

Design Challenge: A Sealed Mini-World That Survives Twenty-One Days

Learning target: I can define criteria and constraints for a sealed model biosphere, use data from earlier prototypes to choose a design, plan the data my model will generate, and justify my decisions with energy and matter reasoning.

Transfer and design

About 55 min

Pairs

MS-ETS1-4 · practice

MS-ETS1-1 · practice

MS-ETS1-3 · practice

MS-LS2-3 · supports

engineering design

data analysis

writing

Standards connections

MS-ETS1-4 (practice): Students design a physical model, specify the data it will generate during a 21-day test, and write a modification rule for the next version. They plan rather than build on this sheet, so it is practice toward the PE; the build is an optional follow-up, not one of this chapter's labs.

MS-ETS1-1 (practice): Part A asks for criteria and constraints stated precisely enough to test, taking the science (energy entering a sealed tub, decomposers using oxygen) and the welfare of the living things into account.

MS-ETS1-3 (practice): Part B compares three prototypes' test data to find the best feature of each and combine them into a new design, which is the practice this PE describes.

MS-LS2-3 (supports): Choosing plants, soil and animals so that matter cycles inside a sealed boundary while energy flows in and out draws on the ecosystem ideas of this PE as background.

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

Answers with reasoning

The brief from the science club — For spring Science Night the club will display a sealed mini-world: a clear 20-liter tub, closed to matter, holding two pond snails, living plants, water and soil or gravel, sitting on the south-facing windowsill of Room 14. It must be sealed on day 0 and stay sealed for 21 days, with the snails and plants alive and healthy at the end. The club has \$25 to spend beyond the tub, no electricity may be used, nothing may be opened or added during the test, and the tub must not get hot enough to harm the animals. Sensors the club already owns read oxygen (%) and temperature (°C) through the lid.

Last year's club built three prototypes in the same tub on the same windowsill and tested each for 21 days. Their results are summarized below. All three were sealed to matter; sunlight entered through the clear walls.

Three prototype tests from last year (teaching dataset)

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

Prototype	Soil or gravel	Plants	Water	Shade	Lowest oxygen (%) and day	Highest temperature (°C) and day	Snails alive on day 21	Other notes
P1	4 L garden soil	3 sprigs water plant (about 40 g)	6 L	none	16.8 on day 15	31 on day 9	0 (both died about day 16)	Soil darkened; carbon dioxide reading rose steadily
P2	2 L washed gravel	10 sprigs water plant (about 150 g)	8 L	none	20.6 on day 3	35 on day 11	0 (both died about day 12)	Water very warm by midday; plants pale after day 14
P3	1 L potting soil + 2 L gravel	8 sprigs water plant (about 120 g) and 2 small land plants	7 L	shade cloth over the sunny half	19.7 on day 18	28 on day 10	2	Heavy condensation on the walls from day 6; plants yellowing on day 19

Simulated results written for teaching. The patterns (oxygen falling with rich soil, temperature climbing in a sealed clear tub in direct sun, condensation blocking light) are realistic, but these numbers were not measured in a real classroom.

Materials the club can buy (prices are teaching estimates)

Item	Cost	Notes
Water plant sprigs (bundle of 5, about 75 g)	\$4	Produce oxygen in light; need light to reach them
Small land plant	\$3 each	Needs soil; adds oxygen in light
Potting soil, 1 L	\$1	Holds roots; contains decomposers
Washed gravel, 1 L	\$1	No decomposers; holds nothing for roots
Shade cloth, 1 m ²	\$5	Cuts sunlight on the covered part by about half
Reflective foil, 1 m ²	\$2	Reflects sunlight; blocks light where applied
Pond snails	free	Two provided by the club; need oxygen in the water and algae or plant matter to eat
Dechlorinated water	free	Any amount up to 12 L

Part A: Define the problem precisely

A criterion describes what success looks like and must be testable with a number or a clear yes/no check. A constraint is a limit the design must stay inside. 'The snails should be happy' is not testable; 'both snails alive and moving on day 21' is.

1. Write three criteria for a successful mini-world, each with the test that would show it was met. At least one must involve oxygen and one must involve temperature.

Answer: Examples of acceptable criteria: (1) Oxygen stays at or above 19.0% on every reading through day 21 (sensor reading). (2) Temperature never exceeds 30 °C and never falls below 15 °C (sensor reading, daily peak). (3) Both snails alive and moving and all plants green on day 21 (visual check). Other acceptable: condensation does not cover more than half of the sunny wall (visual check); carbon dioxide stays below 1% (sensor).

Why: Each criterion must describe success and be testable with a number or a check; the oxygen and temperature criteria are required by the prompt.

Also acceptable: Accept an oxygen threshold between 18.5% and 19.5% and a temperature ceiling between 28 and 31 °C.

- Three criteria
- Each testable with a number or yes/no check
- One oxygen criterion and one temperature criterion

2. List every constraint in the brief. Then add one constraint the brief does not state but that the science demands (think about what a sealed tub cannot do with the energy that enters it).

Answer: From the brief: 20-liter clear tub; sealed to matter for 21 days (nothing opened or added); two pond snails plus living plants; sits on the Room 14 south windowsill; \$25 budget beyond the tub; no electricity; must not get hot enough to harm the animals; only the club's oxygen and temperature sensors. The science-based constraint: energy that enters as sunlight can leave the sealed tub only by conduction through the walls and radiation, not by air exchange, so the design cannot rely on ventilation to control temperature (or: oxygen cannot be replaced from outside, so the plants must produce all of it).

Why: Students should list the stated limits and recognize the unstated one that follows from being closed to matter but open to energy.

Also acceptable: Accept 'no fresh air can enter, so oxygen must come from the plants' as the science-based constraint.

- All stated constraints listed
- One added constraint that follows from the sealed boundary

Part B: Learn from the prototypes

3. For each prototype, name the one feature most worth keeping and explain why the prototype still failed, using energy or matter in your reason.

Answer: P1: keep the soil's ability to hold rooted plants (or its stable temperature, 31 °C max); it failed because decomposers in 4 L of garden soil used oxygen faster than three small plants could replace it (matter: oxygen converted to carbon dioxide). P2: keep the large plant mass (about 150 g), which kept oxygen high; it failed because sunlight (radiation) entered the clear tub all day with no shade and the energy could leave only slowly by conduction through the walls, so the water reached 35 °C. P3: keep the shade cloth and the balance of a little soil with many plants (snails survived, 28 °C max); it failed because condensation on the walls blocked light from reaching the plants, so they yellowed late in the test.

Why: Each prototype has one clear strength and one clear failure mechanism; the failure must be explained with energy or matter, not just restated.

Also acceptable: Accept 'P3's plant yellowing was caused by low light under condensation and shade together.'

- A feature worth keeping for each prototype
- Each failure explained with an energy or matter mechanism

4. P2 had the most plants and the highest oxygen, yet it reached 35 °C and its snails died first. Explain where the energy that heated P2 came from, how it got in, and why it could not get out as easily as it got in.

Answer: The energy came from the sun. It entered as radiation (light) straight through the clear walls and was absorbed by the water, gravel and plants, which warmed. In an open tub warm air would rise away by convection and carry energy off, but the sealed tub trapped its air, so the only exits were conduction through the plastic walls and infrared radiation from the warm surfaces, both slow. Energy came in fast and left slowly, so the tub's temperature climbed to 35 °C.

Why: This is the greenhouse effect of a sealed clear container explained with the lesson's transfer methods; the key is the mismatch between a fast entrance (radiation) and slow exits (conduction and radiation only, no convection to the outside).

Also acceptable: Accept 'like a car parked in the sun with the windows up' if the methods are named.

- Sun as source, radiation as the way in
- Sealed tub removes convection to outside air
- Slow exit by conduction (and radiation) leads to heating

5. P1's oxygen fell to 16.8% while P2's never dropped below 20.6%. Name the difference between the two builds that explains this, and the living things responsible.

Answer: P1 had 4 L of garden soil, P2 had only washed gravel. Garden soil contains decomposers (bacteria and fungi) that use oxygen to break down dead material and release carbon dioxide; gravel contains almost none. Inside a sealed tub their oxygen use shows up as a falling reading because nothing replaces it from outside.

Why: Direct application of the W6 reasoning to new prototypes.

Also acceptable: Accept 'microbes in the soil.'

- Soil versus gravel named
- Decomposers named as the oxygen users

Part C: Your design and its test

6. Fill in your design. Amounts and costs are required. Total the cost at the bottom and check it against the \$25 limit.

Answer: Example design: 1 L potting soil in one corner for 2 land plants plus 2 L gravel elsewhere (\$3); 2 bundles of water plants, about 150 g (\$8) plus 2 land plants (\$6); 7 L dechlorinated water (free); 1 m² shade cloth over the sunny half (\$5) and tub set 10 cm back from the glass; a strip of foil on the top rim of the sunny side to reflect midday sun (\$2). Total \$24. Each row should cite its reason: little soil because of P1's oxygen loss; more plants because P2's oxygen stayed high; shade because P2 overheated and P3 stayed at 28 °C; foil and set-back to reduce the condensation and heating seen in P3.

Why: Any design within \$25 that reduces decomposer load, increases plant mass, controls light to prevent overheating, and addresses condensation is sound. Costs must be summed correctly.

Also acceptable: A gravel-only design with heavy shade is acceptable if the student explains how land-plant criteria are met or argues for water plants only.

- Amounts given for every row
- Cost total at or under \$25
- Each choice linked to a criterion, constraint or prototype result

7. Sketch your tub on the windowsill, viewed from the side. Label the soil or gravel, water, plants, snails, and any shade or foil. Add arrows showing energy entering the tub (label the transfer method) and energy leaving it (label the method), and write 'matter: sealed' on the lid.

Answer: A side-view sketch with labeled soil or gravel, water, plants, snails, and shade or foil; an arrow entering the tub labeled 'radiation (sunlight)'; arrows leaving labeled 'conduction through the walls' and/or 'infrared radiation'; the lid labeled 'matter: sealed.'

Why: The sketch checks that the student represents the tub as closed to matter and open to energy, with the correct transfer methods on the energy arrows.

Also acceptable: Accept 'light' for radiation on the entering arrow.

- All physical parts labeled
- Energy in labeled radiation
- Energy out labeled conduction or radiation
- Lid marked sealed to matter

8. Plan the data your model will generate. State what you will measure, how often, and a **decision rule** for each criterion: a number that, if crossed before day 21, means the design has failed and must be modified (for example: 'if oxygen reads below ___ on any day, stop and change ___').

Answer: Example plan: read oxygen and temperature every day at 8:00 and 14:00 (the daily peak); photograph the plants and note snail movement every three days; estimate condensation coverage with a grid drawn on the wall. Decision rules: if oxygen reads below 19.0% on any day, stop and reduce soil or add plants in version 2; if temperature exceeds 30 °C on any afternoon, stop and add shade or move the tub back; if condensation covers more than half the sunny wall for three days, stop and add foil or reduce water volume. Each rule names a number and the change it triggers.

Why: This is the heart of MS-ETS1-4: the model generates data and the data drive a modification. Rules must contain thresholds and named changes.

Also acceptable: Accept a single afternoon temperature reading per day if the student explains that the peak is what matters.

- What is measured and how often
- A numeric threshold for each criterion
- A named modification tied to each threshold

Part D: Justify and plan the next version

9. Justify your design in a paragraph. Explain how each major choice meets a criterion or constraint, which prototype result it is based on, and what trade-off you accepted (something you gave up to get something else). Use the words radiation, conduction, decomposers and closed to matter correctly.

Answer: Model response: My design keeps the plants of P2 and the shade of P3 while cutting P1's soil. Sunlight enters the sealed tub by radiation and can leave only slowly by conduction through the walls, so I shade the sunny half and set the tub back from the glass to keep the peak below 30 °C, the temperature criterion. Because the tub is closed to matter, no oxygen can come in, so I use 150 g of water plants, the amount that kept P2's oxygen above 20%, to meet the oxygen criterion. I keep only 1 L of potting soil, enough for two land plants, because P1 showed that decomposers in 4 L of garden soil used oxygen faster than plants replaced it. The trade-off: less soil means fewer land plants and a plainer display, and shade means slower plant growth; I accepted both to keep the snails alive, which is the criterion that cannot be recovered if it fails. Total cost \$24, inside the constraint.

Why: Full credit requires: each major choice tied to a criterion or constraint, prototype evidence cited, a stated trade-off, and correct use of the four required terms.

Also acceptable: A different design with the same reasoning quality earns full credit.

- Choices tied to criteria and constraints
- Prototype results cited as evidence
- A trade-off named
- Radiation, conduction, decomposers and closed to matter used correctly

10. Suppose your test reaches day 10 with oxygen at 19.2% and falling about 0.2 points per day. Predict the day-21 reading if nothing changes, decide whether a modification is needed, and state the **one** change you would make for version 2. Explain why engineers change one thing at a time.

Answer: Prediction: 11 more days $\times$ 0.2 points per day = 2.2 points; $19.2 - 2.2 = 17.0\%$ on day 21, below the 19% criterion, so a modification is needed. One change for version 2: add one bundle of water plants (about 75 g) or remove half of the soil; pick one. Engineers change one thing at a time so that if the next test improves (or worsens), they know which change caused it; two changes at once would leave the cause unknown.

Why: The calculation is linear extrapolation; the single-variable rule is the core of iterative testing.

Also acceptable: Accept 'about 17%' with the multiplication shown; accept any single sound change.

- Day-21 prediction about 17% with the calculation
- Decision that modification is needed
- One specific change
- One-change-at-a-time reasoning

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Criteria and constraints (Part A)	Three testable criteria with numbers or checks, including oxygen and temperature; all stated constraints listed plus a science-based one about energy or matter at the sealed boundary.	Three criteria, one lacking a test; constraints listed without the added science-based constraint.	Criteria vague or mixed with constraints; constraints incomplete.	Part A missing or copied from the brief without change.

Use of prototype data (Part B)	Each prototype's best feature and failure mechanism identified with energy or matter reasoning; P2's heating and P1's oxygen loss explained correctly.	Features and failures identified; one mechanism thin (for example 'it got too hot') without the energy pathway.	Only outcomes restated (died, overheated) without mechanisms.	Prototype data ignored or misread.
Design and test plan (Part C)	Amounts and costs given, total within \$25, every choice linked to evidence; sketch shows energy in and out with correct methods and a sealed lid; data plan has thresholds and named modifications for each criterion.	Design complete and within budget; one link to evidence or one decision rule missing.	Design lacks amounts or exceeds budget; data plan lists measurements without decision rules.	Design incomplete or unrelated to the brief.
Justification and iteration (Part D)	Paragraph ties each choice to a criterion and a prototype result, names a trade-off, uses all four required terms correctly; q10 predicts about 17%, chooses one change and explains one-at-a-time testing.	Justification sound but a term misused or the trade-off missing; q10 correct.	Justification restates the design; q10 prediction or reasoning incomplete.	Justification absent or contradicts the design.

Teacher notes

The prototype dataset and prices are simulated teaching values; the mechanisms are real. Three science points the sheet depends on: a sealed clear container in direct sun heats because radiation enters quickly while energy leaves only by conduction through the walls and infrared radiation (no air exchange); soil decomposers consume oxygen and release carbon dioxide; condensation on cool walls scatters light. Pond snails tolerate roughly 15 to 28 °C and suffer above about 30 °C, which is why the temperature criterion matters. If pairs go on to build their design (an optional follow-up; none of this chapter's labs builds a sealed tub), animals require a care plan and the teacher's approval; a plant-only version is acceptable and avoids animal-welfare concerns. The extension's Biosphere 2 facts are real: about 1.3 hectares (3.14 acres) under glass, eight crew members for two years (1991-1993), oxygen falling from about 21% to about 14% in roughly sixteen months, with soil microbes identified as the cause.

Scaffold offered to students: Borrow the best, fix the worst

If designing from scratch feels like too much, start from P3, the only prototype whose snails survived, and ask three questions: What went wrong in P3 (condensation blocking light, plants yellowing)? Which P2 feature would fix that (more plants, but P2 also overheated)? Which P1 result warns you about adding soil (decomposers using oxygen)? A design that keeps P3's shade, uses a little less soil than P3, adds a few more water plants, and moves the tub slightly back from the glass is a reasonable starting point; your job is to say how much and why.

Extension: Scale it up to Biosphere 2

The real Biosphere 2 in Arizona enclosed about 1.3 hectares of land under glass and sealed in eight people for two years. Its oxygen fell from about 21% to about 14% in roughly sixteen months, and the cause turned out to be soil microbes. Compare your mini-world's decision rules with what Biosphere 2's designers would have needed: what measurements, what thresholds, and what modifications are possible when you cannot open the lid for two years? Write a short memo (one page) advising the designers on one change you would have made before sealing the doors, based on your prototype analysis.