

Listening Past the Highway: Choose a Shield for the Frog Recorders

Learning target: I can turn vague goals into precise criteria and constraints, evaluate competing designs against them with test data, choose and justify a design, and explain how accurate monitoring lets scientists test a prediction about how two species interact.

Transfer and design

About 55 min

Pairs

MS-ETS1-2 · practice

MS-ETS1-1 · practice

MS-LS2-2 · assesses

engineering design

data analysis

writing

Standards connections

MS-ETS1-2 (practice, the systematic evaluation of four shield designs against stated criteria and constraints): Students check four designs against four criteria and four constraints in a decision matrix, eliminate designs that break a constraint, and justify a choice with test data. The criteria, pass marks and the subtraction for each cell are supplied and only one design survives the checks, so this practices the systematic evaluation the PE describes rather than assessing it; Lab 3, where teams evaluate their own designs, is the fuller version.

MS-ETS1-1 (practice, rewriting vague goals as measurable criteria and constraints, including impacts on wildlife and people): Students sharpen a team's vague goals into measurable criteria and constraints and add one that protects people or the natural environment, using the scientific facts about sound that limit possible solutions. The team's final list is then supplied, so this is practice toward the PE rather than a full assessment of it.

MS-LS2-2 (assesses, the prediction half: an explanation that predicts an interaction pattern in a pond ecosystem from patterns seen in other ecosystems): In Part C students predict what corrected frog counts should show at ponds with, without and after removal of an introduced predator and competitor, and justify the prediction with the same pattern in at least one other ecosystem. That is an explanation that predicts patterns of interaction across ecosystems, applied to a system the chapter does not teach.

Purpose: extend · **Time:** about 55 minutes · **Format:** pairs

Answers with reasoning

The problem

Cedar Flat is a group of five small ponds in the California foothills, each 50 to 150 meters from a four-lane highway. Biologists monitor the ponds' Sierran treefrogs, small native frogs often called chorus frogs, with sound recorders. Each recorder sits on a short post at the pond's edge and switches on every night from January to April, the calling season. Software counts the frog calls in each recording, which tells the team roughly how many males are calling at each pond. The trouble is the highway. Truck and tire noise covers up many of the calls, so the software misses them. Two years ago, American bullfrogs were found in two of the ponds. Bullfrogs are large frogs, not native to California, that eat almost any animal that fits in their mouths,

including treefrogs, and they also eat the same insects the treefrogs eat. The team needs accurate counts to find out whether the bullfrogs are pushing the treefrogs down.

Sound facts that limit the possible solutions — Sound spreads out from its source in all directions and bends around the edges of obstacles, so a shield works best when it blocks the straight line between the highway and the recorder and has no gaps. Heavy, solid, airtight materials such as wood, packed straw or dense board are best at blocking sound, including low-pitched rumble. Soft, porous materials such as foam, felt or blankets soak up sound, especially high-pitched sound, but let more of the low rumble through. The shield cannot surround the recorder completely, because the frog calls come from the pond side. Sound levels are measured in decibels (dB): each drop of about 3 dB cuts the sound energy roughly in half, and a drop of about 10 dB sounds roughly half as loud to a listener.

Part A: Make the goals precise

At its first meeting, the team wrote four goals on the whiteboard: **'Make it quieter.'** **'Don't mess up the frog sound.'** **'Keep it cheap and easy to carry.'** **'It can't hurt anything.'** Goals like these are a start, but nobody can test them, because they do not say how much, measured how, or compared with what.

1. Decide whether each goal is a criterion (what the design must do to succeed) or a constraint (a limit on what designs are allowed), then rewrite it so it can be tested.

Answer: 'Make it quieter': criterion; for example, 'Highway noise at the recorder is at least 8 dB lower than with no shield, measured with the same traffic recording played from the highway side.' 'Don't mess up the frog sound': criterion; for example, 'Frog calls played from the pond side are no more than 2 dB quieter than with no shield, and the software still detects at least 70 of 100 test calls.' 'Keep it cheap and easy to carry': constraint; for example, 'Costs no more than \$100 and weighs no more than 15 kg, so one person can carry and set it up in under 30 minutes.' 'It can't hurt anything': constraint; for example, 'No netting or loose mesh that can trap animals, nothing placed in the water or on the pond-edge plants, and no treated wood or paint that could leach into the pond.'

Why: Criteria describe what success looks like; constraints limit which designs are allowed. A precise version names a quantity, a unit and a test, so two people testing the same shield would agree on the result.

Also acceptable: Accept different numbers if they are measurable and sensible (for example, a 6 dB or 10 dB noise target). Accept 'easy to carry' as a criterion if the student explains it as a requirement for the field team; the key distinction is whether the rewrite is testable.

- First two labeled criteria and last two labeled constraints
- Each rewrite contains a measurable quantity with a unit or a clear yes/no test
- The 'can't hurt anything' rewrite names a specific harm to wildlife or the habitat

The team's final list — Criteria. C1: highway noise at the recorder at least 8 dB lower than with no shield (tested with a recorded traffic sound played from the highway side). C2: frog calls played from the pond side no more than 2 dB quieter than with no shield. C3: the software detects at least 70 of 100 test frog calls played from the pond side during evening traffic. C4: after a 30-minute sprinkler 'rain test', the highway noise at the recorder rises by no more than 2 dB. **Constraints.** K1: no more than \$100 per shield, and \$500 for all five ponds. K2: no more than 15 kg, so one person can carry it along the pond trail. K3: no plastic netting or loose mesh, which can trap snakes, frogs and birds. K4: everything stays within 1 m of the recorder post on the dry, highway side, leaving the water and the pond-edge plants untouched.

- Compare your four rewrites with the team's final list. Name one place where one version is more precise than the other, and explain why that matters for testing. Then add one more constraint the team missed that protects people or wildlife, and give the reason for it.

Answer: Example comparison: the team's C1 says how the noise will be measured (the same traffic recording from the highway side); a rewrite that only says 'at least 8 dB quieter' could be tested at different times of day with different traffic and give different answers. Example added constraints: the recorder must not capture hikers' conversations clearly enough to identify people (privacy, an impact on people); materials must not shed foam crumbs or fibers into the pond, where tadpoles could swallow them; the shield must not shade the pond edge and change water temperature; it must be removable at the end of the season and leave no trace; it must not give raccoons or other predators a hiding place right at the frogs' calling site.

Why: MS-ETS1-1 asks for criteria precise enough to ensure success and for constraints that include impacts on people and the natural environment.

Also acceptable: If the student's version was more precise than the team's (for example, also fixing the time of day for the test), accept that comparison.

- A specific comparison of precision between the student's version and the team's
- Why the difference matters for testing
- One added constraint protecting people or wildlife with a reason

Part B: Evaluate four designs

Four prototype shields (teaching dataset)

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

Design	What it is	Cost per shield (\$)	Mass (kg)	Field notes
A: Foam-lined box	Plywood box with a roof and acoustic foam inside, open only on the pond side	85	9	Foam stays dry under the roof
B: Straw-bale wall	Three straw bales stacked 1.2 m tall, 1 m behind the recorder on the highway side	40	75	About 25 kg per bale; straw rots within about a year
C: Blanket tent	Moving blankets draped over a tent-pole frame on three sides	30	4	Wet blankets sag and open gaps
D: Mesh-and-foam cone	Foam sheets held in a cone shape by plastic garden netting, open to the pond	60	6	Loose netting edges hang near the ground

Simulated descriptions and costs for teaching. Mass is the total a person would have to carry to the pond.

Field test results at one pond (teaching dataset)

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

Setup	Highway noise at recorder (dB)	Pond-side frog calls at recorder (dB)	Test calls detected (of 100)	Highway noise after rain test (dB)
No shield	64	58	41	—
A: Foam-lined box	52	57	88	53
B: Straw-bale wall	56	58	74	56
C: Blanket tent	58	55	66	61
D: Mesh-and-foam cone	50	56	90	51

Simulated test results for teaching. The same traffic recording and the same 100 test frog calls were played for every design.

3. Complete the decision matrix. Calculate each value from the tables (for C1, subtract the design's highway reading from the no-shield reading; for C2, subtract its pond-side reading from 58 dB; for C4, subtract its normal highway reading from its after-rain reading). A design that breaks any constraint is eliminated, no matter how well it scores.

Answer: Design A: C1 $64 - 52 = 12$ dB, pass; C2 $58 - 57 = 1$ dB, pass; C3 88, pass; C4 $53 - 52 = 1$ dB, pass; no constraint broken (\$85, 9 kg, no mesh, within 1 m); keep. Design B: C1 $64 - 56 = 8$ dB, pass (just); C2 $58 - 58 = 0$ dB, pass; C3 74, pass; C4 $56 - 56 = 0$ dB, pass; breaks K2 (75 kg, far over 15 kg); eliminate. Design C: C1 $64 - 58 = 6$ dB, fail; C2 $58 - 55 = 3$ dB, fail; C3 66, fail; C4 $61 - 58 = 3$ dB, fail; no constraint broken but fails every criterion; eliminate. Design D: C1 $64 - 50 = 14$ dB, pass; C2 $58 - 56 = 2$ dB, pass (just); C3 90, pass; C4 $51 - 50 = 1$ dB, pass; breaks K3 (plastic netting); eliminate.

Why: Every value is a subtraction from the two tables. Only Design A meets all four criteria and all four constraints.

Also acceptable: None for the numbers. Accept 'eliminate' or 'fails' for C.

- All sixteen criterion values computed correctly with pass/fail
- B eliminated for K2 and D for K3
- C eliminated for failing the criteria
- A kept

4. Use the 3 dB rule from the sound facts. Design A lowers the highway noise from 64 dB to 52 dB, and Design C lowers it from 64 dB to 58 dB. For each design, how many halvings of sound energy is that, and about what fraction (and percent) of the highway's sound energy still reaches the recorder? How many times more highway sound energy gets through Design C than Design A?

Answer: Design A: $12 \text{ dB} \div 3 \text{ dB} = 4$ halvings; $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 1/16 \approx 0.06$, so about 6 percent of the highway's sound energy still reaches the recorder. Design C: $6 \text{ dB} \div 3 \text{ dB} = 2$ halvings; $\frac{1}{2} \times \frac{1}{2} = 1/4 = 25$ percent. Comparison: $25 \div 6.25 = 4$ (or $(1/4) \div (1/16) = 4$), so about 4 times as much highway sound energy gets through Design C as through Design A.

Why: The 3 dB rule is an approximation of the decibel scale (exactly $10 \times \log_{10} 2 \approx 3.01$ dB per halving), and it gives answers within a few percent of the exact values (6.3 percent and 25.1 percent).

Also acceptable: Accept 6 percent or 6.25 percent for A and 25 percent for C. Accept 'four times' for the comparison.

5. Design D scored best on every criterion, yet it is eliminated. Explain why a broken constraint knocks a design out even when it performs best, and describe the real harm that constraint prevents.

Answer: A constraint is a limit the solution is not allowed to cross, so no amount of good performance makes up for breaking it; the team cannot use a shield that does harm the project exists to prevent. Constraint K3 bans plastic netting and loose mesh because snakes, frogs and birds push into it, get tangled and can die. A shield meant to help study frogs that kills frogs and the snakes that live around the pond would damage the very ecosystem being monitored.

Why: Wildlife entanglement in plastic mesh, such as erosion-control netting, is a documented cause of snake deaths; that is why K3 exists.

Also acceptable: Accept the idea that 'the best score does not matter if the design is not allowed.'

- Explains that constraints are pass/fail limits, not points to trade
- Names entanglement of snakes, frogs or birds as the harm

Part C: Decide, justify and predict

6. Recommend one design for all five ponds. Justify it with at least three numbers from the test data, show the total cost for five shields, and describe one trade-off: something your choice does less well than another design.

Answer: Recommend Design A, the foam-lined box. It is the only design that passes every criterion and constraint: it cuts highway noise by 12 dB (C1 needs 8), loses only 1 dB of frog sound from the pond side (limit 2), detects 88 of 100 test calls (more than double the 41 detected with no shield; C3 needs 70), and loses only 1 dB of its noise cut after the rain test (limit 2). It costs \$85 and weighs 9 kg. Total for five ponds: $5 \times \$85 = \$425$, under the \$500 limit. Trade-off: it is more than twice as expensive as the straw-bale wall (\$40) and loses 1 dB of frog sound where the wall loses none; it also cuts 2 dB less noise than the mesh cone.

Why: The recommendation should follow directly from the matrix, use at least three numbers, include the cost calculation and name an honest trade-off.

Also acceptable: A student who recommends a modified Design D with the netting replaced by an allowed frame earns full credit only if they say it must be retested before use, since no data exist for it.

- Recommends A (or a modified A that still meets every constraint)
- At least three numbers from the test data used as evidence
- Total cost $5 \times \$85 = \$425$ shown and compared with \$500
- One genuine trade-off named

7. Traffic on the highway has grown every year. Explain how unshielded recorders could make it look as if the bullfrogs were harming the treefrogs even if they were not, and why the shield is needed before the team can draw any conclusion.

Answer: Without shields, louder traffic each year covers up more frog calls, so the software detects fewer calls each year even if the same number of treefrogs are calling. Because the bullfrogs arrived during the same years, the falling counts could be blamed on the bullfrogs when the real cause is a change in the measuring conditions. The shield keeps the noise at the recorder low and steady, so a drop in detected calls means fewer frogs calling, not just more noise. Comparing ponds that are the same distance from the highway, with and without bullfrogs, would also help.

Why: This separates a real population change from a measurement artifact, which is why the engineering problem matters for the science question.

Also acceptable: Accept 'the noise is a hidden variable' or 'you cannot tell fewer frogs from more noise' with the reasoning.

- Explains that more noise lowers detections without fewer frogs
- Explains that the timing overlaps the bullfrog arrival, creating a false link
- States that the shield makes counts comparable across years

8. With shields in place, the team will follow three kinds of ponds for three calling seasons: (a) ponds where bullfrogs are present, (b) ponds with no bullfrogs, and (c) a pond where the team removes every bullfrog this year. Name the interaction or interactions between bullfrogs and treefrogs and rate each species. Then predict what the treefrog call counts should show in each kind of pond, including whether any change should appear right away or after a delay. Support your prediction with the same pattern in at least one other ecosystem you have studied.

Answer: Model response: Bullfrogs eat treefrogs, which is predation (bullfrog +, treefrog –), and both eat the same insects, which is competition (both –, although the bigger bullfrogs probably lose less). (a) Ponds with bullfrogs: treefrog call counts should fall from season to season, because bullfrogs eat calling adults and young frogs and take some of their food. (b) Ponds without bullfrogs: treefrog counts should go up and down with weather and rainfall but show no steady decline. (c) The pond where bullfrogs are removed: counts should stop falling and then rise, but not right away; new treefrogs have to hatch, grow up and reach calling age, so the recovery should appear a season or more after the removal. This matches the pattern elsewhere: when sea otters returned to parts of the California coast, the urchins they eat became scarce; at Pine Hollow (W6) an arriving predator was matched by a falling prey population; and in Sierra lakes where introduced trout were removed, mountain yellow-legged frogs recovered. In every case, adding a predator pushes the prey down and removing it lets the prey recover after a delay, even though the species are different.

Why: This is the MS-LS2-2 item: the student must name the interactions with codes, predict the pattern in all three pond types including the delay, and justify the prediction with the same pattern from another ecosystem.

Also acceptable: Accept predation alone if it is rated correctly and the predictions follow. Accept any accurate comparison ecosystem from the chapter (Isle Royale, kelp forest, Yellowstone, Pine Hollow, Lab 1). A student who adds that bullfrog tadpoles also compete with treefrog tadpoles is adding a correct detail.

- Names predation (bullfrog +, treefrog –) and preferably competition (– –)
- Predicts decline where bullfrogs are present
- Predicts no steady decline where they are absent
- Predicts recovery after removal with a delay explained by breeding and growth
- Supports the prediction with the same pattern in another named ecosystem

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Precise criteria and constraints (Part A)	All four goals correctly sorted and rewritten with a quantity, unit and test; the added constraint protects people or wildlife and is justified.	All four sorted correctly; one rewrite is not fully measurable, or the added constraint lacks a reason.	Two or three goals rewritten measurably, or criteria and constraints mixed up.	Rewrites restate the vague goals or are missing.
Systematic evaluation (Part B)	Matrix complete with every value calculated correctly; B and D eliminated for the right constraints and C for its criteria; the 3 dB calculations are correct.	Matrix complete with one calculation slip; eliminations correct.	Matrix partly complete, or an eliminated design is treated as allowed.	No systematic comparison.
Decision and justification	Recommends a design that meets every criterion and constraint, supports it with three or more numbers and the five-pond cost, and names an honest trade-off.	Sound recommendation with two numbers or a missing cost total.	Recommendation with reasons that do not use the data.	No recommendation, or one that breaks a constraint.
Interaction prediction (q7 and q8)	Separates measurement noise from real population change; names the interactions with codes; predicts all three pond types, including the delayed recovery, and supports the prediction with the same pattern in another ecosystem.	Predictions for all three pond types with codes, but the delay or the cross-ecosystem support is missing.	Predicts a bullfrog effect without codes or without the comparison ponds.	No prediction, or a prediction that contradicts the interaction.

Teacher notes

Cedar Flat and all numbers are fictional teaching data. The scenario rests on real practice and real biology: biologists do monitor frog choruses with automated recorders and call-detection software; traffic noise masks frog calls, and studies (for example in Australia) have found some frogs calling at a higher pitch near busy roads; American bullfrogs are an introduced predator and competitor of native frogs in California; and plastic mesh netting is a documented cause of snake entanglement. The decision matrix is built so that each design fails in a different way: A passes everything; B passes the criteria but breaks the mass constraint; C meets the constraints but fails every criterion; D performs best but breaks the wildlife constraint. The 3 dB rule of thumb is close to exact ($10 \log_{10} 2 = 3.01$); the '10 dB sounds about half as loud' rule describes hearing and is approximate. This sheet is the paper counterpart of Lab 3: use it for students who missed the build, or after the lab so students can compare their own shield data with these designs. In q8 the key idea for MS-LS2-2 is the delayed recovery after the predator is removed, the same lag students saw in predator-prey graphs (W4, W5, Lab 1).

Scaffold offered to students: Pass or fail first, then compare

Work one row of the matrix at a time. Noise cut = 64 minus the design's highway reading. Frog-call loss = 58 minus its pond-side reading. Rain rise = its after-rain reading minus its normal highway reading. Write the number, then 'pass' or 'fail' beside it. Next, read the design's cost, mass and field notes and check K1 to K4. Only the designs with no broken constraint stay in the running; compare those using the numbers. For q4, count halvings by dividing the dB drop by 3, then multiply $\frac{1}{2}$ by itself that many times.

Extension: Combine the best features

Design D performed best but broke a constraint, and Design B was cheap but far too heavy. Sketch a new design that keeps D's cone shape and foam but holds them with an allowed material, or that packs B's solid mass into something one person can carry. List its materials and estimated cost, predict its test results compared with Design A, say which prediction you are least sure of and why, and describe the one field test you would run first.