

Pouring Energy Up the Pyramid: A Water Model of Trophic Levels

Investigation question: If producers capture 1,000 units of energy, how many trophic levels can that energy support, where does the rest go, and how does the answer change if the share passed up is larger or smaller than one tenth?

Physical model

Groups of 4

1 session

Setup 5 · Activity 42 · Cleanup 8 min

MS-LS2-3 · assesses

MS-LS2-1 · supports

Scientific purpose

Students use colored water as a stand-in for energy. A liter in the producer bottle is poured up a line of cups, passing on only a measured fraction at each level while the rest is split between a heat jug and a decomposer jug. They watch 1,000 mL become 100, 10, 1 and two drops, account for every milliliter at the end, graph the pyramid on two scales, and then rerun the model with a different transfer fraction to see why real food chains rarely have more than four or five levels and why the ten-percent figure is only a rule of thumb.

Why this helps students with this chapter

Students can recite 'ten percent' without any sense of how fast that shrinks a quantity. Measuring 100 mL into a cup, then 10 mL, then drawing 1 mL into a syringe, then squeezing out two drops makes the collapse physical and memorable. Pouring the other nine tenths into labeled jugs, and finding that the jugs plus the cups add back up to the liter, settles the difference between 'energy lost' and 'energy that left as heat'. Rerunning with a different fraction turns the ten-percent rule into what it really is, an average that varies.

Standards connections

MS-LS2-3 (assesses, the energy-flow half: modeling energy entering, being passed on in shrinking shares and leaving as heat): Students run a physical model in which energy enters once, a measured fraction moves to each next level, and the remainder leaves to heat or decomposers. The accounting table and the graph are evidence that they can model energy flow through an ecosystem, within the PE's boundary (no chemical reactions).

MS-LS2-1 (supports, energy as the resource that limits how many levels and organisms an ecosystem can hold): The run shows that the energy resource shrinks so fast that a fifth or sixth level cannot be supported; this is background for reasoning about resource availability and population size.

Roles (rotate each session)

- **Pourer:** Transfers water from each level to the next using the correct measuring tool, and pours the remainder into the heat and decomposer jugs as the accountant directs.

- **Measurer:** Reads every cylinder and syringe at eye level, calls the volume aloud, and confirms it before the pourer continues.
- **Recorder:** Fills the energy-accounting table row by row and plots the two graphs.
- **Accountant and checker:** Computes what each level should receive before it is poured, keeps the running totals for the heat and decomposer jugs, and runs the final sum check.

Materials

Item	Quantity	Per	Note
1-liter bottle of tap water tinted with a few drops of food coloring, labeled 'Level 1: producers'	1 (plus a refill for round 2)	group	Blue or green shows up best in the cups.
Clear plastic cups labeled 'Level 2', 'Level 3', 'Level 4', 'Level 5'	4	group	
Large containers (about 1 L) labeled 'Heat to surroundings' and 'Wastes, remains and uneaten: to decomposers'	2	group	Empty yogurt tubs or 1 L food containers work.
100 mL graduated cylinder	1	group	
10 mL graduated cylinder	1	group	
1 mL oral syringe marked in tenths of a milliliter	1	group	Pharmacies sell them cheaply; a dropper calibrated at about 20 drops per mL is a fallback.
500 mL or 1 L measuring jug for the final sum check	1	group	Two groups can share.
Plastic tray or baking sheet to catch spills, and paper towels	1 tray, a few towels	group	
Calculator and the recording sheet	1 calculator per group, 1 sheet per student	group	

Estimated cost: 8 to 14 per class (an estimate; Oral syringes about \$0.30 each, a bottle of food coloring about \$3, a sleeve of clear cups about \$4; cylinders, jugs and trays are classroom stock. Water is reused between rounds.)

Safety

- Water on the floor is a slip hazard; keep all pouring over the tray and wipe spills at once.
- Food coloring stains skin, clothing and paper; roll up sleeves and keep the recording sheet away from the tray.
- The water is not for drinking; cups and syringes used here go back in the kit, not to mouths.
- Keep phones and calculators off the tray. No hazards beyond water and dye.

Teacher preparation and setup

1. Tint one liter of water per group plus one refill liter per group (the water from round 1 can be collected from the jugs and reused). Check that the bottle really holds 1,000 mL by filling it from a graduated cylinder or jug.
2. Label cups and jugs ahead of time; the labels are what make the model readable.
3. Practice the 0.1 mL step yourself with the syringe so you can show students how to draw up 1 mL and expel 0.1 mL (about two drops).
4. Write the transfer rule for round 1 on the board: pass on one tenth, pour about two thirds of the rest into Heat and the rest into Decomposers. Assign round 2 fractions to groups before class: 5 percent, 20 percent and 30 percent, with at least one group of each.
5. Decide the 'survival line' and post it: in this model a level exists only if it receives at least 1 mL.

Investigation design

Independent variable	The fraction of energy passed from one level to the next (10 percent in round 1; 5, 20 or 30 percent in round 2).
Dependent variable	The volume received by each level and the number of levels that receive at least 1 mL.
Controlled	Starting volume of 1,000 mL in the producer bottle; The same survival line of 1 mL for every group; The same two-to-one split of the remainder between heat and decomposers; The same measuring tools at each step
Trials	One run per group per fraction; the class pools round 2 results so every fraction has at least one measured run.
Comparison	Number of levels supported at 5, 10, 20 and 30 percent, and the volume reaching level 4 under each.

Student procedure

1. Before pouring, the accountant fills in the 'should receive' column of the round 1 table for levels 2 to 5 using the ten-percent rule (divide by 10 each step), and the group writes a prediction for q1: how many levels will receive at least 1 mL?
2. Level 1 to level 2: measure 100 mL from the producer bottle with the 100 mL cylinder and pour it into the Level 2 cup. Record 100 mL received at level 2. Pour the remaining 900 mL from the bottle into the two jugs, about 600 mL into Heat and 300 mL into Decomposers, using the jug marks as a rough guide. Record the split.
3. Level 2 to level 3: measure 10 mL from the Level 2 cup with the 10 mL cylinder and pour it into the Level 3 cup. Pour the remaining 90 mL into the jugs in the same two-to-one split (about 60 and 30 mL, measured with the 100 mL cylinder). Record.
4. Level 3 to level 4: draw 1 mL from the Level 3 cup with the syringe and squeeze it into the Level 4 cup. Pour the remaining 9 mL into the jugs (about 6 and 3 mL, using the 10 mL cylinder). Record.

5. Level 4 to level 5: draw up the 1 mL from the Level 4 cup and expel 0.1 mL, about two drops, into the Level 5 cup; put the remaining 0.9 mL into the jugs. Record. Try to pass a tenth of the two drops to a sixth level and write what happens in q2.
6. Sum check: pour the Heat jug into the measuring jug and record the volume; do the same for the Decomposers jug; add what is still in the five level cups (level 1 is empty, levels 2 to 5 hold what they received minus what they passed on, which is the 'kept' column). Write the total in q3 and compare it with 1,000 mL.
7. Graph the volume received at each level on the first graph (0 to 1,000 mL). Then graph levels 2 to 5 again on the second graph (0 to 100 mL). Keep both; the analysis asks about them.
8. Round 2: collect the water from the jugs and cups back into the producer bottle, top it up to 1,000 mL, and rerun the transfers using your group's assigned fraction (5, 20 or 30 percent). Compute each 'should receive' value first, measure as before, and stop when the next level would get less than 1 mL. Record the number of levels supported.
9. Report your fraction and the number of levels supported on the class chart. Copy the class results into the round 2 summary table, then answer the analysis questions individually.

Expected observations

- Round 1 volumes: 1,000, 100, 10, 1 and about 0.1 mL (two drops). Trying to pass a tenth of two drops fails; there is nothing measurable to pour.
- The sum check totals 950 to 1,000 mL; the shortfall is spills and water clinging to cylinders, which students should name rather than blame on 'energy loss'.
- Round 2 at 20 percent gives 200, 40, 8 and 1.6 mL, so five levels; at 5 percent it gives 50 and 2.5 mL, so three levels; at 30 percent it gives 300, 90, 27, 8.1 and 2.4 mL, so six levels.
- The full-scale graph shows one tall bar and nothing visible past level 2; the zoomed graph shows the 100, 10 and 1 mL steps clearly.

Likely difficulties

- Reading the 10 mL cylinder and the syringe: insist on eye level and on the bottom of the curved surface. A 10 mL error at level 2 becomes a 1 mL error at level 3 and wrecks level 4.
- Groups forget to pour the remainder into the jugs before moving on, so the level cup still holds 90 mL and the sum check comes out high. The accountant's 'kept in cup' column catches it.
- Students treat the two-to-one heat-to-decomposer split as a law. Say plainly that it is a teaching simplification; the real split depends on the organisms.
- Round 2 arithmetic with 30 percent produces decimals (8.1, 2.43); allow rounding to one decimal and measuring to the nearest 0.1 mL.
- Time: if round 2 is running late, let groups compute round 2 and pour only the first two transfers to confirm the arithmetic.

Structured debrief

1. Collect every group's sum check on the board. Most totals will be a little under 1,000 mL; ask where the missing water went (drops on the tray, wet cylinder walls). Then make the point: in the real ecosystem the

heat is just as real as the water in the jug; it has not vanished, it has spread into the surroundings where no plant can gather it.

2. Compare the two graphs. On the full-scale graph levels 4 and 5 are invisible, which is the honest picture of how little reaches a top predator. On the zoomed graph they appear, which is what scientists do when they draw a pyramid with layers that are not to scale. Ask which graph a newspaper should print and why.
3. Build the class line: fraction passed up versus levels supported (5 percent: 3 levels; 10 percent: 4; 20 percent: 5; 30 percent: 6). Ask why real ecosystems with many cold-blooded animals, such as some ocean food webs, can have longer chains than a grassland full of mammals and birds.
4. Close on q6 and q10 together: the model gets energy right (in once, out as heat) and matter wrong (it has no loop). Ask what the Lab 1 web had that this model lacks: the air and soil card. Matter cycles, energy flows.

Recording sheet: what students fill in

Lab 2 recording sheet: Pouring energy up the pyramid

In this model **1 mL of colored water stands for 1 unit of energy**. The producer bottle holds the 1,000 units the plants captured from sunlight this year. At each level only part of the energy is passed up as food; the rest leaves as heat or goes to decomposers in wastes, remains and uneaten parts. A level exists in our model only if it receives at least 1 mL.

Round 1: ten-percent rule of thumb

Level	Should receive (mL)	Actually received (mL)	Passed up to next level (mL)	To Heat jug (mL)	To Decomposers jug (mL)	Kept in cup (mL)
1 Producers	1,000	1,000				0
2						
3						
4						
5						
6						

1. Prediction before pouring: how many levels will receive at least 1 mL? Explain your reasoning in one sentence.

Answer: Four levels (1,000, 100, 10 and 1 mL). Level 5 would receive 0.1 mL, which is below the 1 mL survival line.

Why: Students divide by ten each step. Accept a prediction of five if the student counts the two drops as a level and says so.

- A number of levels
- Reasoning that uses dividing by ten

2. What happened when you tried to pass a tenth of level 5's two drops to a sixth level? What does this say about how many trophic levels a food chain can have?

Answer: A tenth of two drops is a fraction of a drop; there is nothing measurable to pour, so level 6 gets effectively nothing. Real food chains stop after three to five levels because the energy passed up shrinks so quickly that there is not enough left to keep a population alive.

Why: The physical failure at the syringe is the point; the student should connect it to chain length.

- Describes the failure to transfer a measurable amount
- Links it to the limited number of trophic levels

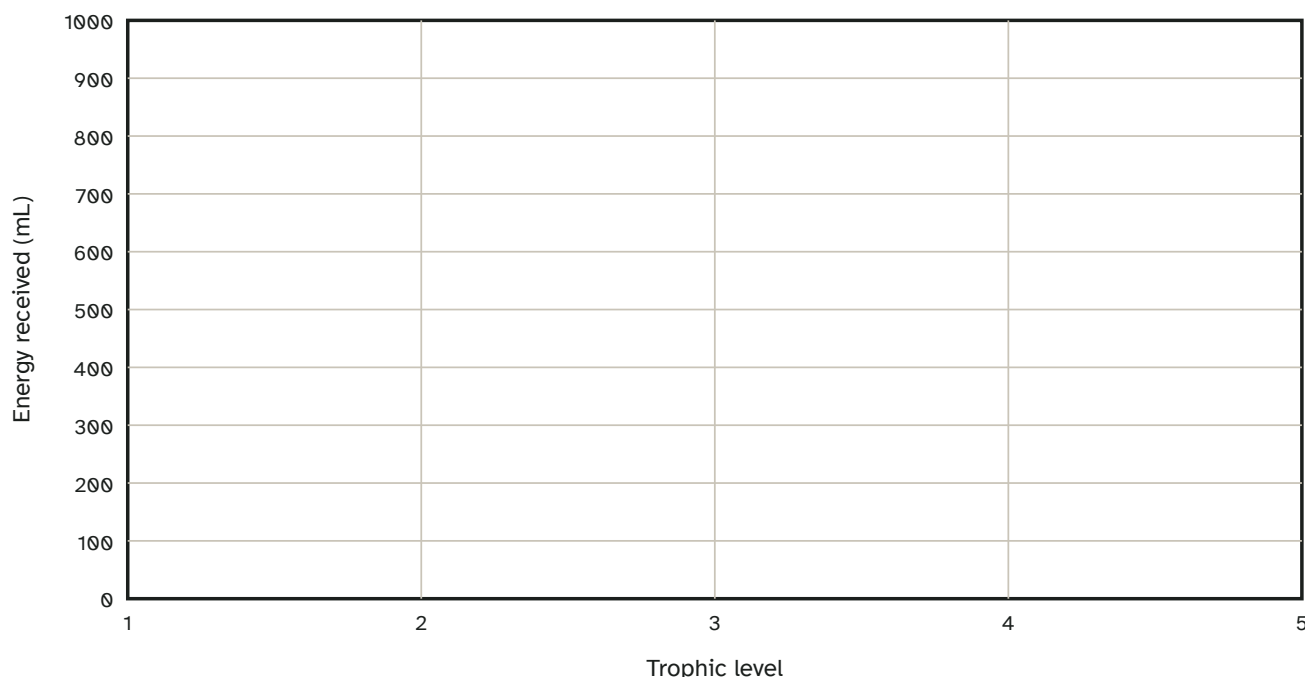
- 3.** Sum check. Heat jug: ___ mL. Decomposers jug: ___ mL. Still in the level cups: ___ mL. Total: ___ mL. How close is this to 1,000 mL, and where did any difference come from?

Answer: Group-specific. Ideal: Heat about 667 mL, Decomposers about 333 mL, cups about 0.1 mL (only the two drops kept at level 5; levels 2 to 4 each passed on a tenth and poured the rest into the jugs, though in practice a few mL cling to every cup), total 1,000 mL. Typical measured totals are 950 to 1,000 mL; the difference is spills and water left on cylinder walls.

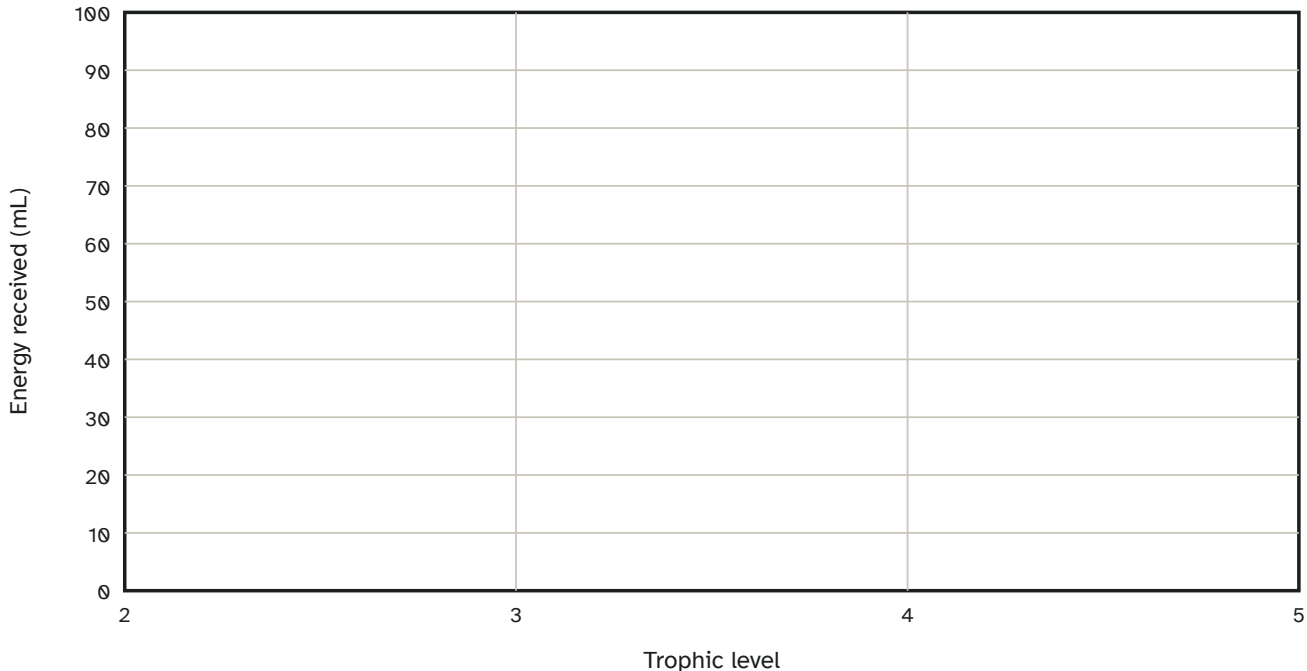
Why: The heat total should be about two thirds of the 999 mL that did not reach level 5 and the decomposer total about one third. The key idea is that the total is close to 1,000: the water (energy) did not disappear.

- All four blanks filled with the group's measurements
- Total compared with 1,000 mL
- Any shortfall explained by spills or clinging water, not by 'energy loss'

Energy received at each level (full scale)



Energy received at levels 2 to 5 (zoomed scale)



Round 2: class results for different transfer fractions

Fraction passed up	Level 2 (mL)	Level 3 (mL)	Level 4 (mL)	Level 5 (mL)	Level 6 (mL)	Levels with at least 1 mL
5 percent						
10 percent						
20 percent						
30 percent						

Analysis questions: answer key

4. Using your round 1 table, explain in your own words why a food chain that starts with 1,000 units of producer energy cannot feed a sixth level, and why most real food chains have only three to five levels.

Answer: Each level receives only a tenth of the level below: $1,000 \rightarrow 100 \rightarrow 10 \rightarrow 1 \rightarrow 0.1$. By level 5 there is a tenth of a milliliter, and a sixth level would get a hundredth, far below the survival line. In a real chain the energy that reaches a high level is too little to keep a breeding population alive, so chains usually stop at three to five levels. The nine tenths that do not move up were used for living and left as heat, or went to decomposers in wastes, remains and uneaten parts.

Why: Full credit needs both the arithmetic collapse and the biological meaning (a population needs enough energy to survive and reproduce).

- Shows the division-by-ten sequence
- Explains the survival line idea
- Mentions where the other nine tenths went

5. Your sum check should come close to 1,000 mL. What does that result say about the phrase 'energy is lost between levels'? Rewrite the phrase so that it is accurate.

Answer: The total comes back to about 1,000 mL, so no energy disappeared; it simply ended up in the heat and decomposer jugs instead of the next cup. 'Energy is lost between levels' is misleading. Accurate: 'Between levels, most of the energy leaves the food chain as heat or goes to decomposers, so only a small share is passed up.'

Why: This is the conservation idea in the CCC Energy and Matter. The rewrite must say where the energy went.

- Uses the sum check as evidence of conservation
- States that 'lost' is misleading
- Rewrites the phrase naming heat and decomposers

6. In the model you could pour the Heat jug back into the producer bottle for round 2. In a real ecosystem, can the heat released by organisms be captured again by producers? Explain where the model stops matching reality.

Answer: No. The heat released by organisms spreads into the air, water and ground and is far too spread out and low in temperature for any producer to capture; producers can only capture light. The model breaks here: water in the heat jug is still usable water that can be poured back, but real heat cannot be poured back into plants. That is why an ecosystem needs new sunlight every day while the model could, wrongly, run forever on recycled water.

Why: This is the central limit of the model and the chapter's central contrast.

- States that heat cannot be recaptured by producers
- Identifies the pour-back as where the model fails
- Connects to the need for continual sunlight

7. Compare the class results for 5, 10, 20 and 30 percent. Describe the pattern in the number of levels supported, and suggest which kinds of animals (for example cold-blooded versus warm-blooded) might pass on a larger fraction of what they eat, and why.

Answer: More levels are supported as the fraction rises: 5 percent gives 3 levels, 10 percent 4, 20 percent 5, 30 percent 6. Cold-blooded animals such as insects, fish and reptiles do not spend energy keeping their bodies warm, so a larger share of what they eat can become new tissue that the next level can eat; warm-blooded mammals and birds burn most of their food as heat to stay warm, so they pass on a smaller share. That is one reason some ocean food webs, full of cold-blooded animals, have longer chains than a grassland of mammals and birds.

Why: The pattern should come from the class table; the biology is the explanation of why efficiency varies. Measured efficiencies for ectotherms are often above ten percent and for endotherms often well below.

- States the levels-supported pattern with numbers
- Proposes cold-blooded animals as higher-efficiency and gives the heat reason
- Treats ten percent as an average

8. A hawk population at level 5 needs 10 units of energy a year. Using the ten-percent rule of thumb, how many units must the producers capture? Show the calculation. Then explain why a preserve can hold thousands of grasshoppers but only a few hawks.

Answer: 100,000 units. Level 5 needs 10; level 4 must hold 100; level 3, 1,000; level 2, 10,000; level 1 (producers), 100,000 units. Each step multiplies by 10 going down. Because so much producer energy is needed for every unit at the top, the preserve's grass can support thousands of grasshoppers at level 2 but only a few hawks at level 5.

Why: Students multiply by ten four times. Accept the answer written as 10×10^4 .

Also acceptable: If a student treats the hawk as level 4 (grass → mouse → snake → hawk), the answer is 10,000 units; give credit when the chain is stated and the multiplication is correct.

9. The decomposers jug received a large share of the water. Decomposers are living consumers too. What eventually happens to the energy in that jug in a real ecosystem, and what does that mean for where all of the 1,000 units end up in the long run?

Answer: Decomposers use that energy to live, and like every consumer they release most of it as heat as they respire; a little passes to animals that eat decomposers, and that also ends as heat. So in the long run essentially all 1,000 units leave the ecosystem as heat. The decomposer jug is a delay, not a different destination.

Why: This extends the heat idea to the decomposer pathway. Energy in remains is still energy flowing through consumers.

- States decomposers respire and release heat
- Concludes that nearly all energy ends up as heat
- Does not claim decomposers return energy to producers

10. This model tracks energy only. Why can it not show matter cycling, and what single change to the model would let it show that matter comes back to the producers?

Answer: The model has no loop: nothing goes from the jugs back to the producers, and the water stands for energy, which should not loop. To show matter cycling you would add a separate set of tokens for atoms (for example beads) that move with the water up the levels, go to the decomposer jug with wastes and remains, and are then carried from the decomposer jug to a 'soil and air' container that feeds the producer bottle again, while the water (energy) still only ever goes to the heat jug.

Why: The strongest answers keep energy and matter as separate currencies with different fates. Any design that returns matter to producers without returning energy earns credit.

- Explains that the model tracks only energy and has no return path
- Proposes a specific matter token and a return route through air and soil
- Keeps energy from returning

Individual evidence of learning

Each student submits their own round 1 table, both graphs, the round 2 class table and answers to q1 through q10. The accounting table with the sum check and q5 are the evidence for conservation and energy leaving as heat; q4, q7 and q8 are the evidence for pyramid reasoning with numbers.

Assessment criteria

Criterion	Proficient looks like
Measurement and accounting	Round 1 table complete with received, passed up, heat, decomposer and kept values that are consistent row by row; sum check within about 50 mL of 1,000 with the difference explained.
Pyramid arithmetic	Correctly predicts each level's share for 10 percent and for the assigned round 2 fraction; q8 shows 100,000 units with the calculation.
Energy flow reasoning	Explains that energy is conserved but leaves as heat that producers cannot recapture, and rewrites 'lost' accurately (q5, q6).
Interpreting the rule of thumb	Uses class data to show that levels supported rise with the transfer fraction and treats ten percent as an average, not a fixed value (q7).
Model limits	States that the model has no matter loop and proposes a specific addition, such as a return path from the decomposer jug to a 'soil and air' container that refills the producers' matter, not their energy (q10).

Accessibility adaptations

- Provide a pre-filled 'should receive' column and a decade chart (1,000, 100, 10, 1, 0.1) for students who need support with the arithmetic.
- Let a student with limited fine-motor control take the measurer or accountant role; a wide-mouth cup with a 100 mL line drawn on it can replace the cylinder for the first pour.
- Offer large-print labels and high-contrast dye (dark blue) for students with low vision; the measurer calls every reading aloud.

- Accept a spoken explanation for q4 to q7 recorded on a device, and allow the graphs to be built with pre-cut paper bars.

Low-cost alternative

Use dried beans or rice instead of water, with 100 beans standing for the 1,000 units (each bean = 10 units): 100 beans to level 1, 10 to level 2, 1 to level 3, and the fourth level cannot be fed because a bean cannot be split. The same tables apply with the numbers divided by 10; the sum check counts beans.

Model limitations

Water is matter, so students must keep reminding themselves that here it stands for energy; the model has no matter loop at all, and pouring the heat jug back for round 2 is a step the real world cannot take. The ten-percent transfer, the two-to-one heat-to-decomposer split and the 1 mL survival line are teaching simplifications; real transfer efficiencies vary widely, and a real level's energy is spread among many organisms rather than held in one cup. The model also ignores time: in a real ecosystem energy flows continuously as the sun keeps refilling the producers. This activity has not been physically tested by the authors; volumes below 1 mL are hard to measure, and the two-drop step is an approximation.

Teacher notes

Check row-by-row consistency in the round 1 table (received = passed up + heat + decomposer + kept). For q8, accept either 100,000 (five-level chain as stated) or 10,000 with a stated four-level chain. The class line for q7 is the key output; post it so W5 can refer to it. If syringes are unavailable, stop pouring at level 4 and have students compute level 5; the failure at level 6 can be argued from the arithmetic.