

Sheets or Networks: Build a Structure That Survives

Investigation question: Which arrangement of connections, flat stacked sheets or a three-dimensional network, best resists a load, a sideways push and a drop, and what does that tell us about graphite and diamond?

Engineering design challenge

Groups of 4

1 session

Setup 5 · Activity 45 · Cleanup 5 min

MS-PS1-1 · practice

MS-ETS1-2 · practice

MS-ETS1-3 · practice

Name _____

Group _____

Date _____

Your role today

- ☐ **Builder:** Assembles the reference structures and the group's designs, keeping to the four-toothpicks-per-gumdrop rule.
- ☐ **Tester:** Runs the push, load and drop tests exactly as written, in the same order for every structure, and calls out the results.
- ☐ **Recorder:** Counts materials used, measures height, writes every test result in the data table and sketches the designs.
- ☐ **Design lead:** Keeps the criteria and constraints checklist in front of the group, proposes the change between Design 1 and Design 2 based on the data, and manages the build time.

Safety

- Toothpick points are an eye hazard. Build and test at desk level, keep faces back from structures being tested, and never flick or throw a structure.
- Drop tests are from 30 cm onto the desk only, measured with the ruler, with hands and faces clear of the landing zone.
- The load bottle can tip and roll off a failing structure; the tester keeps a hand ready beside the bottle (not on it) to catch it.
- No eating marshmallows or gumdrops; pierced candy is not food and allergies may be present. Wash hands afterward, as marshmallow sugar is sticky.
- Broken toothpicks go in the cup immediately; do not leave splinters on desks or floors.

Procedure

1. Build the sheet reference: make a flat honeycomb of 10 marshmallows and 11 toothpicks (two hexagons sharing one side) so that every inner marshmallow has 3 toothpicks and the sheet lies flat. Build a second identical sheet and lay it on top of the first with no toothpicks joining the layers.
2. Build the network reference: make a square of 4 marshmallows and 4 toothpicks, add a fifth marshmallow above the middle joined to all four corners (a square pyramid), then turn it over and add a

sixth marshmallow below the middle joined to the same four corners. You now have an octahedron: 6 marshmallows, 12 toothpicks, every face a triangle, and every marshmallow holding exactly 4 toothpicks that point in different directions. Stand it on any triangular face; the opposite face is a flat triangle on top, about 5 cm up, where the bottle will sit.

3. Test both references in the same order and record each result. Push test: lay the ruler flat against the top layer and push sideways gently; measure how far the top moves and note whether anything slides off. Load test: set the bottle on top and count 10 seconds. Drop test: hold the structure 30 cm above the desk (ruler held upright beside it), release, and count the connections that came apart.
4. Read the criteria and constraints card aloud. Design lead sketches a Design 1 on the sheet using what the reference tests showed; the group agrees before any building starts. Count materials as you take them: no more than 30 toothpicks and 16 marshmallows, no marshmallow with more than 4 toothpicks.
5. Build Design 1 in 12 minutes. Measure its height, count the materials actually used, and run the three tests in the same order. Record pass or fail against every criterion.
6. Look at your data and at the structures that passed on nearby desks. Name the one feature you will change (for example add a diagonal, replace a square with two triangles, add connections between layers) and write it on the sheet with a reason.
7. Build Design 2 in 12 minutes under the same constraints, reusing undamaged materials. Measure, count, test and record exactly as before.
8. Draw Design 2 in the drawing box and circle the feature you added. Answer q1 and q2 on the sheet, then the analysis questions individually.

Record your observations

Lab 3 recording sheet: Sheets or networks?

Test every structure in the same order: push, load, drop. Record what you measured, not what you expected. A structure passes a criterion only if it meets the number on the card.

- ☐ Criterion 1: at least 8 cm tall (measure from desk to top marshmallow).
- ☐ Criterion 2: holds the 500 g bottle on top for 10 seconds.
- ☐ Criterion 3: under a gentle sideways push with the ruler, the top moves no more than 1 cm and nothing slides off.
- ☐ Criterion 4: survives a 30 cm drop onto the desk losing no more than 2 connections.
- ☐ Constraint: no more than 30 toothpicks and 16 marshmallows.
- ☐ Constraint: no marshmallow holds more than 4 toothpicks (an atom has a limited number of bonds).
- ☐ Constraint: 12 minutes per build; no tape, glue or anything but toothpicks and marshmallows.

Reference builds

Structure	Toothpicks per marshmallow (most common)	Directions of connections (flat or 3-D)	Push test: top movement (cm) and anything slide off?	Load test: held 10 s?	Drop test: connections lost
Sheet stack					
Network					

Design tests

Design	Toothpicks used	Marshmallows used	Height (cm)	Push: movement (cm), slide off?	Load: held 10 s?	Drop: connections lost	Criteria met (list numbers)
Design 1							
Design 2							

-  Draw Design 2 (marshmallows as circles, toothpicks as lines). Circle the feature you added after testing Design 1 and label it with the criterion it was meant to fix.

1. What one feature did you change between Design 1 and Design 2, and which test result made you change it?

2. Which criterion was hardest to meet within the constraints, and what did the constraints force you to give up?

Analysis questions

3. Compare the two reference builds in the push test. Which one slid, and what about its connections allowed that? Name the real carbon structure each reference stands for.

4. Use the sheet-stack model to explain what happens when a pencil is dragged across paper. Then explain why the same thing cannot happen with the network model, and what that means for diamond.

5. With 16 marshmallows and at most 4 toothpicks each, what is the largest number of toothpicks a design can contain? If a design used all 30 toothpicks, what was the average number of toothpicks per marshmallow? Show the arithmetic.

6. Structures made only of triangles usually passed the push test, but they use more toothpicks for the same height. Describe this trade-off and explain how the material budget shaped your Design 2.

- 7.** Look at the class results on the board. Name two features shared by the designs that met the most criteria, and describe a Design 3 that combines the best feature of your design with the best feature of another group's.

- 8.** In graphite, nothing joins the sheets except weak attraction, and in diamond every atom has exactly four bonds. Name two ways the marshmallow model matches these facts and two ways it does not.
