Berkeley Engineers and Mentors

Water We Doing?

Target Grade: Elementary/Middle School
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Brief Overview

In this lesson, mentees will explore the concepts of surface tension, cohesion, and adhesion through multiple demos and a build module. The mentees will drop water on pennies, invert test tubes, race soap-powered boats, and build and design their own water striders using the concepts they've learned in this action-packed lesson.

Teaching Goals

- **Surface tension** is the tendency for surface molecules in a liquid to minimize surface area. It is kind of like a "skin" that the water molecules form.
  - Water molecules cling to each other tightly, especially at the surface where there are less water molecules (due to the exposure to air) to bond.
- **Cohesion** is the tendency for similar molecules to stick together.
- **Adhesion** is the tendency for different molecules to stick together.
- **Engineering design process** is a series of steps used to develop a solution to a problem.
- **Polarity** is the property of having two poles with opposite charges.
  - Optional topic for advanced sites

Careers and Applications

Water comprises approximately 70% of the Earth's surface. We need water to survive. The properties of water though are what makes it so special and useful. Understanding surface tension, cohesion, and adhesion allows us to understand how bugs can walk on water, how plants can transport water, and how bubbles form.

Agenda

- Introduction
- Module 1.1: Watering Pennies (5-10 min)

- Module 1.2: Inverted Test Tubes (5 min)
- Module 2: Soap-powered Boats (10-15 min)
- Module 3: Water Striders (20-30 min)
- Conclusion

Introduction

What's so special about water? (Mentees may say something about how water is everywhere and how ice cubes float). Water also has special properties such as unusually high surface tension that make is very useful and allow certain organisms to thrive.

Module 1.1: Watering Pennies (5-10 min)

Introduction

The purpose of this short module is to introduce the students to the topics of cohesion and surface tension. Before the experiment, the students will predict what they think will happen when they add water to pennies. They will add drops of water on top of pennies and observe the dome of water that forms, realizing that more water than they might have expected can fit on the small surface.

Teaching Goals

1. **Surface tension:** tendency of a fluid to minimize its surface area
    a. The water on the penny moves into an optimal dome shape.
2. **Cohesion:** tendency for similar molecules to stick together
    a. In this case, the similar molecules are the water molecules.

Background for Mentors

When water is on a surface, it has the tendency to collect into rounded droplets. This is due to water's cohesive properties. **Cohesion** refers to the attraction between the same type of molecules. Water has strong cohesive properties as it can form hydrogen bonds.

Cohesive forces are the reason for **surface tension**, the tendency for a liquid's surface to minimize surface area and resist stress. In water, molecules at the surface form bonds with their neighboring molecules, which bond with the molecules deeper in the water. The water molecules at the surface, since they're exposed to air on one side, have fewer neighboring water molecules with which to bond. Thus, they form stronger bonds with the water molecules that they can access. This results in the spherical shape of water droplets. The following diagram elucidates on this concept.

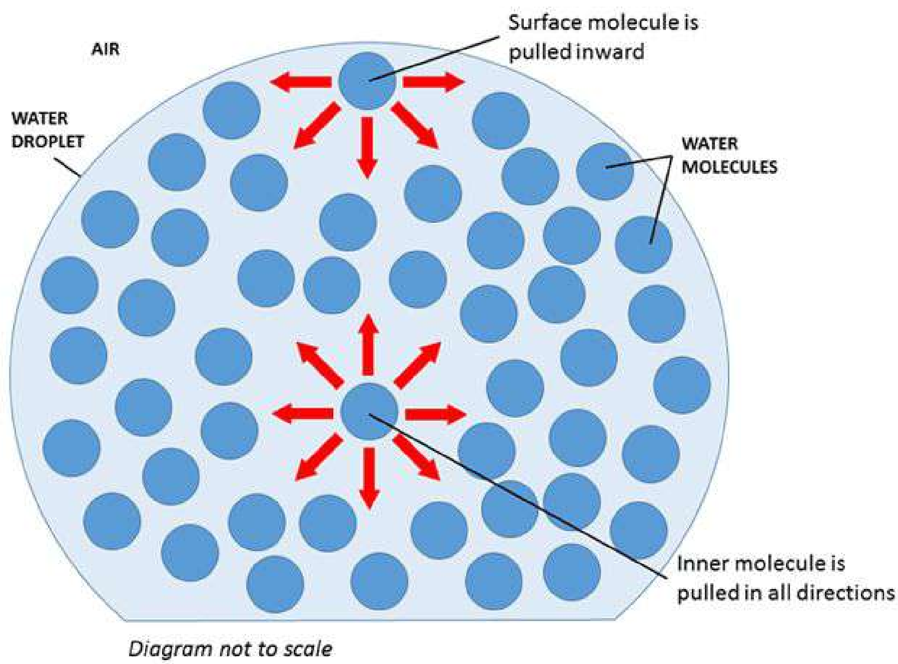

Figure 1. Surface tension in water droplet.

Materials

- Pennies (1 per 2-3 students)
- Pipettes (1 per 2-3 students)
- Small cups (5)
- Paper towels (1 roll)
- Water

Procedure

1. Before the experiment, ask students for their predictions on what would happen if they added water to pennies. Have them guess how many drops of water will stay on the pennies.
    a. They may answer that the water will flow off, which is true. However, more water than they may think will be able to accumulate on top of the penny!
2. Have students separate into groups of around two or three and give each group at least one penny and pipette. They should then follow the next steps:
3. Make sure the penny is dry and then place it on a flat surface.
4. Use a pipette to draw up water from a small cup.
5. Carefully use the pipette to add water dropwise to the penny.
    a. Go slowly and keep the pipette close to the surface of the water forming on top of the coin.
6. Count the amount of water drops until the water runs over the side of the penny. See which group can collect the most water on top of their penny!

Figure 2. Water on a penny.

7. After the mentees understand that the high surface tension of water allows a greater amount of water to reside on the penny, we're going to compare the results if we use a soap solution instead of water.
8. For a demonstration of the different surface tensions of water and soap, make a soap solution (several drops of soap in a cup of water) for the students to test on the pennies.
9. Have the students follow the same procedure as outlined above for the water, and make sure to count the number of drops of solution on the pennies.
    a. The cups and pipettes can be reused for this portion of the module.
10. They should observe that less drops accumulate on top of the penny before the dome of liquid collapses. This is because dish soap has a lower surface tension than water.

Additional Notes for Mentors

Have paper towels ready for spills! After the module is complete, please collect all the pennies and bring them back for use in future site lessons. In addition, make sure to only add soap to the water cups after the original experiment (with water) is over! Otherwise, the pipettes will be contaminated with dish soap and less water will be able to stay on top of the penny.

Module 1.2: Inverted Test Tubes (5 min)

Introduction

This quick demo involving test tubes and water demonstrates the principles of cohesion and adhesion. One can invert a small enough test tube filled with water and observe that the forces of adhesion and cohesion overcome the force of gravity, and the water stays in the test tube. (It's often fun to demonstrate this by inverting the test tube over someone's head).

Teaching Goals

1. **Cohesion**: when molecules "stick" to each other.
    a. Water molecules "stick" to each other
2. **Adhesion:** when molecules "stick" to other types of molecules.
    a. Water molecules "stick" to the glass of the test tube.

Background for Mentors

Water, or H_2O, is a **polar** molecule. This means that the molecule has a slightly positively charged end and a slightly negatively charged end as a result of the shape of the molecule and the differences in electronegativity between the oxygen and hydrogen atoms. **Electronegativity** is a measure of the tendency of an atom to pull shared electrons towards itself. Since oxygen is more electronegative than hydrogen, the oxygen atom carries a partial negative charge.

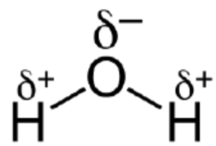

Figure 3. H_2O is a polar molecule.

Cohesion is when molecules are attracted to each other. For example, raindrops form small droplets because of cohesion. Intermolecular forces such as hydrogen bonding and Van der waals forces are responsible for cohesion. In the test tube, water molecules are attracted to each other and stay together (or form droplets). Water is a polar molecule that has strong cohesive forces. **Adhesion** is when molecules are attracted to molecules of a different kind. Similar to cohesion, it results from intermolecular forces. Some of the water molecules in the test tube are attracted to the glass of the test tube, also keeping the water in the test tube. Since these forces are greater than the force of gravity, the water stays in the test tube. Air pressure also helps keep the water in the test tube.

Materials

- 1 x 3 mL glass test tubes for each mentor
- 1 pipette
- Water
- (optional) toothpicks
- Bucket or something for water containment

Procedure

1. This demo should be done in small groups, so each mentor should have a test tube.
2. Fill the test tube with water (pipettes help), leaving a little space in test tube.
3. Invert the test tube. The water should stay in the tube.
4. (optional) With the test tube still inverted, see how many toothpicks you can stick in the test tube.
5. If the test tube is shaken while upside down or too many toothpicks are added, the water will leak out of the test tube. It’s best to hold the test tube over a bucket eventually.

Figure 4. Inverted Test Tube

Additional Notes for Mentors
This video demonstrates what is supposed to happen when the tube is inverted. An alternative technique is to fill the test tube all of the way with water, cover the end with your finger, and then invert. The link to the video: https://www.youtube.com/watch?v=G3Otnpmuw74

Module 2: Soap-powered Boats (10-15 min)

Introduction

This module will allow the students to investigate the effects of soap on the surface tension of water. The students will be launching paper boats by using dish soap to disturb the water's surface tension.

Teaching Goals

1. **Surface tension:** attractive force on surface molecules that minimizes surface area
2. **Engineering design process:** Identify the problem, brainstorm possible solutions, make prototypes, create/test, improve and repeat as necessary
3. **Polarity:** the property of having two poles with opposite charges (optional)
    a. **Marangoni effect:** movement of fluids from low to high surface tension

Background for Mentors

Water's strong attraction to itself contributes to surface tension, which creates a flexible "skin" on the surface. In the case of this module, the layer is caused by the interactions between the molecules in the surface of the water, the paper, and the other water molecules. The attraction between the water and the paper exerts an upwards force on the paper, contributing to the buoyancy force pushing upwards. The density of standard paper (1.201 gram per cubic centimeter) is larger than the density of water, but it is still able to float easily on water due to the buoyant effects of the water on the paper. If the paper is pushed under the water, it will sink since there is no surface tension under the water.

Adding dish soap to the water disturbs the arrangement of water molecules, as the water near the added soap is attracted to the detergent as well as other water molecules. This decreases the surface tension of the water behind the boat where the soap was added. It is important to note that **water molecules move from areas of low surface tension to areas of high surface tension**. This is called the **Marangoni effect**. Thus, though the boats seems propelled away from the soap, it is actually being pulled towards regions of high surface tension by the water in front of the boat. Since soap has a lower surface tension than water, it will move towards the water and away from the boat, which moves forward!

Soap, which has a **hydrophobic** (attracted to water) end and a **hydrophilic** (repelled by water) end, lowers the surface tension of water. The hydrophilic ends bond to the water and break the bonds between individual water molecules, forming a layer on the surface. This lowers the surface tension.

The reason why adding more soap has little to no effect on the boat's movement is that the surface tension of the water has already been disturbed. Soap is a **surfactant**, which means that it breaks the surface tension of water. The force from the disturbance of the surface tension pushes the boat across the surface, but only on the first time the soap is added.

Materials

- White construction paper (~10 sheets)
- Scissors (3-5 pairs)
- Paper plates (~10)
- Water
- Dish soap (2-3 tablespoons)
- Small cups (from previous module)
- Q tips (10)
- 2 site boxes (to transport clean water and discarded soapy water)

Procedure

1. Before the module, have a mentor fill one of the site boxes with water and then use that box to fill the plates with about 0.5 to 1 cm of water. Use the other site box to collect the soapy water to discard later.
2. Ask the students what they've learned from the previous module, specifically concerning the surface tension of water and/or soap.
    a. Hopefully they remember that water has higher surface tension than soap.
3. What happens when soap is added to water? The surface tension of the water will be disturbed and will be lower.
    a. In this module, the mentees will investigate the effects of changing the surface tension of water on the movement of paper boats.
4. Have students separate into groups of two or three. Give each group 1-2 pieces of construction paper and have the groups share scissors.
5. Prepare the dish soap containers by adding ~1 tablespoon of dish soap to the small cups.

6. Have students cut out small boats with notches in the back. Encourage them to experiment with the shapes of the boats, but remind them to keep a notch in their paper boats! The notch stabilizes the direction the boat will go.
7. To make this an **engineering design challenge**, tell the mentees to try to make the fastest boat they can by optimizing the size and shape of the paper. What kind of shape would be more hydrodynamic? Why is a notch recommended? Would folding the paper into a thicker boat be better?
    a. The challenge is to maximize the distance the boats can travel with the same external conditions (e.g. amount of soap and water). The students can try multiple times, but make sure to dump the soapy water for them after each trial! The boats will not move significantly if soap has already been added to the water.

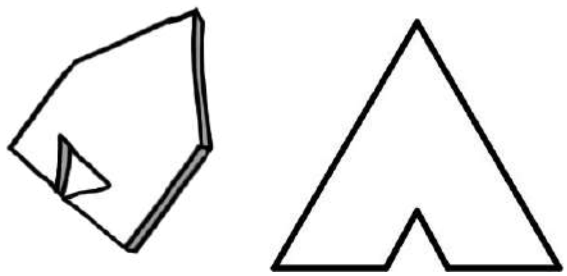

Figure 5. Sample shapes for paper boat.

8. Pass out the plates with water.
9. Have students float the boats on the water.
    a. Preferably the boats should be at a side of the plate with the notch facing outside.
10. Let the mentees dip a Q tip in dish soap, and then lightly touch the Q tip to the surface of the water behind the notch of the boat.
11. The boat should suddenly glide away in the opposite direction!
    a. Make sure the students understand why this is happening.

Figure 6. Movement of paper boat.

Additional Notes for Mentors
The boat does not move nearly as significantly when further drops of dish soap are added to the water, as the surface tension has already been disrupted. For new trials, the plates must be emptied and then refilled with clean water.

Module 3: Water Striders (20-30 min)

Introduction

The mentees will use the concepts they've learned throughout this lesson to build and test their own water striders. Water striders are insects that walk on water.

Teaching Goals

1. Water has a **high surface tension.**
2. Water striders have long legs, allowing them to **distribute the weight of their bodies across a larger area**. (Ask the mentees why this matters.)
3. *(optional)* Water striders have **hydrophobic legs**, so the polar water molecules tend to stay together.
4. **Engineering design process:** Identify the problem, brainstorm, prototype, create/test, improve.

Background for Mentors

Water striders, also known as water skeeters or water skippers, are insects that have the ability to walk on water. They have tiny hydrophobic hairs that cover their entire bodies and long legs. Their long legs allow them to distribute their weight over a greater surface area. Since pressure equals force divided by surface area, increasing the surface area decreases the pressure.

$$Pressure = Force/Area$$

Thus, the water strider's long legs help it stay on top of the water. Additionally, water has a high surface tension and is polar.

Figure 7. Water Strider on Water.

The **engineering design process** will also be used in this module to build water striders. The engineering design process is a multi-step process that involves identifying the problem, creating, and revising.

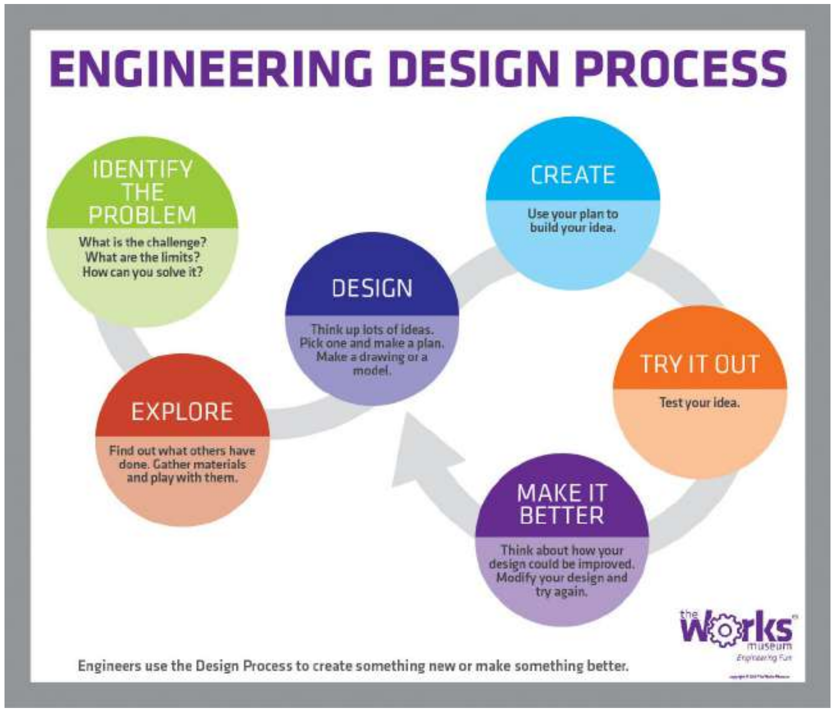

Figure 8. Engineering Design Process

Materials

- Wire
- 50 pipe cleaners (per site)
- Aluminum foil
- 20 Straws
- 20 Styrofoam balls
- Handful of markers
- Scissors (as many as possible per site)
- 20 pieces of Construction Paper
- 3 rolls of tape per site
- 4 Tub/containers for water
- (optional) googly eyes

Procedure

1. Using a variety of supplied materials, the mentees will have the opportunity to make their own water striders that appear to walk on water.
2. Styrofoam works well for feet, and wire or pipe cleaners work well for legs but it’s up to the mentees to decide what they want to use. Remember that increasing the surface

area of the feet helps the water striders float better because of pressure distribution.
    a. I put plastic tape over paper cutouts as my feet (see Fig. 10).
3. The goal is to create a water strider that floats on the water.
4. *(optional)* Try to get the water strider to float on different liquids or add soap to the water and watch what happens.

Figure 10. Dog-like Water Strider on Water.

Additional Notes for Mentors

Bring the models you made during decal as demos. If students are struggling, encourage them to think about how bugs look in real life (aka what does a water strider look like? How does that help make them float?).

Conclusion

Ask the students what they've learned from the lesson and how the concepts covered can be applied to real life. Go over the unique properties of water and their contributions to the necessity of water to human life. Ask which parts of the lesson the students enjoyed the most.

References

- Bugs: Building a Water Strider, Carolyn Klass. https://ecommons.cornell.edu/bitstream/handle/1813/9453/bugs%20building%20a%20water%20strider.pdf;sequence=2
- Build a Soap Powered Model Boat, Science Bob. https://sciencebob.com/build-a-soap-powered-model-boat/
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- Colors on the Mooooove, American Chemical Society. https://www.acs.org/content/acs/en/education/whatischemistry/adventures-in-chemistry/experiments/colors-move.html

- Drops on a Penny, Steve Spangler Science. https://www.stevespanglerscience.com/lab/experiments/penny-drops/
- Falling Test Tubes. https://www.psd1.org/cms/lib/WA01001055/Centricity/Domain/36/Falling_Test_Tubes.pdf
- Power a Boat with Soap, Planet Science. http://www.planet-science.com/categories/experiments/messy/2011/02/power-a-boat-with-soap.aspx
- Surface Tension, HyperPhysics. http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html

Summary Materials Table

Material	**Amount per Group**	**Expected $$**	**Vendor (or online link)**
Pennies	~20 per site	$2.00	Need to order/change
Plastic pipettes	~10 per site	—	Inventory ✓
Dixie cups	~10 per site	—	Inventory ✓
Construction paper (any color)	~30 sheets	—	Inventory ✓
Scissors	3-5 pairs per site	—	Inventory (Order ~12 more)
Plastic/foam plates	10-12	~$10-20	Some in inventory Walgreens/Daiso Foam plates: https://smile.amazon.com/Hefty-Everyday-Plates-White-9-Inch/dp/B000RA9OFA/ref=sr_1_1?keywords=plastic+plates&qid=1550091267&s=gateway&sr=8-1 Plastic plates: https://smile.amazon.com/Basix-Plastic-Plates-Microwave-Count/dp/B01ANYEKUI/ref=sr_1_5?keywords=plastic+plates&qid=1550091267&s=gateway&sr=8-5 Up to logistics which is preferable
Q tips	15-20	—	Inventory ✓

Dish soap	3 tablespoons (¼ cup)	–	Inventory → may need more
Paper towels	1 roll per site	–	Inventory ✓
3 mL glass test tubes	1 for every mentor	$7.47 (for 25 test tubes)	Erica ✓
Pipe cleaners	40 per site	–	Inventory ✓
Foam balls	20 per site (again this can be replaced since there is lots of freedom with design)	$5.77 (for 50 balls)	https://www.amazon.com/Pllieay-Polystyrene-Projects-Christmas-Decorations/dp/B07BP3SYXK/ref=sr_1_18_sspa?s=arts-crafts&ie=UTF8&qid=1547705963&sr=1-18-spons&keywords=small+styrofoam+balls+0.5+in&psc=1
Straws	20 per site	–	Inventory ✓
Water containers	4 per site	–	Site boxes
Wire	Some	–	Inventory ✓
Aluminum foil	2-3 sheets	–	Inventory ✓
Markers	Handful	–	Inventory ✓
Plastic Tape	2-3 rolls	–	Inventory/may need to order
Googly eyes (optional)	Handful per site	–	Inventory → may need to order more
Cheap White Paper Plates	~8 per site	–	Inventory ✓