

Design Brief: A Touchable Salt-Crystal Model for Science Night

Learning target: I can define criteria and constraints for a model of an extended structure, use test data and calculations to compare three designs, and justify a design that correctly shows the repeating pattern and 1:1 ratio of table salt.

Transfer and design

About 55 min

Small group

MS-PS1-1 · assesses

MS-ETS1-1 · practice

MS-ETS1-2 · practice

MS-ETS1-3 · practice

engineering design

data analysis

writing

Standards connections

MS-PS1-1 (assesses, the extended-structure half): The product is a model of sodium chloride that must show its repeating pattern, its 1:1 ratio and the absence of a smallest particle. Deciding what a correct model must show, and sketching it, is direct evidence toward developing models of extended structures. Charges on the particles are not required, in line with the assessment boundary.

MS-ETS1-1 (practice): Students turn a committee's wishes into criteria and constraints with numbers or tests, including a limit set by what visitors can safely handle.

MS-ETS1-2 (practice): Students score three candidate designs against their own criteria and constraints in a systematic table before choosing.

MS-ETS1-3 (practice): Students use drop-test and cost data from three prototypes to identify the best feature of each and propose a combined design.

Purpose: extend · **Time:** about 55 minutes · **Format:** small-group

Answers with reasoning

The committee's brief — 'For Science Night we want a hands-on model of table salt that visitors, including second graders, can pick up. After touching it, a visitor should be able to say: salt is a repeating pattern of two kinds of particles, one for one, with no smallest piece. Budget: \$40. It must fit on a 40 cm by 40 cm table square and stand no taller than 40 cm. It must survive a 1 meter drop onto a tile floor with no more than two pieces coming loose, because it will be handled by about 200 visitors. A team of four must be able to build it in two class periods (about 90 minutes). No small parts that a young child could swallow if they came loose.'

Price list for planning (estimated prices, for this exercise)

Material	Size	Estimated price
Foam balls, two colors	2.5 cm across	\$0.15 each
Wooden balls, two colors	6 cm across	\$1.50 each
Toothpicks	box of 500	\$2.00
Hot-glue sticks	pack of 20	\$3.00
Interlocking plastic bricks, two colors	2 cm cubes	\$0.08 each
Craft wire	10 m roll	\$4.00
Clear acrylic display box	25 cm cube	\$12.00
Poster board	sheet	\$1.00

Prices are rounded estimates chosen for this exercise, not quotes from a store.

Part A: Do the math before you design

A ball-and-stick salt model is a cube of balls, n balls along each edge, with every ball joined to its neighbors up, down, left, right, front and back by a stick. The number of balls is $n \times n \times n$. The number of sticks is $3 \times n \times n \times (n - 1)$. The two colors alternate so that no two neighbors are the same color.

- Complete the table. For the color split, remember that colors alternate; when the total is odd, one color has one more ball than the other. Show the $n = 4$ row's calculations below the table.

Answer: $n = 2$: 8 balls; 4 and 4; sticks $3 \times 2 \times 2 \times 1 = 12$; cost $8 \times \$0.15 = \$1.20$. $n = 3$: 27 balls; 14 and 13; sticks $3 \times 3 \times 3 \times 2 = 54$; cost $27 \times \$0.15 = \$4.05$. $n = 4$: 64 balls; 32 and 32; sticks $3 \times 4 \times 4 \times 3 = 144$; cost $64 \times \$0.15 = \$9.60$. $n = 5$: 125 balls; 63 and 62; sticks $3 \times 5 \times 5 \times 4 = 300$; cost $125 \times \$0.15 = \$18.75$.

Why: Balls are n cubed; sticks are the edges of a cubic grid, $3 \times n^2 \times (n - 1)$; alternating colors split an even total evenly and an odd total 1 apart.

Also acceptable: Accept the odd- n split written either way round.

- The $n = 3$ cube has 14 balls of one color and 13 of the other, yet the model is still a fair model of salt's 1:1 ratio. Explain why, and say what happens to the imbalance as n grows.

Answer: The imbalance comes from the model's edges, where the alternation stops; inside the cube every ball still has neighbors of the other color only. 14:13 is already close to 1:1, and as n grows the extra ball becomes a smaller and smaller share of the total (63:62 at $n = 5$; a real grain with billions of particles is 1:1 to any precision), so the model fairly represents the ratio.

Why: Students must locate the imbalance at the edge and see that it shrinks relative to the total as the model grows.

Also acceptable: Accept '14 $\div$ 13 is about 1.08, close to 1' as the first part.

- Attributes the one-ball difference to the edges of the model
- States that the difference becomes negligible as n grows

Part B: Define the problem precisely

A vague requirement cannot be tested. 'Visitors should understand salt' is vague. 'A visitor who studies the model can point to where the pattern would continue' can be tested by asking ten visitors. Criteria describe what a successful design does; constraints are limits the design must stay inside.

3. Write three **criteria** for a successful model, each with a number or a clear test. At least two must come from the science: the model must show the repeating pattern in all three directions, the 1:1 ratio, and that there is no smallest piece.

Answer: Examples: (1) A visitor can point to a particle of each color and count that it touches neighbors of the other color on every side that is not an edge (pattern in all three directions). (2) A visitor can count the two colors in any row or layer and find equal numbers, or one apart (1:1 ratio). (3) When asked 'where is the smallest piece of salt?', 8 of 10 visitors say there is none or that the pattern keeps going (no smallest piece). (4) A second grader can hold it with two hands without it bending (handling).

Why: Each criterion must be testable: a count, a number of visitors, or a yes/no test. At least two must be the science criteria.

Also acceptable: Accept a criterion such as 'the colors alternate in every row, column and stack' as the pattern criterion.

- Three criteria
- Each with a number or a clear test
- At least two are the science criteria from the brief

4. Write four **constraints** from the brief, each with its number or limit. Then add one constraint of your own that the committee forgot (think about who will handle the model and where it will sit).

Answer: From the brief: cost at most \$40; fits on 40 cm by 40 cm and no taller than 40 cm; no more than 2 pieces loose after a 1 m drop onto tile; built in at most 90 minutes by four students; no small parts that could be swallowed. One of their own, for example: the model must be wipeable, since 200 visitors will touch it; it must not have sharp stick ends exposed; it must weigh little enough for a second grader to lift.

Why: The brief contains five constraints; any four with their numbers earn credit, plus one sensible addition about handling or safety.

Also acceptable: Accept the swallowing limit as the added constraint if the student only counted four in the brief.

- Four constraints from the brief with numbers
- One additional constraint about visitors, safety or the setting

5. Pick one of your criteria and one of your constraints and explain how each one rules out at least one possible design before any building happens.

Answer: Example: the 'no smallest piece' criterion rules out a model that is a single unit of 8 balls with nothing to show the pattern continuing, because a visitor would see a finished object. The drop constraint (at most 2 loose pieces) rules out a loose toothpick lattice unless the joints are reinforced, because foam on toothpicks sheds pieces when it hits tile.

Why: The point is that criteria and constraints are tools for eliminating designs early.

Also acceptable: Accept the size or budget constraint ruling out a very large wooden-ball cube (for example, $4 \times 4 \times 4$ wooden balls would cost \$96).

- One criterion linked to a design it rules out
- One constraint linked to a design it rules out

Part C: Compare three prototypes

Three prototypes built and tested by last year's class

1 Design 1: Foam-ball lattice

A 4 × 4 × 4 cube of 2.5 cm foam balls in two colors on toothpick sticks, joints dabbed with hot glue. About 19 cm on each side. Shows balls and sticks, like the models in class. Materials: 64 foam balls, toothpicks, glue.

2 Design 2: Brick checkerboard

A 6 × 6 × 6 block of 2 cm interlocking bricks in two colors, each layer a checkerboard and each layer shifted so colors alternate up and down too. One corner is left unfinished, with a bag of 50 loose bricks so visitors can keep adding to the pattern. About 12 cm on each side. Bricks touch face to face; there are no sticks.

3 Design 3: The single unit

One 2 × 2 × 2 cube of eight 6 cm wooden balls, four of each color, glued ball to ball. About 12 cm on each side. Labeled 'the salt unit.' Very sturdy; takes 25 minutes to build.

Prototype test results (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Design	Pieces loose after 1 m drop, trial 1	Pieces loose after 1 m drop, trial 2	Build time (minutes, team of four)	Materials cost
1: Foam-ball lattice	9	7	70	\$14.60
2: Brick checkerboard	0	1	85	\$21.28
3: The single unit	0	0	25	\$15.00

Simulated results for teaching, written to be realistic for these materials.

6. Score each design against each criterion: 2 = fully meets, 1 = partly, 0 = fails. In the constraints row, use the brief and the test data.

Answer: Design 1: pattern 2, ratio 2, no smallest piece 1 (edges look finished, but sticks suggest connections continue), constraints: fails the drop test (average 8 loose pieces) and exposes stick ends; also loose foam balls are small enough to be a swallowing risk. Design 2: pattern 2, ratio 2, no smallest piece 2 (the unfinished corner and the bag of bricks show the pattern continuing), constraints: drop (0 and 1 loose), time (85 minutes), cost (\$21.28) and size (12 cm) all met, but the bag of 50 loose 2 cm bricks breaks the no-small-parts rule for a second grader, so the design passes only if that is fixed (glue the extra bricks into a half-built corner, or hand the bag only to an adult helper). Design 3: pattern 1 (one unit only, in three directions but only once), ratio 2, no smallest piece 0 (it is literally labeled as a unit and looks like a molecule of 8), constraints: all met.

Why: The scores depend on the student's criteria, but Design 3 must fail the no-smallest-piece criterion and Design 1 must fail the drop constraint; Design 2 is the only one that meets the science criteria, and its loose bricks are the one constraint problem a careful student should catch.

Also acceptable: Accept Design 1's no-smallest-piece score of 1 or 0 with a reason; accept 'partly' for Design 2's pattern if the student objects that bricks show no sticks (bonds).

7. Check two numbers. (a) Design 2 uses $6 \times 6 \times 6$ bricks at \$0.08 plus 50 extra bricks: calculate the brick cost and compare with the listed \$21.28. (b) Average the two drop-test results for Design 1 and state whether it meets the drop constraint. Show your work.

Answer: (a) $6 \times 6 \times 6 = 216$ bricks; $216 + 50 = 266$ bricks; $266 \times \$0.08 = \$21.28$, which matches the listed cost. (b) Design 1: $(9 + 7) \div 2 = 8$ loose pieces on average, which is more than the limit of 2, so it fails the drop constraint.

Why: Both checks confirm the dataset; the drop average shows Design 1 fails by a wide margin, not by chance.

Also acceptable: Accept the brick cost computed as $216 \times 0.08 = \$17.28$ plus $50 \times 0.08 = \$4.00$.

Part D: Decide and justify

8. Recommend one design, or a specific change that combines the best features of two designs. Justify it with your scores from q6, at least two numbers from the test data or your calculations, and one sentence on how it keeps a visitor from thinking salt is made of molecules.

Answer: A strong recommendation is Design 2 with its loose-brick problem fixed, or Design 2 improved with a feature from Design 1. Example: 'Recommend Design 2. It scored 6 of 6 on the three science criteria, lost 0 and 1 pieces in the drop tests (limit 2), costs \$21.28 (under \$40) and builds in 85 minutes (under 90). Its unfinished corner is what keeps visitors from thinking salt comes in molecules: they can see the pattern stopping mid-row and know there is no final piece. Two fixes: glue the 50 extra bricks into a ragged, half-built corner instead of leaving them loose, because 2 cm bricks are small enough for a young child to swallow; and add a small poster-board card (\$1) showing a ball-and-stick view of one corner, borrowing Design 1's strength (visible bonds) without its fragility.' Design 3 should be rejected because a single labeled unit teaches exactly the wrong idea.

Why: Full credit requires a decision, the use of scores and at least two numbers, and the molecule-misconception sentence. A recommendation of Design 2 that keeps the loose bag without addressing the small-parts constraint is a level-3 decision, not level 4. A recommendation of a reinforced Design 1 (wire instead of toothpicks, in the acrylic box) is acceptable if the student shows the new cost stays under \$40 and explains how the drop test would be passed.

Also acceptable: A student who recommends Design 1 rebuilt with craft wire and glue inside the acrylic box (\$14.60 + \$4 + \$12 = \$30.60) has a defensible plan if the drop problem is addressed.

- Clear recommendation or specific combination
- Uses the q6 scores
- Cites at least two numbers from the data or calculations
- Explains how the design prevents the salt-is-molecules misconception

9. Sketch your recommended model. Label the two kinds of particles with a legend, mark where the pattern continues beyond the model, show how a visitor can see the 1:1 ratio, and label any feature you added to pass the drop test.

Answer: A sketch showing a block with two colors alternating in rows, columns and layers; a legend naming the two colors as sodium and chlorine; an unfinished corner, arrows or dots labeled 'pattern continues'; a row or layer with counts written to show equal numbers; and a labeled reinforcement (interlocking bricks, wire joints, or a display box) for the drop test.

Why: The sketch is the model; it must show the three science features and one engineering feature.

Also acceptable: A flat top-view plus a side view is acceptable in place of a three-dimensional drawing.

- Alternating two-color pattern in at least two visible directions
- Legend for the two kinds of particles
- A feature showing the pattern continues
- Equal counts shown somewhere
- A labeled sturdiness feature

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
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Criteria and constraints (Part B)	Three testable criteria including the three science features, four constraints with numbers from the brief, and a sensible added constraint.	Criteria and constraints are present and mostly testable; one is vague or one science feature is missing.	Several requirements are vague ('it should be good') or criteria and constraints are mixed up.	Requirements missing or untestable.
Use of data and calculation (Parts A and C)	Part A table correct with work shown; q7 checks correct; q6 scores consistent with the data and the student's criteria.	One arithmetic error, or one q6 score not supported by the data.	Several errors or scores assigned without reference to the data.	Calculations missing or mostly wrong.
Decision and justification (q8)	Clear recommendation justified with scores and at least two numbers; names a trade-off; explains how the design avoids the molecule misconception.	Recommendation justified with scores or numbers; the misconception sentence is present but thin.	A choice with a general reason ('it is sturdy') and no numbers.	No decision, or a decision contradicted by the data (for example, choosing Design 3 without addressing the no-smallest-piece failure).
Scientific accuracy of the model (q9 and throughout)	The sketched model alternates two kinds of particles in three directions, shows equal counts, and shows the pattern continuing; no suggestion that salt is a molecule.	Model is correct but one feature (continuation or counts) is not shown.	Model shows the pattern in only one or two directions or treats a small unit as the whole.	Model shows salt as separate pairs or molecules.

Teacher notes

The science criteria are the heart of this task; Design 3 is included because it is sturdy, cheap and fast, and still wrong, since it presents salt as a finished unit of eight. Expect some teams to be tempted by it. Design 2 has a deliberate flaw too: a bag of loose 2 cm bricks fails the brief's no-small-parts rule (a part that fits inside a 3.2 cm tube is a choking hazard for young children by the U.S. toy-safety test), so the best answers fix it rather than ignore it. The prices are estimates for this exercise, and the drop-test data are simulated; if you can, have teams drop a real toothpick-and-foam model once so they see why Design 1 sheds pieces. Part A's stick formula counts the edges of an n by n by n grid; 14-to-13 for $n = 3$ is real and is a good moment to explain that formulas for extended structures describe the inside of the pattern, not its edges. Accuracy note: the particles in salt are ions (charged), which the brief's 'two kinds of particles' wording accommodates without requiring charges; MS-PS1-1 does not assess the ionic nature of subunits. Interlocking bricks with no sticks are a fair model of salt's pattern and ratio but do not show bonds; a student who flags this is reading the model's limits well. Extension: a checkerboard gives 1:1, so quartz needs a method that joins each silicon ball to four oxygen balls while each oxygen ball joins two silicons, for example silicon balls at the centers of tetrahedra sharing corner oxygens; 20 silicon atoms need 40 oxygen atoms; both extended-structure models share a pattern with no fixed size, which a water-molecule model lacks.

Scaffold offered to students: Filling the Part A table

Do one row at a time. For $n = 4$: balls = $4 \times 4 \times 4 = 64$; colors split 32 and 32; sticks = $3 \times 4 \times 4 \times 3 = 144$; cost = $64 \times \$0.15 = \$9.60$. For odd n , the total is odd, so one color gets one extra ball; for $n = 3$ the split is 14 and 13. For Part C, score a design before reading the test data, then adjust the constraints row with the data; this keeps your science criteria separate from the sturdiness question.

Extension: A second model for a different structure

The committee likes your salt model and asks for a companion model of quartz, in which each silicon is joined to four oxygens and each oxygen is shared by two silicons (ratio 1:2). Explain why a simple alternating checkerboard of bricks would be the wrong model for quartz, propose a building method that shows the 1:2 ratio and the sharing, and estimate the number of balls of each color for a model with 20 silicon atoms. Then write one sentence on what both models share that a model of a water molecule would not.