Oh Buoy!

Target Grade: Elementary/Middle School
Author: Stephanie Huang (adapted from Stephanie Zhang, Zachary Su, Kelly Chang, Stephanie Huang, Fall 2017)
Semester: Spring 2018

Brief Overview

In this hands-on and module-based lesson, students will be introduced to the concept of density. The first module, Floating Eggs in Water Demo, will introduce the students to density and its relationship to the concepts of floating and sinking. The second module, Aluminum Foil Boats Engineering Challenge, will encourage students to practice the engineering design process while creating aluminum foil boats optimized to carry a heavy load of pennies while floating. The third module, Lava Lamps, will allow the students to construct a visually-appealing lava lamp creation to further explore the interaction between concepts of density and polarity. In the fourth module, Salad Spinner Centrifuges, students will witness how we can harness the power of density in laboratory techniques by separating fluids into layers of different densities with salad spinners!

Teaching Goals

- **Density:** the amount of mass per volume. How much "stuff" is within a defined space.
  - Students will explore how liquids with different densities interact; why certain liquids do not mix, and why some liquids will float on top of other liquids.
- **Buoyancy:** The ability to float in a fluid, such as water or air.
  - Students will learn how buoyant force, the upward force applied on objects in fluids, is affected by the volume of fluid displaced.
- **Applications of Density:** In this lesson, we'll explore two different applications of density and buoyancy, boat design and centrifuges. The ultimate goal is to show students how useful density is!
  - **Engineering Design Process:** The process of constantly testing and refining models through trial and error.

Careers and Applications

Density is an important property of an object that is considered by materials scientists and engineers when they choose materials in the design of a building or any other structure.

Shipbuilders apply Archimedes' principle to ensure that their ships float. Many major processes on Earth happen due to density disparities between two different materials. For example, the ability of ice to float on water is due to the lower density of ice. Without this phenomenon, lakes would freeze from the bottom up and many marine organisms would cease to exist.

Agenda

- Introduction (5 min)
- Module 1: Floating Eggs in Water Demo (5 min)
- Module 2: Aluminum Foil Boats Engineering Challenge (15-20 min)
- Module 3: Lava Lamps (10-15 min)
- Module 4: Salad Spinner Centrifuges! (15 min)
- Conclusion (5 min)

Modules 1, 2, and 3 are adapted from Stephanie Zhang, Zachary Su, Kelly Chang, and Stephanie Huang, Fall 2017.

Introduction

Mentors should begin by asking students why some objects float on water, while others sink to the bottom. Then, to segue into the first module, mentors can give a brief description of density to help explain why certain objects will float. **Density** relates to the amount of substance in a given volume. Mentors can explain how if there were two boxes of the same size, the box with more objects in it would have a greater density.

Density is a very important physical property used in many different industries, from designing adequate scuba gear to isolating products in chemical reactions. Its role can be seen constantly in our everyday lives. For example, it allows the ice in our oolong milk tea to float or boats to travel in water.

Module 1: Floating Eggs in Water (Demo)

Introduction

In this module, the mentors will visually introduce the concept of density to students with a demonstration comparing an egg sinking in water with no salt to an egg floating in water with salt. By changing the density of the liquid (water) through the addition of salt, we can see how density impacts how different substances interact with each other.

Background for Mentors

Density is a physical property of a particular substance. Density can be defined as the mass (similar to how much something weighs) of the object of interest and the amount of space it takes up i.e. volume. Atom size, mass, and arrangement are factors that make up density. Density can also be identified as the volumetric mass density, and is a substance's mass per unit volume.

We can quantify density using the following equation $\rho = m/V$, where ρ is density, m is mass, and V is volume.

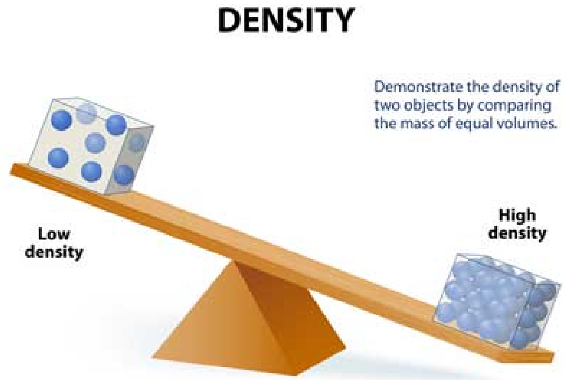


Figure 1: Density Comparison If two objects have the same volume but one has greater mass, the one with greater mass will be considered more dense. *LabQMC.*

If you place an egg in some tap water, it will sink to the bottom of the container that holds the water. The egg sinks because its density is greater than that of water. The density of water is about one gram per cubic centimeter under standard conditions.

If you add enough salt to the water, then the egg should float. The added salt increases the water's density because the salt heightens the water's mass with a negligible change in volume. Thus, the salt water's density is now larger than the egg's density and so the egg can float.

Buoyancy is defined as the ability or tendency of something to float in water or some other liquid. Buoyancy is related to density because density influences buoyancy. When something is put in water, even a floating object displaces some of that water. The amount of water displaced is related to the object's mass.

Materials

- 2 eggs per site (can be plastic easter eggs filled with Play-Doh)
- At least 6 tablespoons of salt per site
- 1 spoon per site
- 2 clear cups (may be plastic or glass, as long as big enough to hold water and an egg) per site
- 2 cups of water (can either use some from the little water bottles or acquire it at site)

Procedure

1. Fill the two cups with water.
2. Add approximately six tablespoons of salt to one cup and stir well enough until the salt has completely disappeared (dissolved) in the water.
3. Place one egg in each of the cups and observe which one of the eggs will sink and which one will float.

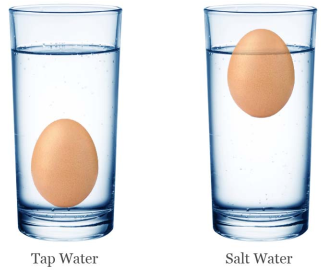


Figure 2: Floating Eggs Demo Expected results for this demo. *Science4Fun.*

Additional Notes for Mentors
In the third module (lava lamps), we will be using the mini water bottles. However, for that activity, each student will only need 1/3 of the water in the bottle. You may take 2/3 of water from each bottle to fill up the cups in this module or the tub in module 2.

Module 2: Aluminum Foil Boats (Engineering Challenge)

Introduction
In this module, students apply what they just learned about density and practice the engineering design process when constructing boats out of aluminum foil. This module is meant to be more of a short hands-on activity, rather than a full engineering design challenge.

Background for Mentors
Boats demonstrate **Archimedes' principle**, which can be applied to overcome the conventional effects of density on floating or sinking. Archimedes' principle observes that the weight of an object appears to decrease as the object is submerged in a liquid. The principle implies that the apparent immersed weight of an object is equal to the weight of the liquid displaced subtracted from the original, unsubmerged weight. A rearrangement of this equation results in the equation for buoyant force: $F_B = Vg\rho$, where ρ is the density of the fluid, V is the volume of the fluid displaced (Figure 3), and g is gravitational constant. Analyzing the buoyant force equation, displacing more fluid increases the buoyant force. In this lesson, the students will be designing boats to displace water. Boats that more effectively displace water when weight is added to them will experience a greater buoyant force and stay afloat.

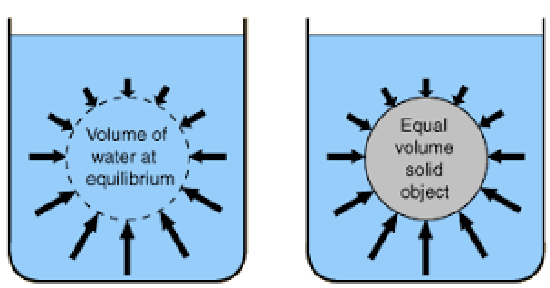


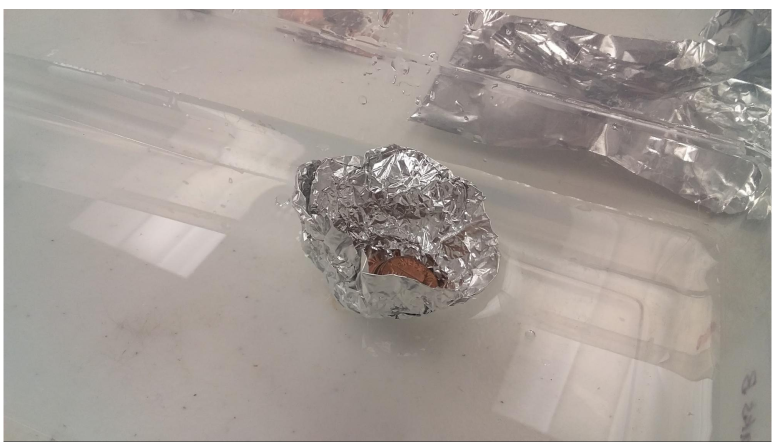
Figure 3: Illustration of fluid displacement in explaining Archimedes' principle. *HyperPhysics.*

Engineers constantly practice the engineering design process when they design new inventions. The **engineering design process** involves prototyping and trial and error. Engineers make models and constantly improve upon them after passing them through various tests. Discuss the importance of the engineering design process (specifically trial and error and prototyping) with students.

Materials
- 1 roll of aluminum foil per site
- 1-2 pairs of scissors per site
- 2 tubs or large containers (that can be filled with water) per site
- water (ideally to be acquired at site)
- 50 or more pennies per site
- 1 Roll of Paper Towels (for clean-up)

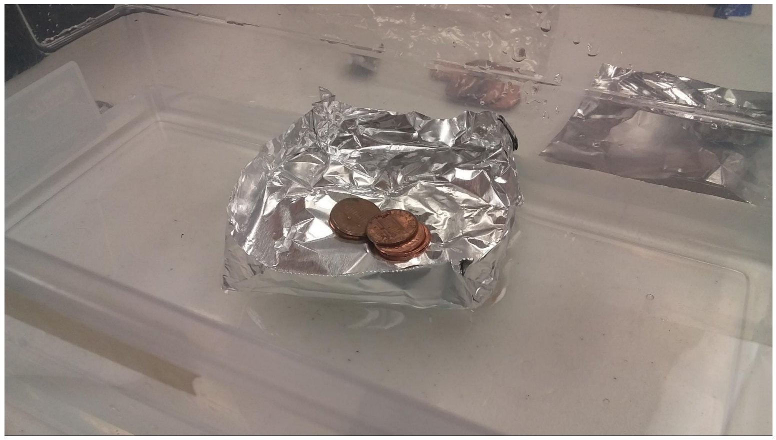
Procedure
1. **Before the lesson begins,** cut aluminum foil into 5 inch x 5 inch squares using scissors. Fill the tubs with some water (Do not fill the tubs up all the way. Height-wise, around 3 inches of water in the tub is enough).
2. Split the students into groups of two or three. Then before distributing materials, have the groups discuss and agree upon designs for their aluminum foil boats.
3. Distribute the aluminum foil. Encourage students to work together and communicate.
4. Have students take turns testing their boats using the pennies. Encourage students to modify their boat designs so that their vessels can accommodate more pennies. See Example Boats for design ideas to suggest.

Example Boats
Bowl Boat



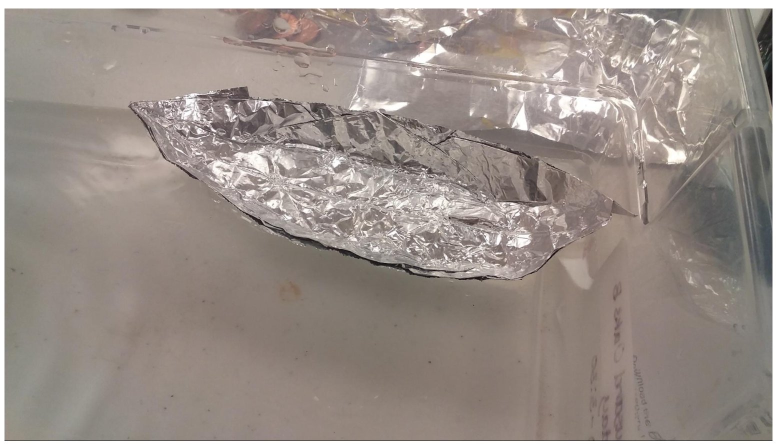
Strengths: deep-bottomed.
Weaknesses: unstable, holes may unintentionally be created.

Platform Square Boat



Strengths: stable both length-wise and width-wise; large bottom area.
Weaknesses: shallow-bottomed.

Origami Boat



Strengths: Stable length-wise; resembles a real boat.
Weaknesses: unstable width-wise; requires origami knowledge to build.

Additional Notes for Mentors
More successful boats will likely be both stable and deep-bottomed. Boats with such designs will displace more water, resulting in a greater generated buoyant force.

Module 3: Lava Lamps

Introduction
In this module, students will have an opportunity to explore the concept of density further by examining how fluids with different densities interact. Students will build their own lava lamps

and learn how density plays a role in how lava lamps work.

Background for Mentors

Oil floats on top of water, because oil is less dense than water. Liquids that are less dense will float, while those with higher densities will sink. The density of water is approximately 1g/mL while the density of extra virgin olive oil is roughly .917 g/mL.

In addition to their differences in densities, oil and water do not mix well because they have different polarities. **Polarity** ”results when a molecule is composed of atoms that exhibit different electronegativity values, which in turn leads to a separation of charge around the molecule. Similarly, a nonpolar molecule results when the molecule is composed of atoms that have similar electronegativity values” (Patrick Oare and Rachel Jang, Polarity, BEAM Fall 2017). For advanced sites, you may briefly explain how oil is relatively nonpolar and hydrophobic (water fearing), while water is very polar. Thus, water forms stronger hydrogen bonds with other water molecules, but can only have weak interactions with oil molecules. There are stronger interactions between water molecules than those between oil and water, leading to two distinct layers when these two liquids are combined. When the food coloring is added, the colors will first be suspended in the oil layer before they eventually reaches the water layer. This demonstrates how the food coloring drops are more dense than oil, because it passes through the oil layer and reaches the water layer, ultimately adding color to the water.

Alka-Seltzer tablets are mainly made of aspirin, sodium bicarbonate, and citric acid. When the tablet is placed in water, it initiates the reaction between sodium bicarbonate and citric acid, creating fizz. This reaction releases carbon dioxide, creating gas that bubbles to the top of the bottle. The gas bubbles carry colored particles of water with them, and once the bubbles reach the top, the gas is released and the water particles fall back down, creating an ongoing cycle of particles in the bottle.

Materials

- 1 empty mini water bottle per student
- 1/2 Alka-Seltzer antacid tablet per student
- 4 different food coloring colors per site
- 2/3 of a mini water bottle of oil per student
- 1/3 of a mini water bottle of water per student

Procedure

1. One mentor should be assigned to a group of students to guide them through all the steps.
2. Fill the bottle $2/3$ of the way with oil, and add water to the rest of the bottle, leaving about an inch of the bottle unfilled at the top. Wait for the water to sink to the bottom. Ask students to explain why water sinks to the bottom and oil floats on top.
3. Add a few drops of food coloring to the bottle.
4. Split an Alka-Seltzer tablet into several pieces, and drop only **ONE** piece into the bottle at a time. Once the tablet reaches the water layer, bubbles will begin to form and colored water particles will start floating around in the bottle.
5. Once the tablet dissipates, the bubbles will stop, but adding another piece of the tablet will make the solution bubble again.

Figure 7: Lava Lamp in Action! (feat. Kelly) *Stephanie's photo archive.*

Additional Notes for Mentors

Adding water and food coloring before oil is quicker than adding oil first. If oil was added first, the food coloring may take a bit longer to reach the water layer. Also, if the oil layer becomes filled with little bubbles, wait for the solution to settle before adding another tablet.

Module 4: Salad Spinner Centrifuges!

Introduction

In this module, students will separate liquids of different densities using homemade salad spinner centrifuges. This module aims to demonstrate why density is important, as we use this intrinsic property everyday in science research.

Background for Mentors

Centrifuges are machines that use centrifugal force to separate substances of varying densities. Centrifuges have containers that rotate very rapidly. Here is an example of a centrifuge.

Centrifugal force, which can be explained by an object's inertia, is the *apparent* force (not actually a real force) that acts on an object moving in a circle, pulling it outward. For example, centrifugal force is what throws out water from your clothes as it spins in the drum of your dryer. Centrifugal force is not to be confused with *centripetal force*. Both forces are related to circular motion; centrifugal force is the *apparent* outward-pulling force of an object (away from the center of axis or rotation) while centripetal force is the inward-seeking pull of an object (reference: Live Science). However, the distinction is not very important for this lesson, so there is no need to explain it to students.

Figure 8: Centrifuge. *Fisher Scientific.*

Centrifuges are incredibly important to many fields of science, from biomedicine to chemistry. For example, we can separate blood based on its different components using a centrifuge (Figure 9). Another example is how ultracentrifuges fractionate cells into their component parts. Density is thus super useful!

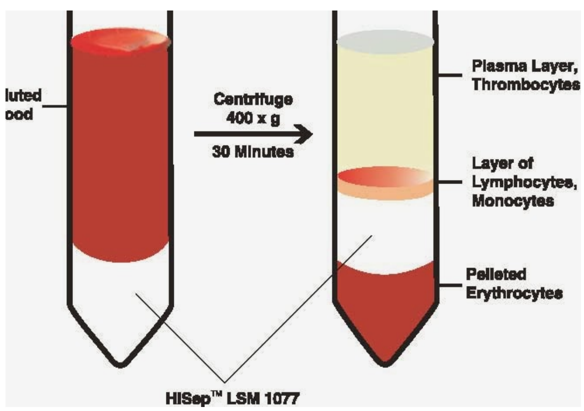


Figure 9: Density Gradient Separation of Blood using a Centrifuge. *A Butterfly and Biotechnology.*

Materials (all reusable)

- 1 Jumbo Salad Spinner per site
- 1 pack of Elmer's Reusable Adhesive Tac N Stik per site
- 4 Centrifuge Tubes per site
- 4 Different Liquids to centrifuge
    1. Pesto Sauce
    2. Sesame Paste
    3. Trader Joe's Apple Juice
    4. Horchata
- 1 Rubber Band per site
- 1 Hairband per site

Procedure

1. Show the four centrifuge tubes to the students and have them notice how the liquids inside are currently only 1 layer. For fun, you can have them guess what liquids they think are inside!
2. Assemble the centrifuge as in the picture below. You will need to separate the adhesive putty into eight balls (four larger ones to stick the centrifuge tubes to the bottom of the spinner and four smaller ones to stick the tubes to each other). Attach the tubes to spinner using the adhesive putty.

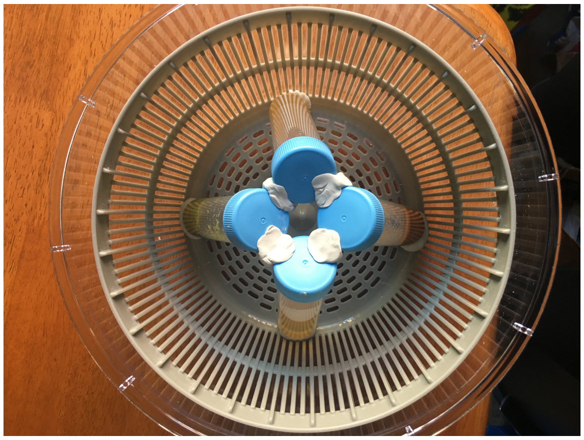


Figure 10: Orientation of tubes in salad spinner. There should be a piece of putty under each tube (sticking it to the spinner) and a piece of putty between the caps of each tube. *Stephanie's photo archive.*

3. Place a rubber band around the top of the tubes. Then place a hair band around the top of the tubes. The rubber bands are generally looser than the hair bands so it'll be easier to wrap the rubber bands around first rather than the hair bands.
4. **While a mentor is assembling the salad spinner centrifuge,** discuss the concept of centrifuges with students. Explain that centrifuges are used to separate liquids into different layers based on their densities. Ask students to predict what the layers will look like after being spun in the spinner.
5. Once the salad spinner centrifuge is assembled and you have finished your discussion with the students, demonstrate to students how to spin the salad spinner. One mentor should hold the salad spinner while another can spin the salad spinner using the crank.
6. Students can now take turn spinning the salad spinner. Have one mentor holding the salad spinner at all times. **It is crucial that you make sure students are careful while spinning the spinners. They should be spinning the spinners at a slow rate. Spinning the spinner too fast may cause the tubes to fall out of the putty and dissemble in the spinner (making you have to start everything over) or completely break the salad spinner.**

Additional Notes for Mentors

The salad spinner can be finicky if not assembled properly. It is important to make sure you're using a lot of force to press the centrifuge tube into the putty to make sure everything sticks well. If not properly assembled, the tubes may possibly fall out of their arrangement during spinning.

Here are some pictures of the liquids after a couple minutes of centrifuging.

Top Left: Pesto Sauce, Top Right: Sesame Paste, Bottom, Trader Joe’s Apple Juice.

Conclusion
At the end of the lesson, ask students what density is and why some objects float while others sink. Talk about centrifuges as an application of density and their importance in science! Ask students if they can brainstorm any other applications of density.

References

- The Simplicity of Propensities Associated with Density, Stephanie Zhang, Zachary Su, Kelly Chang, and Stephanie Huang, BEAM Fall 2017. *[https://drive.google.com/file/d/1l191t6Wv9NmgJ1IKgARyphC10I8lKs0V/view?usp=sharing]*
- Measurement: Density Lab Services, LabQMC. *[http://www.labqmc.quantachrome.com/density.html]*
- Salt Water Egg Experiment, Waleed Alzuhair, Explorable. *[https://explorable.com/salt-water-egg-experiment]*
- Floating Eggs in Salt Water, Science4Fun. *[http://science4fun.info/floating-eggs-in-salt-water/]*
- Shipping Science: Building a Boat That Can Carry Cargo, Science Buddies, Scientific American. *[https://www.scientificamerican.com/article/bring-science-home-shipping-science/]*
- Archimedes' Principle, HyperPhysics. *[http://hyperphysics.phy-astr.gsu.edu/hbase/pbuoy.html]*
- DIY Lava Lamp, Laura Novobilsky, PBS Parents. *[http://www.pbs.org/parents/crafts-for-kids/diy-lava-lamp/]*
- Spin Zone: Separating Butter with a Salad Spinner Centrifuge, Science Buddies. *[https://www.sciencebuddies.org/science-fair-projects/project-ideas/BioChem_p040/biotechnology-techniques/separating-butter-with-a-salad-spinner-centrifuge#summary]*
- Team Builds Centrifuge for $30, Futurity. *[http://www.futurity.org/team-builds-centrifuge-for-30/]*
- Paper and String, the DIY Centrifuge, nature. *[https://www.youtube.com/watch?v=isMYGtCFljc]*
- Eppendorf 5702 Series Centrifuge, Fisher Scientific. *[https://www.fishersci.ca/shop/products/eppendorf-5702-series-centrifuges-package-clinical-cell-culture-3/p-4895867]*
- Isolation of monocytes from PBMC (Peripheral Blood Mononuclear Cells) - Principle and protocol, A Butterfly and Biotechnology. *[http://butterflyandbiotech.blogspot.com/2013/10/isolation-of-monocytes-from-pbmc.html]*
- What are Centrifugal and Centripetal Forces?, Live Science. *[https://www.livescience.com/52488-centrifugal-centripetal-forces.html]*
- Polarity, Patrick Oare and Rachel Jang, BEAM Fall 2017. *[https://drive.google.com/file/d/0B9MnMPcXYKHWLWZDLWs1dkRkRDQ/view?usp=sharing]*

Summary Materials Table

Material	Amount per Group	Expected $$	Vendor (or online link)
50 mL Centrifuge Tubes	4 per site		Amazon
Jumbo Salad Spinner	1 per site		Amazon
Horchata	25 mL per site		Safeway
Pesto Sauce	25 mL per site		Costco
Trader Joe's Apple Juice	25 mL per site		Trader Joe's
Sesame Paste	25 mL per site		Asian Supermarket
Rubber Band	2 per site		Amazon/Inventory
Hair Band	2 per site		Target/Amazon/ask a girl
Tac N Stik	1 pack per site		Amazon
Mini Plastic Water Bottle (pre-filled)	1 per student	3-4 dollars per pack	Costco any nearby grocery store
Alka-Seltzer Antacid Tablets	1/2 per student		*[Amazon/Walgreens]*
Food Coloring	1 pack per site		Amazon/Inventory
Oil (enough to fill up 2/3 of a small water bottle per student)	3-5 bottles per site		*[Amazon]*
Eggs (an alternative is filling up easter eggs with play-doh)	2 per site		any nearby grocery store
Plastic/Glass Cups	2 per site		any nearby grocery store
Morton Iodized Salt	10 tbsp per site		any nearby grocery store
Spoon	1 per site		Inventory
Reynolds Wrap Aluminum Foil (200 Square Foot Roll)	1 per site		*[Inventory/Amazon/any nearby grocery store]*
Pennies	100 per site		Inventory
Tubs	2 per site		Inventory