seam alone cannot.”

A proposal needs a relevant test, question 1 · Old: +6°C; new: +3°C. Describe these complete setups only. Water masses of 100 vs 200 g and starts of 10 vs 12°C differ: neither the lower endpoint nor the smaller change isolates a sleeve improvement.

A proposal needs a relevant test, question 2 · Match water mass, start, room, time, cups, lids, exposure and readout across fresh paired repeats; compare the unchanged old design with the new design. For seam causation, hold layer count and other construction features fixed while varying the seam. Keep raw readings; mark missing readings and record documented departures from the procedure. Repeat a compromised trial without erasing it.

Follow-up check · Whole design or one feature?, question 1 · The new whole design shows 2°C less warming than the old design in each pair: old changes 6/5/6°C, new changes 4/3/4°C. This supports a cautious preference for the new whole design under these conditions. Both seam and layers changed, so a claim that the seam alone caused the difference is unsupported. An additional paired comparison with layer count fixed and only the seam varied, with repeats and accuracy checks, supports the narrower question. Performance is not guaranteed.

Have the learner draw matched old and new setups with labels for mass, start, time and room temperature. Save the “Whole Design or One Feature?” follow-up check until practice ends. It matches test conditions but varies the seam and layers: an accepted conclusion about the whole design must not be confused with isolated feature causation. Unexpected raw readings remain visible.

Transfer and revision

Later check · Changed requirements, question 1 · Originally, X and Y both pass nominally. Under a 4-token budget, only X is feasible at 22°C; Y exceeds the budget: 6>4 tokens. Scope: 100 g, a 10°C start, 20 min, a 22°C room and the supplied construction; no guarantee elsewhere.

Later check · One new environment record, question 1 · X has 17/17.5/17°C, all three >15°C: it does not pass at 28°C. Keep the 22°C conclusion and narrow any generalization. The room changed from 22→28°C; there is no Y record at 28°C, so X cannot be ranked against Y there. X warms 7/7.5/7°C in the new record.

Later check · One new environment record, question 2 · Accept a specified prototype within 4 tokens and 18 mm with a rationale, or a matched X/Y test at 28°C (Y is still over budget but can inform design features). Check matched mass, start, time and procedure, known accuracy, and fresh trials. Close or variable values may prevent a confident preference; they do not prove equivalence. An unmet brief is a valid outcome; do not promise improvement.

Give Initial later-check record, then Later check · Changed requirements, question 1. A response may retain earlier bounded feasibility while concluding that the new record fails the performance criterion. There are no data for Y in the warmer room, so there is no ranking there. A coherent answer elicits revision under changed resources and environment; it does not establish mastery or equivalent forms. A redesign hypothesis need not be successful.

Science and specific standards

Temperature is not total energy; type, state and amount matter. Doubling Celsius does not double energy. In these passive covered-water cases, net thermal energy transfers from the warmer room toward the cooler water. Less warming of matched mass over a matched interval is consistent with less net energy entering the water; endpoints do not give instantaneous rates or identify conduction, convection and radiation separately.

Official NGSS MS-PS3-3 supports transfer direction and the distinction between temperature and energy; prerequisite bridge, guided practice and independent task invoke selected concepts and design ideas, but paper analysis does not complete designing, constructing and testing a device. MS-ETS1-3 informs systematic criteria and constraints and the analysis of design data (matching student pages); paper proposals do not demonstrate an empirical combination of features. MS-ETS1-4 informs proposed iterative model and test thinking (matching student pages), not completed physical tests or generation of model data.

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The tasks use paper and pencil. For practical equipment work, follow the separate cool-water investigation guidance and ordinary school procedures.

Fictional teaching response — sound for the named task

Named task: Independent challenge, question 1: check every design requirement before selecting

Fictional response — sound for the named task: “J and K meet every requirement: J uses 3 tokens/14 mm and its endpoints are 16, 16 and 16.5°C; K uses 5 tokens/19 mm and ends at 15, 15.5 and 15°C. L fails the every-trial temperature requirement at 17°C; N fails the five-token cap at six. I choose K to prioritize less reported warming across all three trials, accepting its larger token/thickness use. This is a priority within the specified conditions, not a universal best design.”

Visible evidence: Every stated constraint checked, all trials retained, and a defensible priority between the two feasible options for question 1.

Not established: Question 2’s modification, prediction and matched test, or a response to the later redesign record.

Clarify: Ask why J remains a defensible choice when minimizing resources is the stated priority.

Next teaching/evidence: Complete and retain the specific modification/test proposal in question 2 before revealing the separate redesign-evidence file. Reserve the later changed-requirements task.

This response is invented for teacher interpretation. Accept defensible alternatives. Record access, prior exposure and the actual response; do not assign an ability label or claim mastery from this example.

Independent challenge: proposal first

Independent challenge: new redesign evidence

Reserve: Later assessment: changed requirements

Fictional teaching response — partially developed

Named task: Independent challenge, question 1: check every design requirement before selecting

Fictional response — partially developed: “I choose K because its temperatures are lowest among the feasible choices.”

Visible evidence: A defensible choice and relevant performance priority if the feasibility claim can be supported.

Not established: The actual checks establishing feasibility or why L and N fail.

Clarify: Ask for the tokens, thickness and every-trial endpoints for each design. Do not infer the missing checks were or were not performed.

Next teaching/evidence: If the every-requirement check remains unclear, use Reteach: meet every requirement, then Fresh requirements recheck. Keep both new-evidence and later files for their intended stages.

This response is invented for teacher interpretation. Accept defensible alternatives. Record access, prior exposure and the actual response; do not assign an ability label or claim mastery from this example.

Reteach: meet every requirement

Fresh requirements recheck

Reserve: Later assessment: changed requirements

Fictional teaching response — plausible error

Named task: Independent challenge, question 1: check every design requirement before selecting

Fictional response — plausible error: “L meets the temperature requirement because its average is about 15.67°C, below 16.5°C.”

Visible evidence: A correctly calculated approximate mean from 15, 17 and 15°C.

Not established: The required EVERY-trial condition: the 17°C trial fails even though the mean is below the threshold.

Clarify: Have the learner point to EVERY, check each row separately and keep the failing trial visible.

Next teaching/evidence: Use Reteach: meet every requirement, followed by the separate Fresh requirements recheck. Do not average away a failed requirement or reveal redesign data before a proposal is retained.

This response is invented for teacher interpretation. Accept defensible alternatives. Record access, prior exposure and the actual response; do not assign an ability label or claim mastery from this example.

Reteach: meet every requirement

Fresh requirements recheck

Reserve: Later assessment: changed requirements