

The Sixty-Thousand-Fork Problem: Choosing a Material for the Cafeteria

Learning target: I can define testable criteria and constraints for a real materials problem, compare four competing options against them using evidence about each material's origin, cost and ending, choose one, justify it, and revise my plan when new information arrives.

Transfer and design

About 50 min

Pairs

MS-ETS1-1 · practice

MS-ETS1-2 · practice

MS-PS1-3 · practice

engineering design

data analysis

writing

Standards connections

MS-ETS1-1 (practice): Students turn a district memo into precise, testable criteria and constraints, including effects on the environment (where each fork goes after use) and on people (lunch pace, staff time, budget). The problem is school-sized, so this builds toward the PE rather than fully assessing it.

MS-ETS1-2 (practice): Students score four fork materials against the same criteria and constraints in a matrix and defend a choice, which is the systematic comparison the PE describes; the data are simulated and the scale is one cafeteria.

MS-PS1-3 (practice): Each option is traced to its natural resource (petroleum, corn, trees, ores) and its impact on the school's waste streams, so the decision depends on the origin-and-impact information this PE is about.

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

Answers with reasoning

Memo from the district (teaching scenario) — Lincoln Middle School serves about 330 lunches a day for 180 school days, roughly 60,000 meals a year, and hands out a single-use polystyrene fork with every one. The board wants each school to propose a fork plan for next year. The plan must: keep the lunch line moving (students should not wait for forks); cost the school no more than \$2,500 per year for forks, washing and replacements combined; and send less fork waste to the landfill than this year. Staff can give at most 30 extra minutes per day to the plan. Submit your criteria, your comparison and your choice.

Facts about Lincoln's waste streams. Trash bins go to the county landfill. The recycling bin accepts bottles and cans only; no cutlery of any kind. The green bin takes food scraps and items marked compostable and is hauled to an industrial composting facility, which at present accepts PLA cutlery. The cafeteria has a dishwasher that already runs every day for trays.

Four fork options (teaching dataset)

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

Option	Natural resource	Cost	Forks that break per 100 uses	Where it goes after use at Lincoln	Mass of one fork (g)
A: Polystyrene, single-use	petroleum	2 cents per fork	1	trash bin: landfill	3
B: PLA, single-use	corn starch	4 cents per fork	4	green bin: industrial composter (accepted at present)	4
C: Birch wood, single-use	birch trees (regrow in decades)	5 cents per fork	3	green bin: industrial composter	3
D: Stainless steel, reusable	iron ore and chromium ore	60 cents to buy; 1 cent per wash	0	washed and reused; about 15 of every 100 forks are lost or thrown away each year	20

Simulated figures chosen to be realistic. Break rates come from an imagined two-week trial of each fork on cafeteria food.

Extra facts for Option D. Covering three lunch periods with washing in between takes about 700 forks in rotation. Collecting, loading and sorting the forks adds about 25 minutes of staff time per day. Lost forks that land in the trash go to the landfill.

Part A: Define the problem precisely

A vague requirement cannot be tested. 'Good for the environment' is vague; 'sends less than 50 kg of fork waste to the landfill per year' can be measured. Criteria say what a successful plan must do. Constraints are limits the plan must stay inside.

1. Write three criteria for the fork plan, each specific enough to test. At least one must be about what happens to the forks after use (their ending) and one about how the forks work during lunch. For each, write how you would measure it.

Answer: Sample criteria: (1) Ending: fork waste sent to the landfill is less than 50 kg per year, measured by counting forks in the trash bins during a two-week sample and scaling up. (2) Lunch line: every student has a fork within 10 seconds of reaching the counter, measured by timing 50 students on three days. (3) Use: no more than 2 forks per 100 break during a meal, measured by counting broken forks returned during the pilot. Other acceptable criteria: forks are made from a renewable resource; forks do not splinter or cut; waste can be sorted correctly by students without a monitor.

Why: Full credit needs three criteria that each state a measurable target and a way to measure it, with at least one about the ending and one about lunch function. Cost should appear in q2, not here.

Also acceptable: A criterion such as 'at least 90 percent of forks end up in the correct bin' is a strong ending criterion.

- Three criteria with numbers or testable conditions
- At least one end-of-life criterion and one lunch-function criterion
- A measurement method for each

2. Write the constraints from the memo and the school facts (there are at least three). Then explain why 'costs no more than \$2,500' is a constraint rather than a criterion, and why a plan that costs \$1,000 is not automatically better than one that costs \$2,400.

Answer: Constraints: total yearly cost no more than \$2,500; no more than 30 extra staff minutes per day; the recycling bin accepts no cutlery, the green bin goes to a composter that accepts PLA at present, and the trash goes to the landfill (so each option has only one real path); the dishwasher already exists and runs daily. Cost is a constraint because it is a limit the plan must stay inside, not a job the fork must do; a plan under the limit passes, and being further under is not by itself success. A \$1,000 plan that fails the landfill or lunch-line criteria is worse than a \$2,400 plan that meets them.

Why: The criterion-versus-constraint distinction is the textbook's loose point about 'inexpensive' being a criterion; here cost is handled accurately as a constraint.

Also acceptable: Accept 'the composter accepts PLA only for now' as a constraint flagged as uncertain.

- At least three constraints from the memo and facts
- Explains cost as a limit rather than a success condition
- Explains that cheaper is not automatically better in terms of criteria

Part B: Compare the options

3. Complete the matrix. Yearly cost for a single-use option is 60,000 forks times the cost per fork. For steel, add the cost of 700 forks, 60,000 washes, and replacing the forks lost in a year. Landfill waste is the number of forks that reach the landfill times the mass of one fork, in kilograms. Show every calculation below the table.

Answer: A: $60,000 \times \$0.02 = \$1,200$; within limit; landfill $60,000 \times 3 \text{ g} = 180,000 \text{ g} = 180 \text{ kg}$; petroleum, not renewable; lunch-line criterion met (single-use forks are handed out instantly). B: $60,000 \times \$0.04 = \$2,400$; within limit; landfill 0 kg if every fork reaches the green bin (forks thrown in the trash would add 4 g each); corn, renewable; lunch-line met, but 4 per 100 break. C: $60,000 \times \$0.05 = \$3,000$; over the limit; landfill 0 kg via the green bin; birch, renewable over decades; lunch-line met. D first year: $700 \times \$0.60 = \$420$; $60,000 \times \$0.01 = \$600$; lost forks $0.15 \times 700 = 105$ forks $\times \$0.60 = \$63$; total \$1,083; within limit; landfill $105 \times 20 \text{ g} = 2,100 \text{ g} = 2.1 \text{ kg}$; ores, not renewable but the forks are reused for years; lunch-line met only if 700 forks and the washing cycle keep up, which the pilot must test.

Why: Each cost is forks times price; steel adds purchase, washes and replacements. The landfill mass assumes perfect sorting for B and C; a student who notes that real sorting is imperfect is reasoning well.

Also acceptable: Accept D at about \$1,080 to \$1,100 depending on rounding; accept B's landfill as 'about 0 kg if sorted correctly.'

4. Which option has the lowest cost in its second year, and why does its cost drop? Which option is ruled out by a constraint no matter how good it is otherwise?

Answer: Steel has the lowest second-year cost: the 700 forks are already bought, so year two is washes plus replacements, $\$600 + \$63 = \$663$, less than polystyrene's $\$1,200$. Birch (C) is ruled out by the $\$2,500$ cost constraint at $\$3,000$ per year, even though it is renewable and compostable.

Why: The point is that a one-time purchase changes the yearly picture, and that a constraint eliminates an option regardless of its other merits.

Also acceptable: A student who notes that steel's advantage depends on the loss rate staying near 15 percent is adding a valid caution.

- Identifies steel with the year-two calculation
- Identifies birch as over the cost limit

Part C: Decide, justify, revise

5. Choose one option (or a combination). Justify it in a paragraph that names the criteria it meets, the constraints it stays within, the natural resource it draws on and where its waste ends up. Then name the trade-off you accepted: what does your choice cost that another option would not?

Answer: Defensible choices with sample justification. Steel (D): meets the landfill criterion (about 2 kg per year against 180 kg now), stays within cost ($\$1,083$ then $\$663$ per year) and staff time (25 of 30 minutes), uses iron and chromium ore once and reuses the forks for years; trade-off: higher first-year cost, daily staff work, water and energy for washing, lost forks going to the landfill, and a risk that losses run above 15 percent. PLA (B): meets the landfill criterion if students sort correctly, stays just within cost ($\$2,400$), needs no staff time, comes from a renewable crop; trade-off: 4 per 100 break, it costs twice as much as polystyrene, it works only while the composter accepts PLA, and any PLA fork in the trash is landfill waste that lasts for years. Keep polystyrene (A): cheapest and reliable but fails the landfill criterion (180 kg, the same as now), so it is not defensible against the memo unless paired with a 'forks on request' habit change. A combination (steel for most students, PLA for field trips) is acceptable if costed.

Why: Grade the match between the student's own criteria and constraints and the choice, the tracing of resource and ending, and the honesty of the trade-off. Steel is the strongest fit to the memo as written; PLA is a reasonable alternative that depends on the composter; polystyrene cannot meet the 'less landfill' requirement.

Also acceptable: A student who chooses PLA and names the composter dependence as the trade-off has anticipated q6 and should be credited.

- Choice named
- Criteria met and constraints satisfied, with numbers from the matrix
- Natural resource and waste destination named
- A real trade-off stated

6. New information: in March, the composting facility announces that starting next year it will no longer accept any plastic cutlery, including PLA, because too much polystyrene has been arriving mixed in with it. Which options does this affect, and how? Rewrite any criterion or constraint that must change, and say whether your choice in q5 survives. If it does not, name your new choice.

Answer: It affects option B directly: PLA forks could no longer go in the green bin, so they would go to the trash and the landfill, where PLA lasts for years, which would make B about as bad for landfill mass as A ($60,000 \times 4 \text{ g} = 240 \text{ kg}$, more than polystyrene) at twice the cost. Option C is not affected (wood is still accepted) but is still over budget. Option D is unaffected except that lost forks continue to reach the landfill. Rewritten constraint: 'the green bin accepts food scraps and wood or paper items only; no plastic cutlery of any kind.' A criterion that depended on composting ('forks are composted') must change to 'forks are reused or are made of a material the green bin accepts.' A steel choice survives. A PLA choice does not; the new choice would be steel, or birch if the district raises the budget by \$500, or polystyrene handed out on request as a fallback that at least cuts the count.

Why: This is the chapter's design-cycle idea: a solution can stop meeting its criteria when the surrounding conditions change, and the criteria and constraints must then be rewritten. Full credit requires identifying B as the affected option, rewriting the constraint, and stating whether the earlier choice survives.

Also acceptable: Accept 'the school could ask the facility to accept clearly marked PLA bins' as a proposed fix, if the student notes it is uncertain.

- Identifies PLA as the option that fails under the new rule, with the landfill consequence
- Rewrites at least one criterion or constraint
- States whether the q5 choice survives and names a new choice if not

7. Sketch your plan as a flow: the natural resource, the fork, the lunch line, and where each fork goes after use (label every bin and its destination). Then add a box describing a two-week pilot test: what you would count each day, and what result would tell you the plan has failed a criterion.

Answer: Sample for steel: ore mined and made into steel → 700 forks bought once → counter at each lunch period → return bin by the tray window → dishwasher → back to the counter; lost forks in the trash → landfill (labeled). Pilot box: for two weeks count forks returned, forks found in the trash, broken forks, students waiting more than 10 seconds, and staff minutes used each day; failure signals: more than 30 staff minutes on most days, forks running out before the third lunch, or losses above about 3 forks per week (about 105 a year, the 15 percent the matrix assumed). Sample for PLA: corn → PLA forks → counter → green bin → hauled to the industrial composter; forks found in the trash → landfill; pilot counts forks in each bin and broken forks; failure signals: more than 4 per 100 breaking, or more than 10 percent of forks in the trash.

Why: The sketch must show every bin's destination and a pilot that measures the student's own criteria with a stated failure condition.

Also acceptable: Any option drawn consistently with the matrix earns credit; the pilot must match the criteria written in q1.

- Flow from natural resource to fork to lunch line to every destination, with bins labeled
- A pilot test that names what is counted daily
- A specific result that would mean a criterion failed

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
-----------	---------------	----------------	----------------	---------------

Criteria and constraints	Three testable criteria including an end-of-life criterion and a lunch-function criterion, each with a measurement; all constraints from the memo and facts listed; cost correctly treated as a constraint.	Three criteria, one not fully testable; most constraints listed; cost distinction stated.	Criteria are vague ('good for the environment') or mixed with constraints; some constraints missing.	Criteria and constraints missing or not connected to the memo.
Comparison matrix and calculations	All four options costed correctly with work shown; landfill masses computed; constraint check and renewable column correct; notes the sorting assumption for B and C.	Matrix complete with one arithmetic slip; work shown for most cells.	Matrix partly complete, or costs given without calculations.	Matrix blank or numbers invented.
Decision and justification	Choice follows from the student's own criteria and constraints and the matrix; names the resource and the waste destination; states a real trade-off honestly.	Choice justified with matrix evidence; trade-off stated but thin, or resource or destination missing.	Choice stated with a general reason (cheapest, greenest) not tied to the criteria.	No choice, or a choice that violates a constraint without acknowledging it.
Revision and pilot plan	Correctly identifies the affected option and the landfill consequence, rewrites a criterion or constraint, states whether the choice survives; sketch shows every destination and a pilot with a stated failure signal.	Affected option identified and choice re-evaluated; sketch complete but the pilot lacks a failure signal.	Notes the change without rewriting anything, or sketch missing bin destinations.	No revision; sketch absent or unrelated to the plan.

Teacher notes

All numbers are simulated and labeled; they are realistic in order of magnitude (single-use forks cost a few cents, a stainless fork under a dollar in bulk, PLA cutlery is brittle, and composting facilities have in fact stopped accepting compostable plastics in several regions because of contamination, which is the basis for the q6 twist). The sheet is built so that steel is the strongest fit to the memo as written, PLA is defensible but fragile, birch is eliminated by cost, and polystyrene fails the landfill requirement; grade the reasoning, not the verdict. Expect two errors: charging steel's purchase price every year, and forgetting that lost steel forks and mis-sorted PLA forks both reach the landfill. If students argue that mining ore for steel is a large one-time impact, agree, and note that it is spread over years of use, which is the same break-even idea as W5. Cost is kept as a constraint throughout; if a student wants 'as cheap as possible' as a criterion, discuss why that would make comparison impossible.

Scaffold offered to students: Criteria frames and the cost formula

Criterion frames: 'No more than ___ forks break per 100 uses.' 'Fork waste to the landfill is less than ___ kg per year.' 'A student gets a fork within ___ seconds of reaching the counter.' Cost formulas: single-use yearly cost = $60,000 \times \text{cost per fork (in dollars, so 2 cents is \$0.02)}$. Steel first year = $700 \times \$0.60 + 60,000 \times \$0.01 + (15 \text{ percent of } 700) \times \$0.60$. Landfill waste = forks reaching the landfill $\times$ grams per fork $\div 1,000$.

Extension: Reduce before you replace

Every option on the sheet assumes 60,000 fork uses. A survey (invent realistic numbers and label them) finds that about one meal in five is pizza, a sandwich or fruit that needs no fork, yet every tray gets one. Redo the matrix with forks handed out only on request, estimate the new yearly cost and landfill mass for your chosen option, and write a paragraph on which saves more, changing the material or changing the habit. Then name one criterion that a 'forks on request' plan might fail and how you would test it.