

The Crystal Clock: Measuring a Change Too Slow to Watch

Investigation question: How fast does a crystal grow when nobody can see it growing, and how long would it take, at that rate, to become a crystal one meter long?

Physical model

Groups of 3

3 sessions

Setup 10 · Activity 135 · Cleanup 10 min

MS-ESS2-2 · practice

MS-ESS2-1 · supports

Scientific purpose

Students grow alum (or Epsom salt) crystals from a cooling solution over a school week, measure the largest crystal every day without disturbing it, graph the growth, calculate a rate in millimeters per day, and extrapolate to a meter-long crystal. Half the class cools its solution slowly and half quickly, so the class also sees that the pace of a process changes the result. The crystal stands in for every Earth process that looks frozen on a human time scale but adds up: it never visibly moves, yet it is measurably bigger each morning.

Why this helps students with this chapter

Students readily say that canyons took millions of years but have never experienced a change too slow to see and then caught it with a measurement. Here the crystal looks identical before and after any class period, yet the daily numbers climb, the graph rises, and the arithmetic turns one week of millimeters into the years a giant crystal would need. That experience is what makes 'the cliff looks the same, so nothing is happening' feel wrong rather than merely being told it is wrong.

Standards connections

MS-ESS2-2 (practice, the 'small changes add up over time' half of the explanation, with a measured rate): Students produce a rate from their own measurements and multiply it by a long span, which is the reasoning MS-ESS2-2 requires for slow surface processes. The crystal is a model of an Earth process, not an Earth process itself, so this builds toward the explanation rather than assessing it.

MS-ESS2-1 (supports, crystallization as one of the processes that form Earth's materials): Crystals growing from a cooling, concentrated solution preview the crystallization step of the rock cycle in Lesson 17, and the fast-versus-slow cooling comparison matches why some igneous rocks have large crystals and others fine ones.

Roles (rotate each session)

- **Solution maker:** Measures the alum into the cup, receives the hot water from the teacher, stirs until a few grains stay undissolved, and labels the cup. Never carries hot water.
- **Measurer:** Each day lifts the cup onto the millimeter grid card (or holds the ruler flat against the cup wall), reads the longest edge of the largest crystal to the nearest 0.5 mm with the hand lens, and counts the crystals, without stirring or tilting the solution.

- **Recorder and grapher:** Writes each day's value and observation in the table, plots the point on the graph the same day, sketches the largest crystal on the first and last day, and keeps the sheet with the cup.

Materials

Item	Quantity	Per	Note
Alum (potassium aluminum sulfate), grocery spice aisle	about 30 g (2 level tablespoons)	group	Epsom salt (magnesium sulfate) works too: about 50 g per 100 mL; it grows fast needle crystals in a day or two.
Clear, sturdy heat-tolerant cup or small jar (glass jar or thick clear plastic deli cup)	1	group	Thin party cups soften in hot water; use a jar or a thick deli container.
Hot tap water or kettle water at about 60 to 70 °C	100 mL	group	Teacher pours. Not boiling; 60 to 70 °C dissolves plenty of alum and is less dangerous.
Measuring cup or 100 mL beaker	1	class	Teacher uses it to pour.
Plastic spoon or stirring rod	1	group	
Safety goggles	1	student	
Millimeter grid card (graph paper laminated or in a sheet protector)	1	group	
Ruler marked in millimeters and a hand lens	1 each	group	
Small towel or cloth plus a cardboard box or foam cup sleeve	1 set	group	Slow-cooling groups wrap the cup and set it in the box.
Shallow tray of room-temperature tap water	1	class	Fast-cooling groups stand their cups in it for the first hour.
Masking tape and marker for labels ('Do not drink. Alum solution. Group —')	1	class	
Digital kitchen scale reading to 1 g	1	class	Optional, for massing the alum and the final crystal.
Thermometer (alcohol or digital probe)	1	class	Teacher checks water temperature before pouring.
Recording sheet and graph	1	student	

Estimated cost: 8 to 14 per class (an estimate; One 110 g jar of alum (about \$5 to \$7) supplies three to four groups, so two jars cover a class of 10 groups; deli cups, grid paper and tape are classroom stock. Epsom salt is cheaper (about \$4 for 1 kg) and covers several classes.)

Safety

- Goggles on whenever solutions are being made, poured or emptied. Alum and Epsom salt solutions are eye irritants.
- No tasting, no sipping, no fingers in the cup. Alum is sold as a food additive but in these amounts can cause stomach upset; Epsom salt is a laxative. Label every cup 'Do not drink'. Wash hands after handling crystals.
- Only the teacher handles hot water: water at 60 to 70 °C is poured by the teacher into cups that are already on a tray at the student station; students never carry a cup of hot solution.
- Carry cooled cups with two hands on a tray; mop any spill at once, since a wet floor with dissolved alum is slippery.
- Do not use thin plastic cups or glass that is not heat-tolerant; hot water can soften or crack them.
- Crystals have sharp edges once removed; handle them by the broad faces, not the points.
- Disposal: small volumes of alum or Epsom salt solution can go down the drain with plenty of running water; crystals go in the trash or home in a bag if your school allows.

Teacher preparation and setup

1. Run one cup yourself a week ahead so you know how fast crystals appear in your room (alum usually shows crystals overnight and grows for 5 to 10 days; Epsom salt grows needles within a day and stops sooner).
2. Heat water to about 60 to 70 °C in an electric kettle or from a hot tap just before class, and check it with a thermometer; keep the kettle on your desk, not at student stations.
3. Pre-weigh about 30 g of alum into a labeled paper cup per group, or set out the jars with a tablespoon and the scale.
4. Decide which groups will cool slowly (wrapped, in a box) and which quickly (in the water tray, then on an open shelf) so the class is split roughly in half.
5. Choose an undisturbed shelf out of direct sun where cups can sit for a week without being bumped; label it 'Crystal clocks: do not touch'.
6. Print the recording sheet with the daily table and a graph with the vertical axis already scaled 0 to 20 mm (alum) or 0 to 40 mm (Epsom salt).

Investigation design

Independent variable	Time since the solution was made (days)
Dependent variable	Longest edge of the largest crystal (mm), read daily without disturbing the cup; also the number of crystals
Controlled	Same mass of alum (about 30 g) and same 100 mL of water for every group; Same starting water temperature (60 to 70 °C); Same shelf, out of sun, never stirred or tilted after day 1; Same crystal measured each day, same measuring method (hand lens, nearest 0.5 mm)
Trials	One cup per group; the class pools results so each cooling condition has four to five cups, and the class compares the two conditions.

Comparison

SLOW cooling (wrapped, insulated) versus FAST cooling (water bath, then open shelf): number of crystals and size of the largest crystal.

Student procedure

1. Session 1 (day 1). Put on goggles. Label your cup with your group number, 'Do not drink' and your cooling condition (SLOW or FAST). Weigh or measure about 30 g of alum into the cup and record the mass.
2. Set the cup on the tray. The teacher pours 100 mL of hot water (60 to 70 °C) into it. Stir gently for about two minutes until nearly all the alum dissolves. If every grain disappears, add half a teaspoon more and stir; stop when a few grains stay on the bottom. Record the water temperature the teacher reads.
3. SLOW groups: wrap the cup in the towel and set it inside the box with the lid loosely on. FAST groups: stand the cup in the tray of room-temperature water for the rest of the period, then move it to the open shelf. Do not stir again. Record the time you put it away.
4. Session 2 (day 2 or 3). Without tilting or stirring, lift the cup onto the millimeter grid card. Find the largest crystal. Using the hand lens and the grid or a ruler held flat against the outside of the cup, measure the longest edge of that crystal to the nearest 0.5 mm. Record it as the first measurement, with the date, and count how many crystals you can see.
5. Sketch the largest crystal with its shape and the number of flat faces you can see. Return the cup to its shelf and condition.
6. Every school day after that (five minutes at the start of class), repeat the measurement of the same crystal, count the crystals, note anything new (new crystals, cloudiness, a crust at the surface) and plot the day's point on the graph before you sit down.
7. Session 3 (day 7 or 8). Take the final measurement in the solution. Then pour the solution into the waste container, lift out the largest crystal with the spoon, dry it on a paper towel, measure it directly with the ruler, and (if a scale is available) record its mass. Sketch it next to your first sketch, at the same scale.
8. Calculate your growth rate: (final length minus first length) divided by the number of days between them, in millimeters per day. Then calculate how many days, and how many years, a crystal would need to reach 1,000 mm (one meter) at that rate.
9. Post your group's cooling condition, number of crystals and largest-crystal length on the class table. Answer the analysis questions individually, then compare within the group.

Expected observations

- Alum cups show a layer of small clear crystals on the bottom by the next morning; the largest grows from about 2 to 4 mm on the first measuring day to roughly 8 to 15 mm after a week, with eight-sided (octahedral) faces visible under the hand lens.
- Daily increases are largest on days 2 to 4 (often 1 to 3 mm per day) and shrink toward the end of the week as the solution approaches saturation at room temperature; graphs rise steeply and then flatten.
- FAST-cooled cups contain many more crystals, each smaller; SLOW-cooled cups contain fewer crystals and usually the class's largest single crystal.
- Some cups grow a crust of crystals at the surface as water evaporates, and a few crystals grow on the cup wall; these do not stop the bottom crystal from growing but may cloud the view.

Likely difficulties

- Measuring through the cup and the solution distorts the view; have students read the longest edge against the grid card from directly above and keep the same viewing position every day.
- A group's largest crystal on day 2 is overtaken by a neighbor later; tell students to keep measuring the crystal they chose, and to note the new leader in the observations column.
- Cups get bumped or someone stirs to 'help'; the shelf label and the no-touch rule matter. A disturbed cup grows many tiny crystals and the group's rate collapses, which is itself a useful data point for the debrief.
- Unit slips in q3 and q4 (days to years, millimeters to meters); have students write every unit in the calculation.
- Students expect a straight-line graph and treat the flattening as an error; it is the real behavior of a limited supply.

Structured debrief

1. Pool every group's rate on the board. Ask why the rates differ even though every cup started the same: differences in cooling, where the largest crystal sat, measurement to the nearest half millimeter. Point out that geologists have the same problem when they measure rates in different places and that is why they report a range.
2. Compare the SLOW and FAST columns of the class table. Slow cooling usually gives fewer, larger crystals because the solution stays warm longer and the few crystals that start have time to grow; fast cooling starts many crystals at once that compete for the same dissolved alum. Connect to Lesson 17: granite cooled slowly deep underground and shows large crystals; lava that cooled in days shows tiny ones.
3. Walk the extrapolation together. A rate of 1.5 mm per day gives about 670 days, under two years, for a meter-long crystal, but every group's graph flattened by the end because the solution ran out of dissolved alum. Ask what would keep a crystal growing for centuries: a steady supply of the right dissolved mineral, a stable temperature and nothing disturbing it, which is exactly the situation in a cave formation or a slowly cooling body of magma.
4. Close on the misconception: the crystal looked the same every time anyone glanced at it, and it was changing the whole time. Ask students to name one landscape feature they have decided is 'not changing' and say what measurement over what time would test that.

Recording sheet: what students fill in

Lab 1 recording sheet: The crystal clock

Session 1: fill in the setup table. Session 2 and every school day after: one line in the daily table and one point on the graph. Session 3: the final line, both sketches, the rate calculation and the questions. Never stir or tilt the cup after day 1.

Safety reminders — Goggles on when solutions are made or emptied. The teacher pours the hot water. Do not taste or touch the solution. Wash hands after handling crystals. Carry cups on the tray with two hands.

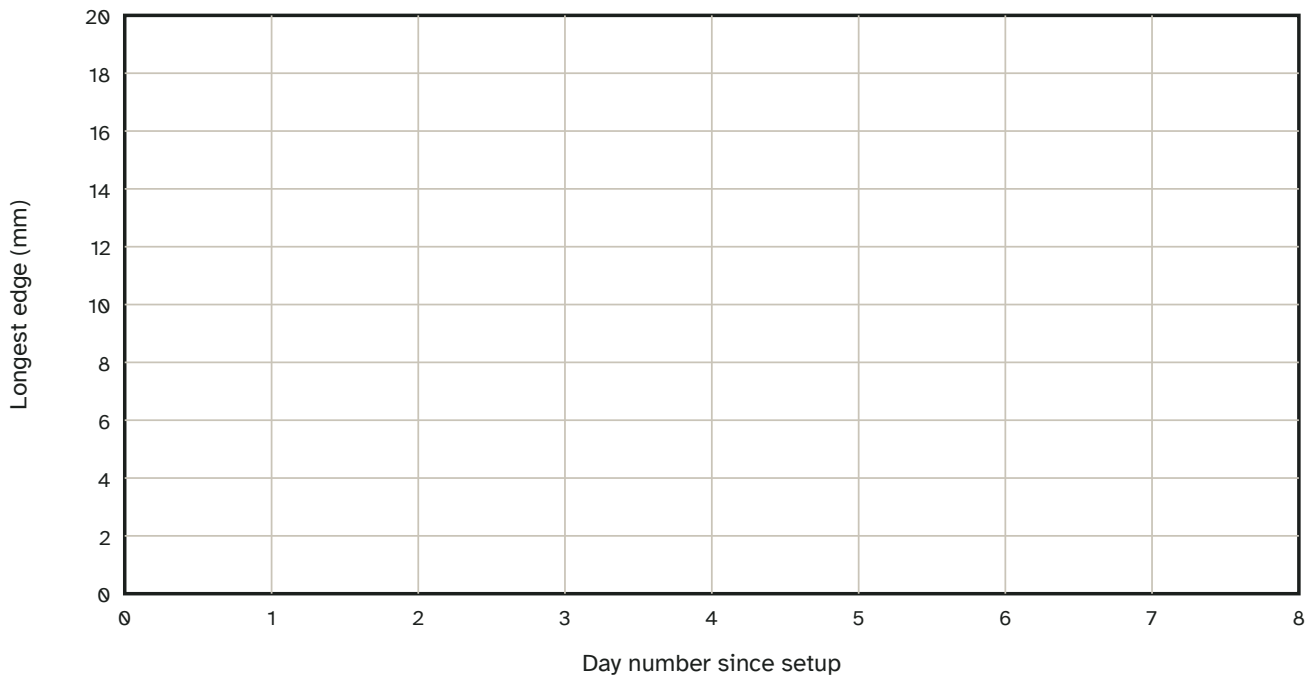
Setup (session 1)

Cooling condition (SLOW or FAST)	Salt used	Mass of salt (g)	Water volume (mL)	Water temperature (°C)	Time put away

Daily measurements of the largest crystal

Day number	Date	Longest edge (mm, to 0.5 mm)	Number of crystals you can see	What else changed (new crystals, crust, cloudiness)
1 (setup, no crystals yet)		0	0	
Final (crystal removed and measured directly)				

Longest edge of the largest crystal over time



-  Sketch the largest crystal on the first measuring day (left) and on the final day (right) at the same scale. Draw a 10 mm scale bar under each sketch, label the number of flat faces you can see, and label any faces that look the same shape on both days.

Answer: Two sketches at the same scale with a 10 mm scale bar under each. The first shows a small crystal (a few mm) with flat faces; the second shows the same general shape noticeably larger, with the same faces labeled where they correspond. Alum crystals show eight-sided (octahedral) shapes with triangular faces; Epsom salt shows long needles or prisms.

Why: The sketches are evidence that the crystal grew by adding layers to existing faces (the shape is preserved as the size increases), which is how crystals grow in nature too.

- Both sketches present with scale bars
- Final sketch visibly larger at the same scale
- Faces counted and at least one matching face labeled on both

Rate and extrapolation

First length (mm) and day	Final length (mm) and day	Change in length (mm)	Days between	Rate (mm per day)	Days to reach 1,000 mm	Same time in years

1. During any one class period, could you see your crystal growing? How did you know it was growing anyway?

Answer: No; within a class period the crystal looked exactly the same. We knew it was growing because the measurement was larger each day and the graph rose, so the change happened between observations even though no single observation showed it.

Why: This is the lesson's core idea: a rate below the limit of what you can watch still adds up to measurable change. Full credit requires the measurement, not just 'the teacher said so'.

- States that growth could not be seen in real time
- Cites the daily measurements or the graph as the evidence of growth

2. Class results: on average, which cooling condition produced more crystals, and which produced the largest single crystal? Write the class numbers you are using.

Answer: Class-specific. Typically FAST cooling gives more crystals (for example an average of 25 versus 8) and SLOW cooling gives the largest single crystal (for example 14 mm versus 9 mm).

Why: Slow cooling keeps the solution above saturation for longer so few crystals start and grow large; fast cooling starts many at once. Accept the opposite result if the class data truly show it, provided the student quotes the numbers.

- Names a condition for each outcome
- Quotes the class numbers used

Analysis questions: answer key

3. Show the calculation of your growth rate in millimeters per day. Then convert it to millimeters per year (multiply by 365).

Answer: Example: first length 3.0 mm on day 2, final length 12.0 mm on day 8. Change = $12.0 - 3.0 = 9.0$ mm over 6 days. Rate = $9.0 \text{ mm} \div 6 \text{ days} = 1.5 \text{ mm/day}$. Per year: $1.5 \text{ mm/day} \times 365 \text{ days} = \text{about } 550 \text{ mm/yr}$.

Why: Check that the student subtracted the first length rather than starting from zero at day 1 (no crystal existed yet) and that the day count matches the dates in the table.

Also acceptable: Any correct calculation from the student's own table earns full credit; rates from 0.5 to 3 mm/day are typical for alum.

4. At your rate, how long would a crystal need to reach one meter (1,000 mm)? Show the calculation in days and in years. Then explain one reason the real answer would be longer than your calculation.

Answer: Example at 1.5 mm/day: $1,000 \text{ mm} \div 1.5 \text{ mm/day} = \text{about } 667 \text{ days}$; $667 \div 365 = \text{about } 1.8 \text{ years}$. The real answer would be longer because the rate fell during the week as the dissolved alum ran out; a meter-long crystal would need a continuous new supply of dissolved material, which the cup does not have.

Why: The extrapolation assumes a constant rate. The flattening graph is the student's own evidence that the assumption fails. Also accept 'the crystal would get too heavy for the cup' or 'evaporation would change the solution' as additional reasons, but the supply reason should appear.

- Division shown with units in days and years
- Names a reason the real time would be longer, ideally the falling rate or limited supply

5. Describe the shape of your graph. Was the growth rate the same every day? Use two numbers from your table to support your answer, and explain what in the cup could make the rate change.

Answer: The graph rises steeply at first and then flattens. No, the rate was not constant: for example it rose 3 mm between day 2 and day 3 but only 0.5 mm between day 7 and day 8. The solution started with more dissolved alum than room-temperature water can hold, and as crystals formed they used it up, so there was less and less available to add to the crystal each day. Evaporation and other crystals competing for the same alum also change the rate.

Why: Students should connect the shape of the curve to a cause inside the cup. The key idea is a limited supply being consumed.

- Describes the rise-then-flatten shape
- Uses two numbers from the table
- Gives a cause related to the dissolved alum being used up or competition among crystals

6. Compare the SLOW and FAST cooling results for the whole class. Explain what the comparison suggests about why some rocks that cool from magma have crystals you can see while others have crystals too small to see.

Answer: Class results typically show FAST cooling made many small crystals and SLOW cooling made fewer, larger ones. When a solution (or a melt) cools slowly, only a few crystals get started and they have a long time to grow large. When it cools fast, many crystals start at once and the material is shared among them, so each stays small. Rock that cooled slowly deep underground (such as granite) has crystals you can see; lava that cooled in days at the surface has crystals too small to see.

Why: This links the lab to the crystal-size pattern in igneous rocks (Lesson 17). Full credit does not require rock names; it requires the time-to-grow explanation.

- States the class pattern (fast: many small; slow: few large)
- Explains it by how long crystals had to grow and how many started
- Applies it to rocks cooling quickly or slowly

7. The crystal is a model of Earth processes such as a cave formation growing from drips or a dune growing from gusts. Give one way the model matches those processes and one way it does not.

Answer: Matches: the crystal, like a cave formation or a dune, changes too slowly to watch but adds up to a measurable change over days, and it grows by material being added a tiny amount at a time from a moving supply (dissolved alum; dripping water; wind-blown grains). Does not match: the crystal grew millimeters per day while a cave formation grows about a tenth of a millimeter per year; the crystal's supply ran out in a week while drips and wind can continue for thousands of years; and the materials and the way they attach are different (crystal faces versus sand piling up).

Why: Any sensible match and mismatch earns credit. The strongest answers mention the rate difference with numbers and the limited supply.

- One accurate way the model matches a slow Earth process
- One accurate way it differs (rate, supply, material or mechanism)

8. The giant gypsum crystals in the Naica cave in Mexico are up to about 11 m long and are estimated to have grown over roughly 500,000 years. Calculate their average growth rate in millimeters per year and compare it with your crystal's rate per year. About how many times faster did yours grow?

Answer: 11 m = 11,000 mm. $11,000 \text{ mm} \div 500,000 \text{ years} = 0.022 \text{ mm/yr}$. A classroom crystal at 1.5 mm/day is about 550 mm/yr. $550 \div 0.022 = \text{about } 25,000 \text{ times faster}$. (With a classroom rate of 1 mm/day, about 365 mm/yr, the factor is about 17,000.)

Why: The Naica figures are rounded estimates from published studies and the point is the order of magnitude: the classroom process is tens of thousands of times faster than the natural one, which is why the natural one is invisible on a human time scale.

Also acceptable: Accept any factor between about 10,000 and 50,000 that follows correctly from the student's own rate.

Individual evidence of learning

Each student submits their own daily table, graph, two sketches, the rate-and-extrapolation table and written answers to q1 through q8. The graph, q3 and q4 are the evidence for the rate target; q5 and q7 are the evidence for understanding what the model shows and where it stops.

Assessment criteria

Criterion	Proficient looks like
Data and graph	At least five daily measurements of the same crystal recorded with dates and units, plotted correctly, with observations noted on at least three days.
Rate calculation	Rate computed as change $\div$ days with units (mm/day), converted correctly to mm/yr, and the meter-long extrapolation shown in days and years with the unit chain.
Reasoning about rate	Explains that the rate changed as the dissolved alum ran out, that the extrapolation assumes a constant rate and a constant supply, and that real growth would take longer.
Model and limits	States one way the crystal matches slow Earth processes (invisible per hour, measurable per day, adds up) and one way it differs (speed, material, mechanism of supply).

Accessibility adaptations

- Provide the daily table with day numbers and dates pre-filled and the graph with axes already scaled; a partner reads the ruler aloud while the student records and plots.
- Offer a large-print millimeter grid and a magnifier on a stand so measuring does not require steady hands; accept measurements to the nearest 1 mm.
- Allow q5 and q7 to be answered as a recorded spoken explanation while pointing at the graph.
- Provide a bilingual glossary card for crystal, dissolve, saturated, rate and extrapolate, and sentence frames for q1 ('I could not see it grow because ___, but I knew it grew because ___').

Low-cost alternative

Use Epsom salt (about \$4 per kilogram) instead of alum, with about 50 g per 100 mL of hot water; it grows needle crystals within a day and the whole run fits in three or four days. If hot water is not available, dissolve Epsom salt in warm tap water and let the cup evaporate on a sunny shelf for a week; growth is slower and the rate is smaller but still measurable. One class set of cups can be shared across periods by assigning each period its own cups on the shelf.

Model limitations

A crystal growing from a cooling solution adds material by a different mechanism and a vastly faster pace than a dune, a cave formation or crystals in magma; it models invisibility per hour and accumulation per day, not the real rates. The rate falls during the week because the dissolved alum runs out, so the meter-long extrapolation is a lower bound and a reasoning exercise, not a prediction. The fast-versus-slow cooling comparison matches the pattern seen in igneous rocks but the cause in a water solution (how many crystals start) is only partly the same as in a cooling melt. This activity has not been physically tested by the authors; the sizes and rates listed in expected Observations are typical classroom figures for alum and should be checked in your own trial run.

Teacher notes

Grade q3 and q4 on the student's own data, not on a target rate; check units at every step. If a cup was disturbed and the rate collapsed, let the student use the class average rate for q4 and q8 and note it. The SLOW versus FAST pattern is strong but not guaranteed in every pair of cups; grade q6 on the explanation applied to whatever the class data showed. Keep the best crystals for the rock cycle lesson (L17) as a display of crystal size versus cooling time.