Pour It Out

Objective: Investigate the effects of forces at different scales.

Key concepts
- As the size of an object decreases, the ratio of surface area to volume increases.
- Surface tension effects are important at small scales.
- Electrostatic forces are many orders of magnitude stronger than gravity.

CA Science Content Standards
Grade 5, Standard 1g – properties of water
Grade 8, Standard 2b – net force
Grade 8, Standard 2c – mechanical equilibrium
Grade 8, Standard 2d – identify forces
Grades 9-12, Physics Standard 5e – electrostatic force

Next Generation Science Standards
Scientific and Engineering Practices – Planning and carrying out investigations; Analyzing and interpreting data; Constructing explanations and designing solutions; Engaging in argument from evidence
Crosscutting Concepts – Cause and effect; Scale, proportion and quantity; Structure and function
Core Ideas – PS2 Motion and Stability: Forces and Interaction

Materials
- Large test tube
- Tiny test tube
- Water
- Soap

Activity instructions
Hand out copies of the pre-lab worksheet to students. Their answers will form the basis of a discussion set in the context of scientific inquiry: posing a question (provided), forming a hypothesis, designing experiments, and making predictions. Try to lead the discussion toward a way to observe or measure the possible differences in behavior of water in different sized containers. After students have brainstormed on possible experiments, hand out copies of the lab worksheet to students and announce that they will be setting up a particular experiment using materials on hand. At this point, ask them what their predictions for this particular experiment are in terms of what they expect to observe. Students will then complete the experiment, collect data, and analyze data by answering the worksheet questions along the way in a guided inquiry. By the end of this activity, students should realize that the main variable is container size, and that smaller containers have a higher surface area to volume ratio than larger containers.

Notes to the teacher
You do not have to do this activity with test tubes. However, the two containers you use should be the same shape (one large, one tiny) in order to prevent misconceptions that the electrostatic attraction is somehow related to the shape of the container. You could even use
different sizes of straws for this activity – the water will flow through large straws, the water will bead up at the end of very small straws.

**What’s going on?**
As the scale of an object decreases, the ratio of surface to volume increases. Therefore, surface effects become more important. In this case, a greater percentage of the water molecules are close enough to the test tube to experience van der Waals attraction to the molecules of the test tube. Since electrostatic forces are many orders of magnitude stronger than gravity, the water drop is more strongly attracted to the test tube than to the Earth, and therefore it stays in the tiny test tube. The increase in surface effects is even more pronounced for micrometer- or nanometer-sized objects. As an example, chemical reactions occur much faster with an increase in surface area-to-volume ratios because of greater contact between the reactants.

In the larger test tube, most of the water is too far from the test tube to experience the electrostatic attraction so the only force being applied is gravity, and the water easily pours out of the large tube. However, even in the large tube, a few small drops may cling to the side or bottom of the cup. They will stay there as long as the electrostatic force from the tube is stronger than the force of gravity from the Earth.

The surface tension (van der Waals attraction between the water molecules) can be strong enough to prevent objects from sinking into the water, as shown with the teaspoon and water striders below. The electrostatic interactions between the water and the container surface are disrupted when soap is introduced. Soap is a surfactant that lowers the surface tension of the water, causing it to pour out easily from the tiny container.

**Extensions**
You can engage students in further inquiry into liquids:

- Ask students to experiment with different liquids to determine how their surface tensions compare to that of water.
- Ask students to experiment with different diameters of straws or tubes of paper. Determine at what diameter the water (or other liquid) will no longer stick to the end of the tube when held vertically.

You can engage students in further inquiry into forces:
• Ask students to experiment with open-ended tubes (or straws) compared to the test tubes. Why will water run out of a small straw but not out of a test tube of the same diameter? Why will water remain in a straw if you hold your finger over up the upper end of the straw? Discuss the impact of air pressure on the water.

Credits
This activity was adapted from “Exploring Forces -- Gravity” by the NISE Network, copyright 2010, Sciencenter, Ithaca, NY.

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