

Choose the Stone: Which Rock Will Last on the Riverside Steps?

Learning target: I can use what I know about how rocks form and weather to evaluate candidate building stones against criteria and constraints, choose one, and justify the choice with evidence and rock-cycle reasoning.

Transfer and design

About 50 min

Pairs

MS-ESS2-1 · practice

MS-ETS1-2 · practice

engineering design

data analysis

writing

Standards connections

MS-ESS2-1 (practice): Predicting which stone will resist frost and acid rain requires applying how each rock formed (interlocking crystals versus cemented grains, calcite versus silica) and how weathering, a Sun-driven process in the cycle, will attack it. The task applies the model rather than building it.

MS-ETS1-2 (practice): Students evaluate four competing stone choices systematically against stated criteria and constraints, using test data and cost calculations, which is the practice this ETS standard describes.

Purpose: extend · **Time:** about 50 minutes · **Format:** pairs

Answers with reasoning

The design brief

What the council needs — The steps need about **40 cubic meters** of cut stone. Millbrook has cold winters with about 90 nights a year when wet stone freezes, and its rain is slightly acidic, like rain in most towns. The council's requirements: (1) the steps must stay safe and solid for at least 100 years without replacement; (2) the stone must cost no more than **\$60,000** in total; (3) the stone must come from a quarry within **300 km**, to keep delivery practical; (4) the surface should not become dangerously smooth or crumbly when wet. The council would prefer a light color but says that is a wish, not a rule.

Quarry test results for four candidate stones (teaching dataset)

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

Stone	Description under a lens	Water soaked up (% of block mass)	Weak acid test	Freeze-thaw cycles before damage	Cost per cubic meter	Quarry distance
A	Pink-gray; interlocking crystals 3 to 6 mm, no layers	0.3	No fizz	More than 300, no damage	\$1,400	120 km
B	White; interlocking crystals 1 to 3 mm, faint swirls	0.4	Fizzes; surface dulls	More than 300, no damage	\$1,900	250 km
C	Tan; rounded sand grains glued together, visible gaps, layers	6.0	No fizz	Cracked along layers at 45	\$600	40 km
D	Dark gray; crystals too small to see, scattered tiny holes	1.5	No fizz	Minor flaking at 220	\$900	500 km

Simulated data for teaching. The acid test drips a weak acid on the stone and watches for fizzing. The freeze-thaw test soaks a block and freezes and thaws it repeatedly until damage appears.

Part A: Define the problem

1. Complete the table from the design brief.

Answer: Durability: must last 100 years without replacement; criterion (though with a hard minimum); test with freeze-thaw and acid results. Budget: total cost no more than \$60,000; constraint; test by multiplying 40 m³ by cost per m³. Distance: quarry within 300 km; constraint; read the distance column. Wet surface: must not become dangerously smooth or crumbly; criterion; check acid dulling and crumbling evidence (no direct slip test given). Color: light color preferred; criterion, a wish only; read the description.

Why: Constraints are limits that cannot be exceeded (budget, distance); criteria describe how well a solution performs. Durability has a threshold (100 years) so students may call it either; accept both with reasoning.

Also acceptable: Accept durability labeled as a constraint if the student points to the 100-year minimum.

- All five rows completed
- Budget and distance labeled as constraints
- Color labeled as a preference
- A test named for each row

2. Calculate the total stone cost for each candidate (40 m³ × cost per m³). Which candidates stay within the \$60,000 budget? Show all four calculations.

Answer: A: 40 m³ × \$1,400 = \$56,000 (within budget). B: 40 × \$1,900 = \$76,000 (over budget). C: 40 × \$600 = \$24,000 (within). D: 40 × \$900 = \$36,000 (within).

Why: Simple multiplication; B is the only stone over \$60,000.

Also acceptable: None; all four values must appear.

3. Which candidates are eliminated by a constraint before you even think about durability? Name each and the constraint it breaks.

Answer: Stone B is eliminated by the budget constraint (\$76,000 is more than \$60,000). Stone D is eliminated by the distance constraint (500 km is more than 300 km). Stones A and C survive the constraints.

Why: Constraints are applied before criteria; the data make B and D fail on constraints regardless of their durability.

Also acceptable: A student who also notes B's acid problem is adding a criterion failure, which is fine but not the constraint.

- B eliminated for budget
- D eliminated for distance

Part B: Explain the test results with the rock cycle

4. Stone C soaked up 6 percent of its mass in water and cracked after 45 freeze-thaw cycles. Use how a rock like C forms (grains, gaps, glue, layers) to explain why it failed, and name the type of weathering that destroyed it. Then estimate how many Millbrook winters 45 cycles represents, using 90 freezing nights a year, and say whether C could meet the 100-year criterion.

Answer: Stone C is a sedimentary rock: sand grains that were compacted and glued together by mineral cement, leaving small gaps, in layers. Water soaks into those gaps (6 percent of its mass). On freezing nights the water expands as it turns to ice, pushing the grains apart and prying open the layers; repeated freezing and thawing cracks the rock along its weakest planes, the layers. This is physical weathering (frost wedging). Estimate: $45 \text{ cycles} \div 90 \text{ freezing nights per year} = 0.5 \text{ year}$, so the block was damaged in the equivalent of half a winter. Even if the test is harsher than real weather, C is nowhere near 100 years; it is the same kind of stone that crumbled after 60 winters.

Why: Full credit links porosity to cemented-grain texture, names frost wedging as physical weathering, and does the division. Real steps last longer than the lab test suggests because not every freezing night soaks the stone, which the student may note.

Also acceptable: Accept 'less than one winter' for the estimate; accept 'mechanical weathering' for physical weathering.

- Explains gaps from compaction and cementation of grains
- Describes water expanding on freezing and cracking along layers
- Names physical weathering (frost)
- Calculates $45 \div 90 = 0.5 \text{ year}$ and concludes C fails

5. Stone B passed the freeze-thaw test but fizzed in weak acid and its surface dulled. Explain what the fizzing tells you about B's minerals, which type of weathering slightly acidic rain would cause, and why a stone that passes the frost test can still fail the 100-year criterion. What safety problem could a dulling, dissolving surface cause on steps?

Answer: Fizzing with weak acid means B's crystals are a mineral that reacts with acid, the kind found in limestone and in marble made from it. Slightly acidic rain would cause chemical weathering: the mineral slowly dissolves, which is why the surface dulled in the test. Frost is only one of Millbrook's attacks; rain falls every year, so a stone that is frost-proof can still lose its surface grain by grain over a century. On steps, a dissolving surface becomes smooth and slippery when wet, and carved edges wear away, which is a safety problem.

Why: Two independent weathering pathways must both be survived; passing one test is not enough.

Also acceptable: Naming calcite or marble is acceptable but not required; the PE's boundary does not require mineral identification. For the safety problem, also accept rounded, worn step edges or a gritty, crumbling surface.

- Fizzing linked to an acid-reactive mineral
- Names chemical weathering by acidic rain
- Explains that frost-proof does not mean rain-proof
- Identifies a slippery or worn surface as the safety issue

6. Stone A and Stone D both have interlocking crystals and no fizz, but D flaked after 220 cycles and A showed no damage after 300. Using the descriptions, suggest what feature of D let water in, and explain how each stone's cooling history produced that difference.

Answer: D has scattered tiny holes left by gas bubbles, which let water in (1.5 percent) and give ice a place to push; A has none, so water barely enters (0.3 percent). D's tiny crystals and gas holes show it cooled quickly at the surface as lava, trapping bubbles; A's large interlocking crystals show it cooled slowly underground, where gas stayed dissolved and crystals grew together with no gaps.

Why: This connects igneous cooling history to porosity and therefore to frost resistance.

Also acceptable: Accept 'D is extrusive, A is intrusive' with the holes explained.

- Identifies the gas holes in D as the water entry
- Links D to fast surface cooling and A to slow underground cooling

Part C: Decide and justify

7. Write your recommendation to the council. State the stone you chose, show that it meets every constraint, use at least three pieces of test data as evidence, and explain in rock-cycle terms why it will resist Millbrook's frost and rain for 100 years. End with one honest limitation of your choice.

Answer: Model recommendation: Choose Stone A. Constraints: total cost $40 \text{ m}^3 \times \$1,400 = \$56,000$, under \$60,000; quarry 120 km away, under 300 km. Evidence: A soaked up only 0.3 percent water, the lowest of the four; it showed no damage after more than 300 freeze-thaw cycles, the equivalent of more than three Millbrook winters in the lab with no cracking, while C cracked at 45; it did not fizz in acid, so acidic rain will not dissolve it the way it dulled B. Rock-cycle reasoning: A is an intrusive igneous rock whose magma cooled slowly deep underground, so its crystals grew into each other with no gaps and no gas holes; there is nowhere for water to collect and freeze, and its minerals do not react with weak acid, so both physical and chemical weathering act very slowly on it. It is also light pink-gray, meeting the color wish. Limitation: A is the most expensive surviving option and takes almost the whole budget, leaving little for installation; and polished intrusive rock can be slippery when wet, so the steps should have a roughened surface.

Why: Full credit requires the choice, both constraints shown with numbers, three data points, formation-based reasoning about weathering, and an honest limitation.

Also acceptable: A student who recommends D with a plan to negotiate the distance constraint is breaking a hard constraint and should not get full credit; use it to discuss why constraints are not preferences.

- Recommends Stone A
- Shows budget and distance constraints met with numbers
- Cites at least three test results
- Explains resistance through slow cooling, interlocking crystals, no gaps, no acid reaction
- States a real limitation

8. Trade-off: suppose the council's budget is cut to \$30,000. Which stone would you recommend now, what would the town have to accept, and what maintenance plan would you suggest so the steps still last as long as possible?

Answer: With \$30,000, only Stone C fits (\$24,000); A (\$56,000) and D (\$36,000) are over, and D is too far anyway. The town would have to accept a stone that cracks in frost and will need replacement, perhaps within a few decades like the old steps. Maintenance plan: seal the surface to reduce water soaking in, lay the stone with its layers horizontal so water cannot easily enter along them, make sure water drains off the steps instead of pooling, inspect each spring, and set aside money for replacement. Alternatively, buy a smaller amount of A for the most-used steps and use C elsewhere.

Why: The trade-off is cost against durability; a good answer names what is given up and proposes maintenance that attacks the water-entry problem.

Also acceptable: The mixed-stone solution earns full credit if the costs are checked (for example, 10 m^3 of A for \$14,000 plus 30 m^3 of C for \$18,000 = \$32,000, which is still over; the student would need to adjust).

- Identifies C as the only stone within \$30,000
- States the durability trade-off
- Proposes at least two maintenance actions that reduce water entry or freezing

9. Even the best stone will not last forever. Describe what will eventually happen to the steps over thousands of years, and which part of the rock cycle, driven by which energy source, is responsible.

Answer: Over thousands of years, rain, frost, roots and the river will slowly break even Stone A into grains and chunks (weathering), and water and gravity will carry the pieces to the river and beyond (erosion and deposition), where they may one day be buried and cemented into a new sedimentary rock. This is the surface part of the rock cycle, powered by sunlight (which drives rain, wind and freezing and thawing) and by gravity.

Why: The point is that resistance only slows the cycle; nothing stops it.

Also acceptable: A student who adds that burial and heat could later metamorphose or melt the material is extending the answer correctly.

- Predicts weathering and erosion of the steps
- Names the Sun (and gravity) as the energy source
- Connects to the sediment or sedimentary stage of the cycle

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Problem definition (Part A)	All criteria and constraints identified and correctly classified; cost calculations complete and correct; B and D eliminated on the right constraints.	One classification or one calculation error; eliminations correct.	Criteria and constraints confused, or an elimination based on the wrong reason.	Part A largely incomplete.
Rock-cycle reasoning (Part B)	Each test result explained through how the rock formed (cemented grains and gaps, acid-reactive minerals, gas holes, interlocking crystals) and the correct type of weathering; the 45-cycle estimate is calculated.	Explanations mostly correct; one link between formation and weathering is missing or the estimate is missing.	Results described but not explained through formation; weathering types confused.	No connection made between formation and test results.
Recommendation and justification (Part C, q7)	Recommends A, shows every constraint met with numbers, cites three or more data points, reasons from formation to resistance, and states a genuine limitation.	Recommends A with constraints and data but weak formation reasoning or no limitation.	Recommendation made with little data, or recommends a stone that breaks a constraint without acknowledging it.	No recommendation or no justification.
Trade-offs and long view (q8, q9)	Identifies the only affordable stone under the cut budget, names what is sacrificed, proposes targeted maintenance, and describes the steps' eventual fate within the Sun-driven surface part of the cycle.	Trade-off and maintenance present but generic, or long-view answer lacks the energy source.	One of q8 or q9 answered adequately.	Neither answered adequately.

Teacher notes

The four stones stand for granite (A), marble (B), sandstone (C) and vesicular basalt (D); the patterns are real (porous sandstone fails by frost wedging, marble and limestone dissolve in acidic rain, dense granite is the classic durable building stone, vesicular basalt is weakened by its gas holes), but every number is invented for the exercise and the lab freeze-thaw test is far harsher than real weather, which q4's answer acknowledges. Do not require mineral names; students may say 'the mineral that fizzes' instead of calcite. The intended answer is A; the only constraint-respecting alternative is C with heavy maintenance, which q8 explores. The extension's wet-slip test is a real concern: polished granite is slippery, which is why outdoor granite steps are flame-textured or bush-hammered.

Scaffold offered to students: Eliminate, then compare

Engineers rarely compare everything at once. First use the constraints to cross out any stone that breaks a hard limit (over budget, too far away). Then compare only the survivors on the criteria, one criterion at a time, in a quick grid with stones across the top and criteria down the side: write a check, a cross or a question mark in each box. The stone with the most checks and no crosses is your recommendation. For q4 and q5, go back to how each rock formed: cemented grains have gaps that water can enter; interlocking crystals do not; minerals that fizz with acid dissolve slowly in acid rain.

Extension: Design the fifth test

The quarry's tests did not measure how slippery each stone becomes when wet, which the council listed as requirement 4. Design a fair test for wet slipperiness: name the variable you would change, the variable you would measure, three things you would keep the same, and how many trials you would run. Predict which of the four stones would do best and worst, using their textures as your reason. Then explain how a stone that scored best on durability could still be rejected after your test, and what that says about why engineers use several criteria instead of one.