PHASE THREE: CONTROL
DESIGNING 2D MATERIALS

Mission: How do we control properties of super thin materials?

Age: 11+
Materials: $10

Time: 2 hrs (1 hr active)
(Set-up: 15 min | Activity: 90 min including chilling time | Clean-up: 15 min)

What you need:

Materials:
- 1 6-oz. package of Jell-O or other gelatin dessert (any flavor)
- 2 cups hot water
- 2 cups cold water
- 7 coated paper plates (or more for additional experimentation)
- Uncooked rice
- Chunky cereal (like Chex or similar size and texture)
- Milk (about 1 cup)

Equipment:
- 2-cup liquid measuring cup
- Mixing bowl
- Spoon for mixing
- Table knife
- Baking tray with raised edges
- Small paper cup (or any easy-to-pour container)
- Pen or marker
- A few sheets of paper
- (Optional) Smartphone or camera for recording video

What to do:

Initial Set-up:

1. Let's start building models of some 2D materials! With help from an adult, prepare the gelatin in a mixing bowl with hot and cold water according to the package instructions. Stir carefully to avoid making bubbles.

2. Prepare space in the refrigerator for 4 plates to each lay flat on a shelf. Spoon a little bit of the gelatin onto each plate—just enough to cover the bottom of the plate, making sure it spreads out evenly into a thin, smooth surface. Add slowly to avoid bubbles. Set aside any leftover liquid gelatin; don't throw it away or chill it yet!

3. Build your first model material:
   - Model #1: Allow one plate to chill untouched. Model #1 represents a 2D material with a perfectly smooth structure.

4. For the next three models, we're going to change up this perfect structure by adding what scientists call "defects." In real materials, defects in their structure change their properties and behaviors.
   - Model #2: Randomly sprinkle uncooked rice onto the gelatin, enough to create a slightly rough or uneven surface. The rice in Model #2 represents tiny defects.
   - Model #3: Randomly scatter cereal pieces around the gelatin. The cereal in Model #3 represents large defects.
   - Model #4: Leave the final plate untouched for now. After it is completely chilled, use a table knife to carefully cut or "draw" long lines through the gelatin in different directions. These cuts in Model #4 represent another type of defect called "grain boundaries." When scientists "grow" real materials, the building process of placing atoms often starts in several different locations at the same time. Grain boundaries form when the different sections come together.

5. Chill the plates in the refrigerator until the gelatin solidifies (about 30 minutes). Take the plates out and put them in your work area (preferably near a sink). Don't forget to finish Model #4! You now have four different 2D material models to experiment with and observe how they affect the flow behavior of milk.

PHASE THREE: CONTROL
COLOR CONTROL

Experiment with your model 2D materials:

6. Ready to observe the properties of your models? To do so, you'll watch how a little bit of milk travels down and across each plate. In this model, milk represents a property of the material, like electricity or heat. The flow of the milk represents how this material property "behaves." (Optional: Ask a partner to record a video as the milk flows across each model so you can compare the milk's behavior more carefully later!).

7. Fill a small cup or container with milk for easy pouring control. If using a paper cup, pinch the rim to make a spout.

8. Let's start with Model #1, the perfectly smooth plate of gelatin. Prop up one edge of the plate on the side of your baking tray. Notice where the edge of the plate is highest; this will be your starting point for pouring milk. The baking tray will catch the milk at the bottom.

9. Slowly pour the milk from the starting point as you watch and/or record video. What do you observe? How does the milk flow down—fast or slow? Does it travel in a straight line or spread out randomly? Where does the milk first reach another edge of the plate?

10. Repeat steps 8-9 with your other three models, pouring milk onto the starting point of each plate. How do rice, cereal, or cuts in the surface each change the flow of the milk? In real materials, the type of defect, how many defects there are, and their location in the main material determines the behavior of a particular property. For example, defects might act as a speed bump or even completely change the direction of the flow.

Design challenge with model 2D materials:

11. Now that you've modeled how different 2D materials behave, you're ready to design a new material! Sometimes defects occur naturally, but scientists often purposely place defects into materials to achieve desired property behaviors. The process of building new materials is called "fabrication." Like building with atomic-sized Legos, scientists use special tools to fabricate new materials, almost atom by atom.

12. Take your remaining three plates, and mark point "A" anywhere on the edge. Point A will be your starting point. Then mark point "B" about a third of the way around the edge of each plate.

    Your challenge: Can you design a 2D material—using combinations of tiny defects, large defects, and grain boundaries—that will direct your milk from point A to point B?

    Based on your earlier observations of the milk's behavior, sketch your plans for three different designs on a plain sheet of paper.

13. Time for fabrication! Use the remaining liquid gelatin that was set aside in Step 4 to make three fresh plates of gelatin. Based on your plans, add your defects either before or after cooling.

14. Once your new models are solidified, it's time to put them to the test! Prop up each plate under Point A. Slowly pour a little milk at Point A. Does it successfully flow to Point B? Which of your designs worked best?

14. Explore further! Can you think of other ways to design the model to control flow? Look for other foods that could create different types of defects in the gelatin, or try making tiny holes in the gelatin with a straw. Predict and test what will happen in each model!

Clean-up:

The food ingredients in this activity are safe to eat, but they may not taste good together. Pour the milk into the sink and dispose of your experimental gelatin plates in the trash. Chill any leftover gelatin for a snack!