

Spare the Snail-Eaters: Design a Net That Lets By-Catch Escape

Investigation question: Can your team design a net that keeps the large fish a village needs while letting at least 8 of every 10 small snail-eating fish slip through, using no more than 20 strands of string?

Engineering design challenge

Groups of 4

1 session

Setup 5 · Activity 45 · Cleanup 5 min

MS-ETS1-1 · practice

MS-LS2-5 · practice

MS-ETS1-2 · practice

Scientific purpose

Students take on the Lake Malawi design problem: fishing families need the large fish, but the small fish that eat disease-carrying snails must survive. With dry pasta as fish (rigatoni for the large target species, ditalini for the small snail-eaters), groups measure their fish, sharpen the starting criteria and constraints into measurable statements, build a string-mesh lift net on a cardboard frame, test it in three standard hauls, modify it from the results and retest. The class then pools every design into one graph of percent kept against mesh opening, the same kind of selectivity curve fisheries scientists use when they set mesh rules.

Why this helps students with this chapter

Mesh size is the lesson's own solution, and it is easy to say and hard to get right. Students find that the right opening is set by the sizes of the animals, that string thickness and slipping strands change the real opening, and that the two criteria pull against each other: smaller holes keep more of the target and more by-catch, while bigger holes release by-catch and lose some of the target. Writing criteria with numbers before building forces precision, testing and rebuilding makes iteration real, and pooling class data shows a pattern no single group could see.

Standards connections

MS-ETS1-1 (practice, stating criteria and constraints precisely, including impacts on people and the environment): Students start from supplied criteria (keep the large fish, release the small fish) and constraints (string budget, build time, durability), add one measurable criterion or constraint of their own, and use measured fish sizes to define the opening range a solution must hit. Because the core criteria are supplied, this is practice toward the PE.

MS-LS2-5 (practice, comparing competing designs by how well they maintain a by-catch species): The class compares many net designs by how well they spare the small snail-eating fish while still feeding families, a design problem about maintaining a species whose survival protects people from disease. It is a single, simplified criterion set, so it is practice toward evaluating competing solutions for biodiversity and ecosystem services.

MS-ETS1-2 (practice, evaluating competing designs with shared test data): Every design is tested the same way and judged against the same two numerical criteria, and the class graph lets students compare designs

systematically. The test procedure is supplied, so this is practice.

Roles (rotate each session)

- **Measurer and designer:** Measures the pasta, proposes the spacing, marks tick lines on the cardboard border and checks the spacing with a ruler as strands go on.
- **Builder:** Tapes strands snugly across the window at the marked spacing and keeps count against the 20-strand budget.
- **Hauler:** Runs every haul the same way: same pour height, same straight lift, five gentle shakes counted aloud.
- **Data manager:** Counts kept and escaped fish of each kind, fills the tables, calculates percentages and posts the group's results on the class chart.

Materials

Item	Quantity	Per	Note
Dry rigatoni pasta (large target fish)	15 pieces	group	Most brands are about 14 to 16 mm across; measure yours.
Dry ditalini pasta (small snail-eating fish)	30 pieces	group	About 7 to 9 mm across. Small elbow macaroni can substitute; measure it.
Corrugated cardboard frames, 20 cm × 20 cm, with a 12 cm × 12 cm window cut in the center	3	group	The teacher cuts the windows in advance.
Cotton kitchen twine or similar string about 1.5 mm thick, pre-cut into 18 cm strands	45 strands	group	Twenty for each design plus spares.
Masking tape	1 roll	group	
Plastic tub or shallow bin at least 25 cm across (the lake)	1	group	
Small cup holding one haul (10 rigatoni and 20 ditalini)	1	group	
Metric rulers with millimeter marks	2	group	
Blunt-tip scissors	1	group	
Recording sheet	1	student	
Class chart and blank class graph on the board or poster paper	1	class	

Estimated cost: 8 to 11 per class (estimate) (an estimate; A 1 lb box each of rigatoni and ditalini, about \$1.50 to \$2 each, supplies every group with spares; a roll of cotton twine is about \$3 to \$4; printing a recording sheet of about 3 pages per student is about \$2 to \$3 at 2 to 3 cents a page; cardboard comes from shipping boxes; tubs, rulers, tape and scissors are classroom stock. The pasta can be bagged and reused for several classes.)

Safety

- Wheat allergy or celiac disease: dry pasta sheds flour dust. Students with a wheat allergy use the plastic-bead version described in the low-cost alternative, or take the data-manager role and wear gloves.
- The pasta is not food once it has been handled: no eating it, and wash hands after the lab.
- Only the teacher uses the craft knife, before class. Students use blunt-tip scissors to trim string.
- Dropped pasta is slippery on hard floors and breaks into sharp little shards; sweep it up rather than stepping on it, and never throw pasta.

Teacher preparation and setup

1. Cut a 12 cm × 12 cm window in the center of each 20 cm × 20 cm cardboard square with a craft knife on a cutting mat, before class and away from students. Make 3 frames per group.
2. Pre-cut the string into 18 cm strands and bundle 45 per group so strand counting is easy.
3. Measure a few rigatoni and ditalini from your boxes across their narrowest width (the tube diameter). If the ditalini are wider than 10 mm or the rigatoni narrower than 13 mm, swap in another shape so the two sizes differ by at least 4 mm.
4. Count 10 rigatoni and 20 ditalini into a cup for each group (the standard haul), plus a few spares of each.
5. Draw the class chart and a blank class graph: clear mesh opening from 0 to 24 mm on the x-axis, percent kept from 0 to 100 on the y-axis.
6. Make one demonstration frame with strands about 12 mm apart so you can show the taping method, but do not test it in front of students.

Investigation design

Independent variable	The mesh opening, set by the spacing between strands in each direction (plus any other single change a group makes for design 2).
Dependent variable	Percent of large fish kept and percent of small fish released over three hauls.
Controlled	The same 10 rigatoni and 20 ditalini in every haul; The same 12 cm window, string type and taping method; The same pour height, lift height and five shakes; The same hauler for every haul of a design
Trials	Three hauls per design; the class pools every group's designs so that a range of openings is tested.
Comparison	Design 1 versus design 2 within each group; all class designs compared by clear opening on one graph.

Student procedure

1. Measure your fish. Measure the narrowest width (the tube diameter) of 3 rigatoni and 3 ditalini to the nearest millimeter, record them and find each average. Answer q1.
2. Sharpen the problem. Read the starting criteria and constraints. In q2, add one criterion or constraint of your own, written so it can be checked with a number or a yes/no test.

3. Plan design 1. Choose the spacing between strands in each direction (center to center), work out how many strands it needs on a 12 cm window (no more than 20), sketch the grid, and predict the percent of each fish it will keep (q3 and the sketch).
4. Build design 1 in 12 minutes or less. Mark tick lines on the cardboard border at your spacing. Tape one set of strands across the window, pulling each snug, then a second set at right angles to make a grid. Tape only on the cardboard, never across the window. Record the strands used.
5. Haul test. Lay the net flat in the bottom of the empty tub. Pour the haul cup (10 rigatoni, 20 ditalini) onto the window from about 5 cm above, and push any fish resting on the cardboard border onto the window. Lift the frame straight up about 15 cm, hold it level, and shake it gently side to side 5 times, counting aloud. Fish still on the net are kept; fish in the tub escaped.
6. Count and record the kept and escaped fish of each kind, return all 30 to the cup, and repeat for three hauls in all with the same hauler, pour height and number of shakes. A ditalini stuck inside a rigatoni counts as kept.
7. Calculate the percent of large fish kept ($\text{large kept} \div 30 \times 100$) and the percent of small fish released ($\text{small escaped} \div 60 \times 100$), and check each criterion and constraint.
8. Modify. Use your results to change one thing (the spacing in one or both directions, the number of strands, or how the strands are fixed), build design 2 on a fresh frame, write your evidence in q4, and run three more hauls.
9. Measure the clear opening of your better design: the gap between the edges of neighboring strands, not center to center, at three places, then average. Post the opening, strands used and both percentages on the class chart, and plot the class data on your graph: percent of large fish kept and percent of small fish kept against opening.
10. Clean up: bag the pasta for reuse, strip tape from the frames, sweep up broken pieces and wash hands. Answer the analysis questions on your own.

Expected observations

- These are predictions; the activity has not been physically tested. With ditalini about 8 mm and rigatoni about 15 mm wide, clear openings under about 8 mm keep nearly all the small fish; openings of roughly 10 to 13 mm should release most small fish while keeping nearly all large fish; openings above about 15 mm let rigatoni slip through end-first during the shakes.
- Planned and measured openings differ: string 1.5 mm thick makes the clear opening about 1.5 mm smaller than the center-to-center spacing, and strands taped loosely sag or drift.
- A few small fish stay even on good nets, wedged where strands cross, resting on a sagging strand or caught inside a rigatoni tube; a few large fish escape over the frame edge if the lift tilts.
- A square grid at 12 mm spacing needs 9 strands each way (18 in all) on the 12 cm window. A rectangular grid of about 11 mm by 20 mm ($10 + 5 = 15$ strands) can also stop the rigatoni and release the ditalini, because a fish passes only if both sides of the opening are wider than the fish.

Likely difficulties

- Uneven spacing from measuring each strand by eye. Have the measurer mark tick lines on the cardboard border first, then tape strands to the ticks.

- Loose strands that sag under the pasta make the middle openings bigger. Pull each strand snug before taping its second end.
- Inconsistent hauls: a higher pour or harder shaking changes the results more than the mesh does. Keep one hauler per design and count shakes aloud.
- Ditalini hiding inside rigatoni. Count them as kept, since real small fish also get trapped in a catch, and note how many.
- Running short of time for design 2. Groups can move strands on the same frame instead of starting fresh, as long as they record the new spacing.

Structured debrief

1. Build the class graph together. Two patterns should appear: the percent of small fish kept falls steeply once the opening is wider than the ditalini, and the percent of large fish kept stays high until the opening nears the rigatoni width. The window between the two drops is the design target. Ask what would happen to that window if the two species were closer in size.
2. Compare planned center-to-center spacing with the measured clear openings. Many groups find the real opening smaller than planned (string thickness) or uneven (strands that slipped). Ask why real fishing rules specify mesh by measurement and why inspectors measure nets with gauges.
3. Connect to Lake Malawi and to the California swordfish story on slide 21: a mesh rule works when the target is bigger than the by-catch; when the by-catch is bigger, such as turtles and dolphins, the fix has to be a different design, like an escape grid or different gear.
4. Ask which criterion the group would relax if it had to choose, and who would bear the cost: the families who eat the large fish, or the people exposed to more snails. That is the tradeoff at the heart of the lesson.

Recording sheet: what students fill in

Lab 2 recording sheet: Spare the Snail-Eaters

A fishing village on a large lake needs its large fish for food and income. Small fish of another species eat the snails that carry the bilharzia parasite, so the village wants them left in the lake. **Rigatoni = large target fish. Ditalini = small snail-eating fish.** Your net is a lift net: it rests on the bottom, the fish gather over it, and it is lifted straight up.

Measure your fish (narrowest width, mm)

Fish	Piece 1	Piece 2	Piece 3	Average
Rigatoni (large target fish)				
Ditalini (small snail-eaters)				

Starting criteria and constraints — Criterion 1: keep at least 24 of the 30 large fish (80 percent) over three hauls. **Criterion 2:** let at least 48 of the 60 small fish escape (80 percent) over three hauls. **Constraint 1:** no more than 20 strands of string per net, because string is costly for the village. **Constraint 2:** build each net in 12 minutes or less. **Constraint 3:** after three hauls, every strand is still taped in place.

1. Use your measurements: what range of clear openings, in millimeters, should let the small fish through but stop the large fish? Explain your range.

Answer: Measurement-dependent. With typical pasta (ditalini about 8 mm, rigatoni about 15 mm across), any clear opening wider than the ditalini and narrower than the rigatoni, for example about 9 to 14 mm, should work; the safest choice sits in the middle, around 11 to 12 mm, because strands sag and pasta sizes vary.

Why: A piece passes only if it fits through the opening, so the opening must be larger than the small fish's narrowest width and smaller than the large fish's narrowest width. A margin on each side allows for uneven strands.

- Uses the group's own measured averages
- Opening range lies between the two widths
- Explains why the range needs a margin or why the middle is safest

2. Write one more criterion or constraint of your own, stated so that it can be checked with a number or a yes/no test.

Answer: Group-specific. Good examples: 'The net must keep at least 8 large fish in every single haul, so each family gets a fish every day.' 'Strands may shift no more than 2 mm after three hauls.' 'A broken strand must be replaceable with tape in under 1 minute.'

Why: Credit any criterion or constraint that can be checked with a number or a clear yes/no test and relates to people, the lake or the net's use. 'The net should be good' or 'strong' without a test does not earn credit.

- Measurable or yes/no checkable
- Clearly a criterion (goal) or a constraint (limit)
- Relevant to the fishing problem

3. Design 1 plan: spacing between strands in each direction (mm, center to center), number of strands, and your predicted percent of large fish kept and small fish released.

Answer: Group-specific. Example: '12 mm spacing both ways, $9 + 9 = 18$ strands; predicted 90 percent of large fish kept and 85 percent of small fish released.'

Why: Check that the strand count matches the spacing: on a 120 mm window, strands spaced s mm apart need about $120 \div s - 1$ strands per direction (10 mm: 11; 12 mm: 9; 15 mm: 7; 20 mm: 5). The plan must stay within 20 strands.

- Spacing stated in both directions
- Strand count consistent with the spacing and within 20
- Numerical prediction for both fish

-  Sketch design 1's grid from above. Label the spacing in millimeters in both directions and number the strands.

Answer: A top-view sketch of the 12 cm window with two sets of parallel lines at right angles, spacing labeled in millimeters in both directions and strands numbered so the total can be counted.

Why: The sketch lets the teacher check that the plan, the strand count and the built net match.

- Two directions of strands shown
- Spacing labeled in millimeters
- Strands numbered or counted

Design 1: haul results

Haul	Large fish kept	Large fish escaped	Small fish kept	Small fish escaped
1				
2				
3				
Total				

Design 1: summary

Strands used	Percent of large fish kept	Percent of small fish released	Criterion 1 met?	Criterion 2 met?	All constraints met?

4. What will you change for design 2, and which result from design 1 is your evidence for that change?

Answer: Group-specific. Example: 'Design 1 had 16 mm spacing and kept only 19 of 30 large fish (63 percent), so we will tighten the spacing to 12 mm in both directions.' Or: 'Design 1 released only 31 of 60 small fish (52 percent), so we will widen the spacing from 9 mm to 13 mm.'

Why: Credit a change that responds to the criterion that failed or was closest to failing, with the number that shows it.

- Names one specific change
- Cites a specific design 1 result as evidence

Design 2: haul results

Haul	Large fish kept	Large fish escaped	Small fish kept	Small fish escaped
1				
2				
3				
Total				

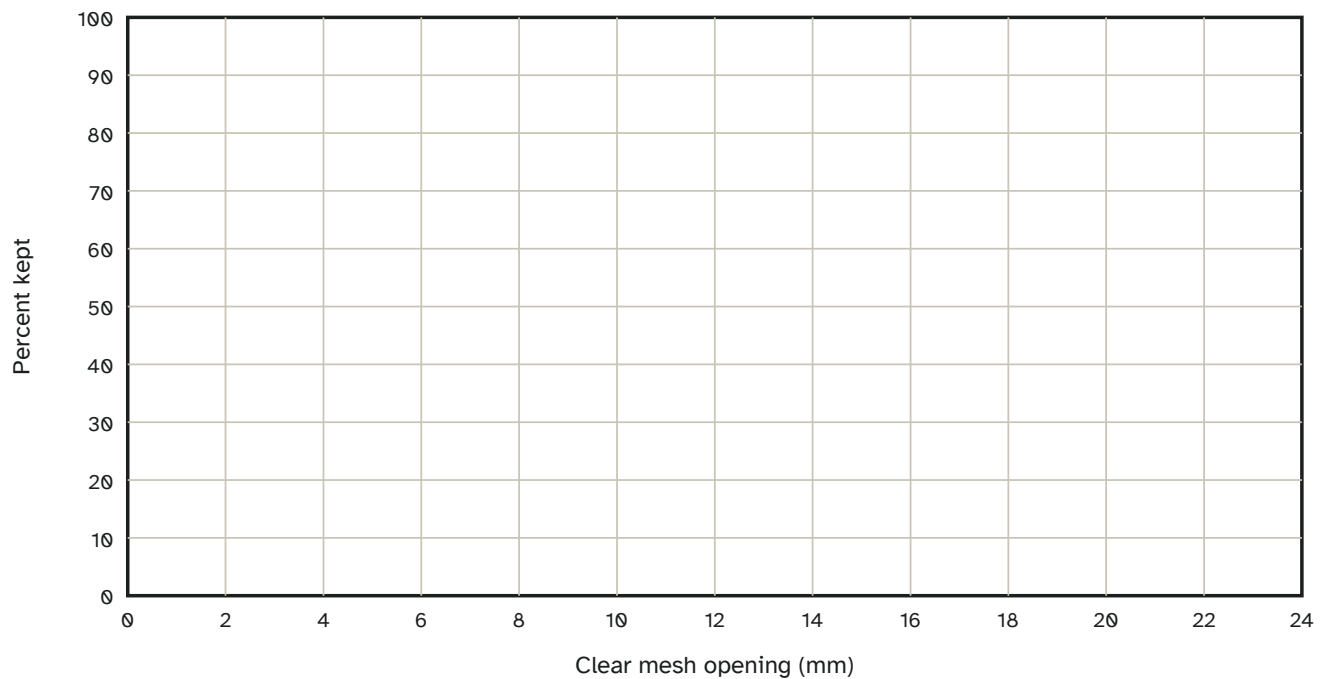
Design 2: summary

Strands used	Percent of large fish kept	Percent of small fish released	Criterion 1 met?	Criterion 2 met?	All constraints met?

Class chart: every group's better design

Group	Clear opening (mm)	Strands used	Percent of large fish kept	Percent of small fish kept	Met both criteria?

Class selectivity graph: percent kept against mesh opening



Analysis questions: answer key

5. A net's strands are taped 14 mm apart, center to center, and the string is 1.5 mm thick. What is the clear opening? Would a fish 8 mm wide fit through it? A fish 15 mm wide? Show your work.

Answer: Clear opening = $14\text{ mm} - 1.5\text{ mm} = 12.5\text{ mm}$ (half the string's thickness, 0.75 mm, intrudes from each side). An 8 mm fish fits through ($8 < 12.5$). A 15 mm fish does not ($15 > 12.5$), so it is kept.

Why: Students must subtract the string thickness from the center-to-center spacing; this is why planned and measured openings differ.

Also acceptable: Accept 12 to 13 mm if the student rounds the string thickness, with the same conclusions.

6. Did design 2 meet more of the criteria and constraints than design 1? Use your percentages to explain what your change did.

Answer: Group-specific. Example: 'Yes. Design 1 kept 63 percent of large fish and released 95 percent of small fish, so it failed criterion 1. Tightening to 12 mm gave 93 percent of large fish kept and 85 percent of small fish released, so design 2 met both criteria with 18 strands.'

Why: Full credit compares both designs on both criteria with numbers and links the change to the result. A design 2 that did worse still earns credit if the student explains what the change did.

- Percentages for both designs
- States which criteria each met
- Explains the effect of the change

7. Use the class graph. What range of clear openings met both criteria? Explain why nets with smaller openings failed one criterion and nets with larger openings failed the other.

Answer: Class-specific; predicted about 10 to 13 mm. Nets with openings smaller than about the ditalini width (roughly 8 to 9 mm) kept most small fish, so they failed criterion 2 (too much by-catch). Nets with openings near or above the rigatoni width (about 15 mm) let large fish slip through end-first, so they failed criterion 1 (too little catch).

Why: The answer should come from the class graph and name both failure modes. The two percent-kept lines drop at different openings, and the useful range is the gap between those drops.

- Gives a range read from the class graph
- Explains the small-opening failure (by-catch kept)
- Explains the large-opening failure (target lost)

8. Some small fish stayed on nets whose openings were much wider than a ditalini. Give two reasons from your observations.

Answer: Any two: small fish wedged where strands cross or between two strands that slipped close together; small fish resting on a sagging strand or on the tape; small fish trapped inside a rigatoni tube; pieces clumped together that could not fall through as a group; the shakes were too gentle to tip every piece through.

Why: This mirrors real by-catch: animals small enough to escape still get caught by tangling, crowding and gear that is not perfectly even.

- Two distinct, plausible reasons
- At least one based on an observation from the lab

9. A fishing boat lands 600 kg of its target fish a day. With its old net, by-catch made up 40 percent of each haul's mass. A new net cuts by-catch to 10 percent of the haul and still lands 600 kg of target fish. How many kilograms of by-catch does the new net avoid each day? Show your work.

Answer: Old net: target fish are 60 percent of the haul, so the haul = $600 \div 0.60 = 1,000$ kg and by-catch = $1,000 - 600 = 400$ kg. New net: target fish are 90 percent of the haul, so the haul = $600 \div 0.90 \approx 667$ kg and by-catch $\approx 667 - 600 = 67$ kg. By-catch avoided $\approx 400 - 67 = 333$ kg a day.

Why: The common error is taking 40 and 10 percent of 600 kg (240 and 60 kg, a difference of 180 kg). The percentages are of the whole haul, not of the target catch.

Also acceptable: Accept 330 to 335 kg with correct work.

10. At Lake Malawi, why did sparing the small fish matter to people as well as to the fish?

Answer: The small fish eat freshwater snails, and those snails carry the parasite that causes bilharzia. Sparing the small fish keeps snail numbers down, so fewer people who wade or wash in the lake are infected. The large fish still feed families and bring in income.

Why: The answer must connect the by-catch species to the snails and then to human health.

- Small fish eat snails
- Snails carry the bilharzia parasite
- Fewer snails means fewer human infections

11. Shrimp trawl nets can catch sea turtles, which are far larger than shrimp. Explain why changing the mesh size cannot solve that by-catch problem, and describe a design that could.

Answer: A mesh small enough to hold shrimp also holds anything larger, including turtles, so making the mesh bigger would lose the shrimp and still trap turtles. The fix must sort by size the other way: a grid of bars set across the net (a turtle excluder device) lets small shrimp pass between the bars into the back of the net, while a turtle hits the bars and slides out through an escape opening.

Why: Mesh sizing works only when the by-catch is smaller than the target. Credit any design that separates large animals from small ones and gives the large ones a way out, such as an escape grid, a hatch or a different fishing method.

- Explains why mesh size cannot release animals larger than the target
- Describes a design that lets large animals escape while keeping shrimp

12. Name two ways the pasta test differs from fishing a real lake, and say how each might change the results.

Answer: Any two, each with an effect. Real fish swim and push through or away from nets, so they may escape more or less than pasta. Real fish vary in size within a species, so some young of the target species slip through and some large by-catch is kept. Real nets work underwater, where flowing water opens or closes the mesh. Weeds and mud can clog real mesh, making openings smaller over a day of fishing. Real nets are much larger, so uneven patches matter less or more.

Why: The goal is to treat the test as a model with limits, not as a measurement of real nets.

- Two specific differences
- A plausible effect of each on the results

Individual evidence of learning

Each student submits the measurement table, the written criterion or constraint (q2), the design 1 sketch, both designs' haul tables and summaries, the class chart and graph, and their own answers to q5 to q12. The criterion statement and the design 2 justification (q2, q4, q6) are the evidence for defining and iterating; q7 and q11 are the evidence for evaluating designs that protect by-catch.

Assessment criteria

Criterion	Proficient looks like
Defining the problem	Adds a criterion or constraint that can be checked with a number or a yes/no test, and states a workable opening range from the measured fish sizes (q1, q2).
Fair testing	Runs three hauls per design the same way, records all four counts and calculates both percentages correctly.
Using evidence to modify	Changes one feature for design 2, justifies it with a specific result from design 1, and compares the two designs with numbers (q4, q6).
Interpreting class data	Uses the class graph to identify the opening range that met both criteria and explains why openings on each side fail (q7).
Transfer and limits	Explains why mesh size alone cannot fix turtle by-catch, proposes an escape grid or other design, and names limits of the pasta model (q11, q12).

Accessibility adaptations

- Provide a mesh guide card printed with lines at 8, 10, 12, 14 and 16 mm that sits under the window, so students can tape strands along the lines without measuring each one.
- Students with limited fine-motor control can direct strand placement and spacing while a partner tapes, or take the hauler or data-manager role.
- Use high-contrast pasta or beads for students with low vision, and count kept fish by moving them into a labeled tray.
- Offer a calculator and a percent strip: with 30 large fish each one is about 3.3 percent; with 60 small fish each one is about 1.7 percent.

Low-cost alternative

Use plastic craft beads instead of pasta: round beads about 16 to 20 mm across as the large fish and pony beads (about 9 mm by 6 mm) as the small fish. Beads are reusable for years and safe for students with wheat allergies. Any two sizes work if they differ by at least 4 mm; students measure them first.

Model limitations

Pasta does not swim, bend or choose where to go, and every piece of one kind is nearly the same size, while real fish of one species range from tiny young to large adults; real mesh rules are set from data on what sizes a net keeps across that whole range. The lift-and-shake test stands in for fish swimming against a net underwater, where mesh shape, water flow, weeds and the fish's own behavior all change what escapes. The

20-strand budget and the 80 percent targets are teaching choices, not real regulations. This activity has not been physically tested by the authors, and pasta sizes vary by brand, so the opening that works best must come from each class's own data.

Teacher notes

The activity is untested, so treat the expected openings as predictions and let the class graph decide. Check pasta sizes before class: the design space depends on a clear gap between the two widths. The most common errors are measuring spacing center to center but reporting it as the clear opening (q5 addresses this), counting a ditalini inside a rigatoni as escaped, and computing the small-fish percentage as kept rather than released. For q9, walk through why the 40 percent applies to the whole haul. If time allows, extend with a third species, small shells standing for young large fish that should also escape, and ask whether one mesh can meet three criteria at once.