

Design a Hallway Timeline That Tells the Truth About Time

Learning target: I can define the criteria and constraints of a scale-model design problem, calculate where events belong on a true-scale timeline, recognize when the criteria conflict, and choose and justify a design that meets them.

Transfer and design

About 50 min

Pairs

MS-ESS1-4 · practice

MS-ETS1-1 · practice

MS-ETS1-2 · practice

engineering design

data analysis

writing

Standards connections

MS-ESS1-4 (practice, scale and proportion of the time scale; the events are supplied, not recalled): MS-ESS1-4 is a California Grade 8 performance expectation. Building a true-scale model of 4.54 billion years and discovering that all of human history fits inside a pencil line is the proportional reasoning behind explaining how the time scale organizes Earth's history. The event table gives names and dates, so the assessment boundary on recalling period names is respected.

MS-ETS1-1 (practice): Students must state the criteria and constraints precisely enough to test a design (for example, 'no two labels closer than 3 cm'), and they discover that two criteria conflict, which is the heart of defining a design problem well.

MS-ETS1-2 (practice): Three candidate layouts are compared against the same criteria and constraints in a decision table before one is chosen and justified.

Purpose: extend · **Time:** about 50 minutes · **Format:** pairs

Answers with reasoning

The design brief

Your school's science hallway is exactly 30.0 meters long. The principal has asked your class to build a timeline of Earth's history along one wall so that any visitor can walk from Earth's formation at the entrance to today at the far end. She wants it to be **honest about time**: the distance along the wall must be proportional to the number of years, with no cheating. There is one obstacle: a classroom door, 1.0 m wide, whose frame runs from 20.0 m to 21.0 m from the entrance, and nothing may be attached to the door or its frame.

Criteria and constraints — Criteria (what a good design does): C1: the wall is a true-scale model, so a visitor can measure a distance and convert it to years with one scale factor. C2: all four eons, the three eras of the current eon, and at least eight of the events in the table are shown. C3: every label is readable: no two labels may be closer than 3.0 cm along the wall. C4: a visitor can find where modern humans appear. **Constraints (limits you cannot change):** K1: total length 30.0 m. K2: nothing on the door or frame (20.0 to 21.0 m). K3: budget of 40 dollars for tape, card and markers. K4: the class has two build sessions of 50 minutes.

Events to place (real reference values)

Event	Age (millions of years ago)
Earth forms (start of the Hadean Eon)	4540
Start of the Archean Eon; oldest known Earth rock	4000
Oldest widely accepted fossils (microbial mounds)	3500
Start of the Proterozoic Eon	2500
Oxygen begins to build up in the air	2400
Start of the Phanerozoic Eon and Paleozoic Era (animal groups diversify)	539
End-Permian mass extinction; start of the Mesozoic Era	252
First dinosaurs	230
Asteroid impact; start of the Cenozoic Era	66
First primates	55
Current ice-age cycles begin	2.6
Modern humans appear	0.3
Current interglacial period begins	0.0117

Part A: Do the math before you design

- Calculate the scale factor: how many centimeters of wall represent one million years? (30.0 m = 3,000 cm stands for 4,540 million years.) Then state how many million years one meter of wall represents.

Answer: Scale factor: $3,000 \text{ cm} \div 4,540 \text{ million years} = 0.661 \text{ cm per million years}$ (0.6608). One meter of wall: $100 \text{ cm} \div 0.661 \text{ cm per million years} = 151 \text{ million years per meter}$.

Why: The scale factor converts years to wall distance; its inverse gives the years per meter, which helps with the door question.

Also acceptable: Accept 0.66 cm per million years and 150 to 152 million years per meter.

- Complete the table using your scale factor. Distance from the today end = age $\times$ scale factor. Distance from the entrance = 3,000 cm – distance from the today end. Round to 0.1 cm.

Answer: Phanerozoic 539: $539 \times 0.661 = 356.3 \text{ cm}$ from today; $3,000 - 356.3 = 2,643.7 \text{ cm}$ from the entrance. End-Permian 252: 166.6 cm from today; $2,833.4 \text{ cm}$ from the entrance. Asteroid 66: 43.6 cm ; $2,956.4 \text{ cm}$. First primates 55: 36.3 cm ; $2,963.7 \text{ cm}$. Ice-age cycles 2.6: 1.7 cm ; $2,998.3 \text{ cm}$. Modern humans 0.3: 0.2 cm ; $2,999.8 \text{ cm}$. Interglacial 0.0117: 0.008 cm (about 0.1 mm); $2,999.99 \text{ cm}$.

Why: Each distance is age $\times$ 0.6608; small rounding differences are acceptable. The last three rows show the collision that drives the design decision.

Also acceptable: Accept values within 0.5 cm for the large ages; accept 0.0 cm for the interglacial if the student notes it is under a millimeter.

3. Which labels break criterion C3 (closer than 3.0 cm to another label)? List the groups of labels that collide, with the distances between them.

Answer: One unavoidable collision group: the ice-age cycles (1.7 cm), modern humans (0.2 cm), the interglacial (0.008 cm) and the 'today' end label (0 cm) all lie within 1.7 cm of one another, far closer than 3.0 cm. The asteroid (43.6 cm) and first primates (36.3 cm) are 7.3 cm apart, so they are fine. Three pairs share one spot but can be written as a single combined label: the Cenozoic Era start and the asteroid (both 66), the Mesozoic Era start and the end-Permian extinction (both 252), and the Phanerozoic Eon start and the Paleozoic Era start (both 539).

Why: Students should compute gaps, not just list small numbers. The ice-age, human, interglacial and today cluster is the unavoidable conflict.

Also acceptable: A student who counts the asteroid-primates pair as a collision because stacked labels need more than 3 cm of height is making a reasonable design point; accept it if the 7.3-cm gap is stated.

- Identifies the cluster of ice-age cycles, humans, interglacial and today as the collision
- Gives the distances between them
- Notes that same-spot era and event labels can be combined

4. What span of ages falls on the door and its frame (20.0 to 21.0 m from the entrance)? Show the calculation, then check the event table and say whether any listed event lands on the door.

Answer: At 20.0 m from the entrance the distance from today is $3,000 - 2,000 = 1,000$ cm, which is $1,000 \div 0.661 = 1,513$ million years ago. At 21.0 m it is $900 \div 0.661 = 1,362$ million years ago. So the door covers about 1,513 to 1,362 million years ago, inside the Proterozoic Eon. No listed event lands there; the nearest are oxygen buildup at 2,400 million years (about 14.1 m from the entrance) and the Phanerozoic start at 539 (26.4 m).

Why: The door happens to fall in a long stretch with few recorded events, so constraint K2 costs nothing except a gap in the line, which the design can mark as 'line continues.'

Also acceptable: Accept 1,510 to 1,360 million years with rounding.

5. Explain in your own words why criteria C1 and C3 cannot both be fully met by a single straight line at this scale. Which event is the clearest proof?

Answer: C1 fixes the position of every event: distance equals age times one scale factor. At 0.661 cm per million years, everything younger than about 4.5 million years lands within 3.0 cm of the today end, so the ice-age cycles (1.7 cm), modern humans (0.2 cm) and the interglacial (0.008 cm) cannot each have their own 3.0-cm space. The clearest proof is modern humans: at 0.2 cm, less than the width of a label line, their marker would sit on top of the today label no matter how carefully it was drawn. To separate those labels you would have to move them, which breaks C1.

Why: The conflict is built into the numbers; students should state it as a consequence of the scale factor, not as a drawing problem.

Also acceptable: Accept the interglacial (0.1 mm) as the clearest proof.

- Explains that true scale fixes positions
- Shows that several events fall within 3 cm of today
- Names modern humans (or the interglacial) as the proof

Part B: Compare, choose, sketch, justify

Three candidate layouts — Layout 1, one line: a single true-scale line for the whole wall; where labels collide, stack them on top of each other with leader lines pointing to the same spot. **Layout 2, line plus zoom panel:** a true-scale line for the whole wall, plus a separate 1.0-m 'zoom' panel at the today end that shows only the last 66 million years at a larger scale, with a bracket on the main line showing which tiny stretch it magnifies. **Layout 3, bent line:** one line with two scales: the first 4,474 million years at a reduced scale of about 0.58 cm per million years, then the last 66 million years at ten times that scale (about 5.8 cm per million years) so the recent labels spread out and the whole line still fits the 30.0-m wall, with a note at the bend.

6. Score each layout against each criterion and constraint: write 'meets', 'partly' or 'fails' and a few words of reason. Use your numbers from Part A.

Answer: Layout 1: C1 meets (one scale); C2 meets; C3 fails (ice-age, human, interglacial and today labels stacked on one spot; stacked labels do not give 3 cm of wall each); C4 partly (humans findable only as a label in a pile); K2 meets with a gap; K3 and K4 meet (cheapest and fastest). Layout 2: C1 meets on the main line (the panel is clearly a separate magnified view with its own scale); C2 meets; C3 meets if the panel spreads the recent labels (see q7); C4 meets (humans on the panel, with a bracket to the main line); K2 meets; K3 and K4 meet, with a little more card and time for the panel. Layout 3: C1 fails (two scales on one line means a visitor cannot use one factor, and the main scale had to shrink to 0.58 cm per million years to make room; a bend is cheating about time unless clearly flagged); C2 meets; C3 partly (at 5.8 cm per million years, humans sit about 1.8 cm and the ice-age cycles about 15 cm from today, so humans and the interglacial still collide with today); C4 partly; K2 meets; K3 and K4 meet.

Why: The table should show that Layout 1 fails C3, Layout 3 fails C1 and still has a collision, and Layout 2 meets all criteria with a small cost.

Also acceptable: Accept 'partly' for Layout 1 on C3 if the student argues that stacked labels are still readable; the justification in q8 must then address the honesty of stacking.

- Each cell has a judgment and a reason
- Layout 1 marked failing C3
- Layout 3 marked failing or partly meeting C1
- Layout 2's small extra cost noted under K3 and K4

7. For Layout 2, calculate the scale of the 1.0-m zoom panel (100 cm for 66 million years), then the positions of first primates, the ice-age cycles and modern humans on the panel, measured from the today end. Does the panel fix every C3 collision? Show your work.

Answer: Panel scale: $100 \text{ cm} \div 66 \text{ million years} = 1.52 \text{ cm per million years (1.515)}$. Positions from the today end of the panel: first primates $55 \times 1.515 = 83.3 \text{ cm}$; ice-age cycles $2.6 \times 1.515 = 3.9 \text{ cm}$; modern humans $0.3 \times 1.515 = 0.45 \text{ cm}$. The panel fixes the collision between the ice-age cycles and the rest (3.9 cm from today, more than 3.0 cm from humans), but modern humans (0.45 cm) and the interglacial (0.018 cm) still sit within 3 cm of the today label. A second, smaller zoom of the last 3 million years (for example 30 cm for 3 million years, 10 cm per million years, placing humans at 3.0 cm and the interglacial at 0.1 cm) is needed to separate humans from today, and even then the interglacial stays stuck to the end.

Why: The point is that one zoom is not enough; nested zooms mirror the nested units of the real time scale (eon, era, period, epoch).

Also acceptable: Accept 1.5 cm per million years and positions within 1 cm; accept a proposal for a second zoom with any reasonable scale that places humans at least 3 cm from today.

-  Sketch your chosen (or improved) layout as the wall seen from the hallway: mark the entrance, the door at 20.0 to 21.0 m, the today end, the four eon boundaries, and at least eight events at positions that match your calculations (not to scale on paper, but in the right order and with the distances written beside them). If you use a zoom panel or a bend, draw it and label its scale.

Answer: A sketch showing the entrance at 0 m, the door gap at 20.0 to 21.0 m labeled 'line continues, about 1,510 to 1,360 million years', the today end at 30.0 m, eon boundaries at the entrance (4,540), 3.6 m (4,000), 13.5 m (2,500) and 26.4 m (539), at least eight events with their computed distances written beside them, and, for Layout 2, a 1.0-m zoom panel at the today end with its scale (1.52 cm per million years) and a bracket on the main line showing the 43.6-cm stretch it magnifies; strong designs add a second zoom for the last 3 million years.

Why: Grade the sketch for correct order, written distances that match Part A, the door gap, and a clearly labeled scale on any zoom or bend. Eon boundary distances from the entrance: 4,000 Ma at $3,000 - 2,643 = 357$ cm (3.6 m); 2,500 Ma at $3,000 - 1,652 = 1,348$ cm (13.5 m); 539 Ma at 2,644 cm (26.4 m).

Also acceptable: A Layout 3 sketch is acceptable if the bend is clearly flagged and the justification admits the C1 cost.

- Entrance, door gap and today end marked
- Four eon boundaries in the right order with distances
- At least eight events with computed distances
- Any zoom or bend labeled with its own scale

8. Justify your choice. Your justification must (1) name the layout and any improvement you made, (2) explain how it meets every criterion and constraint or admit which one it only partly meets, (3) explain what is **lost** in your design compared with a perfect single true-scale line, and (4) say why that loss is acceptable.

Answer: Model justification for Layout 2 with a second zoom: (1) Layout 2, improved with a second 30-cm zoom panel for the last 3 million years. (2) C1 is met on the main line, which stays one true scale from entrance to today; the panels are separate, clearly labeled magnified views with their own scales, like an inset on a map. C2 is met: all eon and era boundaries are on the main line and ten events are shown. C3 is met: the first panel separates the ice-age cycles from the recent cluster, and the second panel puts modern humans 3.0 cm from today; the interglacial is the one label that still touches the today line, which I state honestly on the panel. C4 is met: a visitor finds humans on the second panel, with brackets leading back to the main line. K1 and K2 are met: the main line skips the door with a 'line continues' note across a stretch with no listed events. K3 and K4 are met: two extra cards and about 20 extra minutes. (3) What is lost: a visitor can no longer see the last 66 million years and the whole 4,540 million years at one scale in one glance; the panels could mislead someone who does not read the scale notes. (4) This loss is acceptable because the alternative, a pile of labels on one spot, hides the information entirely, while a labeled zoom is exactly how scientists handle the problem: the real geologic time scale nests smaller units inside larger ones for the same reason.

Why: Full credit requires all four parts; the honesty about what is lost and the parallel to nested time units are the marks of a strong response. A Layout 3 justification can earn full credit only if it admits that C1 is compromised and explains how the bend is flagged.

Also acceptable: A student who chooses Layout 1 and argues that stacked labels are honest because every label still sits at its true position has a defensible position if the C3 failure is admitted and a reading aid (numbered labels with a key) is added.

- Names the layout and any improvement
- Checks every criterion and constraint, admitting any partial
- States what is lost compared with a perfect single line
- Explains why the loss is acceptable

9. A visitor walking your timeline says, 'The last 66 million years must be the most important part of Earth's history, because it has the most labels.' Write what the timeline's builder should reply.

Answer: The builder should reply that the number of labels shows how much we know and how finely we can divide recent time, not how important or how long it is: the last 66 million years is about 1.5 percent of the wall (43.6 cm of 3,000 cm), and it carries many labels because its rocks and fossils are abundant and well preserved and because human events are recent. The earlier 98.5 percent of the wall holds the formation of the planet, the first life and the oxygen in our air, which are at least as important. A true-scale line exists precisely so that the visitor can see that difference.

Why: Transfers the chart-space misconception from W3, W5 and W7 to the student's own design.

Also acceptable: Accept 'labels show knowledge, not time' with any correct supporting number.

- Separates number of labels from length or importance
- Uses a number (43.6 cm, 1.5 percent, or the 0.661 scale)
- Names a major early event

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
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Calculations (Part A)	Scale factor, all seven positions, the door span and the collision list are correct with units and shown work.	One calculation error that does not change the collision conclusion.	Scale factor correct but several positions wrong, or distances from the wrong end.	Scale factor wrong or calculations missing.
Defining the problem (criteria, constraints, conflict)	Explains precisely why C1 and C3 conflict at this scale, using computed distances, and treats the door as a constraint with a computed age span.	Identifies the conflict with one number; door handled without calculation.	States that 'labels overlap' without connecting it to the scale factor.	Does not recognize the conflict.
Comparing and choosing a design	Decision table complete with reasons in every cell; the chosen layout meets or honestly flags every criterion and constraint; an improvement is proposed where the layout falls short.	Table complete; choice defensible; no improvement where one was needed (for example, a single zoom left humans colliding).	Table partly complete; choice made without reference to the table.	No comparison; choice unexplained.
Justification and trade-off	All four required parts present; states clearly what is lost and why it is acceptable; connects the solution to how scientists nest the time scale or to the chart-space idea.	All four parts present but the loss is vague or the acceptability is asserted without a reason.	Justification restates the design without addressing criteria or loss.	Justification missing or unrelated to the design.

Teacher notes

All event dates are current reference values (Earth 4,540; eon boundaries 4,000 and 2,500; Great Oxidation Event about 2,400; Phanerozoic 538.8 rounded to 539; end-Permian 251.9 rounded to 252; first dinosaurs about 230 to 240; Chicxulub 66.0; first primates about 55 to 56; Quaternary 2.58; Homo sapiens about 0.3; Holocene 0.0117 million years). Key numbers: scale 0.661 cm per million years; Phanerozoic at 356 cm from today; asteroid 43.6 cm; ice-age cycles 1.7 cm; humans 0.2 cm; interglacial 0.1 mm; door spans about 1,513 to 1,362 million years ago (Proterozoic, no listed events). The intended discovery is that one zoom panel does not rescue the human label (0.45 cm on a 1-m panel for 66 million years) and a second nested zoom is needed, which mirrors the nested eon-era-period-epoch structure. If the class builds the real thing, 30 m of painter's tape, index cards and markers cost well under 40 dollars; a 'line continues' card on each side of the door keeps K2. This sheet can replace Lab 1 (the scaled timeline) when hallway space or time is short, or follow it as the design extension.

Scaffold offered to students: Keep the units straight

Write the scale factor with its units, cm per million years, and multiply every age in million years by it. For ages given in decimals (2.6, 0.3, 0.0117), the answers will be small; that is the point, not a mistake. To find distance from the entrance, subtract from 3,000 cm. A quick check: the Phanerozoic boundary should land about 3.6 m from the today end, which is about an eighth of the wall. For q6, fill one column at a time, and use the collision list from q3 to judge C3.

Extension: Add the engineering trade-off the brief left out

The principal adds a fifth criterion: 'A visitor should be able to see that the first three eons are most of Earth's history, without reading a single number.' Propose one design feature that meets it (think about color, width, texture or lighting rather than labels), explain how you would test whether it works on a sample of ten visitors, and describe one way the new feature could conflict with criterion C3 or constraint K3. Then rank all five criteria in order of importance and defend your top choice in two sentences.