

Build, Test, Improve: a Solar Distiller That Runs on Sunlight and Gravity

Investigation question: How can you change a simple solar still so it turns more salt water into fresh water in a day, and how will your test data tell you whether the change helped?

Engineering design challenge

Groups of 4

3 sessions

Setup 10 · Activity 120 · Cleanup 10 min

MS-ETS1-4 · assesses

MS-ETS1-3 · practice

MS-ESS2-4 · practice

Scientific purpose

Students build a working solar still from a bowl, a cup and plastic wrap, measure how much fresh water it collects in a day, change one feature at a time, and retest. The still is a small water cycle with the parts labeled: light energy drives evaporation, a cooler cover drives condensation, and gravity drains the drops into the cup. The design log and output data are the student's evidence for iterative testing.

Why this helps students with this chapter

Students have heard that the Sun lifts water and gravity brings it back, but in a lake they cannot see either happening. In the still they can: fog on the cover appears within minutes under a warm lamp, drops run downhill to the low point, and the cup fills with water that has left the salt and dye behind. Because output is measured, the design loop is real: a change either raised the number or it did not, and the class table shows which features are worth keeping.

Standards connections

MS-ETS1-4 (assesses, generating test data from a model and using it to modify the design over several rounds): Students measure the output of version 1, predict the effect of one change, build version 2, measure again and decide what to change next; the design log with measured outputs for at least two versions is direct evidence for this performance expectation.

MS-ETS1-3 (practice, comparing data from several groups' designs to identify features worth combining): The class comparison table pools every group's feature change and output; students use it to propose a combined design, which builds the practice of analyzing several solutions without fully assessing it.

MS-ESS2-4 (practice, a physical model of water changing state under energy from light and moving under gravity): The still is a physical model of evaporation, condensation and gravity-driven collection; students label those steps and the energy transfers, which supports the model-development PE that W4 and Lab 3 assess more fully. This PE is a California Grade 6 expectation revisited here.

Roles (rotate each session)

- **Builder:** Assembles the still exactly as the design sketch shows, seals the cover, places the weight, and sets the still in the agreed light position without moving the bowl afterward.

- **Measurer:** Pours the salt water in with the measuring cup, draws the collected water out with the syringe or pours it into the cylinder, reads the volume to the nearest 0.5 mL, and runs the salt-residue test.
- **Data lead:** Keeps the design log, records every prediction before the test and every result after, and copies the group's numbers to the class comparison table.
- **Design lead:** Reads the data after each run, proposes the single change for the next version with a reason in water cycle terms, and makes sure only one feature changes at a time.

Materials

Item	Quantity	Per	Note
Large clear bowl or clear food-storage container, about 2 to 3 L, at least 20 cm across	1	group	Glass or clear plastic both work; the wider the water surface, the more it collects.
Small cup, shorter than the bowl is deep (a 100 mL plastic cup or a clean yogurt cup)	1	group	
Plastic wrap	about 1 m per version	group	
Large rubber band or masking tape to seal the cover to the rim	1 to 2	group	
Small clean pebble or coin to weight the cover above the cup	1	group	
Prepared salt water: 2 teaspoons of table salt and 2 drops of food coloring per liter of tap water	300 mL per version	group	Mix a class batch in a labeled jug; the dye makes it obvious that only water, not the dissolved stuff, reaches the cup.
Black construction paper or a piece of black plastic bag (optional feature for testing)	1 sheet	group	
10 mL syringe (no needle) or a 10 or 25 mL graduated cylinder	1	group	A 0.1 g balance also works: weigh the dry cup, then the cup with water; 1 g of water is 1 mL.
Black plastic lid or dark tile for the salt-residue test	1	group	
Ruler and permanent marker	1 each	group	
Desk lamp with a warm bulb (incandescent or halogen, 40 to 60 W) if the room has no sunny windowsill	1	group	Most LED bulbs give off little heat and will not run the still well; a south-facing window is the best light source.
Thermometer (optional) and paper towels	1 and a roll	class	

Estimated cost: 10 to 20 per class (an estimate; Estimate. Plastic wrap, salt, food coloring, black paper and a pack of 10 syringes cost about 15 dollars together; bowls, cups, rubber bands and lamps are borrowed classroom or home items. Lamps are the only

expensive item if the school has none; a sunny window replaces them.)

Safety

- Lamp bulbs get hot enough to burn skin and to melt or ignite plastic wrap and paper. Keep every part of the still at least 30 cm from the bulb, never touch the bulb, switch lamps off before adjusting anything, and never leave lamps on unattended overnight; use the window for overnight runs.
- Never drink or taste any water in this lab, including the collected water. The still is a model, the equipment is not food-safe, and the salt-residue test is the only way you will check the water.
- Wipe spills at once; water on a hard floor is a slip hazard. Keep cords along the wall.
- Handle glass bowls with two hands and carry them only when nearly empty. Report any chips or cracks.
- Food coloring stains clothing and skin; wash hands after handling the salt water.
- If a group tests warm starting water, the teacher prepares it from warm tap water no hotter than 45 °C and checks it with a thermometer; anything above 50 °C is handled only by the teacher.

Teacher preparation and setup

1. Mix the salt water the day before and label the jug 'NOT FOR DRINKING: salt water for Lab 1'.
2. Run one still yourself for a day in the spot you plan to use. A sunny window in spring can give tens of milliliters; a 60 W lamp 30 cm above the cover may give only a few. Knowing your room's output lets you choose the syringe or the balance and tells students what a 'big' change looks like.
3. Choose and mark the still positions (windowsill or lamp spots) so every group gets the same light; tape an outline on the sill so bowls go back in the same place after measuring.
4. Print one recording sheet per student and one class comparison table for the wall.
5. Decide the run length: the same number of hours for every version (for example, from the end of one class to the start of the next day's class).
6. Check that the lamps' cords run along walls, not across walkways, and that bulbs are at least 30 cm from any plastic or paper.

Investigation design

Independent variable	One design feature changed between versions (liner color, cover slope, cup height, starting water temperature, seal tightness, cover layers)
Dependent variable	Volume of fresh water collected in the cup during the run, in mL
Controlled	Volume and salt concentration of the starting water (300 mL from the same class batch); Same light position and the same run length for every version; Same bowl, cup and syringe for every version within a group; Only one feature changed per version
Trials	One run per version per group; the class comparison table pools 6 to 8 groups so that each feature change is seen alongside others.
Comparison	Version 2 output against version 1 output within the group; each group's change against the other groups' changes in the class table.

Student procedure

1. Session 1. Sketch version 1 on the recording sheet: the basic still is the bowl with 300 mL of salt water, the empty cup standing in the middle (its rim above the water), plastic wrap sealed tight over the bowl, and a pebble on the wrap directly above the cup so the cover sags to a point. Label where light enters, where water evaporates, where vapor condenses, and how the drops reach the cup.
2. Build version 1 exactly as sketched. Measure the inside diameter of the bowl and record it. Write a prediction of how many milliliters you expect in the cup after the run and why.
3. Place the still in your marked light position and note the start time. Over the next 15 minutes, watch the cover and record the time the first fog appears and where the first drops gather.
4. Session 2 (after the agreed run time). Without tilting the bowl, peel back the cover, lift the cup out, and measure its contents with the syringe or cylinder to the nearest 0.5 mL (or weigh it). Record the volume, the hours the still ran, and whether the collected water is colored or clear.
5. Run the salt test: put three drops of the collected water on the black lid and three drops of the original salt water beside it, label both with the marker, and leave the lid to dry until the next session.
6. Design lead proposes one change for version 2 based on the data and the water cycle (for example a black liner under the water, a taller or shorter cup, warm starting water, a tighter seal, a steeper cone). Change only that one feature. Write the prediction and the reason in the design log, rebuild with fresh salt water, and restart in the same position for the same run time.
7. Session 3. Measure version 2 the same way, record it, and read the dried salt test: a white ring or crust means dissolved salt was in the drop; little or no residue means the water left its salt behind.
8. Copy your feature change and both outputs to the class comparison table. As a class, look for features that raised output in more than one group and features that lowered it.
9. Answer the analysis questions individually. If time allows, propose and sketch a version 3 that combines the two most promising features from different groups.

Expected observations

- Under a warm lamp, the inside of the cover fogs within 5 to 15 minutes; in a sunny window it takes longer and depends on the weather. Drops first gather at the lowest point of the cover under the pebble and then fall or run into the cup.
- Collected water is clear, not dyed, and its dried drop leaves little or no residue, while the salt-water drop leaves an obvious white ring.
- Outputs are small: typically a few mL under a lamp and up to a few tens of mL for a full sunny day in a window, with a 20 to 25 cm bowl and 300 mL of water. A dark liner and a well-sealed, steeply sagging cover typically raise output; a loose cover or doubled wrap lowers it.
- Groups that change two things at once get results they cannot interpret, which is a useful teaching moment for the one-variable rule.

Likely difficulties

- The cup rim sits below the water line and salt water floods into it. Use a taller cup or less water, and have the Measurer check the rim before sealing.

- Condensed drops run down the cover to the rim and back into the salt water instead of into the cup. The pebble must sit directly above the cup and the cover must sag to a single point.
- Outputs below 2 mL are hard to read in a cylinder. Use the syringe or weigh the cup on a 0.1 g balance.
- Students want to taste the water to 'prove' it is fresh. The salt-residue test and the clear color are the evidence; tasting is never allowed.
- Lamp heat warms the cover as well as the water, which reduces condensation. Raising the lamp or aiming it at the water rather than the cover can help; this is a legitimate version 2 change.

Structured debrief

1. Collect the first-fog times. Lamp stills fog within a few minutes; window stills depend on the Sun. Ask what the fog is (condensed droplets, not vapor) and why it forms on the cover (the cover, cooled by the room air outside it, is cooler than the warmed water below).
2. Walk the class table feature by feature. A dark liner, a steep cone and a tight seal usually help; a loose cover or a cover that blocks light usually hurts; warm starting water helps early and fades. Where two groups disagree, ask what else differed (window versus lamp, run length, bowl size) and whether the comparison was fair.
3. Make the water cycle mapping explicit: bowl is ocean, light is Sun, cover is the cool upper air or a cold mountainside, drops are precipitation, the cup is a lake or reservoir. Then ask what is missing: no transpiration, no runoff over land, no infiltration or groundwater, no wind, and a closed system that never loses vapor to the sky.
4. End on q5. A classroom still makes a few mL to a few tens of mL; a person needs about 2 L of drinking water a day, which at classroom efficiency works out to several square meters of still per person. Well-built field stills make roughly 2 to 4 L per square meter on a sunny day, so even they need about a square meter per person. That is why real solar stills are big and why fog nets and desalination plants exist. Scaling a design is itself an engineering decision.

Recording sheet: what students fill in

Lab 1 recording sheet: Build, test, improve a solar distiller

Fill in each prediction before the still runs. Record every measurement to the nearest 0.5 mL. Change only one feature between versions, and write down why you chose it.

-  Sketch version 1 from the side. Label: where light enters, where liquid water evaporates, where vapor condenses, the path the drops take to the cup, and the one place gravity is doing the work.

Answer: A side view showing light entering through the clear cover, salt water in the bowl with an arrow up labeled evaporation, fog or droplets on the underside of the cover labeled condensation, the cover sagging to a point under the pebble, drops labeled with a downward arrow running to the point and falling into the cup, and the word gravity on that downward path.

Why: The sketch is the student's first model of the still as a water cycle; all five labels should be present before the build so that observations can be checked against predictions.

- Light path drawn entering through the cover
- Evaporation labeled at the water surface and condensation labeled on the cover
- Drop path from the cover's low point into the cup, with gravity named
- Cup rim shown above the water line

Design log (one row per version)

Version	What is different from the last version	Prediction (mL) and reason	Run time (hours)	Water collected (mL)	Color of collected water	Salt test result	Keep this feature? (yes/no and why)
1 (basic)	nothing: this is the starting design						
2							
3 (if built)							

First 15 minutes of version 1

Minutes after start	Fog on the cover? (none / patches / all over)	Drops forming? where?	Other observations
5			
10			
15			

Class comparison table (copy from the wall chart)

Group	Feature changed in version 2	Version 1 output (mL)	Version 2 output (mL)	Change (mL)	Helped, hurt or no clear effect?

1. Describe what you saw on the cover in the first 15 minutes. Where did fog appear first, and where did the drops collect? Explain both using the words evaporation, condensation and gravity.

Answer: Fog appeared first on the cover above the water (often near the center or wherever the light hit hardest) because the cover is the coolest surface the vapor reaches; vapor made by evaporation from the warmed water condensed there as tiny droplets. The droplets merged and ran down the sloping cover to the low point under the pebble, pulled by gravity, and dripped into the cup.

Why: Students should connect each observation to its process: fog is condensation, the source of the vapor is evaporation, and the motion of drops is gravity on a slope.

- Fog identified as condensed droplets on the cooler cover
- Source of vapor named as evaporation from the warmed water
- Drop motion explained by gravity and the cover's slope

2. What color was the collected water, and what did the dried salt test show for each drop? What do those two results tell you about what did and did not travel from the bowl to the cup?

Answer: The collected water was clear, not colored, and its dried drop left little or no residue, while the salt-water drop left a white ring. Only water molecules evaporated and condensed; the dye and the salt do not evaporate at these temperatures, so they stayed in the bowl.

Why: Both tests show that evaporation separates water from dissolved substances, which is the point of distillation and the reason rain from ocean clouds is fresh.

- Reports clear water and the residue difference
- Concludes that only water moved; dye and salt stayed behind

Analysis questions: answer key

3. Trace one water molecule from the salt water to the cup. For each step, name the change of state (if any), say whether the water gained energy, gave energy off, or just moved, and name what drove the step.

Answer: Step 1: the molecule in the salt water gains energy from the light, moves faster, and escapes the surface as vapor (liquid to gas, energy in, driven by light energy). Step 2: the vapor drifts up to the cover, which is cooler; the molecule slows, sticks to others on the plastic and becomes liquid again (gas to liquid, energy given off to the cover and air, caused by cooling). Step 3: the droplet merges with others until it is heavy enough to run down the sloped cover and drop into the cup (no change of state, moved by gravity).

Why: This is the energy-accounting target applied to the still: energy in for evaporation, energy out for condensation, gravity for collection. Full credit needs all three steps with the right driver on each.

- Evaporation with energy gained from light
- Condensation on the cooler cover with energy released
- Gravity moving the liquid drops with no change of state

4. Explain why the water in the cup has no dye and little or no salt even though it came from dyed salt water. Then explain what this means for rain that falls from clouds formed over the ocean.

Answer: Evaporation takes only water molecules off the surface; salt and dye are dissolved in the liquid and do not become gas at these temperatures, so they stay in the bowl and the vapor that condenses on the cover is pure water. In the same way, water that evaporates from the ocean leaves its salt behind, so clouds over the ocean and the rain that falls from them are fresh, not salty.

Why: This links the still to the real cycle and answers the common question of why rain from the ocean is not salty.

Also acceptable: Accept 'the salt is too heavy to evaporate' only if the student also says it stays dissolved; push for 'does not become a gas' rather than 'heavy'.

- States that only water evaporates; dissolved salt and dye do not
- Applies the idea to ocean evaporation and fresh rain

5. Use your bowl's inside diameter to find the area of the water surface (area = $3.14 \times \text{radius} \times \text{radius}$, in cm^2). Divide your best output by that area to get mL per cm^2 per run. Then estimate how many square meters of still ($1 \text{ m}^2 = 10,000 \text{ cm}^2$) you would need to make 2,000 mL of fresh water per run. Show your work.

Answer: Worked example for a 24 cm bowl and a best output of 15 mL: radius = 12 cm; area = $3.14 \times 12 \times 12 = 452 \text{ cm}^2$. Output per area = $15 \div 452 = 0.033 \text{ mL per cm}^2$. For 2,000 mL: $2,000 \div 0.033 = \text{about } 60,000 \text{ cm}^2$, which is $60,000 \div 10,000 = 6 \text{ m}^2$ of still per run. Students use their own diameter and output; answers will range from about 2 m^2 (a very productive window run) to more than 20 m^2 (a weak lamp run).

Why: The scale-up is proportional reasoning with units. Check that the radius, not the diameter, is squared, that the division is output over area, and that the final cm^2 to m^2 conversion divides by 10,000. The size of the answer is the lesson: at classroom efficiency one person's drinking water needs a still the size of a room. Well-built field stills do better, roughly 2 to 4 L per square meter on a sunny day, but even they need about a square meter per person.

Also acceptable: Accept answers computed with 3 instead of 3.14, or with the class average output if the group's own still gave too little to measure, provided the steps are shown.

6. Did your version 2 change help, hurt, or have no clear effect? Compare the numbers to your prediction and explain the result with the mechanism (light absorbed, evaporation rate, condensation on the cover, drops reaching the cup).

Answer: Depends on the change. Typical correct explanations: a black liner helped because dark surfaces absorb more light, so the water warmed more and evaporated faster; a steeper cone or a pebble placed exactly over the cup helped because the drops reached one point above the cup instead of running back into the salt water; a tighter seal helped because vapor stopped leaking out; doubled wrap hurt because it blocked light and kept the cover warmer so less vapor condensed; warm starting water helped at first and then faded as the water cooled. A result that matched the prediction counts as support; a result that did not should prompt a new hypothesis, not a changed number.

Why: Credit depends on the mechanism matching the change and the data; the student should compare the two outputs explicitly and say whether the difference is bigger than measurement noise (about 1 mL).

- States the two outputs and the direction of change
- Explains the result with evaporation rate, condensation on the cover or drop collection
- Compares the result to the prediction honestly

7. Two groups each found a change that helped. Describe the test you would run to find out whether combining both changes gives an even larger output, and name two things you would keep the same.

Answer: Build three stills side by side for the same run: one with change A, one with change B, one with both, using the same bowl size, the same 300 mL of salt water from the same batch, the same light position and the same run time. If the combined still's output is clearly higher than either single change, the changes add; if it is about the same as the better single change, they do not. Keep the same: starting water volume and salt content, light position and run length (any two).

Why: A fair test of combination needs the single-change stills as comparisons in the same run, because output varies day to day.

- Includes the combined still and at least one single-change comparison in the same run
- Names two controlled factors

8. Match the parts of the still to parts of Earth's water cycle (the salt water, the lamp or sunlight, the cover, the cup, the drops running down). Then name two real water cycle processes the still does not model at all.

Answer: Salt water in the bowl is the ocean; the lamp or sunlight is the Sun; the cover is the cooler air high up or a cold mountainside where vapor condenses; the drops running down and falling are precipitation; the cup is a lake, reservoir or river that collects fresh water. Not modeled: transpiration from plants, runoff across land, infiltration and groundwater flow, sublimation from snow and ice, wind carrying vapor from one place to another, and the open sky (the still is sealed, so no vapor escapes). Any two of these earn credit.

Why: Mapping and limits together show the student understands the still as a model, not as the water cycle itself.

- Maps at least four parts correctly
- Names two processes the still omits

9. Using the class comparison table, choose two features from different groups to combine in a version 3. Justify each choice with the numbers, and name one reason the combined output might not simply add up.

Answer: Example using a class table in which the black liner raised one group's output from 6 to 11 mL and a steeper cone (a heavier weight so the cover sags lower) raised another's from 7 to 14 mL: combine the liner and the steeper cone because each raised output by 5 mL or more, far beyond the 1 mL measurement noise, and they act at different stages (the liner on evaporation, the cone on collection). The combination might not simply add because the cover can only condense vapor as fast as it stays cool; if the liner warms the whole still, the cover may warm too and condense less, so the gain from the cone could shrink. A version 3 test is needed.

Why: This is the MS-ETS1-3 practice: pick features with evidence, justify with numbers, and recognize interactions. Any two data-backed features with a stated interaction risk earn full credit.

- Chooses two features from different groups and cites their outputs
- Explains why each works at the mechanism level
- Names a reason the effects might interact rather than add

Individual evidence of learning

Each student submits their own labeled sketch, the completed design log with predictions and measured outputs for at least two versions, the class comparison table, and written answers to q1 through q9. The design log and q6, q7 and q9 are the primary evidence for iterative testing; q3, q4 and q8 are the evidence for the water cycle model.

Assessment criteria

Criterion	Proficient looks like
Iterative testing with data	Design log shows a prediction before each run, a measured output after it, one feature changed per version, and a data-based decision about what to change next.
Mechanism in water cycle terms	Explains the still's operation as evaporation (energy in from light), condensation on the cooler cover (energy released) and gravity draining drops to the cup, and uses these to explain why a change helped or hurt.
Comparing designs	Uses the class table to identify features that helped in more than one group, proposes a combined design, and notes a reason the effects might not add.
Model evaluation and scale	Maps the still's parts to the real cycle, names processes it leaves out, and completes the area scale-up calculation with units.

Accessibility adaptations

- Provide a pre-labeled sketch template for students who need support with the drawing, and allow the salt test and the color observation to be recorded with photos.
- Allow the Measurer and Data lead roles to be shared by one student who records on a device, and accept spoken answers for q3 and q8 recorded by the teacher or a partner.
- Offer a calculator and a worked example for q5; the key includes one. Students can use the class average output if their own still produced too little to measure.

- Keep stills on a low, stable surface so students who use wheelchairs or have limited reach can build and measure without lifting the bowl.
- Provide a word strip with evaporation, condensation, vapor, gravity and seal in English and the home language.

Low-cost alternative

Use clear takeout containers or cut-down 2 L bottles as bowls, bottle caps or shot glasses as cups, and sandwich bags stretched over the rim instead of plastic wrap. Skip the syringe and measure output by counting drops into a spoon (about 20 drops is 1 mL) or by weighing on a kitchen scale. A single sunny windowsill shared by the class in shifts works if lamps are unavailable.

Model limitations

The still is a closed system that cannot lose vapor to the sky, has no wind, no plants, no soil and no groundwater, and uses one small water surface at one temperature, so it models only evaporation, condensation and gravity-driven collection. A lamp is a poor stand-in for the Sun and heats the cover as well as the water. Outputs in a classroom are small and sensitive to room temperature and light, so a difference of 1 or 2 mL between versions may be noise rather than a real effect; the class table helps separate the two. This activity has not been physically tested by the authors; the output ranges given are estimates, and the teacher's pilot run in the prep steps is the real calibration.

Teacher notes

Check q5 for the radius-versus-diameter error and the final unit conversion. In q6 and q9, grade the reasoning against the group's actual numbers, not against the typical results listed here; an honest 'no clear effect' with a 1 mL difference is a better answer than a forced explanation. Keep the dried salt-test lids for the next class; a crust of salt beside a clean spot is persuasive evidence. If no group achieved a measurable output, run the analysis on the slide 22 teaching dataset and say so on the recording sheets.