Introductory discussion:

- What are granular materials? Suggest some examples.
- Examine the box of materials. Which is the odd one out?
- What are the different states of matter? How do we define each?
- In what state of matter should we classify granular materials?

Activity 1: Volume occupied by a collection of grains

Granular material can be poured into a container like a liquid. But does it have fixed volume? Lightly pour rava into a cup till it is about three-quarters full. Gently move the cup around to make sure the surface of the rava is flat. Then mark the level of the rava on the cup with a marker. Next, tap the bottom of the cup lightly on the table a few times. Mark the level of the sand again – did it change?

If the level of the sand in the cup dropped when you tapped the cup, how does that compare with a regular liquid like water? What happens if you try repeating the experiment with water?

Activity 2 (challenge): Pick up a cup of rava without touching the cup!

Instructions: Use the plastic cup with rava, and the provided cardboard cylinder (which is just the inside of a paper towel roll, available at home) or PVC pipe. Put the cylinder and the rava in the cup, and pick up the cup using only the cylinder.

Activity 3 (challenge): Brazil Nut Effect

Instructions: Take the capped tube and place a sphere at the bottom. Next, pour in rava till it is 3/4 full. Close the top. Now figure out how to move the marble to the top of the column without reopening the tube. (This is called the Brazil Nut effect).Can you move the sphere from one end of the tube to the other? What strategy did you use to succeed?

Have you seen this effect anywhere?

Activity 4 (Challenge, at 1 table): Play the game ***Squeezed out*!**

Here are the rules:

This is a game for two or more players. There are 3 sizes of disks trapped by a spring-loaded piston. The yellow are worth 3 points, the red worth 2, and the green worth 1 point. Once the board is set up with the spring-loaded piston, players take turns in trying to remove a piece without moving the bar. If you do so successfully, you gain the points associated with the disk, but if you make the bar move, you lose the same number of points. The player with the most points wins. Here's the crucial rule: you're not allowed to test disks – if you touch it, you must remove it.

Keep going and keep track of your points till only 2 – 3 disks remain. What do you observe? Are the larger disks easier to remove, or the smaller ones? Can you tell just by looking which ones are easy to remove?

Activity 5: Instructor demos: Reynolds dilatancy, Janssen effect

In school, you have likely learned about solids, liquids, and gases. What physical properties or behaviors characterize each state of matter? One way to think about this is to see what happens when you try to put a material into a container. ***Solids*** *usually have fixed shape and volume, and it is difficult to squeeze them into a container of different shape.* ***Liquids****, by contrast, take the shape of the container you put them into. However, you cannot squeeze a liquid, say water, into a smaller volume – the word scientists use for liquids is "incompressible", meaning, cannot be easily compressed. G****ases*** *(such as air), like liquids, take the shape of the container you put them into, but you can confine them to a smaller volume. Both liquids and gases can flow, and therefore can be '****poured****'.*

Central Question: Is an individual grain of sand solid, liquid, or gas? When you take a collection of them together, is this **granular material** solid, liquid, or gas? If one state of matter or the other, does it behave as expected?

The demonstrations and activities that you have tried show you that granular materials are not ordinary solids with defined volume, nor do they behave like regular fluids. They fall in a category labeled "soft matter" or "complex fluids".

Properties of liquids: Surface Tension

The properties that distinguish a liquid from a gas are (i) liquids are incompressible and (ii) liquids have a more clearly defined surface, which exhibits surface tension. Molecules at the surface of a liquid have higher (potential) energy than molecules in the bulk, and thus need to reduce the surface area they occupy. This is why liquid droplets tend to be spherical, since spherical surfaces minimize surface area.

Activity 1: Paper clip on water

Float a paper clip on the surface of water in a bowl. Try using a piece of paper under the paper clip to make this easier. Surface tension holds up the paper clip when it lies flat on the water (this is why it hurts to do a pancake dive into a pool), but the clip will sink when placed on its side. Add a little soap – what happens?

Activity 2: Cheerios effect

Place a single plastic thumbtack, flat side down in a bowl of water. Place a second one near the first. What happens? Add a few more near the first two, and observe what happens. Next, add one far away from the first few – what happens to it?

The spherical/disk shaped object creates a curvature at the point of contact on the outside surface (the angle depends on the liquid/solid/vapor interface and how it wets). A second object does the same, but when the objects get closer, surface area cost is reduced by flattening the region between the two objects, which can be achieved by bring them closer together.

Activity 3: Water + pepper + detergent

Sprinkle pepper on the surface of a thin layer of water in a plate. Allow a drop of soap to fall in the center. What happens?

A drop of soap placed in the center lowers the local surface tension, causing the pepper to move out. Since a liquid with a high surface tension pulls more strongly on the surrounding liquid than one with a low surface tension, the gradient in surface tension causes the liquid to flow away from regions of low surface tension. This is called a Marangoni flow.

Activity 4: Milk + food coloring + detergent

Add a few drops of food coloring to the surface of a plate of milk. Then place a swab dipped in dishwashing soap at the center of the plate. What happens?

Properties of Non-Newtonian fluids

Activity 1: Oobleck

To create oobleck (the name is derived from a Dr. Seuss book, Bartholomew and the Oobleck), mix roughly 1 part of water to 1 part of corn starch. Then try grabbing a handful and making a ball by kneading it. Once it feels firm, open your hand. What happens? How is this different from kneading atta?

Oobleck is an example of a non-Newtonian fluid. Newtonian fluids have the property that when subjected to a shear force, they flow at a rate proportional to the rate of strain. The proportionality constant is called the viscosity. This is an example of "linear response" in Physics. For non-Newtonian fluids, the viscosity changes with the applied stress. Oobleck is an example of a ***shear-thickening fluid****: as a force is applied to it, its viscosity increases, i.e. it flows less easily, and is firmer to the touch. This is usually seen in suspensions, of which corn starch is an example: materials in which particles are suspended in a fluid. Shear-thickening is often seen in suspensions of small particles, where the short-ranged attractive forces between particles dominates over other forces, such as gravity, causing particles to coagulate and fall out of solution, and respond in a solid-like way.*

Another non-Newtonian fluid is toothpaste: when you press the tube, it flows out more easily. Toothpaste is an example of a ***shear-thinning fluid****: as a shear force is applied to it, it flows more easily.*

Activity 2: Instructor Demo: Flow of Sand vs flow of water

Sand takes the shape of the container it is in, and flows out under gravity. Is the flow of sand exactly analogous to that of a fluid like water?

This experiment shows us that unlike water, sand flows at a constant rate out of a tube. This is the reason why sand is used for hourglasses. The reason why water slows as it drains is because the pressure at the base decreases as the volume of fluid above the opening drops, as does the outflow velocity from conservation of energy. Why does a similar argument not apply to the column of granular material? This is because grains are macroscopic, and display friction; as the height of the grains in the column is increased, the pressure at the base saturates – this is the Janssen effect seen earlier. This means much of the weight of the grains is borne by the friction at the walls. This in turn implies a constant outflow velocity.